In 1986, the Single European Act included a title VII called "Environment in the Policy of the Community". The article 130r mentioned that « *the action by the Community relating to the environment shall have the following objectives : (i) to preserve, protect and improve the quality of the environment; (ii) to contribute towards protecting human health; (iii) to ensure a prudent and rational utilization of natural resources* ». So, one year before the Brundtland Report (1987) and its definition of sustainable development (« Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs »), the European path to sustainable development was already prepared. In 1997, *the Treaty of Amsterdam* explicitly inserted commitments to the principle of sustainable development. In particular, sustainable development was established by the countries of Europe as a Community objective in order « *to promote economic and social progress for their peoples, taking into account the principle of sustainable development and within the context of the accomplishment of the internal market and of reinforced cohesion and environmental protection, and to implement policies ensuring that advances in economic integration are accompanied by parallel progress in other fields* » (article 1). In 2001, the Gothenburg European Council adopted the Commission's Sustainable Development Strategy, which calls for further development and rapid implementation of environmental integration. The main threats to sustainable development included : (1) emissions of greenhouse gases from human activity, causing global warming ; (2) severe threats to public health, posed by new antibiotic-resistant strains of some diseases ; (3) poverty and social exclusion effects ; (4) increases in life expectancy combined with low birth rates, threatening a slowdown in the rate of economic growth ; (5) the dramatic acceleration of bio-diversity loss in Europe; (6) transportation congestion approaching gridlock…

Since 2001, the EU's contribution to sustainable development was associated with the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan (SCP-SIP). It included a series of proposals that would contribute to improving the environmental performance of products and increase the demand for more sustainable goods and production technologies. In 2014's report untitled « *A Decent Life for All: From Vision to Collective Action* », the European Commission recognized the need to build the right framework to put the world on a sustainable path to ensure a decent life for all by 2030. That book identifies challenges and opportunities for sustainable development in the European Union. The first part is concerned by the different dimensions (economic, social, cultural…) of sustainable development. The second part is focus on the thematic scope such as biodiversity, energy transition and climate change, industrial ecology, urban metabolism, food which are issues for the policy and the strategy of European Union.

Arnaud Diemer, Florian Dierickx, Ganna Gladkykh, Manuel E. Morales, Timothée Parrique et Julian Torres are members of OR2D (Observatoire des représentations du développement durable) and CERDI (Centre d'Etudes et de Recherches sur le Developpement International) at University Clermont Auvergne (France). Their topics are concerned by degrowth, energy's transition, industrial ecology, natural resources, circular economy and political ecology. They are involved in the European Marie Curie project "AdaptEcon II" (2015 - 2019) with icelandic and swedish universities.

Co-funded by the Erasmus+ Programme of the European Union

OR2D Observatoire des représentations du développement durable

9791092495041

Prix : 15 euros

DIEMER, DIERICKX GLADKYKH, MORALES PARRIQUE, TORRES

EUROPEAN UNION AND SUSTAINABLE DEVELOPMENT *Challenges and Prospects*

Editions Oeconomia

Arnaud DIEMER, Florian DIERICKX,
Ganna GLADKYKH, Manuel E. MORALES,
Timothée PARRIQUE, Julian TORRES

EUROPEAN UNION AND SUSTAINABLE DEVELOPMENT

Challenges and Prospects

Preface Eva Quistorp and Ulrich Goluke

Editions Oeconomia

EUROPEAN UNION AND SUSTAINABLE DEVELOPMENT

CHALLENGES AND PROSPECTS

Arnaud Diemer, Florian Dierickx,
Ganna Gladkykh, Manuel E. Morales,
Tim Parrique, Julian Torres

Preface Eva Quistorp and Ulrich Goluke

Editions Oeconomia

In Appreciation

The book “*European Union and Sustainable Development*” was inspired by the symposium “Europe and sustainable development; challenges and prospects”, located in Clermont-Ferrand (France) in october 2016. This symposium was held within the framework of the Jean Monnet European Program.

We would like to thank many people who participated to that event and brought ideas, technical expertise and criticism to this book.

Gerd Ahlert, Therese Bennich, Emmanuel Bertrand, Andrea Cederquist, Patricia Coelho, David Collste, Florian Dierickx, Etienne Espagne, Maria Fedoruk, Sylvie Ferrari, Ganna Gladkykh, Ulrich Goluke, Besma Harguem, Habib Hadj-Marbrouk, Maria Kovaleva, Elisabete Linhares, Conor Meeham, Mark Meyer, Manuel E. Morales, Eva Quistorp, Anne Snick, Nathalie Spittler, Christina YP Ting, Julia Torres.

PhD who provided inspiration and information for Jean Monnet Program, some have been involved in the edition of the book and in an Intensive Training Network (ITN) - Marie Curie Program, *AdaptEcon II*, coordinated by Vala Ragnarsdottir (University of Iceland).

Tara Alvarez, Fayez Araji, Elena Bakhanova, Therese Bennich, Frederik Bernard, David Collste, Florian Dierickx, Christian Dorninger, Ganna Gladkykh, Maria Fedoruk, Maria Kovaleva, Jennifer Hinton, Manuel Eduardo Morales, Eduard Nedelciu, Nga Nguyen, Maartje Oostdijk, Elenor Siebring, Nathalie Spittler, Johanna Gisladottir, Timothée Parrique, Marie Schellens, Julian Torres,

People who brought their support or participated to the discussions:

Danielle Auroi (european deputy), Fabienne Baudot (ESPE Clermont Auvergne), Jean Paul Besset (european deputy), Anne de Béthencourt (Circular Economy’s Institute), Nicolas Bonnet (City de Clermont-Ferrand), Birgit Daiber (european deputy), Céline Leroy (CPU), Violaine Magne (Clermont-Communauté), Christophe Noiseux (France, Bleu Auvergne), Valeh Nasiri (European Parliament - Former Members Association), Jenneth Parker (Schumacher Institute), Delphine Pommeray (UVED), Jean-François Pujante (France Bleu Auvergne), Eva Quistorp (european deputy), Vala Ragnarsdottir (University of Iceland), Patricia Roche (ESPE Clermont Auvergne), Marie-Christine Toczek-Capelle (ACTE, ESPE Clermont Auvergne), Michel Troquet (Polytech Clermont Ferrand)…

Two authors of this book received the Jean Monnet Prize (Andrea Cederquist, Christina YP Ting)

Editions Oeconomia
9791092495
Imprimerie Chaumeil
Clermont-Ferrand, France
ISBN : 979-10-92495-04-1

9791092495041

Foreword

Challenges, successes, defeats and hopes with sustainable science, media, cultures, mass consumption and policies and politics

In 1979 with the first direct european elections to the European Parliament, the german and french greens where demanding a strategy of the EU to give up nuclear energy and nuclear weapons and dissolve Euratom and change it into a treaty for renewable energies in Europe.

This aim could be called heroic and enlightened and starting sustainable futures at the same time including women and minority equal rights within the process of rebuilding new social-ecological economies within Europe and within its trade and cooperation alliances with Africa, Latin America and Asia.

The Club of Rome, the Stockholm Un-conference on environment but many un-academic women and farmers, pastors, some trade union leaders too, the world council of churches, the thousands of citizen initiatives for a better and saved environment and democracy as against air and water pollution, noise, degradation of soil and deforestation, destruction of the cities by cars with toxic waste in the air-all together creating health and social problems - all had contributed to the beginning of environmental science, journalism, philosophy and politics in parliaments on local, national and European levels. Only when I became member of the European Parliament (EP) in 1989 coming from Berlin, I heard or read the word sustainability the first time in the preparations of the Un Rio-conference 1992, where I was made part of the national delegation by the first german environmental minister Klaus Toepfer. The german word "nachhaltig" is older and comes from the knowledge and science and Praxeno of caring for a healthy, long living forests. The last years it became fashionable in academic and Elite - cultural discourses to talk about the Anthropozaen - the term invented by Paul Crutzen, a scientist, who helped to get the Montreal protocol into UN and EU - laws. I do not think that changing the terms and frames and indicators as such are overcoming the big gap between talk and acting, which is not only a problem of the churches and religions and politics but of academics and sciences too.

Maybe 1000000 and more books about sustainability have been written since Rio agenda 21 and at least 10000 about environmental and sustainable policies and politics within and of the EU. After Rio 1992 many local groups grew on the municipal level and became partly coordinated by ICLEI in the solar city Freiburg, where the political struggle against the nuclear Power plant in Wyhl had been non-violent and successful and the german-french struggle against the old nuclear power-plant Fessenheim is going on - Maybe the promises of Hollande and environmental minister Hulot are fulfilled soon and the Alsace can become nuclear free region with sustainable agriculture, vinery and cities and villages and the mayor of Paris will go on with her Courage to fight climate change and air pollution by restricting traditional cars and high ways and defend public management of the water.

For many years, the EU has really been a public and democratic space to open and change consumer and research and agrarian policies with huge budgets into the direction of more sustainibility with public debates and hearings and co-decision of the European Parliament, giving a good example for the changes in Eastern Europe as well in some cooperation fields with North Africa, South Africa of Mandela and some other non-european regions. But intransparent lobbies of sugar, tabacco, cement, car, coal fuel chemical and biotech -industries beside mining industries in Africa, Monsanto and big agrobusiness and big banks and financial oligarchies are going on - they tried to enter my office, convince assistants or colleagues from other parties especially. So, more research on the lobby groups and science serving these rich and clever and hiding Lobby groups is necessary for sustainable economies, politics and livelihoods. With the growing of right wing parties in Europe the rules and laws and knowledge and spirit to stop climate change relating to the science of IPCC is weakened. Strengthening the European Parliament and the european citizen initiatives like that against the privatisation of public water services and that against Glyphosat are necessary. They need the defense of good common sense, the respect for good compromises of different interests and political parties and trade unions, religious groups to overcome extremism, shit storms and fake news in the so-called social media and educate for democratic thinking and participation. The debates on Ttip and Ceta and Data control and Lux leaks show how urgent we need qualitative mass media and good debates in and outside the European Parliament, the United Nations and in national, local parliaments and within universities and social-ecological movements.

Plastics in the oceans killing fishes, overfishing by big trailers, climate change becoming real in all its forms in daily lives in Europe and Africa with storms, desertification, heavy rains, endangering agriculture, even tourism which is with too much flying one of its sources... are enough reasons with all the health problems and migration flows and violence, social disasters included to think and work and build intercultural and european and international as local alliances for sustainable futures. Sciences have to be critical to their own money flows, bureaucracies and fraud - too far away from the needs of concerned citizens.

A good example is the cooperation of scientists of the Wuppertal - Institut and the Oekoinstitute in Germany and the establishment of a "Nachhaltigkeitsrat " during the social-democratic -green government since 1998-2005, the time of establishing the "Energiewende", the phasing out of nuclear energy and the special law to use and pay and earn money, establish a market for renewable energies. To integrate this into an european market and politics soon needs the help of good european and international studies. Maybe the enquete commission of the german Bundestag on "good living " and that on "globalisation" and the rethinking and redefinition of the "Bruttosozialprodukt" GNP – BSP, which gave no value to all the necessary fields of unpaid or badly paid care-work and the gratis -work of nature, the deepest coalition of human lives and civilisations. In the last years of the christian -democratic-liberal coalition and the first years of the great coalition of christian-democratic-social-democratic coalition under chancellor Merkel is a good example for cooperation of science for sustainability and eco-social reform politics in the spirit of Rio conference and its follow up 2012.

There is not enough interest for studies for sustainability in the mass media and in the global industries for mass consumption, there is greenwashing in many fields of big companies.

In big science too, the german BUND the national association of environmental groups linked with the friends of the earth on european and international level initiated the last years a network of science for Nachhaltigkeit - sustainability, including workshops on journalism for sustainable science and politics. Networks on the transition cities, the big transformation and the degrowth movement try to find their places at universities. The debate on indicators and of ressource efficiency and about the implementation of the Un 2030 goals and its 17 main demands including the rights of girls and women, are urgent tasks for young scientists with open minds for their responsibilities and not just careers. Chernobyl, Hiroshima, Bhopal, Seveso and the waste of computers in the slums of Africa show that science is not innocent as I learned in 1972 from a theatre play on Robert Oppenheimer and Edward Teller by Reinhardt Kipphardt. We could need better learning from best examples of cooperation of art, spirituality, science and politics for sustainable cities and villages and countries and universities and change the entertainment industry, control better the arms trade and stop human trafficking and others forms of new slaveries in our so-called modern times which include roll backs in fanatism and terrorism.

I wish this book and its authors all the best to be part of better european and international Dialogues, which touch the daily needs of millions of people and the needs to vitalize, renew und defend democracies, women and citizen rights, by different parties and the Pulse for Europe and of an international network of universities for a more just and peaceful world, respecting "mother earth ". Films which only play with catastrophic images or imaginären dystopias or science fiction with only technological inventions or portraying only the aggressive, destructive and egocentric aspects of human beings are not helping to motivate people for action of solidarity and do not strengsten the common sense and the social and cultural fight to defend the global common and prevent apocalypses and more failing states.

I recommend the readers and the scientists to connect with the global network of the women mayor group at the UN, working on the Sdags and within the commission of sustainable development, which we have been creating in Juni 1992 together with Bella Abzug and 500 women scientists, activists and members of parliaments and lawyers, artists in a tent in Rio de Janeiro. Even in 1978 the french feminist and essayist Francoise d'Eaubonne has argued in her book "Feminisme et écologie" for reduction of overpopulation by free reproductive rights for girls and women against rigid rules of the catholic church and Islamist countries and macho-dominated tribal customs. Hunger and misery and even wars cannot be stopped, if in some countries the population is doubling within 10 or 15 years and too many young men like in Africa and arabischen countries and in some cities in Europe do not find good education and no jobs but radical ideologies in the internet. Silicon Valley and its Chinese counterparts will not solve these problems and artificial intelligence neither. In opposition to these tendencies of big money-big technology-big media, I prefer to include in my thinking and lobbying Indigenous women and their old knowledge which are an important part of the women mayor group at the UN.

I hope this book helps to give them enough space and attention and respect in science for sustainability too and opens the way for necessary rethinking of natural and social science and more modest attitudes, we all need. As we have to Interrupt and transform business and entertainment as usual seeing the destruction of climate and countries and peace, if we are ready to see and feel it- we have to change sciences as usual too, if we respect the creation, mother earth and the coming Generation of living beings and the best of the civilizations given to us.

Eva Quistorp

Preface

Challenges and Prospects for Sustainable Development in the EU: Frames and Questions

"*Those who tell the stories will rule the world*" (Attributed to Plato, 300 BC)

To support our way of life we need 1.6 planets (Wackernagel and Rees, 1996). This is only possible by living on borrowed time (Streeck, 2014), it is, in reality, an illusion – that we all will pay dearly for.

Ever since the "Limits to Growth" in 1972 (Meadows et al) and "Silent Spring" in 1964 (Carson), innumerable ways have been proposed by many well-intentioned people to help us mend our ways. Yet the root cause of the problem – unsustainable growth, unsustainable consumer behavior and an economic system that needs both to survive – has not been successfully addressed. Instead, our strategy has continued to be to first get rich and only then use the wealth thus created to try to solve the problem. This strategy has failed (Rockström et. al., 2009).

It has failed because we have spent the last 40 years primarily to get rich, and again and again postponed solving the problem. "To get rich is glorious", a quote attributed to Chairman Deng, aptly describes our way of life. While we are perhaps not quite enslaved to (economic) growth, we have not been able to loosen its grip on our collective desires, motivations and dreams of what a better life looks like.

Our task, then, is to create and spread far and wide different plausible, desirable and novel narratives of what a better life means, without relying on economic growth and unsustainable consumer behavior as their core drivers. To express it in Yuval Harari's words, we must create a new "imagined reality" that exerts real force in the real world (Harari, 2015).

So, what precisely is our task and how are we doing?

Frames simplify our lives

If I were to ask you how you decide what you decide, you most likely will talk about facts, constraints and truths. About weighing the pros and cons, about listening to a friend or celebrity who you admire and who's judgment you trust. You might mention the hidden persuaders. Finally, you may talk about your intuition and your excellent gut feeling.

While true, all of that happens within a narrative frame - a story which comes long before any of the considerations above. The catch is that these frames are so much a part of us, that we don't recognize them as such. We may think we have 20/20 vision, but it is the frame we use, almost always subconsciously, that limits, shapes and distorts what we see, notice and pay attention to. The frame largely determines what we consider possible, how we shape our responses and deliver our re-actions. We really do only hear what we want to hear, and disregard the rest.

This is not a shortcoming of ours. On the contrary, it is a brilliant way to make it through the day, the seasons, in fact through life. As Shiller and Akerlof (2009) point out in their book Animal Spirits : "*The human mind is built to think in terms of narratives, of sequences of events with an integral logic and dynamic that appear as a unified whole. ... Life could be 'just one damn thing after another' if it weren't for these stories*".

Yuval Harari (Harari 2015) goes even further. He elevates our human ability to create collective narratives about things that don't exist to what he calls the cognitive revolution; and to which he traces the fact that we, homo sapiens, dominate the earth.

These narratives are the frames that are our windows onto the world. Just like real windows in their window-frames they can be tiny, vast, dirty, clean, distorting or completely invisible. Even though we hardly ever think about them - unless we are professional window cleaners - they determine what we see. And if they become collective, they determine the ways that societies, and all the members of that society, choose to see, act upon and interpret the world around them. That, in a way, is the bad news.

The good news is that these collective frames are not cast in stone. You can clean your windows - at least once in a while; you can even replace them and make the opening larger! Similarly, collective societal frames can and have been changed in the past. Not in some haphazard or arbitrary way, mind you. Because narrative frames are purposeful.

The task of narrative frames is to instill meaning, direction and structure, and by doing so, help answer the question of what a life worth living is. As Shiller and Akerlof note, without them life's just one damn thing after another. To avoid that fate, we have become the story-telling animal.

Challenges for sustainable development

After this introduction, you will not be surprised that I see two challenges for sustainable development:

1. we use the wrong frame,
2. and we ask the wrong question.

At the highest, most aggregated level, humanity lives and tells each other a very purposeful, strong and overarching story. For this big story to work its magic, it must be situational. It must relate in one way or another to the objective reality in which we find ourselves. And as situations have changed over the course of human history, so has the big story. In fact, since the dawn of time there have been four:

1. the heroic one,
2. the religious one,
3. the scientific one,
4. and the current economic one.

In this short preface, I cannot do justice to the first three. I will, however, write a few words about the current, the economic, story – because that is the wrong frame we are using when we examine the challenges of sustainability.

Each big story is characterized by five attributes:

1. its ideal
2. its key actors
3. its language
4. its behavior of its key actors
5. and its fuel or energy.

The wrong frame

The *ideal* of the economic story is growth, and, at the end of its lifetime, not the crucial, desirable growth of a seedling or an embryo, but the relentless, the merciless, the devouring growth of a cancer, of a nuclear chain reaction, or of a black hole. Growth as Tomáš Sedláček (2013), an economist from the Czech Republic and author of "Economics of good and evil" forcefully reminds us, "growth … knows nothing but itself, because it has no goal to measure. The feeling of aimlessness binds it to meaninglessness and homelessness". And on the next page he writes "if maximum growth is the imperative of our time, at any cost, then true rest and satisfaction are not possible."

The *key actors* of the economic frame are consumers and producers, *not* humans, in all their splendor, wittiness, complexity, beauty and loveliness, but only in the two-dimensionality as buyers and sellers. All the fancy words, their seductive tone and their promise that it's all about you – and you alone – should not deceive you that in the end it is only about your financial standing – your wallet, if you wish.

In the economic frame, I am only interested in you if you have something to sell that I want, or if you have enough money to buy what I make. If you are sick, the economic story does not view you as someone in need of care and comfort but merely as a source of revenue. Same thing, if you want to learn or study something, even falling in love has been thoroughly commercialized in our world.

Education, public infrastructure, even public security is increasingly organized according to the economic story. We are all economic actors, each maximizing our own advantage, contributing to an ever-increasing nation's gross national product. We all try to buy at 2 and sell at 3.

The *language* of the economic story is images and numbers, which allows it to be the first truly universal story. A Western pauper can participate, as well as an Indian millionaire, a child as well as a pensioner, as CEO as well as an unemployed father of two.

The *behavior* of our current frame is that of maximizing our advantage.

Maximizing: there is never enough, not enough things, not enough friends, not enough wealth. Maximization fuels and thus serves slavishly the ideal of growth.

Your: the frame sets you up in competition with everybody else, across time and across space, even with your next of kin.

Advantage: you are constantly comparing; thus, you can never be content and you can never relax.

The *fuel* of the economic story is fossil. It is the enabler of the story due to its incredibly high energy density, compared to anything we can get from solar sources. Fossil fuels allow this all-devouring growth to actually happen. Because we use in the blink of an eye – geophysically speaking – the fuel it took millennia to create.

To tell the story of the end of the economic frame I could talk about resource constraints, climate change – a direct, but delayed, response to fossil fuel use – and also about morality. But I won't. Instead, I simply ask you if, for you, the big economic story still fulfills its task. Its task, remember, is to help you give sense and direction to your daily life, to help you lead a life worth living. I suggest to you, that it no longer does. Just think of un- and underemployment especially among the young people of the world, remember the staggering inequality it has produced, remember the personal toll it takes in the form of burnout, depression, alcoholism and drug abuse, remember the rampant disrespect for any- and everything other than money. Remember, in short, Tomáš Sedláček who writes about the feeling of aimlessness that binds it to meaninglessness and homelessness.

Thus, we humans will collectively create a new big story, better suited to the task than the old and fading economic story. I'll get to that when I write about the prospects.

The wrong question

But first to the second challenge : the wrong question. The economic frame asks one, and only one, question over and over again: *What is in it for me?* You yourself can and should ponder its destructive potential next time you interact with people, family and friends, colleagues and even nature.

Prospects

After all this, it may surprise you that I am very upbeat about our prospects.

Why am I upbeat? Because we have begun to recognize both the economic frame and the question as wrong. This recognition is the first and absolutely crucial step towards creating the right frame and asking the right question. If you don't know where you are going, all roads lead you astray. But if you know, if you sense that you are heading in the wrong direction, there is a chance that you can do something about it. Thus, in the rest of my preface are some suggestions to help you grab that chance.

The new frame

New frames emerge because they are better at dealing with an obvious shortcoming of the previous frame. What is the economic frame lacking? After all, it lifted more people out of poverty than any before it; it got rid of hereditary privileges and their capricious favors; it delivered choices for ordinary people that even our grandparents could not have imagined; it adds years to your life expectancy, all over the world.

So, why are we questioning it? Why are we looking for alternatives ? From the unemployed youths, all the way to the head of research at the IMF – the International Monetary Fund?

Because the economic frame is utterly devoid of respect.

It has no respect for young people to have a real chance of building a life without being passed on from one internship to the next, without real pay and real opportunity to learn.

It has no respect for women all over the world who are not treated as equals, also and especially when it comes to their paycheck.

It has no respect for laborers who get 4 USD per unit from your 400 USD smartphone.

It has no respect for nature that we plunder for our short-term enjoyment.

It has no respect for old people who are stored in old people's warehouse and treated like imbeciles.

It has no respect for migrants, old and young, who are not treated as humans in need but are generally assumed to be freeloaders who should be returned to where they came from – the sooner the better.

It has no respect for sick people who do get the distinct feeling that they only exist to generate revenue for the health care system each time they go to the doctor.

It has no respect for low paid workers are replaced at the drop of a hat, whenever it suits the bottom line of their employer.

It has no respect for the animals we eat for food. They are raised by ruthlessly minimizing the cost so our advantage is maximized.

Ideal of respect

So, quite simply, the new frame will replace the ideal of growth with the ideal of respect. This may sound odd to our ears and feel funny in our stomachs – but that is because we have been raised and socialized entirely and exclusively in a world of growth.

Way back in time, there have always been frames – big stories – with ideals other than growth: the heroic frame idealized excellence; the religious frame idealized goodness; and the scientific one idealized truth. The ideal, like the frame, is *not* immutable, it serves a purpose - to help all of us make sense of what is happening around us, to help us lead a life worth living. When it stops doing that, it is rather unceremoniously dropped.

And here, I suggest, the circle closes, because, to me, respect equals sustainability. When you have and live respect vis-à-vis yourself, your fellow human being – not just in the here and now, but across large geographies and very long times - vis-à-vis all the critters, nature and life itself, then you lead a sustainable life.

With one huge difference: The word 'sustainability' has long been associated with sacrifice. Whether this is intrinsic to the concept itself of whether this is simply because the advocates of sustainability have from the start chosen to present their story as one of sacrifice, is beside the point. The vast majority of people today equate instinctively sustainable development with sacrifice, denial and a dreary life. Very, very few of us are motivated by that prospect !

In contrast, the word *respect* is positively loaded. I have yet to meet a person, young or old, rich or poor, sick or healthy, smart or not so smart, who deliberately strives to be disrespected.

Thus, a “side effect” of switching to a frame whose ideal is *respect* – rather than growth – is that, in a casual way, you have set free the energy of each and every one of us seven billion people. As a result, you do not have to save the world all by yourself any more. Occasionally, you can put your feet up, let your mind wander and enjoy the moment.

In this new frame, sustainability will happen not because one, or two, or three master minds have a) seen the problem b) found the solution and c) succeeded in convincing the rest of us to follow their paths of their infallible wisdom.

The new question

On the contrary, all our energies will be set free by a new question: “What is the most respectful thing to do – in the current, concrete situation I find myself in?” Whenever we need to take a decision, whenever we need to weigh alternatives, whenever we are unsure of what the right thing to do actually is, finding an answer to the new question will take us one step at a time closer to a sustainable world.

The new question serves as a heuristic, an algorithm, which, if you apply it over and over and over again will create the new, just, generous and sustainable world. Recall how you can create the most amazing fractal visuals by applying very simple rules over and over again.

Over time, the new question will re-arrange all the damn little things during the day and during our lifetime in a way that provides us, once again, with “an internal logic and dynamic that appear as the unified whole”, as Akerlof and Shiller put it. It will motivate us to create stories of our lives that we tell to ourselves and our children and that create a framework for motivation. Our joint work will be driven by a deep yearning for a better life beyond relentless growth and consumption, not by the paralyzing fear that our current way of life is collapsing.

And that, I submit to you, is a good prospect. I look forward to working with anyone of you willing to join me in this endeavor.

Ulrich Goluke, Blue Way

References

AKERLOF G.A, SHILLER R.J (2009), *Animal spirits : how human psychology drives the economy, and why it matters for global capitalism*. Princeton : Princeton University Press.

CARSON R. (1964), *Silent Spring*, New York : Fawcett Crest.

HARARI Y.N (2015), *Sapiens : a brief history of humankind* (First U.S. edition. ed.). New York : Harper.

MEADOWS D. H. et al. (1972), *The Limits to growth*; a report for the Club of Rome's project on the predicament of mankind. New York, Universe Books.

ROCKSTROM J., STEFFEN W., NOONE K., PERSSON A., CHAPIN F.S, LAMNI E.F… FOLEY J.A (2009), « A safe operating space for humanity », *Nature*, 461(7263), p. 472-475.

SEDLACEK T. (2013), *Economics of Good and Evil: The Quest for Economic Meaning from Gilgamesh to Wall Street*, Oxford University Press, 241 p.

STREECK W. (2014), *Buying time : the delayed crisis of democratic capitalism*. Brooklyn, NY: Verso.

WACKERNAGEL M., REES W.E (1996), *Our ecological footprint: reducing human impact on the earth*. Gabriola Island, BC; Philadelphia, PA: New Society Publishers.

Over the last four or five decades, the European Union has increasingly sought to promote and implement the basic principles of sustainable development. Drawing on the history of sustainable development policy in the EU, the objective of this book is to assess the challenges Europe currently faces regarding sustainable development policy, while at the same time addressing the prospects for further progress in this area.

In June 1972, the United Nations Conference on the Human Environment (Stockholm) proclaimed that « *The natural resources of the earth, including the air, water, land, flora and fauna and especially representative samples of natural ecosystems, must be safeguarded for the benefit of present and future generations through careful planning or management, as appropriate* » (Principle 2). One month later at the 1972 Paris Summit, European Heads of State discussed? the « *non-material values* » reconciling development and the environment in Europe and launched the Community Environmental Policy (CEC, 1972) … Carlo Scarascia-Mugnozza, the first EU Commissioner for the Environment, was appointed in 1973. Between 1973 and 1976, the Environmental Action Programme, the first in the area of European environmental policy, was launched. That program was based on a top down approach and the division of ecological problems into sectors that « *started with nature conservation, noise and waste policies* » (Morand, Barzman, 2005). In 1986, the Single European Act included a title VII called "Environment in the Policy of the Community". Article 130r stated that, « *The action by the Community relating to the environment shall have the following objectives: (i) to preserve, protect and improve the quality of the environment; (ii) to contribute towards protecting human health; (iii) to ensure a prudent and rational utilization of natural resources* ». Thus, one year before the publication of the Brundtland Report (1987) and its definition of sustainable development (« *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs* »), Europe had already begun on the path to sustainable development.

In 1997, the Treaty of Amsterdam explicitly inserted commitments to the principle of sustainable development. In particular, sustainable development was established by the countries of Europe as a Community objective, in order to « *promote economic and social progress for their peoples, taking into account the principle of sustainable* *development and within the context of the accomplishment of the internal market and of reinforced cohesion and environmental protection, and to implement policies ensuring that advances in economic integration are accompanied by parallel progress in other fields* » (Article 1). The following year, the European Council requested that the Commission submit a strategy for promoting sustainable development (Cardiff Process). In 2001, the Gothenburg European Council adopted the Commission's Sustainable Development Strategy, which called for further development and rapid implementation of environmental integration. The main threats to sustainable development included: (1) greenhouse gas emissions as a result of human activity, causing global warming ; (2) severe threats to public health, posed by new antibiotic-resistant strains of some diseases ; (3) poverty and social exclusion effects ; (4) increases in life expectancy combined with low birth rates, threatening a slowdown in the rate of economic growth ; (5) the dramatic acceleration of bio-diversity loss in Europe; (6) transportation congestion approaching gridlock…

From 2001 to 2014, the EU's contribution to sustainable development was associated with the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan (SCP-SIP), which included a series of proposals that would contribute to improving the environmental performance of products and increase the demand for more sustainable goods and production technologies (see the report, "*A Decent Life for All: From Vision to Collective Action*", June 2014). In this report, the European Commission recognized the need to build the right framework to put the world on a sustainable path "to ensure a decent life for all by 2030". This book identifies ongoing/current challenges and opportunities for achieving sustainable development in the European Union.

The first part is concerned with the different pillars of sustainable development. Anne Snick determines four drivers at the European level that influence the dynamics of the socioeconomic system: technical, social, eco-monetary and paradigmatic. She argues that the European Union (EU) mostly addresses the technical drivers for nature conservation and social justice as a smart way to refuel competitiveness and growth in the economy without taking into account the leverage of the three others. Most EU legislation is intended to limit the excess of extraction and exploitation, yet does not question the model itself, because the EU mostly believes these to be reconcilable with a growing linear economic model. The EU responds to planetary challenges in different, often contradictory or ambiguous ways. Circular Economy (CE) is a first example of European strategy. It has a strong framework considering it as a leverage of radical transitions, if it is supported by economic and social innovations, even though in practice it mainly relays the possibility to allow economic growth in a sustainable way. Yet, if the current economic model causes the ills it seeks to address, it is unjustified to believe that 'more of the same' will cure them.

The Responsible Research and Innovation (RRI) is the second European strategy that aims to find solutions for global challenges through a systemic approach in the following domains: ethics, gender equality, city engagement, education, open knowledge and governance. These solutions are research innovations that respect and restore planetary ecosystems sustaining life and pursue equal access to social justice

Gerd Ahlert, Mark Meyer and Martin Distelkamp (GWS) have proposed a sustainable welfare model associated to a positive impact (the structure of a normative decision was discussed in detail by Alhert and al., 2014). The conceptual model provides a description of the "world" which is able to assess the effects of the various options for action on the environmental, social and economic systems in an understandable and reliable holistic modelling framework. The starting point for all reflections presented is the human being as part of nature. In accordance with Daly (1992) the socio-economic system is represented as a part of the larger planetary ecosystem. In a gradual approach, the necessary structures of a sustainable impact assessment model are shown by discussing in detail the relevant interdependencies between the economic, social and planetary ecological spheres. In a final section, the authors shift their analysis from the general holistic conceptual modelling perspective to a practical empirically founded modelling experiment by introducing the multi-regional input-output simulation model GINFORS with environmental extension in the field of emissions and resources.

Christina Yp Ting argues that challenges such as resource depletion, climate change and increasing greenhouse gas emissions call for the integration of the three pillars of sustainable development: economic development, social development and environmental protection. The approach to sustainable development, therefore, needs individuals and organizations to effect changes leading to low carbon and low resource consumption. Current knowledge regarding the mitigation of resource and carbon reduction has focused on issues such as the built environment, behavior changes, and the installation of resource-efficient technologies and transport infrastructures. Ting's studies find that the conventional factors influential on household consumption levels range from socio-economic status, and housing and dwelling size and type, to conservation behaviors, including adoption of resource efficient technologies and environmental awareness. Research on the sustainability practices of Chinese-born migrants and an Australian-born group found that the subjects' ethnic and host cultures contributed significantly to the two groups' consumption levels. Cultural influence on population groups plays an important role among countries in the European Union (EU), because of its diverse demographics and changes in the population structure due to migration – both within and outside of the EU. To promote sustainable development, it is necessary for the EU to recognize differences in migrants and their host societies' cultural practices regarding sustainable living. In the context of sustainable living within the sustainable development framework, Yp Ting explores the variabilities among ethnic cultures in terms of the CALD Index, which measures the strength of individuals' connectedness with their ethnic culture(s).

Concerning the social pillar, Besma Harguem and Habib Hadj-Mabrouk examine the European Occupational Safety and Health (OSH) strategy and in particular the commitments of the Member States on the prevention of psychosocial risks (PSR) at the work place. They propose an analysis of the common principles between sustainable development and the promotion of mental health at work, such as sustainability, transparency, solidarity, prevention, partnership and participation, enacted at the Rio Convention In 1992 and reaffirmed in 2002 at the United Nations World Summit on Sustainable Development in Johannesburg.

To finish the first part of the book, Andrea Cederquist studies the case of Lesvos, a Greek island where a holiday paradise and the refugee crisis collided and became the hotspot for the refugee influx to Europe in 2015. The role that civil society has been taking in tackling the migration crisis on Lesvos, as in many other places in the EU, has been immense. However, the sheer number of refugees arriving, the interplay between local and international initiatives, conflicts between actors, the specific, and often one-sided, attention of the media, the clash between the holiday paradise and the humanitarian- ecological disaster and the fact that volunteers have been at the frontline of response at the borders of Europe for quite some time makes this a special case. Cyderquist's research contributes, on a conceptual level, to understanding how the discourse on European migrant crisis unfolded and to identifying potential intervention points for actions. It uses public values as a conceptual frame and tests the applicability of the strategic triangle by Moore (1995) in a situation of institutional void (relating to the refugees' reception) and their causal relationships. The story on Lesvos is the culmination of a situation which we are facing, it is the story of coping under radically different circumstances.

Part Two focuses on the thematic scope of sustainable development and issues related to the European Union's sustainable development policy and strategy such as biodiversity, energy transition and climate change, industrial ecology, urban metabolism, food…

Sylvie Ferrari, Sébastien Lavaud and Jean-Christophe Pereau provide an analytical framework to address sustainability issues that arise in the functioning of ecosystems, and more particularly, of wetlands. The building of this framework rests upon the adoption of a functional approach of critical natural capital while accounting the property of ecological resilience. That framework is applied to the case of coastal wetland ecosystems in France's Gironde Estuary region and is used to assess the sustainability of their functioning.

Addressing technical aspects of sustainable development, Emmanuel Blanc and Alii discuss the study of research on collection of filamentous fungi of the phyla Ascomycota and Basidiomycota which provide a large repertoire of genes that encode a diverse combination of enzymatic mechanisms involved in the degradation of lignocellulosic biomasses. The collection of the CIRM-CF (International Centre for

Microbial Resources – Filamentous Fungi, Aix Marseille University, INRA) hosted by the Joint Biodiversity Research Unit and Biotechnology of Fungi (UMR 1163 BBF) is responsible for the conservation and valorisation of fungal strains that exhibit selective or simultaneous degradation activities towards lignin and polysaccharides. During the last five years, several field collecting campaigns have contributed to the development of the collection. Four were carried out on mainland France and 5 in tropical forest areas overseas: French Guyana, French West Indies, French New Caledonia (Lechat and al., 2013, 2015; Welti and ali., 2012). In total, 620 specimens were collected, identified by morphological criteria, cultured and added to the collection. In addition, the collection has been enriched by the deposit of strains by French or foreign mycologists. Thus, increasing over the last five years by 535 wild strains (including 38 new species that were not previously represented in the collection). To allow phenotype characterization and facilitate genomic sequencing and assembly, 250 monokaryotic strains have been generated from various wild strains. This genetically stable material is used in several genome sequencing projects such as the Community Sequencing Programs at the Joint Genome Institute and were also deposited in the collection. Finally, the integration of other collections such as 377 Fusarium strains also ensure the growth of the collection. Therefore, the CIRM-CF currently includes approximately 2,200 strains that have been characterized based on morphological and molecular criteria. All the strains of the collection have been authenticated by molecular methods such as ITS sequencing, and phenotypic characterization is currently ongoing through research projects. All of the public information and data related to the strains are available through the BRFM-DB database. The collected biological material is maintained under high quality standards and has achieved ISO 9001 certification for the acquisition, authentication and distribution of fungal material in 2006. It is intended for the dissemination to the scientific community through academic and industrial projects. In 2016, within the scope of the ISO 9001 certification, the CIRM-CF mission was also extended to the screening of fungal strains for targeted biological functions and white biotechnological applications.

From biodiversity protection to the food supply chain, there is one step. Eduard Nedelciu, Nga Nguyen, Johanna Gisladottir, Araj Fayez and Elena Bakhanova analyse post-harvest food wastage. Food wastage is a major social, economic and environmental issue. The sheer magnitude of food waste and loss poses a significant challenge to ensuring global food security and tackling worldwide hunger. Apart from the monetary ramifications, long-term consequences and costs will impact the integrity of our natural resources and the ability of future generations to meet their food needs. In their review of food wastage causes across the post-harvest supply chain, they show that it is not only the lack of technology and infrastructure in developing countries that leads to high amounts of food being lost or wasted. Food wastage is a complex socio-economic issue and is caused by lack of information, miscommunication, cultural differences, limited access to financing and investment, and policy environment. Similarly, food wastage in developed countries is not so much a result of technical limitations/ but human ones. It is deeply embedded in unsustainable consumption and a continuing desire to maintain/achieve the illusion of abundance. Solutions to food wastage need to be approached from a holistic, cross-sectoral and interdisciplinary perspective, combining market and social policies with the application of food wastage reduction technologies. This is needed in the context of a growing world population and increasing pressure on our natural resources and addressing food wastage would impact some of the Sustainable Development Goals that the international community has agreed on.

If biodiversity conservation and food production are two important challenges for Europe, energy and climate introduce us in the field of prospective and future for the human species. Etienne Espagne develops the notion of climate systemic risk. Climate change is usually considered as a negative externality, against which society can insure itself through a carbon tax or emissions trading market. However, except under the unrealistic efficient market hypothesis, there is little chance that such a simple approach to climate policy will succeed in mitigating climate change. Climate change is also often considered as a risk, although of a special kind: it is a collective risk, and it is unhedgeable at the global scale. The analogy of the financial systemic risk is apt. We argue here that it is more than a simple analogy. Financial and climate fragility reinforce each other. A collective insurance approach to climate change has to target the financial sector, as well as its articulation with monetary policy in order to break this positive feedback loop. The Paris Agreement and the broader initiatives among the Paris Alliance ignore the policy consequences of such an approach to the climate threat, but the exegesis of the text still offers some indispensable pillars to promote a new financial order mitigating climate systemic risk.

Ganna Gladkyh, Nathalie Spittler and Florian Dierickx have focused their attention on our current fossil-fuel-based energy system, which has been identified as one of the main drivers of Earth's system change. Although impacts of human beings are observable even earlier, none of the changes before (e.g change in the agricultural system) have caused such a significant impact on the environment as that of the energy system. Hence, it is no surprise that the energy system is also modeled as a main driver for climate change in many macroeconomic energy-climate models. One of the suggested solutions to climate change is a transition from a fossil-fuel-based energy system to a renewable-energy-based one. In the IPCC's report, renewable energy is defined as, "*Any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. Renewable energy is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes low-carbon technologies such as solar energy, hydropower, wind, tide and waves and ocean thermal energy, as well as renewable fuels such as biomass*". It is assumed by the authors that the definitions and assumptions made for various energy sources in macroeconomic energy-climate models affect the modelling results depending on how the relations between climate change and the energy system are analyzed. Characteristics chosen to be considered when modelling renewable energy technologies can influence modelling results. Hence, Gladkyh, Spittler and Dierickx deal with the following research question: How are characteristics of renewable energy represented in macroeconomic energy-climate models? To answer this question, they start from the above-mentioned definition of renewable energy. Then, in a disaggregated manner, they analyze characteristics of different renewable energy technologies, relevant for the interaction between climate change and the energy system. This is followed by an overview of several macroeconomic climate-energy models including a description of the authors' assumptions about renewable energies and a description of the connection between renewable energy and climate change.

For decades, humans have been migrating from rural to urban places. So, cities are increasingly exposed to climate, energy and food problems to the point of generating research that integrates the concepts of ecosystem services, sustainable cities and industrial symbiosis. Patricia Coelho, Manuel E. Morales and Arnaud Diemer propose different investigations to understand how a city becomes sustainable. They make the following hypothesis: a city becomes more and more sustainable if it is able to develop and improve symbiotic relationships. From Nature, a symbiotic relationship is defined as any relationship between individuals of different species where both individuals benefit. Thus, a symbiotic city has "*mutually beneficial relationships with its macro and micro ecosystems. It produces ecosystem services that are equal or greater than its net use of those services. The transition to a symbiotic city requires a cultural and economic recognition that we are embedded in and dependent upon our ecosystems. A symbiotic city enhances the natural environment, sustainable economic activity and quality of life*". To challenge that idea, they explore the complexity of symbiotic relationships with an interdisciplinary perspective. They propose methods and materials (System dynamics, Material Flow Analysis, circles of sustainability) to improve their model. Finally, they present several examples of sustainable European cities and discuss the challenges and prospects of that social innovation.

Manuel Morales, Marina Kovaleva, Maria Fedoruk and Julian Torres describe the servitization tendency of sustainable cities. The servitization concept offers an alternative way for a company to deliver customers a package of services, goods, support and knowledge that provide a solution, and not just a product. Their article aims to understand the potential contribution that the introduction of servitization in the energy, housing and mobility sectors would provide to sustainable cities, with a different framework based on a dynamic, complex and ecosystemic approach. This is just a theoretical outlook of these 3 sectors after a literature review of different case studies, considering two different approaches: sustainable urban metabolism and circles of sustainability. The analysis shows that servitization in the energy sector can be seen as the conjunction of energy supply and energy-related services, suggesting energy efficiency, energy savings and sustainability. In housing servitization takes into account the entire life-cycle of a building and its raw material origins and might also create additional business opportunities for housing service suppliers in the refurbishment sphere. In the mobility sector, the concept is presented in the form of the Sustainable Combined Mobility (SCM) system, which combines different mobility options without the property of the user in any of them. The findings could be considered as an initial step of further research focused on the qualitative and quantitative effects of the dynamic and systemic interrelations over those three areas in a city.

To close this analysis of urban ecosystems, Arnaud Diemer addresses the question of industrial symbiosis within the European Union. Since 1989, industrial ecology has created a new perspective on industrial development arguing that industrial complexes should be designed to resemble natural ecosystems in order to use energy, water, and material resources optimally while at the same time minimizing wastes. As a part of industrial ecology, the study and promotion of industrial symbiosis has gained increasing attention. Building on the notion of biological symbiotic relationships in nature, industrial symbiosis *is a collaboration between different industries for mutual economic and environmental benefits*". The article looks at what can be learned from experiences using/practicing industrial symbiosis. Firstly, it presents the different processes which can play a role in the conceptualization of industrial symbiosis, particularly the ideas of Kalundborg. Secondly, it focuses on the key factors of success and failure of industrial symbiosis. Two levels seem to be involved in industrial symbiosis, the regional level of industrial systems and the societal level (institutional and organizational mechanisms: routines, distribution of the symbiotic relationship). Thirdly, Arnaud Diemer introduces some industrial symbiosis case studies to understand if it would be feasible to use the example of Kalundborg as a model for industrial symbiosis initiatives at other locations. The industrial symbiosis of the Guitang Group, which has developed a complex system of interactions in many business activities (sugar, paper, cement, fertilizer) and different European initiatives are discussed and analyzed.

The end of the book is devoted to an important theme for the European Union: education for sustainable development (ESD). Indeed, living together sustainably means changing our behavior of Education for sustainable development aims to empower people to change the way they think and work towards a sustainable future.

Conor Meehan, Therese Bennich and David Collste present a training module for education for sustainable development, addressing common challenges faced by educators in different settings. The module was developed in a collaboration between Loops Consulting and The Sustainability Laboratory, a US-based non-profit seeking to address urgent sustainability issues facing the planet. Grounded in The Sustainability Lab's Five Core Principles of Sustainability, Sustainability Science and Systems Thinking, the module makes use of tools such as system dynamics and educational technology. System dynamics enables the discovery and understanding of endogenous sources of complex system behavior, which we consider useful in explaining sustainability concepts such as carrying capacity, entropy, and circular economy. The aim of the module is to provide a hands-on tool for teachers and students concerned with sustainability issues and to make a contribution to the discussion on new models for sustainable development education. The module was designed with third level students in mind; however, the authors believe it is useful for anyone from secondary school and upwards seeking to learn more about sustainability concepts and system dynamics.

For their part, Elisabete Linahres and Reis prefer analyzing Education for Sustainable Development (ESD) as the science of education. A science of education focused on knowledge and understanding of science and technology and their role in our daily lives is fundamental in a society marked by progress. The objectives of this research action conducted with future teachers were: to assess both the potential and the limitations of the discussion of controversial environmental issues through role-play in environmental education courses. The data obtained allows the authors to verify the development of various skills among future teachers as well as the negative aspects related to the management of the discussion and the lack of communication skills and teamwork.

Arnaud Diemer, Florian Dierickx, Ganna Gladkykh,

Manuel E. Morales, Tim Parrique, Julian Torres

UNIVERSITY CLERMONT AUVERGNE

CERDI, CONACYT, OR2D, ADAPTECON II, France

PLAN

PILLARS OF SUSTAINABLE DEVELOPMENT FOR EUROPE

EU Politics for sustainability: systemic lock-ins and opportunities

Anne SNICK

Club of Rome – EU Chapter
Member of the Advisory Board of the FoTRRIS project

Since 1972 European leaders have issued policies aimed at safeguarding the wellbeing of ecosystems and the prosperity of all people. Yet the threats have since increased steadily. In terms of system dynamics this indicates a lock-in, mechanisms that make the system veer away from its stated goal. A systemic analysis of EU policies and their (lack of) impact reveals various factors driving the socioeconomic system; a transition in each of them is required for politics to really change course. Four drivers determine the dynamics of the socioeconomic system: technical, social, eco-monetary and paradigmatic. EU policies mostly address the technical driver without taking into account the leverage of the three others. Yet the growing focus within EU research policy on Responsible Resarch and Innovation (RRI) may offer strong opportunities for transition.

The EU facing big challenges

The origins of the European Union can be traced back to the second World War, a global scale catastrophe. To prevent future wars, European leaders set up economic cooperation among their national states. For several decades this 'unification of the market' brought prosperity and a long period of peace to the states involved. The dream was that by enlarging the EU, more and more countries would be able to enjoy the same socioeconomic wellbeing. Yet, today this political project appears to be arriving at turning points.

1. Unequal economic realities among European countries threatens the internal cohesion. Geopolitical conflicts with countries looking for EU support at our eastern border lead to military escalation with Russia. Lack of economic perspective in many countries worldwide causes mass migration and makes young people vulnerable to the call of radical or terrorist organisations. All this raises doubts about the effectiveness of the EU's 'soft' approach to security, and the call for military investments is heard (Krastev & Frank, 2015). Yet, the causes of these threads can all be traced back to the very economic model, in which competitiveness and private or national interests are (structurally) given priority over global concerns and solidarity (Snick, 2016b).

The very economic model the EU heralds as the source of peace and prosperity, is in fact contributing to increasing global insecurity (Snick, 2016a).

2. Ecological threats such as climate change, pollution and mass extinction may be even more dangerous conditions, and no increase in weapons or military intervention can avert them Scientists call the current era the 'antropocene', indicating that it is human (industrial) activity which today impacts the planetary ecosystem. Again, a model that once seemed to bring prosperity in fact is shown to be a serious threat that may jeopardize our survival. Scientists found that the extreme drought that killed ten million Ethiopians in the early 1980s was caused by the pollution haze in industrialized countries keeping the water-laden tropical air from moving northward (Gibson-Graham, 2006, p. ix).
3. Thirdly, the economy is confronted with increasing scarcity of primary materials. Even sand, the second most frequently used raw material (after water) is being depleted at a fast rate, while the mining of sand destroys beaches and marine ecosystems, especially in the global South (Platt, 2016). Economic growth is confronted with the limits of planetary resources, and models that conceive of economics within the boundaries of the planet are tentative and not fully established or embedded in laws and institutions. By depleting natural resources unprecedented wealth was created in some countries, but the prediction that through a trickledown effect this would lead to prosperity for all has been falsified (Picketty, 2014). Yet, politics still hang on to the current model in which fighting poverty is made dependent on the creation of more material wealth (by increasing productivity).

Today these 'big challenges', diverse as they may be, all are recognised as complex and intertwined. In other words, our socio-economic model is reaching tipping points where what once seemed to be beneficial, at a larger time scale appears to threaten our very wellbeing and survival. Therefore, doing 'more of the same' may well turn out to be disastrous, and the call for an urgent paradigm shift is voiced by many researchers, citizens, politicians and business leaders. The EU is responding to these challenges in different, often contradictory or ambiguous ways. We will look at two of these responses, viz the Circular Economy and Responsible Research and Innovation. They will be analysed from a systemic perspective in order to better understand under what conditions they may really foster a transition towards a more sustainable economic model.

The Circular Economy as a response to material scarcity

The EU reactions to big challenges are often ambiguous and even contradictory. On the one hand the EU propagates environmental conservation and social inclusion, yet at the same time invests even more in regulations, trade agreements and innovation programs with a view to increasing competitiveness and reinvigorating the very economic model that causes inequality and natural depletion. Although European policy stresses the importance of nature conservation and social justice, it still believes these to be reconcilable with a linear (growing) economic model, even though it is obvious that a model requiring growth in a non-growing planet can only lead to a fierce rat race and ruthless competition for scarce resources and the exploitation of human labour (Snick, 2016b). This indicates a lock-in that undermines ecological and social policies.

It is therefore a hopeful sign of resilience that inside the corporate world there is a growing willingness to acknowledge this change of context and to explore innovative ways of doing business. Loss of available resources (entropy) encourages the industry itself to innovate. An example is the Circular Economy (CE), a movement which receives quite some EU attention and support even if it is still far from being the 'new normal'. The CE is meant to replace a linear-extractive model in which economic production follows the path of mining, producing, consuming and throwing away as waste. Instead it proposes a model in which goods and materials are kept in circulation as long as possible, and waste eventually is recycled as a primary resource for new products. But even political support to the CE can remain an ambiguous or superficial response to the current tipping points. Not only is it still seen as a 'side track' or a niche rather than as the standard for all economic activity, but it is also considered a smart way to refuel competitiveness and growth. Yet, it is obvious that if a company wants to 'grow' its productivity by using waste as a resource, this requires a growing influx of waste, and so at a larger scale this model remains extractive (albeit less visible at first sight). The CE focuses on technical solutions that are expected to allow the industrial economy to continue growing in a 'sustainable' way (which may indicate that the 'sustainability' of the industry is still considered more crucial than that of the planetary ecosystem on which human live depends). It is clear that circular production cannot safeguard planetary wellbeing as long as it has to occur at increasing rates (growth), and so the CE – for it to really become circular - widens the horizon to include sharing initiatives, putting 'access to services' before 'buying products' (i.e. social innovation). This inevitably entails the emergence of alternative business models (or corporate goals) that aim at community benefits rather than private profit, and imply less noxious concepts of and indicators for economic 'growth'. In turn these innovative business models open up a space for community oriented monetary systems (monetary innovation).

So the CE may well be the leverage of a more radical transition (Snick, 2016b). If the aim of the CE really is to halt the depletion of resources, then decreasing production and consumption (or 'degrowth' of material throughput) is an even more powerful way to get there. However, in the current economic system a company that does not increase its productivity may well be forced out of the market. So for a CE to become the 'new normal', innovative economic models and financial tools – translated into legislation and taxation adapted to the current context – will be necessary (Capra &

Mattei, 2016). This will require research and innovation not only on technical questions (e.g. "how to make mobile phones that last longer and use less energy, how to make sure they are easily reparable and recyclable...?"). Companies in the CE are faced with questions that are beyond technical innovation. How can citizens be motivated to buy 'sustainable' products rather than the 'extractive' ones (that may be cheaper), or to repair them or otherwise give them a second life, or to eventually bring them back to be recycled? If the dominant market mechanism allows companies to make a profit by selling (increasing numbers of) products and so rewards them for increasing the 'dissipation' of resources, then what 'mechanisms' is needed to allow the CE to close the circle again and counteract this dissipation? If citizens are contributing to the closing of the loop, e.g. by sharing, repairing or recycling their 'stuff', then that turns them into 'prosumers', i.e. at the same time consumers of the products and participants in the 'production' of user value. If their efforts to make resources go round longer is considered crucial for the CE, then how is their 'work' to be valorised and protected? All current legislation is built on the extractive model, whereby a producer will try to make a maximum private profit by selling his products to a consumer. In this model, planned obsolescence is not some deviant nasty trick, but a clever marketing instrument that allows a company to bolster its profits. To increase productivity a company has to pay labour as little as possible. So most EU legislation is intended to limit the excesses of extraction and exploitation, yet does not question the extractive and exploitive model itself. Initiatives in which consumers and producers 'cocreate' value therefore have no adequate legal frameworks and may even be suspected of illegal pursuits (Orsi, 2012). These examples show that an evolution such as the Circular Economy, promising as it may seem from a technical point of view, is ineffective in the face of big challenges as long as it is not supported by innovations in the economic, social and legal domains (Von Hippel, 2005, p. 2-3). Without social, economic and legal innovation, the economy will not be able (or not be *allowed*) to remain within planetary boundaries. Now companies are rarely specialised (or skilled) in social or legal innovation, so for 'saving our resources' they will need to work together with other actors, citizens' initiatives, civil society organisations, (social) scientists or public services and politicians. All of them have a specific 'expertise' that is crucial for the CE (and so for EU politics) to really turn the tide. This 'transdisciplinary approach' also appears to be the most effective way to deal with large epidemics (such as Ebola) in the South, where complex community structures and traditions have a large impact on the spreading of the disease; fighting the epidemic by focusing exclusively on specialist medical institutions or health systems may therefore make the epidemic worse (Piot, 2016, p. 484). Coping with the complex challenges of today is no longer the exclusive domain of one specialist (or technical) discipline, but requires collaboration and innovation with what is called the quadruple helix: scientists, citizens, business and politics as four equally important sources of expertise (Dijkgraaf, 2012, p. 23).

Responsible R&I as a potential leverage for innovating politics

The EU also encourages research and innovation to find solutions to the big crises. Specifically the concept of Responsible Research and Innovation (RRI) is coined to denote R&I that deals with sustainability and is structured around six themes: ethics, gender equality, citizen engagement, education, open knowledge and governance. A growing percentage of the EU budgets for R&I are allocated to RRI programs. Yet, the question how 'responsibility' is to be defined, and who exactly is responsible for what and how the six principles are to be put into practice, remains a matter of debate. Few research institutions will be ready to admit that what they normally do is 'irresponsible', and contributing technical solutions for greening products or medical techniques for beating epidemics definitely cannot be considered as 'unethical' in itself.

Yet, as a lot more research has gone into technical (green, medical...) innovation than in the innovation of economic models, governance or social management, there is a real risk that researchers will already consider their research 'responsible' if they contribute just the technical part, leaving the economic and social questions to other disciplines. Since these other dimensions (social, legal and economic innovation) are not integrated from the start into the innovation projects, there is a real risk of a lock-in. For example 'green' technical innovations – e.g. cleaner cars - may be 'co-opted' into the dominant economic and consumption model; since consumers may (be made to) believe that it is less harmful to drive a 'clean' car, they may tend to drive it more (causing social change in the *wrong* direction), and the net effect of this technical innovation at a larger scale may be neutralised or even negative. Also, as long as there are no clear specifications of what exactly is to be considered RRI, the concept may be diluted and exploited as an additional access to research funding. For example, can the search for life on other planets be considered RRI? Does it contribute to solutions for the great challenges, and if so can it be argued that this solution will be efficient and timely? Does it suffice that (a survey revealed that) most people find the quest for extraterrestrial life the most fascinating question about the universe, to claim that this research is therefore contributing to a big societal problem or is based on 'citizen engagement'? If research to increase the competitiveness of - say - the weapon industry is performed without fraud, does that make it 'ethical' (and therefore RRI)? Do efforts to attract more women to this line of research prove its 'gender-sensitiveness' (and therefore make it RRI)?

Yet, given the political decision of the EU to orient the majority of its R&I budget towards RRI (Galiay, 2016), this concept may offer a real opportunity to foster the transition. Yet, the above examples make it clear that this will only be the case if the concept and practice of RRI as a driver of transition is more clearly delineated, and differentiated from R&I within the current (specialist) paradigm, embracing one of the themes of RRI as a mere cosmetic addition. We will propose a framework to explore under what conditions RRI can effectively contribute to solutions for big challenges. This proposal is currently being investigated by the FoTRRIS-project[1] (financed within Horizon 2020). This is not to imply that R&I policy is the only or even the main road to sustainability; in fact the challenges are so complex and so intertwined that no single approach can ever pretend to bring the sole answer, and academia is only one strand in the quadruple helix of transition (Dijkgraaf, 2012). Since transition requires integrated change (or innovation) processes in four domains (technical, social, economic-monetary and legal), research into how this can be accomplished will certainly be an important leverage.

On the EC website we learn that Responsible R&I has been launched with a view to "better aligning both R&I process and outcomes with the values, *needs* and expectations of society. Responsible research and innovation is an approach that anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim to foster the design of *inclusive and sustainable* research and innovation. In practice, RRI is implemented as a package that includes multi-actor and public engagement in research and innovation, enabling easier access to scientific results, the take up of gender and ethics in the research and innovation content and process, and formal and informal science education." (italics AS) In the Horizon 2020 program, RRI is promoted via both actions on thematic elements of RRI (public engagement, open access, gender, ethics, science education), and via integrated actions that for example promote institutional change to foster the uptake of the RRI-approach by stakeholders and institutions[2].

Key concepts in this description are the 'needs of society' as well as 'inclusive and sustainable' innovation. It is of course a crucial question how the needs of society are to be delineated. In the light of the current big crises, one of the needs for human society is to be able to reproduce itself (and allow future generations to survive). So the development of solutions for the ecological and social crises and of alternative models leading to a sustainable and inclusive socioeconomic system is certainly needed. Yet, the concept of RRI as it is described above can be interpreted in a minimalistic (or 'weak') way, e.g. by focusing on just one thematic element of RRI, whereby research projects that do not aim at sustainability or inclusiveness take additional steps to, say, enable access to the scientific results. In its more ambitious approach, however, integrated actions for RRI can foster institutional change with a view to including diverse stakeholders into innovative models for sustainable and inclusive outcomes. In the current context of big challenges, this more ambitious (or 'strong') reading of RRI offers tremendous opportunities.

---

[1] The FoTRRIS-project has received funding from the European Union's Horizon2020 research and innovation programme under grant agreement Nr. 665906. This communication reflects only the author's view and the EU is not responsible for any use that may be made of the information it contains.

[2] Source : https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation.

What would such an 'integrated action' or 'institutional change' have to look like in order to really contribute to a transition - in response to the lack of sustainability and inclusiveness of the current socioeconomic system? Since today's challenges are recognised as complex systemic crises, solutions have to take into account the dynamics of complex systems. Since most R&I institutions today are based on a specialist rather than a systemic paradigm, it can be argued that RRI will require specific institutions and intellectual and legal infrastructure for tackling crises in a transdisciplinary way. Insights about how these 'RRI-institutions' have to function to really serve their purpose are still tentative. In the literature we find analyses of different ways to tackle big challenges, comparing classical (specialist, technical) approaches with more transdisciplinary ones. These analyses are a source of insights into how effective RRI should be conceived, organised and valorised (Piot, 2016).

Proposal for a conceptual framework for RRI

The proposal that will be presented here is mainly based on literature and on systemic analysis of various policies and projects. This proposal will be further tested in the FoTRRIS-project[3]. FoTRRIS proposes the concept of 'Community Oriented Responsible R&I' (or 'CO-RRI') as a synthesis of the crucial characteristics of Responsible R&I developed in collaboration with citizens, CSO's, companies and public services for common wellbeing. This orientation towards (local) communities is what distinguishes FoTRRIS from many other RRI-projects. For R&I to take responsibility in the face of the big challenges, it should also integrate six thematic lines: citizen engagement, gender, governance, education, open access and ethics. FoTRRIS considers public engagement not as a feature that is added in later stages of the RRI-process, but as a building block of RRI itself. RRI is not possible without deeply democratising R&I. Solutions for the big challenges can only succeed if they imply society and recognise the innovative competences of citizens in communities as a basic building block of RRI. Yet, to integrate this community based innovation – in which citizens are recognized as peers – into the current R&I landscape requires specific infrastructure, methodologies and policies. This FoTRRIS aims to develop.

Responsibility means 'contributing to solutions'

R&I has always been an important driver of economic growth. Today the world is facing big ecological and social crises, and in many parts of the world the economy is struggling. It is agreed that *Responsible* R&I should aim at solutions for these challenges. However, what is to be understood by this 'responsibility' and who is responsible for what is still a matter of debate. What we do know is that current threats are complex systemic problems at a global scale. Therefore RRI must adopt a

[3] See http://fotrris-h2020.eu/

systemic approach to understand the root causes of these phenomena. This will allow it to foster sustainable solutions and to reveal what policies can restore planetary and social wellbeing. RRI should be a catalyst of change allowing the global society to work together towards a new, more viable system. This avoids tackling only certain drivers of the crises while blinding us for others, and aggravating the crisis while making us believe we solved it. RRI is responsible insofar as it *justifies* what aspects of complex socio-economic and ecological dynamics it takes into account for tackling big challenges (Ulrich 1987). Given the global scale of today's crises RRI has to take the *planet earth* as a relevant context. RRI contributes to research and innovations that respect or restore planetary ecosystems sustaining life, and pursue equal access to healthy ecosystem services for all (including future generations and other species).

A common denominator for the crises: Anthropocene

Scientists call the current era the Anthropocene since human economic activity influences the dynamics of the planetary system and leads to problems like climate change, oceanic pollution, soil erosion and mass extinction threatening human survival. This comes as a shock since for centuries politicians and economists predicted that growing economic productivity (combined with social legislation) would bring wellbeing for all. Yet with spreading industrial activity we see the depletion of natural ecosystems and unequal access to increasingly scarce resources. This entails loss of economic perspective in many regions of the world, mass migration, geopolitical tensions and security threats, problems our political and social institutions are not prepared for. Moreover, since the 2008 crash the economic engine itself is faltering in many countries. At first sight this seems to make it hard to address the crises. Yet, if the current economic model causes the threats it is unjustified to believe that 'more of the same' will cure them. These unpredicted outcomes (anomalies) reveal that the current paradigm is untenable, and lead to the emergence of alternative practices and paradigms.

R&I has long been driving economic growth. It provided innovations allowing companies to increase their competitiveness by increasing resource throughput at a lower cost. It brought innovation *within* the very economic model that is today identified as the driver of planetary and humanitarian crises. In a sense R&I is co-responsible for these problems as it sustained or invigorated an extractive and competitive economic model. The emergence of RRI means the science community assumes this responsibility. For RRI to lead to solutions for the threats, it must necessarily include innovation of the economic model itself. RRI contributes to economic growth within planetary boundaries. How this can be conceptualised and organised is itself a matter of learning and innovation. RRI must include research on - and innovation of - the economic model so as to contribute to social justice and planetary wellbeing.

Planetary boundaries determine the conditions for RRI

RRI should pursue 'economic growth' that guarantees a dignified and healthy life for all beings within the boundaries of the planet. It therefore has to acknowledge the basic laws of the planetary system and find new economic models to bring prosperity in a planet that is a semi-closed thermodynamic system. This means:

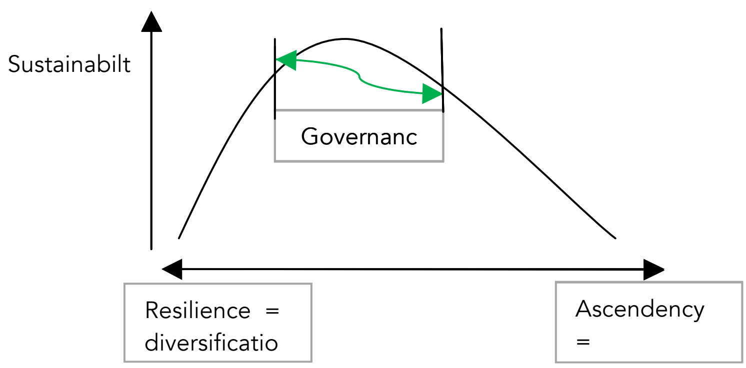
a. There is **no exchange of matter** with the surrounding space. Growth of productivity in one place inevitably causes depletion and/or pollution in other places. Most economic theories do not include this fact in their mental models and treat the effects as 'externalities' or 'side effects'. Since this type of economic activity is rolled out globally, externalising is no longer possible. The backlash comes in the form of climate change, depletion, pollution and mass migration. This feedback forces RRI to recognise the planetary context as the real basis for justified economic models.
b. There is **exchange of energy** with the surrounding space. The best-known source of external energy is the sun. Solar heat is distributed unevenly between the earth's equator and poles, fuelling weather systems that in the course of evolution have created ecological niches (climate zones, ecosystems, soils...) and spurred other energy sources (wind, water...). Plants turn solar energy into carbon and feed other forms of life, produce useful materials and yield energy. The yearly influx of solar energy determines the amount of renewable energy and (plant) matter that is available for economic use.
c. There is always an **increase of entropy** (or disorder). Entropy refers to the degree in which energy or matter are dissipated and become unavailable for use. In the evolution of Earth it is solar energy that creates order (life, available energy) and keeps the planet from reaching maximum entropy (death). In the course of evolution pockets of (mineral or fossil) materials have formed that are available for use. But once extracted and dissipated in the environment it is hard to retrieve them in a useful form and they may even become harmful. E.g. plastic once dissipated in the ocean is no longer available for economic purposes and - eaten by fish - impairs marine and human health. Efforts to 'restore order' always require higher inputs of resources and energy, so at a large scale speed up overall entropy. Products can be recycled but their quality always degrades (entropy); up-cycling (restoring internal order) requires extra resources and increases overall (external) entropy (Roddier, 2016).

For human survival it is crucial to change socioeconomic systems to restore internal order (increased prosperity for people and other beings) while keeping overall entropy low. RRI fosters this by building knowledge on socioeconomic practices that are more adapted to planetary laws and by promoting economic models that guarantee access to a quality life for all people and restore planetary ecosystems.

Evolutionary framework for RRI: growth, collapse and emergence

RRI is to provide answers to crises that threaten life as we know it. Throughout (pre)history, life on earth has gone through several extinctions after which new forms of life emerged. The best known is the ecosystem collapse in which the dinosaurs died out. These were 'successful' animals, capable of a huge throughput of matter and energy. This however made them extremely dependent on (food form) specific ecosystems, and unable to adapt timely to a sudden change in the context. Small, more adaptable mammals survived and eventually evolved into new (emergent) forms of life. Human systems can learn a lot from studying the way natural systems react to changes in the context and can thrive by imitating those (biomimicry). Research on the sustainability of complex flow systems reveals that this depends on three structural elements (graph 1).

Graph 1: Curve of sustainability of complex flow systems (Goerner et al, 2009)



Firstly, it requires resilience, i.e. the capacity to choose alternative paths to pursue its goal in case of a crisis. If a farm grows diverse crops with varying harvest dates, it will survive if a storm ruins one crop. But if an ecosystem just consists of small niches competing for energy, resources may get dissipated and make the system stagnate. So a second element is ascendency, i.e. the capacity to process larger amounts of energy and reducing overhead. Agro-ecology uses combinations of crops that allow for maximum productivity on a given surface, selecting plants (e.g. basil, tomato and grape) that among them optimally share light, water and nutrients and yield plural crops on one plot of land. Reducing diversity (selection) raises ascendency, moving the farm (system) towards the curve's apex. But too much streamlining leads to a tipping point where chances of success decrease again. Monocultures are hyper-ascendant. They extract resources while excluding other flows that can replenish them, and in case of a collapse no alternative paths are available. Resilience and ascendency depend on opposed parameters (much versus little diversification) that must be balanced. So the third factor is governance, the capacity of a system to adjust resilience or ascendency in response to context changes. These correcting feedback loops have to be active before the system is too far on the downward slope, keeping it within a 'window of viability' (around the curve's apex). When (socio-technical) regimes get too ascendent and collapse, the system often veers up by the emergence of resilient ('alternative') niches. This implies that CO-RRI (up-scaling niche innovations in response to great challenges) should no longer be valorised using the instruments (such as Intellectual Property Rights) of the regime that contributed to the crises in the first place. In evaluating RRI-projects the number of patents should no longer be used as a (positive) indicator for success.

Research reveals that all kinds of sustainable systems can be compared to dynamic networks keeping a balance between these two opposite features (Ulanowicz, 2015). Their ability to efficiently maximize throughput depends on streamlining processes that are adapted to (and successful in) a given context (internal order, increasing external entropy). Their resilience on the other hand depends on their capacity to allow for divergent processes, maintaining a degree of freedom that diminishes efficiency but increases adaptability. Sustainable systems in all kinds of contexts show a surprising consistency in their degree of order at around forty percent, whereas divergent pathways account for sixty percent of their flows. The dinosaurs' hyper efficient adaptation to a very specific context explains their collapse once this context changed, while small mammals' resilience and adaptability allowed them to survive and enabled the emergence of new life forms that were better adapted. As these life forms get successful (efficient), they in turn have an impact on their context, leading to changes that again require adaptability. Keeping the system's ascendency and resilience within a window of viability is what is needed to avoid large collapses, and this requires governance. Governance for sustainability means maintaining the right balance between freedom (60% adaptability) and order (40% efficiency).

The current economic infrastructure is extremely efficient at maximising energy throughput, turning other forms of life and planetary resources into means for economic growth far beyond the yearly renewable influx. This socio-technical regime is strongly institutionalised on a global scale and very slow to adapt. Yet as a response to dramatic and threatening context changes, small niches of alternative socioeconomic practices are emerging worldwide, more in tune with the laws of the planet and oriented towards local or global wellbeing. The sustainability of society depends on its capacity to upscale resilient initiatives; research in process ecology suggests that sixty percent of socioeconomic transactions should be enabled through innovating pathways while efficiency accounts for forty percent. RRI aims at up-scaling more adapted socio-economic approaches and at designing R&I infrastructure that assures high resilience in the long term (Goerner et al. 2009). RRI also has to develop governance models (innovative legislation and taxation) that allows the system to break out of this political lock-in and restore the balance between ascendency and resilience.

RRI is required in response to a historical lock-in

RRI is needed to design economic models and legal frameworks that guarantee the prosperity of all life while respecting the yearly influx of resources and causing minimum entropy. Economics is a human activity shaped by political and scientific decisions that are in turn influenced by historical events and evolutions. Yet socio-cultural processes also crystallise into institutions and habits that are less adaptable. These institutions tend to be seen as realities to be taken as a 'given' rather than as a process based on choice and values. RRI focuses again on economics as a societal *function* and fosters the emergence of more adapted infrastructure, practices and value systems. The economic function can be described as the wise allocation of scarce resources to the wellbeing of all. As the earth is a dynamic system shaped by fluctuating energetic, thermodynamic and evolutionary factors, this requires *ongoing* research and innovation. It forces humankind to constantly find more adapted ways to allocate (renewable) resources available at a given time and place to the needs of all. The current economic system is dysfunctional since it destroys life sustaining ecosystems and increases social inequality while pursuing its own growth. RRI must clarify what drivers explain this escalation and what leverages can bring timely change.

A historically unique event has steered economic processes on a path away from 'normal' planetary laws. Stocks of billions of years of solar energy (in fossil form) were found. This sped up economic activity to a degree surpassing many times the annual influx of energy and resources. It spurred the creation of infrastructure based on (diminishing) stocks of non-renewable energy; this led to centralised, industrial production units whose aim is to make a profit by selling a maximum amount of products at the lowest cost. The greenhouse gasses released in the process exceed the absorbing capacity of the planet; this capacity comes from plants (photosynthesis) which depend on complex ecosystems that are themselves degraded by economics. This historically 'unique' economic infrastructure appeared efficient in a context of fossil energy, but brought dramatic context changes that ask for an urgent change. However, it is so strongly institutionalised that the term 'economy' today is mainly used to refer to this system (and its infrastructure), which makes it hard even to think of economics again as a function. The economy is seen as a sector whose growth is deemed more important than the thriving of people and planet, a total means-end reversal. Achieving the aim of prosperity again will require the 'degrowth' of this infrastructure and the 'regrowth' of our capacity to fulfil the economic function. RRI has to restore the economic function which the current (fossil based) infrastructure does not serve, and explore innovative (resilient) means and infrastructure to realise this. RRI aims at 'regrowth', i.e. increasing (again) our capacity to sustainably allocate resources to the needs of all while keeping entropy low.

RRI allows adapted monetary systems to emerge and upscale

Debates on RRI always end up in the question whether there is enough money to solve ecological, geopolitical or social problems. Money is an agreement within a community to use something as a means of exchange in a systematic way. Saying 'there is no money for sustainable development' in fact means 'the current agreements do not allow us to allocate available resources to human and planetary wellbeing'. So for RRI to restore the economic function it has to change the 'agreements' that are used to allocate resources, and contribute to the innovation of the financial system. Therefore, it is crucial to understand the lock-in of current money.

Industrial scale production was made possible by the centralisation of capital and power. National governments gave private companies (banks) the sole power ('fiat') to create money and to impose rules for financial transactions. Today money is created virtually when banks write out a loan (digits on an account) to be paid back by the debtor with an interest. As digits are unlimited in number debt can grow endlessly. Economic actors however cannot repay debts by adding digits to the bank's account, but have to 'make money' in the real economy on a non-growing planet. Money is thus systemically imbalanced, since (virtual) outflow is larger than (real) available inflow. That makes it 'scarce by design' and urges economic actors to exploit human and natural resources, extract profits from speculation on resources and worry more about price than about social or ecological value. 'Making money' becomes the primary aim of business transactions and organisations, at the detriment of the wise allocation of smart resources to the needs of all (the economic function), i.e. a means-ends reversal.

The monopoly of this money creates a lock-in for it is often seen as 'given' rather than an agreement that has to be (re)designed for the common good and the wellbeing of all. It makes pursuing self-interest *seem* more rational than fostering common wellbeing, and diminishes our adaptability. If CE-companies use waste as a raw material this should decrease entropy; yet as companies are required (by scarce money) to make profits (financial 'results'), they need growing flows of waste (increasing extraction). Taxes raised to restore the common good (e.g. poverty alleviation, health care, nature conservation...) are payable only in money that disrupts common goods. Governments expect businesses to respect ecological and social rules yet force them to compete for extractive money, a *double bind* explaining behaviour like tax evasion or information distortion.

In the industrial era 'work' has been narrowly defined as 'being employed' for (private profit of) a company rather than as 'contributing' to the wellbeing of the community. The term 'income' since then denotes a monthly payment on one's account instead of 'access to collective (human or physical) resources or services needed for a quality life'. This narrow view has been institutionalised in legislation and social security systems, and still today has a negative impact on the status, wellbeing and empowerment of people (mainly women) who take care of future generations or communities. The profit-drive entails a scarcity of and competition for jobs. Available human resources are left unused (unemployed) while work for social or planetary wellbeing is left undone. To restore the economic function, concepts like 'work' and 'income' will have to be redefined.

Today more cooperative financial systems (such as gift economy, local currencies, social crowdfunding, ethical investments or interest-free loans) are emerging worldwide, mobilising resources to meet community needs which the private profit market does not meet or for which governments do not have (scarce) money. Local communities set up exchange systems of mutual aid that serve goals like elderly care and social cohesion or a cleaner and greener environment. These initiatives increase access to resources (i.e. regrowth of 'income') without fuelling exploitation. In response to poverty they valorise all human talents that contribute to community or planetary wellbeing without exclusion or exploitation, respecting the needs of next generations. Ethical companies use combinations of local and national currencies to make goods and services accessible to people in poverty. Yet since cultural and linguistic habits are hard to change, the economic potential of these initiatives is not recognized, resources remain unused and needs unmet. RRI has to turn these initiatives into catalysts of change by making them visible, raising awareness of their value and fostering political support. RRI should foster the development of exchange systems that valorise and exchange resources and lead to regrowth of the economic *function*. It has to support the valorisation of all roles needed for human wellbeing and thus foster gender equality. It should also build knowledge on innovative monetary systems that emerge in response to the crises, and investigate what governance they need and how communities can integrate them in their economic fabric.

The concept of 'regrowth' is visualised in table 1. Since currently overshoot day falls in August, we can say that the current system uses 150% of the renewable resources, and since the majority of the world population (estimated at 80% for the sake of the argument) lives in poverty, these resources serve only 20% of the population. If the economy could allocate 100% of the resources to 100% of the population, the economic function would be better fulfilled (regrowth of economic function). If further decoupling and other RRI allow us to use less than 100% of resources (allowing natural ecosystems to restore and build buffers) for more than 100% of the population (foreseeing population growth in future generations), regrowth goes up again.

Table 1 : Modelling the impact of various scenarios on economic function and social/ecological wellbeing (exempli gratia)

Economic function / Scenarios	Used % of Yearly Available Resources = R	Allocation by means of	For % of World Population's Wellbeing = P	**P/R-Ratio = Regrowth index**	Impact on context
Current situation	120 Planet overshoot	Monopoly of scarcely designed (extractive) money	20 - Worldwide competition	20/150 = 0,13	Social, ecological and geopolitical threats
Continued growth & private profit	125 Increasing entropy	Competition & speculation for financial profit	15 - Capital Accumulation	15/125 = 0,12	Lock-in aggravation of crises
Inclusive & green **growth**	110 External entropy	Competition with (patented) clean products and services	25 Social corrections	25/110 = 0,23	Slowing down crises, no systemic solutions
Regrowth supported by RRI	100 Entropic degrowth	Innovative financial rules & community currencies protecting common goals	100 Solidarity & cooperation	100/100= 1 Baseline	**Access** to (commons based) resources to fulfil all **functions**
Sustainable Regrowth	80 Further decoupling	Commons-based RRI up-scaling & fostering uptake of new economic paradigms	105 = Including next generations with population growth	105/80= 1,31 Regrowth	Restoring ecosystems, social justice & prosperity

RRI decentralises commons-based knowledge

Scientific insights on emergence of order in complex systems reveals that most domains of human behaviour cannot be regulated by reductive systems. Reductionism breaks down complex systems into their constituents parts and try to predict the outcome of the whole based on the knowledge of the basic elements, like a clockwork. However, this does not allow to account for non-linear (or chaotic) processes in which chance plays a role and which turn out to determine almost all of human behaviour. So for RRI to facilitate the resilience of complex human socioeconomic systems, it should build on the knowledge of how order (or 'life') emerges in complex dynamic systems. From observing how live ecosystems reach states of relative stability and order, RRI can then create the circumstances in which this learning can be applied to socioeconomic adaptation (Sapolsky, 2011). In terms of R&I this means that specialist (or reductionist) knowledge is not able to produce solutions for problems (or create order and control) in a complex dynamic system like the planetary ecosystem. Adaptability and emergence of new order appears to come from bottom-up input, converging over time into new, self-organised and self-adaptive structures that appear to be more accurate than specialist – centralised – knowledge is able to produce (Surowiecki, 2004). This insight is a basic building block for CO-RRI. For innovation processes to result in self- adaptive and self-correcting solutions adapted to the complex dynamic (non-linear) ecosystem of (life on) the planet, it needs infrastructure where this collective, bottom-up adaptive capacity is facilitated and fostered. Local communities have embedded (indigenous) knowledge of local needs and resources, and can create solutions for local manifestations of global crisis based on short feedback loops, allowing for rapid adaptation. For certain aspects of these solutions, more distant connections are also needed, but in diminishing degrees. This means that decentralised infrastructure to foster local solutions to global threats (or 'glocal' RRI), supported by a smaller number of institutions at the meta-level, is what is needed for rapid adaptability.

Fossil-based infrastructure typically centralises production of goods or services *for* consumers. In line with this top-down approach classical R&I sees citizens as *objects* of knowledge or *users* of innovations. R&I is embedded in highly specialised institutions requiring a centralisation of resources and money. These institutions are themselves seen as economic actors making money with patents or spin-offs. Scarce money puts them under pressure to generate incomes, steering their activity towards lucrative (high entropic) sectors. Innovative initiatives emerging in response to big crises are more decentralised. In line with (thermodynamic) planetary laws they rely on renewable resources that are available locally in varying quality or quantity. New allocation systems foster the use of these resources for the needs of the community. The 'market' of private profit driven initiatives does not lead to collective wellbeing, while high order (ascendent) state services have trouble steering away from the industrial, centralised model. Therefore, emergent alternatives invest in a new kind of public space where resources are allocated to the common good while involving citizens as 'prosumers', producing as well as consuming the services they co-create. This space for economic regrowth is called 'the commons', a concept that delineates where resilience is to be found today, and therefore crucial for RRI.

Local communities and cities appear quicker to adapt than the private market or the state (Gibson-Graham, 2006, p. 165). They are big enough to be able to pool (human and physical) resources and design their own allocation systems for the common good. They are small enough to allow for short feedback loops, since there is a more direct contact with citizens in their daily environment. Cities have more freedom and flexibility for different policy departments to join forces in innovative initiatives than the state. Citizens can be more easily motivated to engage in work for their community as they feel the positive impact of their efforts and have access to the results. Commons are seen as the level with the highest resilience and adaptability.

That makes them into 'real life' (urban or rural) labs for RRI. The number of 'resilient city' networks today is large, including labels such as Smart cities, Sharing cities, Climate friendly or Green cities, Covenant of Mayors etc. These networks too often receive support from the EU; their innovative capacity is a crucial resource for RRI.

Emergent initiatives can hardly upscale for lack of adapted legal and institutional leverages. Current legislation is based on the assumption that economic relations are essentially exploiting and pursue private profit; this is institutionalised by business legislation. Environmental and social legislation curbs excesses of exploitation and makes the competitive model (seem) more 'just' (Capra & Mattei, 2015). Commons however are built on relations of cooperation (Orsi, 2012). Commoners pool their resources with a view to increasing collective wellbeing, blurring the lines between owner and renter, employer and employee or producer and consumer. Existing legislation does not offer adequate models to formalise those new relations, and they risk being suspected as attempts at increasing exploitation while evading state control. For the economy to reach a level of sixty percent 'resilient' transactions, leverages at higher (legal and political) levels are urgently needed. This involves specialist knowledge developed by RRI. To raise societal adaptability this knowledge cannot be privatised but must itself be a common good. RRI-infrastructure to strengthen the potential of regrowth initiatives should be based in the public space uncovered by private market and state. Commons initiatives should be seen as real life laboratories where citizens, CSO's and companies experiment with more adapted practices and models. Local, decentralised RRI-infrastructure (which we will call 'hubs') is needed to help them to upscale by exploring higher (political, monetary or technical) leverages, systematise the expertise they co-produce and make it freely accessible to society.

RRI co-designs by integrating different types of innovation

Traditional R&I institutions are built on specialist, non-systemic mental models. This explains why economic science for centuries could deny physical laws, why money is seen as a given rather than a social construct, and why many people believe solving great challenges can lead to growth. Economics rely on mathematics for scientific robustness. However, calculating economic functionality in a complex dynamic flow context (Earth) implies an enormous number of variables that defy linear proof or mathematical calculation. Therefore, economists use a limited number of quantifiable parameters such as money, productivity or jobs, and neglect others. Economic laws are valid *ceteris paribus*, i.e. *supposing* other factors remain unchanged. If economic (financial) success is measured with bank money as the only unit of account, 'more' (profit, productivity) will seem 'better,' even though in our planet growth leads to increased entropy and *loss* of economic functionality.

Initiatives emerging today use a more integrative, holistic approach. Social innovation – redesigning economic relations including care and community work – is combined with monetary and technological innovation; their innovative governance models and ownership regimes make functions accessible to more people while using less natural resources. If you want to put up a picture, you need a hole made in the wall (access to a function), not a drill (product ownership). Commons allow access to functions by pooling resources. Local Exchange & Trade Systems or Mutual Aid Networks encourage people to ask a neighbour to drill the hole in return for some other help to the community. Tool libraries give access to machines owned by (someone in) the community and define rules and regulations for use. Up-scaling these niches also requires changing the socio-technical regime, for established institutions think in terms of producing goods rather than of increasing functionality. In the Circular Economy (CE), the concept of selling function instead of products is being explored. Interestingly, if a company sells a function (e.g. light instead of lamps, washing capacity instead of washing machines) it is in the interest of the company to make its products last as long as possible, and the systemic driver for 'planned obsolescence' disappears automatically. However, as long as the company is forced (by economic and financial models) to make a profit, it may be in the interest of the company to urge consumers to burn the lamps day and night or wash as often as possible, causing other externalities (in terms of energy, water, etc).

In socio-economic institutions of the industrial system, functions are mostly organised in silos with specific goals and means. The function of 'transport' e.g. is translated into 'things' like roads, harbours, a logistics sector or car industry requiring growth etc. In terms of function, however, transport could mean 'the capacity to bridge the distance between people and what they need with low entropy'. Urging the car industry to sell cleaner cars is not functional as (without financial innovation) more cars have to be sold. If however twenty families share a car, access to function is offered with less resources. CSO's that ask a local farmer to bring baskets of food to the community once a week increase prosperity (easy access to local food– i.e. mobility function fulfilled - more free time, less cars in the street...) and lower the entropy. If participants in this kind of commons are valorised with (local money allowing them to buy) train tickets, functionality and 'mobility' go up again, including for people in poverty. Technology can create ICT-tools to facilitate access or develop renewable and low tech products or tools. Low tech is easier to share with and disseminate in regions in the world that have fewer specialised R&I institutions and therefore contributes to economic regrowth on a global scale. Economic RRI is needed to investigate how goods and services can be made available without urging companies to accumulate capital; examples are P2P models (Troncoso & Utratel 2015), B-corp or Economy of Communion. The conditions that would allow community currencies to strengthen local economies or the indicators that are needed to monitor regrowth in a complex context should be investigated. In order for the commons economy to upscale, this expertise must be made available to society by RRI-hubs exchanging knowledge and making it freely accessible. RRI-hubs are needed to mediate between specialist R&I institutions and the 'real life laboratories' of citizen or city initiatives by providing methodological frameworks that focus on socioeconomic functions as well as on technical and legal preconditions, allowing them to map in a transdisciplinary way leverages needed to upscale emergent solutions. They should integrate social, economic-monetary and technological leverages into new governance models and paradigms. By sharing their methods and results, they foster the uptake of RRI for transitions at regional, national or transnational scales. Table 2 visualises relevant partners for these hubs.

Table 2 : Stakeholder analysis for CO-RRI-hubs

Positive power **=** **(current) leverage** for systemic impact	**high**	**Pioneers in regime/expert institutions** - Academic sustainability research - Legal experts for sharing economy - Circular economy, biomimicry R&I… - Benefit corporations, Economy of communion movement... ➔ **Partners for knowledge co-creation**	**CO-RRI** local hubs (with regional clusters & www-platform) mediating between real life laboratories and Pioneer experts **Developing strategic partnerships with** - Systems analysts, Future Earth Research… - RRI-community, P2P- network … - Research network on community currencies - Associations of cities and communities…
	low	**Financial growth oriented (in regimes and niches)** - Classical for-profit companies - Technological innovation for growth - 'Sharing' companies to raise private profit (Uber, AirBnB...) ➔ **Invite and encourage to learn**	**Real life labs** - CSO's (transition towns, ecovillages, LETS…) - Cities (Smart, Sharing, CO2neutral, Ville Ravie…) - Prosumers (Community Supported Agriculture, Car sharing initiatives, Cohousing projects...) ➔ **Partners for knowledge co-creation**
		Low (sub-systemic goal= own growth)	**High (systemic goal= regrowth)**
		Innovative potential = **Capacity for shifting paradigm towards common good & regrowth**	

References

CAPRA F., MATTEI U. (2015), *The ecology of law. Toward a legal system in tune with nature and community.* Oakland (CA): Berrett-Koehler Publishers.

DIJKGRAAF R. (2012), *Beyond the horizon of Rio +20. Science for sustainable development*. Amsterdam: Royal Netherlands Academy of Arts and Sciences.

GALIAY P. (2016), *Responsible Research and Innovation, a focus of the European Commission*. (http://www.ewi-vlaanderen.be/sites/default/files/rri_sep2016_galiay.pdf).

GIBSON-GRAHAM J.K. (2006), *A postcapitalist politics.* Minneapolis: University of Minnesota Press.

GOERNER S., LIETAER B., ULANOWICZ R. (2009), "Quantifying economic sustainability: Implications for free-enterprise theory, policy and practice", *Ecological Economics 69*, p. 76–81.

KRASTEV I., FRANK J. (2015), "New paradigms for European security policy", *International. Zeitschrift für internationale Politik IV/2015*, p. 31-34.

MEADOWS D. (2008), *Thinking in systems*, White River Junction, VT: Chelsea Green.

ORSI J. (2012), *Practicing law in the sharing economy*, Chicago: American Bar Association Publishin.

PICKETTY T. (2013), *Le capital au XXI siècle,* Paris : Editions du Seuil.

PIOT P. (2016), « Beating Ebola", *Nature*, vol. 537, p. 484-485.

PLATT J.R. (2016), The conservation crisis no one is talking about. *Takepart, 21/09/2016* (http://www.takepart.com/article/2016/09/21/conservation-crisis-no-one-talking-about-sand).

RODDIER F. (2016), *The thermodynamics of evolution*. Artignosc-sur-Verlon : Editions Parole.

SAPOLSKY R. (2011), *Chaos and reductionism. https://www.youtube.com/watch?v=o_ZuWbX-CyE.*

SNICK A. (2015), *MISC: Mapping Innovations on the Sustainability Curve. A methodological framework to accelerate the transition*. https://cidd2015.sciencesconf.org/52807/document.

SNICK A. (2016a), New paradigms for European Security. Reaction to I. Krastev & J. Frank. *International. Die Zeitschrift für internationale Politik I/2016,* 25-27.

SNICK A. (2016b), Is a different kind of currency possible? *Politique Internationale 151 – Special issue 'Of money and men'*, 55-62.

SUROWIECKI J. (2004), *The Wisdom of Crowds.* New York: Anchor House.

TRONCOSO S., UTRATEL A. M. (2015), *Commons transition. Policy proposals fo an open knowledge commons society.* Amsterdam: P2P Foundation.

ULANOWICZ R. (2015), *Process Ecology: philosophy passes into praxis*. https://www.ctr4process.org/whitehead2015/wp-content/uploads/2014/06/PhilPrax.pdf.

ULRICH W. (1987), "Critical heuristics of social systems design", *European Journal of Operational Research, 31*, p. 276-283.

VON HIPPEL E. (2005), *Democratizing innovation*. Cambridge MA: MIT Press.

Structures of a welfare-oriented sustainable impact assessment model and practical implementation experiences

Gerd Ahlert, Mark Meyer, and Martin Distelkamp

Institute of Economic Structures Research (GWS)

In recent years, the criticism on gross domestic product (GDP) as a measure of welfare (e.g. at the OECD conferences, at the EU Conference "Beyond GDP" 2007 in Brussels, in the work of the Stiglitz Commission) led to the formulation of a variety of new welfare concepts committed to the principle of sustainable development. The various transition strategies and practical policy recommendations are discussed under labels such as Growth", "Zero Growth" and also "Degrowth".

Starting point for this conceptual work on the necessary complexity of measuring welfare by applying a comprehensive impact assessment model was a systematic comparison of the various transition studies within the research project “Cornerstones of an ecologically sustainable welfare concept as a basis for eco-political innovation and transformation processes” funded by the German Ministry of Environment (Meyer et al., 2012). The reflections presented here are directly related to the shortcomings identified in the synopsis (Meyer et al., 2013b). Typically the applied models are too simplistic for estimating the impacts of the recommended policy measures on environmental, economic and social sustainability in a holistic modelling perspective. Besides there is also often no explicit statement as to which normative basic assumptions and particularly environmental objectives the authors have used for their policy recommendations.

The proposed sustainable welfare model consists of a normative decision and a positive impact model. The basis structures of the normative decision model have been discussed in detail by Ahlert et al. 2014. In this paper we will focus on key features of the positive model. The conceptual model provides a description of the “world” which is able to assess the effects of the various options for action on the environmental, social and the economic systems in an understandable and reliable holistic modelling framework. The starting point for all reflections presented here is the human being as part of nature. In accordance with Daly (1992) the socio-economic system is represented as a part of the larger planetary ecosystem. In a gradual approach the necessary conceptual detail structures of a sustainable impact assessment model as well as the central effects inside the sustainable welfare model are shown by discussing the relevant interdependencies between the economic, the social and the planetary limited ecological spheres. In a final section, we shift our analysis from the general holistic conceptual modelling perspective to a practical empirically founded modelling experience by introducing the multi-regional input-output simulation model GINFORS (global inter-industry forecasting system) with environmental extension in the field of emissions and resources will be presented. The model has been under development since 1995 and enables integrated socio-economic and environmental-related sustainability studies from a global perspective with planetary boundaries.

The general policy decision framework and related impact assessment

A critical review of more than 30 different approaches to welfare measuring already carried out in the course of the research project "Cornerstones of an ecologically sustainable welfare concept as a basis for eco-political innovation and transformation processes" funded by the German Ministry of Environment is the starting-point of the reflections presented within this paper. The review has shown that, on one hand, in most studies it remains unclear which informational bases of the complex links between the ecological, the social and the economic systems were taken into account in the creation of the concept (Meyer et al. 2012 and Meyer et al. 2013b). On the other hand, there is often no explicit statement as to which normative basic assumptions, and particularly environmental objectives, the authors have used for their policy suggestions. Very often, one-sided or even wrong political priorities are set by excluding important effective contexts in an observation based on a partial analysis. As far as the ecological target system is concerned, there is often a one-sided approach which is only focused on the 2-degree climate target.

It may be legitimate for the description of a policy concept not to include an explicit discussion of these fundamentals. However, in the development of a concept for political action, a rationally acting environmental policy cannot neglect reflecting on which economic, ecological and social contexts have to be taken into account and on which normative statements its decisions should be grounded. The basic structures of a sustain-able welfare model consist of two sub-models:

- A positive model[1] is needed to provide a description of the "world" with which the effects of the various options for action on the environmental, social and the economic systems can be assessed and which are important for the issue under discussion;
- a normative model is also required as a tool for selecting and assessing the options for action in pursuing the desired goal of sustainable welfare development.

[1] In the sense of an empirical or theoretical analytical concept of science, which is based on hypotheses and intersubjectively verifiable results.

These basic structures of a sustainable welfare model must be explicitly worked out and made transparent, so that the conclusions drawn from the research can be understood on the basis of such a model.

The reflections presented here are directly related to the shortcomings identified in the already cited synopsis of the project, concerning welfare and "green" growth concepts currently under discussion, and their relationship to the welfare model of social market economy now long-established in the Federal Republic of Germany; these are too simplistic in terms of environmental, economic and social sustainability. Against this background a broader normative decision model was developed within project (Meyer et al., 2013a, Ahlert et al. 2014). This model provides the reference points for the development of a sustainable welfare concept, which can be used as a political action plan in the context of environmental policy. In this paper the development of the directly related positive “real world” model for assessing the impacts of alternative courses of action plays a central role.

The basic system relationships from a global perspective

The starting point for all the reflections presented here is the human being as part of nature. The human being uses nature, in that it takes raw materials from it and returns waste to it. Starting from a certain order of magnitude, both interchanges harm the planetary ecosystem, so that the various services that human beings receive from nature and without which they cannot live (the provision of clean water, of clear air and of healthy biomass, protection against hard radiation, recreation in nature etc.), are at risk. These fundamental relationships between the socio-economic system and the planetary ecosystem, as a whole, are reproduced in figure 1, in accordance with a representation by Daly (1992). The socio-economic system is represented as a part of the larger planetary ecosystem. The planetary ecosystem receives solar energy and emits heat into space.

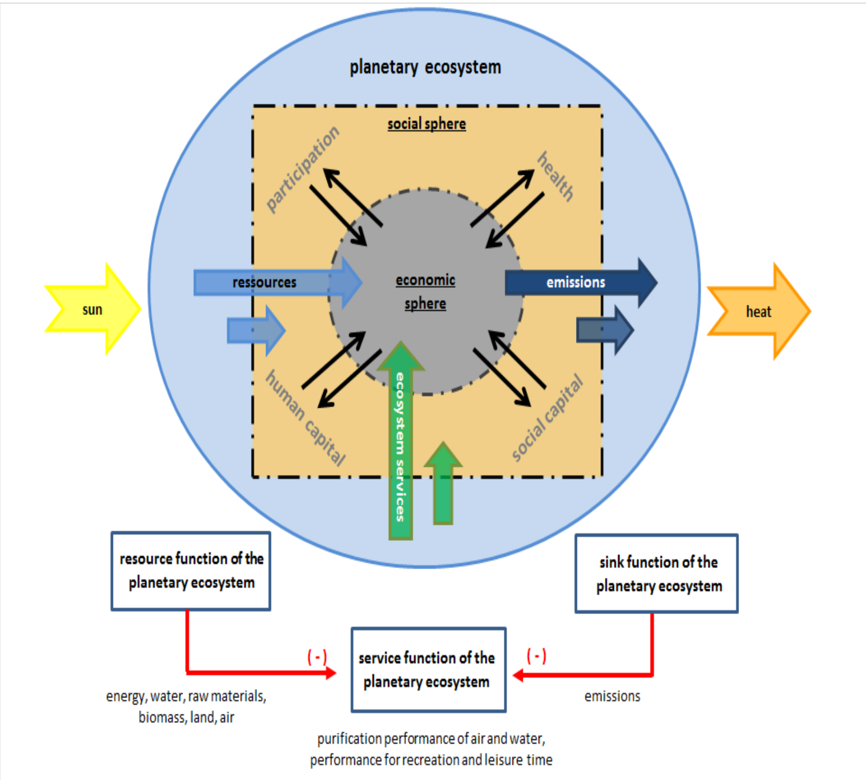
The socio-economic system uses the environment in three relationships:

(1) It takes energy resources (wind, solar, hydro) and material resources such as fossil fuels, metals, non-metallic minerals and biomass from the environment. All this is what we call the resource function of the environment. Within the socio-economic system these stream of resources is transformed through energy, labour and capital, into goods, which are consumed by people or used in further production processes (capital).

(2) Although the socio-economic system is able to reduce the “waste" material flow by recycling it uses the environment as an emission absorbing medium for used energy and waste. In this context, we speak of the environmental sink function. Waste includes emissions of gases into the air, as well as solid and liquid waste from industry, agriculture and households.

Figure 1 illustrates the interactions inside the socio-economic system between the central values of the social sphere, such as human and social capital, and the economic sphere. Human capital, which includes the store of knowledge of society but also, among other things, the competence, skills and creativity of its members, is generated, to a decisive extent, by the education system, which is also a component of the economic sphere, and provides performance to the economy. Social capital includes all of social institutions, but also, among other things, social networks and the relationship skills of people as well as their cultural diversity. It is influenced by economic development and acts upon the economic sphere, in turn. The economic sphere, which performs the supply of goods, includes all markets of the economic cycle (goods markets, labour markets, capital and financial markets) with their respective actors (non-financial and financial companies as well as state companies; private non-profit organizations; private households; the state and foreign countries) with their capital stocks or infrastructures in the context of the existing economic system.

Figure 1 : Basic structures of the positive model - interdependence between the economic, the social and the planetary limited ecological spheres



Source: Own representation.

The economic sphere has to be analyzed at a regional or individual country level. The single countries are economically interconnected with one another through the circulation of labour and capital, as well as through the trade of goods. Gaining an overview of trade is extremely important because what a country takes from the environment and what a country emits into the environment can only say little about the global ecological effects of the economic activities of that particular country, if it imports goods causing heavy environmental impact abroad. In the case of an isolated observation of one single country, the impacts caused by foreign trade must be taken into account.

(3) The third way in which the socio-economic system uses the environment consists of the fact that the environment provides services such as the cleaning of water and air and recreation for people. As a whole, the extraction of raw materials and the returning of emissions negatively affect the service function of the planetary ecosystem – at least starting from a certain order of magnitude. Moreover, certain system properties, such as climatic conditions or the chemical properties of seas and soils, or the preparation of a new gene pool, which is only possible thanks to biodiversity, are to be named to this respect. These are indispensable prerequisites for the growth of plants, for the life of animals and for the wellbeing of people. Summing it all up, this is what is called the service function of the environment for the socio-economic system.

The schematic representation of basic structures of the positive model makes it clear that the quantities that characterize the economic and social dimension of a welfare concept (including participation, human capital, health, the supply of goods, economic capital), are not independent of each other; on the contrary, they interact with each other. The activities of the socio-economic system lead to disruptions in the planet's natural capital (biodiversity, climate, acidification of the seas, etc.), which then cause, as a feedback, changes in the services provided by nature to the socio-economic system, thus affecting the social and economic dimension of welfare.[2]

The basic system relationships from an individual country perspective

After deriving the fundamental structures of a sustainable welfare model from a global perspective we now focus on the description of crucial "real word" interdependencies among the economy, the environment and society. The description will be centered on the national country level, although the global context will be taken into consideration, too. Only a resolute analysis of political action recommendations and measures in an overall context allows a reliable assessment of their various economic, ecological and

[2] Science has usually turned to this task by dividing its work by discipline: the science of ecosystems has worked on the development of ecosystem models; economists have developed more or less detailed socio-economic models which now also explain the withdrawals from nature and the emissions into nature as "pressures" for the situation of nature. So far, however, there have only been isolated attempts at linking a detailed ecosystem model with a socio-economic model. On a global level, such attempts have so far meant abandoning the depiction of complexity (cf. UNEP 2011). An acceptable kind of integrated modelling was achieved with the IMAGE model (cf. Bouwman et al., 2006) and in linking the two global models GINFORS (economiy and environment) and LPJmL (ecosystem) (cf. Meyer, Distelkamp and Beringer 2015).

social effects. This is particularly important for highly industrialized and globalized countries like Germany, France or China, which produce their wealth, to a very large extent, in the international competition with complex goods and services.

From the Standard Model of Macroeconomics to the Fundamental Environmental Economic Model

Starting from the standard model of macroeconomics which shows the central relationships between goods, capital and labour markets at the aggregate level without distinguishing any details in sector industries (grey marked area within figure 2), we begin the derivation of a sustainable welfare model at the national level, in which the central economic interdependences gradually extend to include ecological and social interrelated effects.

The yearly published National Accounts results are the starting point for an empirically founded modelling of all macro-economic interrelations. In the grey marked area in the middle of figure 2 you can find the activities of the goods market with its circulation of goods, money and income. The black arrows represent the money flows flowing in a certain period of time among the actors of the economic process. Consumers receive an income from producers for the use of labour and of capital and must pay a part of it to the state as fees and taxes. Moreover, consumers receive a transfer income from the state in the form of benefits from social insurance. Consumers use the available income for consumption, and what is left after consumption constitutes savings.

Producers achieve their turnover from the sales of consumer and investment goods, as well as from the exports to other countries, countered by payments abroad for imports. Producers pay income to consumers as well as taxes and fees to the state, from which they receive subsidies in turn.

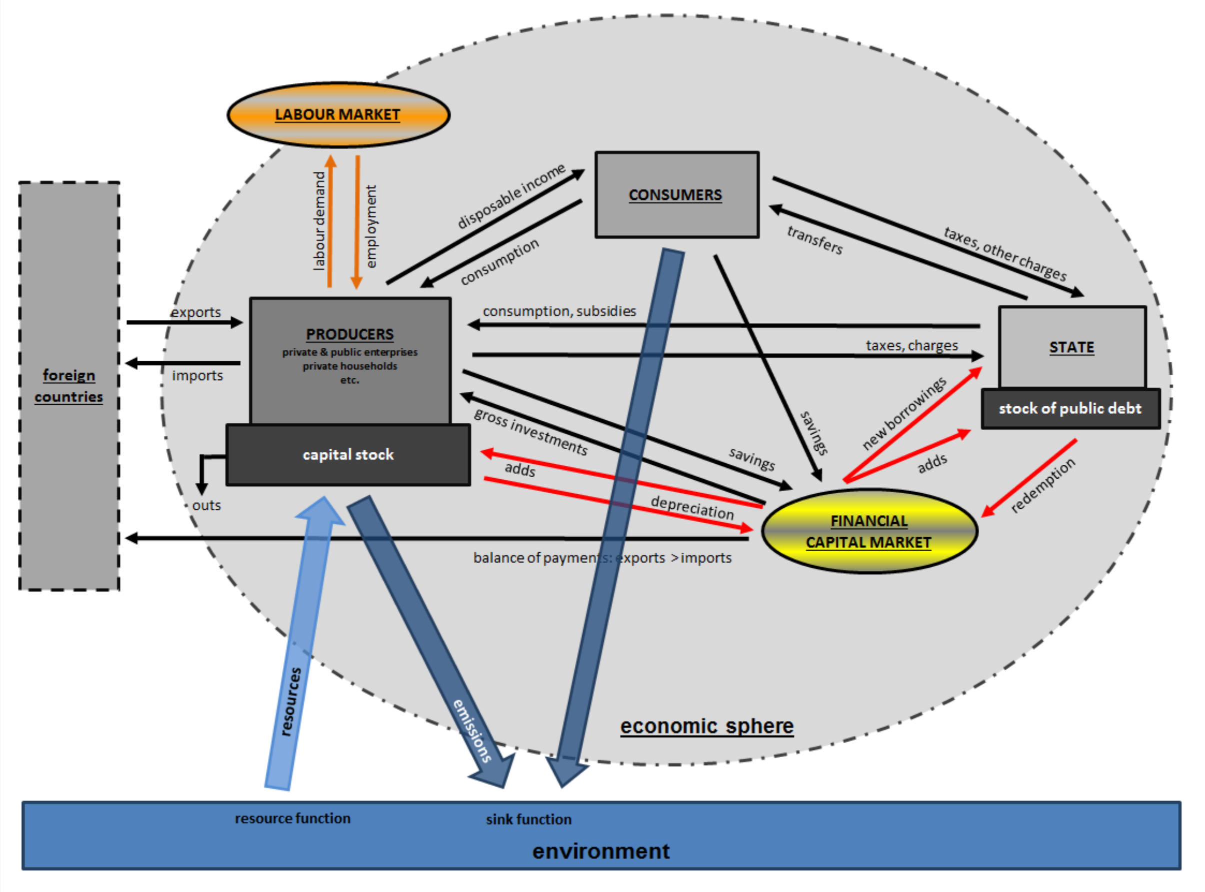
Within this simple model of macroeconomics, the consumers' savings are the central component of supply on the capital market, as the other actors, i.e. the producers and the state, usually demand capital for investments. In Germany, for instance, foreign countries have also been capital demanders for some time because Germany has been achieving a strong surplus from trade in goods for years. If the exchange rate is built on equilibrium on the currency market, then trade surplus must correspond to net capital export, which is represented in the figure as the outflow from the capital market towards other countries, thus as the capital demand of foreign countries.

Within the simple macroeconomic standard model, the analysis of economic-ecological issues is not possible because the ecological repercussions of economic activities are not taken into account. Both the resource function and the sink function of the environment for the economic system are ignored (see fig. 1). However, this dilemma can be overcome through the explicit inclusion of the physical material flows connected with the monetary money flows, as they are usually represented in the

Economic and Environmental Accounts published by the National Statistical Institutes. In the broadened economic environmental model, shown in figure 2, the drawing of resources from the environment in the form of energy (i.e. wind, sun, water power) and materials (amongst others fossil fuel, metals, non-metal minerals and biomass) are consistently represented, since they are transformed into goods through the use of energy, labour and capital. Producers extract raw materials from the environment and discard the waste and pollutants generated during the production processes into the environment. At least some of the waste material flow can be reduced through recycling. Particularly in the area of metals, but also with regards to building materials and to other non-metallic minerals, there is a considerable potential already being used, at least in part to higher the resource efficiency.

Private households, as consumers, do not produce any goods and therefore they do not take any raw materials from the environment but, in spite of this, they release waste material and harmful substances through the consumption processes as it is the case, for instance, while driving a car or heating home.

Figure 2: The fundamental structure of an environmental economic model



Source: Own representation.

At the same time, an overall analysis of the repercussions of the economic circulation of a country on the ecological metabolism requires an overall representation of the diverse interrelations in production technology among the different economic domains or production domains of the national economy, as well as of the components of final demand (consumption, investments and exports). The very different resource and emission intensities of the various industries can be correctly represented through a dual inclusion of the physical material flows accompanying the related money flows in the form of resources extracted and emissions discarded.

In the course of a broader environmental economic analysis it is necessary to consider the various value creation chains and their dependence on international trade both in imports and exports in the inter-sectorial context on the whole. The results of the Input-Output calculation of the National Statistical Institutes represent the starting point for an empirically founded modelling of the described sectorial interrelations. Instead of insisting on the macro-economic aggregate level, a sectorial differentiation with regard to individual product and industry groups, and a differentiation among the different types of income, are introduced into the broadened model of figure 2, following below.

In the broader environmental economic model the production activity of the producers encompasses all production activities within the national economy, i.e. of government-owned, public and private companies represented in the detailed sectorial level, of private households and of the state. In this way, the “state” accounts merely for the distribution and redistribution of income through taxes, fees and transfers, as well as through its own debt, while its production activity is considered as an independent activity on the producers’ side. “Private households” take part in the economic process as consumers, or as employers’ and employees’ households, as beneficiaries of benefits or as suppliers in the labour and capital market. Their production activity is considered in the item household production as an independent activity on the producers’ side, too.

The broadened model of figure 2 shows in which way two important parameters are influenced by flows. It is the case of the stock of state debt (state debt) and of the capital stock of producers. The latter encompasses the stock of real capital (the stock of capital assets of companies, public infrastructures, the patrimony used by private households) and human capital.

Including state debts is indispensable, since the state, in the fulfilment of its tasks, defined in the political process, usually spends more than it receives through taxes and fees. This new indebtedness is financed by means of the capital market (new borrowings) and, on one hand, it enhances the stock of debts (adds). On the other hand, this state debt also extinguishes when credits received are paid back (redemption).

Besides foreign countries and the state, investors represent the most important group of capital demanders: Because of the dual form of investments, they lead not only to a widening of production (demand effect) but also to an increase in the capital stock (stock effect). During an investment activity, for instance, in the purchase of a machine, two things can happen: On one hand, the mechanical engineering industry enhances its business volume and, on the other hand, an increase in capital stock takes place in the industry which bought the machine.

From the Fundamental Environmental Economic Model to a Sustainable Welfare Model

In figure 3, following below, the social sphere, which was added to the model and underlined in yellow, represents the whole social environment of consumers, the labor market as well as the human and social capital at the national level. The economic sphere, or the economic process, is included in the figure and underlined in grey. Together, they represent the socio-economic system at the national level.

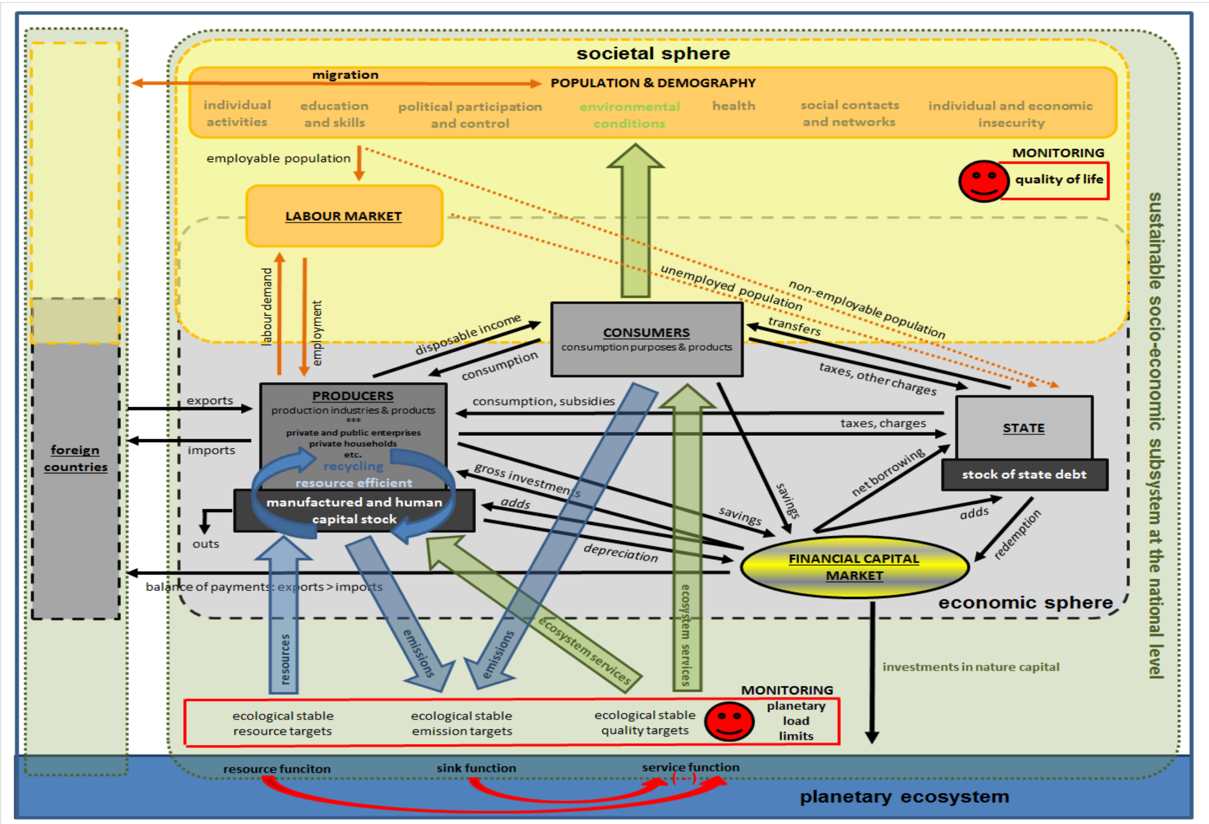
In opposition to the "monetarily" determined economic sphere, in the broadened socio-economic system the social sphere can be described more adequately through other quantitative indicators (amongst others population, number of employees and labor volume) and qualitative indicators (amongst others health and education) concerning the quality of life and social participation. This broadened model also takes account of some important demographic aspects which are relevant in the analysis of future developments. Population related migration activities among the countries of the global sustainable welfare model are depicted, too.

Within the broadened model, the labor market is explicitly included in the analysis. In the labor market, the labor supply provided by the population able to work and the labor demand provided by entrepreneurs encounter each other. Labor supply is determined by demographic development, by the level of wages and by many socio-economic factors. The number of the unemployed results residually in the model and influences the expenditures of social insurances and of the state, which are also depicted in the model in terms of income redistribution.

A fundamental requirement for labor supply is a certain health condition, which is strongly influenced by the health care system as well as by the environmental and the working conditions. Furthermore, education, the involvement in a partnership and the safety of this relationship also play an important role. Labor demand is mainly determined by production developments, by the level of wages and by technological development.

The extent to which labor supply and labor demand can be coordinated depends on the distribution of companies and of households in the area of the economic region, and mainly on the matching of the supplied quality with the demanded one. In this context, two dimensions are to be distinguished: the professional skills and the quality of education. For the welfare of a country, it is of decisive importance that this matching is achieved, so that the largest possible part of the population can participate in the economic development. Moreover, a faulty coordination on the labor market always implies a higher redistribution of income and consequently higher burdens for people in employment.

Figure 3 : Key structures of a planetary limited sustainable welfare model



Source: Own representation.

In the expansions of the model the limitedness of natural resources and the quality of the environment are not represented explicitly. In the broadened model of figure 3 the planetary ecosystem is also indicated with its limits (outer border highlighted in blue). Against the background of planetary load limits, the model, besides the resource function and the sink function of the environment, also considers its service function. Producers use the service performances of the environment (water, soils, air, features of the ecosystems, i.e. the climate). Consumers use the service performances of the environment in a particular way because, besides all features which are important for companies as well, they use the environment for leisure and recreation, too.

In the broadened model it is shown that both the extraction of raw materials and the discarding of emissions, at least above a certain order of magnitude, has a negative impact on the service function of the planetary ecosystem, which, in turn, causes negative feedback within the socio-economic subsystem.

Sustainability monitoring within a sustainable welfare model

Figure 3 also depicts the main features of the environmental policy for the national level. In the drafted sustainable welfare model the set-up of the environmental, economic and social policy goals are achieved in a frame of ecological goals, i.e. there is a maximization of welfare under the secondary condition that all ecological goals previously defined are achieved. The latter have a scientific background and are agreed in the political dialogue among stakeholders. They derive from the more general goal of the preservation of the natural basis for life and depend on planetary load limits in such a way that the functional capability of providing the service performances indispensable for life can be preserved for the future. The compliance with the ecological targets previously defined is systematically monitored in the course of a regular social monitoring for the various ecological target areas. [3]

Central sets of effects within the sustainable welfare model

In order to avoid the emission of pollutants and waste, environmental policies can address private households and companies directly. For the successful implementation of such a political strategy within a sustainable welfare model of environmental policy, it would be required to know exactly with what intensity the environment is affected, by what consumption activities and by the production of what goods. To gain a deeper comprehension of all this, the economic context represented in figure 3 is further decomposed into "producers" and "consumers" against the background of the load limits of the planetary ecosystem.

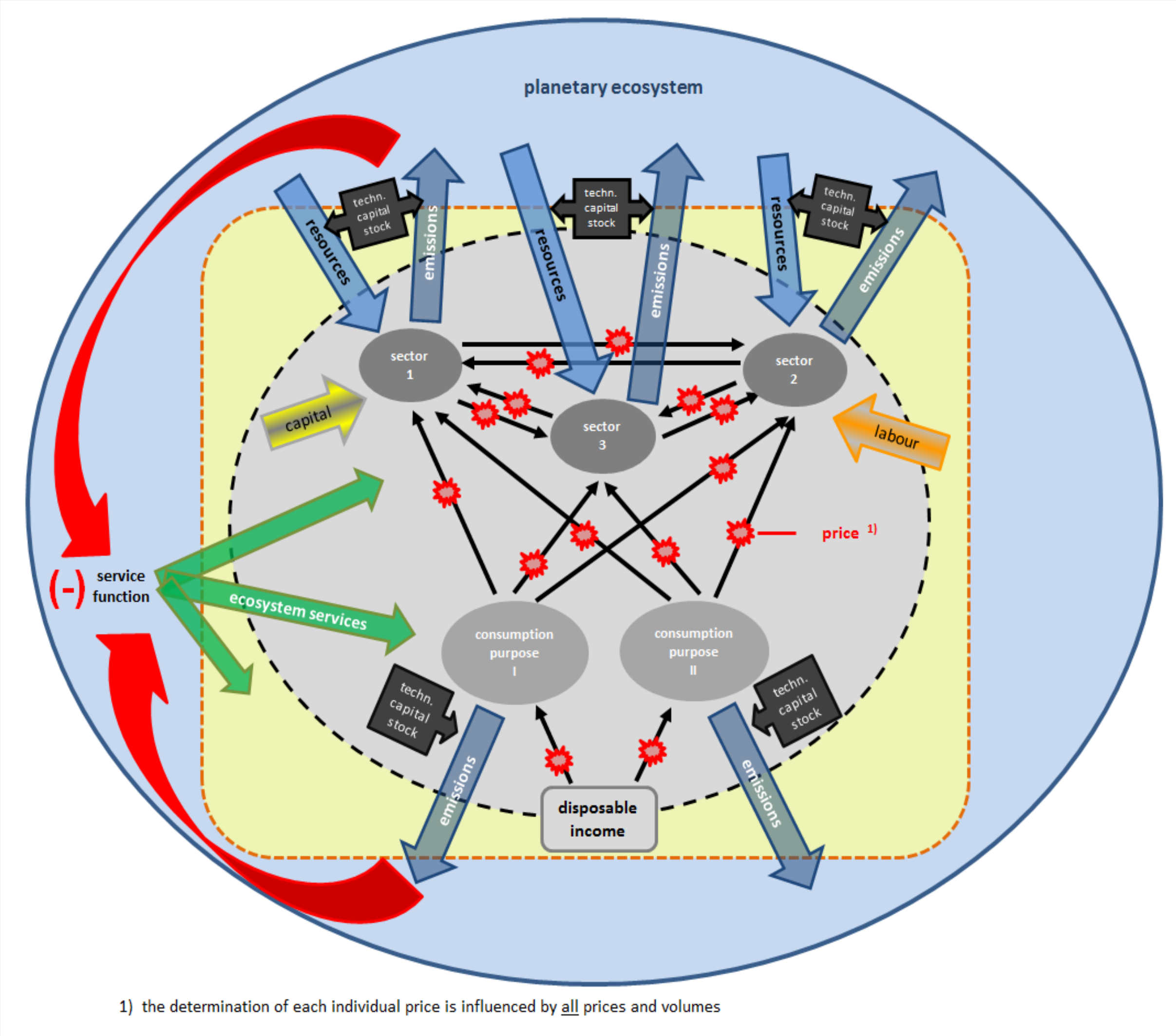
In figure 4, starting from the decisions of private households concerning the use of their income, the economic consumption process of the households is brought in relationship with the production process of enterprises and with the physical metabolism of the planetary ecosystem. Prices play a central role here, as they coordinate the decisions of all market actors and thus the interactions between supply and demand on all markets.

Private households decide first of all about the use of their income with regard to the various purposes of use in consumption. Their choices depend on their needs and on the prices related to the different purposes of use. As an example, in the following paragraphs the consumption category I will indicate the purpose of use "Mobility" and the consumption category II "Home". The decision to spend more for one's home if possible obviously depends, besides several social factors, on the prices that must be paid for home and for mobility. If mobility becomes relatively more expensive, then some consumers will decide to move to a more central flat in order to reduce their

[3] For this purpose, for example, the accounting approaches developed for an improved welfare measurement would be consistent with the model structures of the proposed global impact assessment model (World Bank 2011, Diefenbacher, Zieschank, Held and Rodenhäuser 2013, Lutz, Zieschank and Drosdowski 2015, Distelkamp and Meyer, 2016).

mobility costs. Such decisions affect households in quantity-based parameters, which are meant to be adjusted for prices.

Figure 4 : On the meaning of prices in a sustainable welfare model of environmental policy



Source: Own representation

Apparently, the single purposes of use in consumption are related to different consumer goods, which may, to some extent, differ considerably from each other in the production technique. So, for instance, "Mobility" is guaranteed partly by public transport, but predominantly by private cars. According to their consumption decisions, private households buy durable consumer goods (cars), advance performances (fuel) and service performances (public transport). The composition of this bundle of goods is determined by long-term habits and by the prices of goods. If, for instance, fuel becomes relatively more expensive, consumers will increase their demand for public transport services. This simple example shows that even little changes in the consumption demand related to the purpose of use could lead to remarkable changes in the consumption demand related to goods. The composition of the bundle of consumer goods related to the purpose of use also has a significant influence on the emissions caused by the consumption of mobility. Moreover, emissions are also influenced by the technical features (like for example, average consumption or pollutant emission of cars per kilometre) of the used durable consumer goods, i.e. of the capital stock of private households.

The demand of consumer goods influences the production of these goods. This is indicated, in a simplified way, in figure 4 showing a three-sector economy. At the production level, a filigree net of delivery relationships determines the outcome on the whole. If households buy more cars and therefore more cars are produced, then the car industry increases its demand of sheet metal, of tyres and services. These delivery relationships are not fixed, since the prices of goods play a role here as well.

Within the production process the use of material can be chosen relatively freely by enterprises. First of all, the question arises whether they produce themselves the goods demanded by consumers or if they purchase advance performances from other companies. At industry level this is the question of the structural organization of production, which could be explained with the example of the car industry: Are the motor and the car body entirely produced in the domestic industry, or are there pre-fabricated parts bought from foreign countries that are finally only assembled in the home country? However, independently from the origin of the material there arises the question as to what amount of material and what material the final good of the analyzed industry should contain. This often depends on the product design that is partly determined by the desires of consumers, which also include a considerable influence on the part of producers. Does the car have a steel, aluminium or carbon fiber car body? What requirements regarding the solidity of the car body must be met? Does the car industry mainly produce lighter or heavier, larger or smaller cars?

At every single production level in this multi-level production process the use of material can be decreased, which reduces the raw material consumption at the first level, at which natural mineral ore, non-metallic minerals, biomass and fossil fuels are either directly extracted from nature by particular branches of the economy or imported. At the following level, at which steel and nonferrous metals are produced from natural mineral ores, building materials and industrial minerals are produced from non-metallic minerals, the consumption of raw materials can surely be diminished through an efficiency enhancement of the processes. However, the most important contribution to this should be achieved through the recycling of secondary materials. A similar consideration applies to the consumption of fossil fuels which can be replaced by renewable energies. A lower consumption of raw materials, on the whole, also reduces the emission of waste and pollutants into the environment and therefore it has a positive impact on the service function of the planetary ecosystem, too. This is sensible for health reasons and finally also for economic reasons because, in order to preserve the quality of ecosystem services, above a certain load limit both consumers and producers must face considerable "reparation" expenses and/or adjust their consumption and production patterns, which would affect economic and ecological parameters, in turn.

The production of goods obviously determines also the use of both so-called primary factors labor and capital. Both production factors stay in a substitution relationship: more production can be achieved through more labor and/or through more capital. Technical progress always continues to make new production processes available. Whether the latter are applied or not, it depends on the profitability of the investments required. The cost of wages and the size of the outlet markets play an important role in this context.

Prices, which apparently have a large stake in the regulation of these complex processes, are represented only as given quantities for reasons of clarity. Therefore, it seems appropriate to provide a brief explanation on what determines them. Generally speaking, two theoretical approaches can be distinguished:

- The neoclassical approach of perfect competition assumes for every sector the existence of a production function describing the interrelation of all inputs (labor, capital, advance performances) with the production quantity. Under the assumption that enterprises maximize their profit, a supply function (marginal cost function) can be determined. Prices are then defined in such a way that the supplied quantity perfectly equals the demanded quantity. This is what we call a competitive market balance.
- The alternative to this presupposes that enterprises practice mark-up pricing. They determine the costs incurring in the production process per unit of goods produced and they set the price in such a way as to achieve the desired profit per unit.

Whichever of the two economic theoretical approaches we adopt, all prices and all quantities are taken into account in the determination of every single price in any case.[4] This interdependency in market pricing is graphically not representable anymore, not even in the very simple case of figure 4, showing an economy with three sectors (producers) and one consumer, who merely decides between two alternative bundles of consumption in the use of his income. In spite of this, the interdependency must necessarily be included in the interpretation in the graphic.

The considerations mentioned above show that the assessment of the effect of a measure of environmental policy on the emissions of pollutants, on the consumption of resources, on ecosystem services, employment and welfare in a world with planetary load limits cannot be evaluated through deep pondering thoughts alone. To this regard, one should also consider that we just excluded the international context

[4] A detailed theoretical discussion concerning the stickiness of prices due to market imperfections in a Neokeynesian and Neoclassical macro-econometric modelling framework is given by Meyer and Ahlert (2016).

for simplification. In addition, it must also be taken into account that the amount of production of a specific good depends on the imports of competing goods and on the competitive position on the relevant foreign market. Both exports and imports largely depend on the relationships between the relevant home price and the prices abroad. If we do not use complex computable models, having the necessary levels of articulation and representing the control mechanisms on the overall circulation, price relationships and the technological context, we will achieve incomprehensible and questionable results.

Economic growth and the use of capital

Up to now we considered the socio-economic system at a certain time and we analyzed the interdependencies given in the system from this perspective. In the discussion, a central role is played by economic growth, understood as a process of on-going enhancement of the absolute magnitude of the production of the whole economy.[5] Which system features must be considered in addition?

Market economies generate economic growth

Market economies are locally controlled by the competition of enterprises. In the static perspective of the general equilibrium theory the balance of the competitive market with profitless production is the result of competition. Helmstädter (1986) emphasized that the static point of view in the context of the analysis of economic growth is misleading, because profitless production is to be found in the absence of technical progress only.

According to him, it rather depends on the analysis of the dynamic effects of competition in this context. Building on Schumpeter (1909), Helmstädter talks about the oncoming competition of innovators which produces additional profits through the introduction of new products and production processes, and about the following competition of imitators which tries again to smooth out these profits. At every point of time, thus, there is a profit gap and the width of this gap between the suppliers is a measure of the intensity of technical progress generated by competition. The enterprises are obliged to take part in this process either as innovators or as imitators if they do not want to risk their decadence. Other explanations for the endogenous character of technical progress can be also found in the more recent literature on the theories of growth (Romer, 1986, Romer, 1990, Aghion and Howitt, 1992).

Technical progress primarily addresses to the production factor labor, since it reduces the use of labor per unit of production, that is to say it increases its reciprocal value: labor productivity. Furthermore, when a national economy does not use its income entirely, but it saves a part of its income and adds it to the capital stock, then some essential prerequisites for a durable growth are met, in the sense that the production

[5] Of course, the demographic development also influences the overall production level. This can possibly have the effect that growth in absolute quantities falls apart from growth in per cap sizes.

potential is increased. This additional potential is also completely exhausted when all savings are used as demand of investment goods in the capital market. That part of the income which does not represent the demand of consumer goods (savings) corresponds to the demand of investment goods. The value of the demand of goods corresponds to the income and thus to the total value of the finished products which are produced. If this condition of equilibrium is given, then such a market economy grows. At least, there is a growth trend. To what extent the respective increase in the production potential is really exploited depends amongst other things on the developments on the capital market.

Obviously, the process of transfer of savings towards the demand of investment goods is of decisive importance for the stability of this process. For this reason, in the following paragraph the developments in the capital market will be considered in a more detailed way.

On the function of the capital market

At the beginning of this chapter it was already mentioned that the savings of households are the central components of supply on the capital market. At least in Germany, all other actors, the state, producers and foreign countries, generally demand capital (cf. figure 2).[6]

The so called financial intermediaries (banks, insurances, funds etc.) carry out the coordination of supply and demand in the capital market. The Central Bank is involved in this process; being the bank of other banks, it provides money to them per credit. At equilibrium, as depicted in the previous figure, private savings correspond to the sum of investments, new indebtedness (net borrowing) of the state and capital export to foreign countries. The system can also evolve differently from this scheme, at least temporarily. Financial intermediaries take the savings from households; in addition, they can also go into debt with the central bank or with one another. Thus, in a speculative overheating, the receivables and debts of the financial intermediaries can be clearly set apart from the development of savings. This affects the goods markets through the circular flow relationship: in such processes the investments of enterprises rise and increase the demand of goods, production and the income of households which, in turn, expand their consumption, in so doing, the demand of goods, leading to rising production but also to higher prices. In commodity markets, the rising production on one hand, but also, on the other hand, the direct speculative demand of financial intermediaries, lead to a dramatic rise in prices, as it was observed at the beginning of his decade for oil, metals and food items, which, in turn, has considerable negative effects on the real economy. But it is mainly the rise in food

[6] For companies this is, of course, complementary to the fact that they finance a large part of their investments through retained earnings, that is, from the cash flow (Brearley and Myers, 1996).

prices which is extremely problematic, with regard to welfare, as it affects poor people at national as well as at international level.

Such a speculative development in the capital market can trigger off a crash for many reasons: in 2008 it was loan defaults in investments abroad which caused, together with the subprime crisis in the USA, enormous holes in the balance sheets of financial intermediaries. The Central Bank can also trigger off such a development, when it reduces the credit volume because of price increases and thereby it inverts the expectations of investors; otherwise, it can also be the result of a mere chain reaction, which is determined by few people, who recognize that the boom cannot last forever.

For the welfare of a country, it is extremely important to avoid such crises: in phases of speculative expansion, capital is focused on a kind of use for which it is not required permanently. In crashes capital is destroyed. The whole process usually leads to considerable redistributions of income and wealth between well informed and badly informed investors. In hectic movements in the capital market, investments in natural capital (for instance, forestation activities) have a lower probability of fulfilment. Speculative movements in financial markets spread more and more on commodity markets, including food items, a situation with which developing countries cannot cope.

It is required to carry out an observation making distinctions among the different industries with regard to real investments, as the capital invested in a given industry is usually immobile and cannot be used elsewhere in the national economy. For instance, an assembly line with welding robots is so specifically adapted to the features of a given industry that it can be used only there, for example in the car industry. This largely applies to infrastructures, while real estates can rather be used in different ways. This immobility of real capital causes path dependencies in the economic system on the whole, and it is extremely important to take them into account for an adequate understanding of environmental economic problems.

Implications for a Sustainable Welfare Model

As a consequence of the set of interrelated effects between economic growth and the use of capital elucidated in this subchapter about market economies, within the illustrated sustainable welfare model the growth question is still open. The maximization of welfare under the secondary condition (dominance) of the achievement of environmental goals can implicate growth, constancy, but also reduction of the gross domestic product. On the one hand, the sign and the strength of growth are determined by the weighing of the social components of welfare and, on the other hand, they are also defined by the shaping of the environmental measures and instruments which are applied in a sustainable welfare concept (for conceptual details see also Ahlert et al. 2014) Their optimal shaping decides whether and to what extent growth arises within a sustainable welfare model.[7] Concepts of an economy with marginal growth rates or even "Zero-Growth" Economy (Jackson, 2009) arouse dramatic fears among economists with a neoclassical background, as the lack of quantitative growth carries in itself the danger of an incalculable collapse as well as of social and democratic instability. However, from the ecological point of view, one must see that, even in the case of zero growth without an enhancement of energy and resource efficiency, the consequent waste and emission flows, the intensive utilizations of land, of natural resources and of ecosystems, can go on constantly and add themselves to the environmental impact accumulated so far. Against this background, the possibility drawn by Victor (2008) of a "Low Growth"- growth path for Canada represents an interesting alternative, since it faces politics with the challenge of dealing with poverty, state indebtedness and the employment rate, not only through economic growth, but also by launching tightly focused and specialized programs.[8] Similar considerations of a slowly rising national economy were made in a study for Austria with the complex environmental economic model called e3.at (Stocker et al., 2011).

Creation and Distribution of Income

Incomes derive from the production of goods and services in private, public or government-owned companies. The value creation of a company is basically the difference between the business volume of the company (more exactly the production value), which is left in the company after the deduction of taxes on goods (value-added tax etc.), and the value of the pre-products that the company used. By deducting from value creation the taxes depending on the production activity and the depreciation applied for the wearing out of investments, we can find the primary incomes which are made up of the employees' remuneration and the profit of the company.

The employees' remuneration is given by the employment numbers of the company and by the agreed wages. The development of wages depends, on one hand, on the overall economic situation in the labour market and, on the other hand, on sector-specific, and also mainly on profession-specific developments. The profit is actually a residual amount, which can be interpreted as the income of the production factor capital. The splitting up of primary incomes between labour and capital is also called functional income distribution. Therefore, it is important to take it into account in the analysis of environmental economic issues, since the amount and the development of labour income is a first determinant of participation of dependent employees in economic development. The resulting scenario is incomplete, though, because within

---

[7] In a project for the Anglo-German Foundation, the models E3ME and GINFORS were applied to examine the possibilities and effects of a comprehensive ecological tax reform in Europe with a view to international competition. (Ekins and Speck, 2011, Barker and al., 2011).

[8] The study is under the methodological reservation that the model-based results must be questioned because of the very simple structure of the underlying low-growth model, which neglects both global economic and interindustry relationships as well as price effects.

labor income, but also within profit, there remain considerable differences in the amount of that income. Therefore, it makes sense to consider a second dimension of income distribution, in which the amount of the total incomes belonging to households (profits + labor incomes + earnings from properties) are classified according to income classes. This is what is called personal income distribution.[9] Its social dimension even gets clearer if it is divided in sub-classes (income quintiles, socio-economic types of household).

Jeopardising welfare through defensive costs and rebound effects

Those costs which must be incurred in order to face losses in terms of economic, natural or social capital (a. o. the relief of old damage, renaturing, rehabilitation measures after accidents) are referred to as defensive costs. In the traditional economic approaches they are considered as parts of the economic performance and they go into the general economic indices with a positive value. In the frame of this concept, on the contrary, we notice a consistent, welfare conform evidence of the jeopardising of welfare through defensive costs. Similarly, this is true for rebound effects. They consist in the fact that efficiency gains (e.g. through an increase in material and energy efficiency), which, in a way, should contribute to a partial decoupling of economic growth and environmental impact, are reduced by quantitative growth as a consequence of budget relief. In a sustainable welfare model, the complex context of resource consumption, efficiency measures, price effects and income effects must be fully reproduced.

From conceptual to practical modelling: Chances of sustainable welfare models in environmental economic consultation

The sustainable welfare model drafted above in its fundamental conceptual structures, in the case of an empirically funded, computer assisted application, allows an evaluation of the effects of the most diverse measures of environmental policy on the environmental goals, on the economic and on the social system. In principle, the assessment of impacts of policy measures and instruments within the so-called "green transformation" and sustainable development debate should be carried out on the basis of empirically validated model interrelations. By doing so it would be possible to choose the one policy, with its underlying policy mix, which achieves environmental goals and increases social welfare. To this purpose, we need models with structures which have been derived through the application of processes of econometric statistics. In the existing models there are still some deficits in the

[9] The distributional effects of the German energy transition program have been analyzed systematically by Lutz and Breitschopf (2016).

representation of the social system. Nonetheless, we are able to deal with gigantic model systems although the models are nonlinear, dynamic and highly interdependent.

The multiregional macro-econometric input-output model GINFORS

For instance, the global multi-regional input-output simulation model GINFORS even uses several hundreds of thousands of equations (cf. Meyer et al. 2013c). It permits wide-ranging ex ante as well as ex post simulation studies, particularly on globally-relevant topics in areas such as global developments and resource use. It has been under development since 1995. The current GINFORS3 version of the model is the first version of GINFORS to be based on a time series of completely harmonized national supply and use tables. The corresponding source data set, which also includes environment and energy-related data, was published for the first time in 2012 as part of the World Input-Output Database Project (see http://www.wiod.org/). The model also makes uses of United Nations Statistics Division population and system of national accounts data and International Monetary Fund financial data (e.g. public debt).

GINFORS can be divided into four interlinked logical modules. The centerpiece is a bilateral trade module which models exports and imports of 59 goods and services between 38 countries (the EU-27 countries, Russia, Turkey, Brazil, Canada, Mexico, the United States, China, India, Japan, Korea and Australia) and a 'rest of the world' region. The trade model incorporates import and export prices by goods category from each country. It also provides export and import prices to all other countries.

The share of trade for individual goods categories depends on price changes and technical trends. If, for example, car prices in Germany in US dollars rise faster than in the US, German car makers' market share in the US falls and German imports of US vehicles rise.

A very detailed model of the socioeconomic system is chosen for all 38 countries. Production, trade and use interdependencies are modelled in an input-output system broken down into 59 goods categories and consistently supplemented by effects on employment. Projections are also made for developments in the system of national accounts for the private households and private non-profit organizations, business, state and overseas sectors. As well as many details, this also allows changes in disposable income and financial balance to be examined for each sector. Additionally, global environmental interdependencies are comprehensively modelled via an energy-emissions and a resources module.

The comprehensive modelling approach maps global interrelationships between consumers, producers and investors. It accounts for imperfect markets and limited rationality of agents and indicates the complex international feedbacks from structural changes in individual countries or changes in international trade patterns. The model is highly endogenous – key exogenous variables are population changes and the price of various resources[10]. GINFORS is suitable for evaluating individual policy measures intended to achieve a specific objective by a future date and for analyzing complex scenarios. The model can be used to simulate global economic growth and environmental pollution in iterations of one year through to 2050. Thus it has the characteristics of a completely integrated simulation model. The effects of national policy measures and environmental policy measures can be extensively analyzed assuming alternative global conditions; indirect international spill-over effects are modelled automatically.

It multi-annual research projects it has been applied to answer the following questions:

- What decarbonizing policy mix could be able to meet the global '2 Degrees' target until 2050? (Meyer, Meyer and Distelkam,p 2014)
- What are possible pathways to a resource-efficient and low-carbon Europe? What are the implications for the footprint indicators like the RMC (raw material consumption)? (Distelkamp and Meyer, 2016)
- Is the assumption of free combinability of alternative climatic representative concentration pathways (RCP) and shared socioeconomic pathways (SSP) reliable? (Aaheim et. al., 2015)

Conclusion

There is no alternative to a solid and comprehensive empirically based modelling unless one denies the fundamental complexity of the interactions among the economic, the ecologic and the social system. But, particularly in the case of highly developed industrialized countries with globally intertwined value creation chains, this would not be desirable in view of the worsening of ecological and social crises. Using a computer model allows reducing complexity in thinking without ignoring it. Experience shows that, in spite of the complexity of model structures, the results of simulation calculations are understandable thanks to the knowledge of the model interrelations and that can also be communicated to people without such knowledge. In view of the highly complex interrelations, using the suitable models would allow the decision makers of environmental policies to carry out a relatively consistent and rational preparation of the decisions to be made.

[10] In the just finished SimRess project (http://simress.de/) some resource prices have been endogenized in an integrated modelling framework which links the econometric GINFORS with the system dynamics WORLD model. While the GINFORS is strong in simulating demand for resources reflecting a detailed picture of global economic developments and interdependencies, it lacks endogenous information on the advancing depletion of global resource reserves. The WORLD model, on the other hand, is strong in the simulation of supply-side developments of various minerals and metals, but it relies on a comparatively simple consideration of global economic developments that have impacts on resource demand.

References

AAHEIM A., AHLERT G., MEYER M., MEYER B., ORLOV A., HEYNDRICKX C. (2015), *Integration of top-down and bottom-up analyses of adaptation to climate change in Europe - the cases of energy, transport and health.* European Community's 7th Framework Program under Grant Agreement No. 308620 (Project ToPDAd), Deliverable D3.4, Oslo.

AGHION P., HOWITT P. (1992), "A Model of Growth Through Creative Destruction", *Econometrica*, 60-2, p. 323-351.

AHLERT G., MEYER B., ZIESCHANK R., DIEFENBACHER H. (2014), «Basic Structures and Political Implications of a Sustainable Welfare Model», *Journal of Environmental Science and Engineering, A3*, p. 189-203, ISSN 1934-8932.

BARKER T., LUTZ C., MEYER B., POLLITT H., SPECK S. (2011), Modelling an ETR for Europe. In: Ekins, P. and Speck, S. [ed.]: *Environmental Tax Reform (ETR) - A Policy for Green Growth*, Oxford University Press: New York, pp. 204-235.

BOUWMAN A.F., JRAM T., KLEIN GOLDEWIJK K. (2006), *Integrated modelling of global environmental change.* An overview of IMAGE 2.4. Netherlands Environment Assessment Agency. Bilthoven, The Netherlands.

BREALEY R.A., MYERS S.C. (1996), *Principles of Corporate Finance*. McGraw-Hill Inc.

DALY H. E. (1992), *From Empty World to Full World Economics*. In: Good-land R., Daly H.E., Serafy S. El (eds), *Population, Technology and Life-style: the Transition to Sustainability*, Washington DC: Island Press, p. 23-37.

DIEFENBACHER H., ZIESCHANK R., HELD B., RODENHÄUSER D. (2013), *NWI 2.0 – Weiterentwicklung und Aktualisierung des Nationalen Wohlfahrtsindex.* Endbericht zum Vorhaben UM 10 17 907.

DISTELKAMP M., MEYER M. (2016), Quantitative Assessment of Pathways to a Resource-Efficient and Low-Carbon Europe. *GWS Discussion Paper 2016/10*, Osnabrück.

EKINS P., SPECK S. (2011), *Environmental Tax Reform (ETR). A Policy for Green Growth.* Oxford University Press.

HELMSTÄDTER E. (1986), Dynamischer Wettbewerb, Wachstum und Beschäftigung. In: Bombach G., Gahlen B., Ott A.E., *Technologischer Wandel – Analyse und Fakten*, Tübingen, S. 67-82.

JACKSON T. (2009), *Prosperity without Growth? Economics for a Finite Planet.* London: Earthscan.

LUTZ C., BREITSCHOPF B. (2016), Systematisierung der gesamtwirtschaftlichen Effekte und Verteilungswirkungen der Energiewende. *GWS Research Report 2016/1*, Osnabrück.

LUTZ C., ZIESCHANK R., DROSDOWSKI T. (2015), Measuring transformation towards a green economy in Germany. *GWS Discussion Paper 15/3*, Osnabrück.

MEYER B., AHLERT G. (2016), Imperfect Markets and the Properties of Macro-Economic-Environmental Models as Tools for Policy Evaluation. *GWS Discussion Paper 2016/9*, Osnabrück.

MEYER B., AHLERT G., ZIESCHANK R., DIEFENBACHER H. (2012), Synopse aktuell diskutierter Wohlfahrtsansätze und grüner Wachstumskonzepte. Studie I im Rahmen des Projektes "Eckpunkte eines ökologisch tragfähigen Wohlfahrtskonzepts als Grundlage für umweltpolitische Innovations- und Transformationsprozesse" für das Bundesumweltministerium, *ffu Report 03-2012*, Berlin.

MEYER B., AHLERT G., DISTELKAMP M., MEYER M. (2013c), «Macroeconomic Modelling of the Global Economy-Energy-Environment Nexus - an Overview of Recent Advancements of the Dynamic Simulation Model GINFORS», *GWS Discussion Paper 13/5*, Osnabrück.

MEYER B., AHLERT G., ZIESCHANK R., DIEFENBACHER H., NUTZINGER H. (2013a), Eckpunkte eines ökologisch tragfähigen Wohlfahrtskonzepts. Studie III im Rahmen des Projektes "Eckpunkte eines ökologisch tragfähigen Wohlfahrtskonzepts als Grundlage für umweltpolitische Innovations- und Transformationsprozesse" für das Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). *GWS Research Report 2013/1*, Osnabrück.

MEYER B., AHLERT G., ZIESCHANK R., DIEFENBACHER H., NUTZINGER H. (2013b), «Synopsis of Approaches to Welfare and of Green Growth Concepts Currently under Discussion», *GWS Discussion Paper 13/1*, Osnabrück.

MEYER B., DISTELKAMP M., BERINGER T. (2015), Report about integrated scenario interpretation: GINFORS/LPJmL results. *Deliverable 3.7a POLFREE project*, Osnabrück.

MEYER B., MEYER M., DISTELKAMP M. (2014), Macroeconomic routes to 2050. *CECILIA2050 WP3 Deliverable 3.3*, Osnabrück.

SCHUMPETER J. (1909), "On the Concept of Social Value", *The Quarterly Journal of Economics,* 23 (2), p. 213-232.

ROMER P. (1986), "Increasing Returns and Long Run Growth", *Journal of Political Economy*, vol. 94, p. 1002-37.

ROMER P. (1990), "Endogenous Technological Change", *Journal of Political Economy*, vol. 98, p. S71-S102.

STOCKER A., GROSSMANN A., WOLTER M.I., PIRGMAIER E., HINTERBERGER F. (2011), *Auswirkungen einer anhaltenden Wachstums-schwäche. Eine Szenarienanalyse.* Gutachten im Auftrag des Bundesministeriums für Arbeit, Soziales und Konsumentenschutz, Bundesministeriums für Wissenschaft und Forschung, Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft. Wien.

UNEP (2011), Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication [Green Economy Report]. Nairobi.

VICTOR P. (2008), *Managing Without Growth. Slower by Design, Not Disaster.* (Advances in ecological economics series). Cheltenham, UK.

WORLD BANK (2011), *The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium.* Environment and development, ISBN 978-0-8213-8488-6.

Understanding immmigrants' ethnic cultures and consumption behaviours within the context of sustainable development in the EU

Christina YP Ting

Swinburne University of technology, Melbourne, Australia

Climate change and increasing greenhouse gas (GHG) emissions are intertwined with sustainable development. The importance and urgency of tackling climate change is emphasised, with 'climate action' as one of the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development (United Nations, 2015). Each goal has a set of targets. Under the 'climate action' goal, the targets include integrating climate change measures into national policies, strategies and planning; improving education; raising awareness; and human and institutional capacity for climate change mitigation, adaptation, impact reduction and early warning. Anthropogenic activities are found to have an impact on environmental issues, such as climate change, GHG emissions and resource depletion (IPCC, 2013, UNFCCC, 2009). In the 21st century, the relationship between environment and consumption is also critical, as one of the SDGs is 'responsible consumption and production'. The targets for this goal focus on sustainable consumption, efficient use of natural resources, reduction in waste generation, and in particular, ensuring that 'people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature' by 2030. The targets identified in these two goals, which are 'climate action' and 'sustainable consumption and production', stress the importance of individuals' consumption behaviours and the need for governments to put in place policies that relate consumption behaviour to its impact on climate change and sustainable development. The SDGs therefore reiterate the significance of sustainable development, defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (United Nations, 2015). This paper thus focuses on households and individual consumption within the context of sustainable development.

For countries to attain sustainable development and realise the SDGs by 2030, there is a need to better understand individual consumption behaviours that align with low-carbon and low-resource consumption. Current knowledge on mitigation of resource and carbon reduction has focused on issues such as the built environment, behaviour changes, installation of resource-efficient technologies and transport infrastructures (OECD, 2011, 2012; Newton and Meyer, 2012; Newton and Newman, 2013). These studies show that the influential conventional factors on households and individual consumption levels ranged from socio-economic status, housing size and type and dwelling size and type, to conservation behaviours, adoption of resource-efficient technologies and environmental awareness. Research on sustainability practices of China-born migrants and an Australia-born group has found that their ethnic and host cultures contributed significantly to the two groups' consumption levels (Ting, 2015). The discovery that culture as an enabler plays a central role in the pursuit of sustainability living aligns with the UN's Secretary General, Ban Ki-moon's (2013) call that '(t)o mobilise people, we need to understand and embrace their culture'. Karlin et al. (2015) point out that population groups have different barriers to overcome and are motivated by different factors. The authors also stress that what works in one community might fail in another. To mobilise individuals, there is thus a need to recognise cultural differences and their influence on population groups, how these groups can contribute to sustainable development, and also their capacity to adapt to environmental change (World Population Program (IIASA) and Wittgenstein Centre for Demography and Global Human Capital, 2012). Cultural influence on population groups could play an important role among European Union (EU) countries, because of the diverse demographics and changes in population structure due to migration – both within and outside of the EU. For the EU to promote sustainable development, it is thus necessary to recognise migrants' and the host societies' differences in cultural practices regarding sustainable consumption.

The following section first discusses conventional factors that influence consumption, such as income and age. The influence of culture on consumption is also addressed. Reference is made to the Culturally and Linguistically Diverse (CALD) Index, which measures individuals' strength of connectedness to their ethnic culture (Ting, 2015). Secondly, the make-up of the EU's migrant populations is explored, followed by a discussion on the relevance of the CALD index to the EU. Recommendations are then provided for future research on the role of migrant groups and their ethnic culture on sustainable development within the EU.

Conventional factors influencing consumption

With sustainable consumption as a key target of one of the SDGs, an understanding of the factors that influence consumption will aid in countries' progress towards sustainable development and the alleviation of environmental impacts. Current research has shown that various conventional factors influence one or more consumption categories such as energy and water use, food, travel, housing, and waste generation and management (Biesiot and Noorman, 1999; Brandon and Lewis, 1999; Dey et al., 2007; Hamilton et al., 2005; OECD, 2010, 2011). These influential factors range from socio-demographics such as age and income to behavioural attributes such as conservation behaviours, adoption of resource-efficient technologies and environmental awareness. Household size and type and dwelling size and type are also factors influencing consumption. A high income is generally associated with a large home, and high energy and water use (Dey et al., 2007). Income is also found to be a key determinant of travel and types of food consumed (Carlsson-Kanyama et al., 1999; OECD, 2011; Reusswig et al., 2003). In addition, high income is associated with high GHG emissions. In a similar vein, high energy and water use and GHG emissions are generally associated with large and detached homes, since large spaces require more energy for heating and cooling (Høyer and Holden, 2001; Lutzenhiser, 1997). Income also has a positive and significant effect on both car ownership and driving distance (IEA, 1997; OECD, 2011). In relation to car ownership, gender is a factor that influences consumption. For instance, the most frequent private vehicle users were "*men, middle-aged people and those with higher incomes and education*" (OECD, 2012, p. 358). Males' travelling patterns also resulted in greater environmental impacts – 2.3 tonnes of CO2 compared with 1.5 tonnes for females (Carlsson-Kanyama et al., 1999). Age is another factor that influences consumption, such as travel, and waste management and generation. For instance, car use increased for individuals aged over 20 years old till middle age, accounting for 60 per cent of their trips, while older age groups used cars less often (NSW Department of Transport, 2001). Moreover, younger people tended to waste more compared with the older age groups.

In terms of education, though individuals with higher levels of education were more likely to practise energy conservation compared to those with lower levels of education, the reverse was true for water conservation (Gregory and Di Leo, 2003; Wilhite and Ling, 1995). Households with higher levels of education also tended to adopt more resource-efficient technologies such as solar (photovoltaic) panels, thereby reducing their households' GHG emissions. Research has also shown that home owners rather than tenants were more willing to invest in technologies such as home insulation. This difference in the level of adoption could be attributed to the split incentive issue. Homeowners benefit directly from insulation, while landlords are unlikely to install resource-efficient technologies (Shove et al., 1998; OECD, 2011). Renters also have little incentive to invest in a property that they do not own. Behavioural attributes such as the adoption of resource-efficient technologies and resource conservation behaviours also result in less resource use and GHG emissions. Additionally, these behavioural attributes are also associated with more environmental awareness (Dahlstrand and Biel, 1997; Markowitz and Doppelt, 2009). These interrelationships illustrate that individuals make conscious decisions to curb their resource consumption and waste generation, thereby reducing their total GHG emissions (Barr, 2004; Syme et al., 2000).

If the influence of conventional factors on households' and individuals' consumption is understood, governments can put in place policies to encourage people to adopt low-resource and low-carbon consumption in order to drive the country's sustainable development.

Cultural influence on consumption

To promote sustainable development in multi-cultural societies, governments not only seek to understand the influence of conventional factors on households and individuals' consumption, but also the influence of ethnic culture. Cultural influences "*most areas of our life, such as the way we should dress and what we should eat*", and in "*almost everything we do, see, feel, and believe*" (Cullen and Parboteeah, 2008, p. 46-7). The pervasiveness of culture in shaping behavior is because "*culture … consists of standards for deciding what is … what can be … what one feels about it … what to do about it, and … how to go about doing it*" (Bhawuk et al., 2009; Simpson et al., 1961, p. 522). Acculturation studies reveal that upon settling in a host society, migrants are likely to adopt elements of the host culture while retaining aspects of their ethnic culture (Berry, 2006; Phinney et al., 2006). These behavioural changes among migrants vary depending on "*the extent to which they wish to retain their ethnic culture and the extent to which they wish to become involved with the …. (host) society*" (Phinney et al., 2006, p. 72). Ting's (2015) research on the sustainability practices of China-born migrants and an Australia-born group in Melbourne, Australia, found that ethnic and host cultures make significant contributions to the two groups' consumption levels. The author drew on various indicators of acculturation and ethnic identity to create the unique Cultural and Linguistic Diversity (CALD) Index, which measures individuals' strength of connectedness with their ethnic culture. The summation of these indicators, which are listed in Table 1, made up this index.

Table 1: Measurement of CALD (Culturally and Linguistically Diverse) Index [1]

Component	Determinant	Code
Ethnicity	Country of birth (2 categories)	1=Australia 2=China-born and baby migrant 3=China-born and adolescent migrant 4=China-born and adult migrant
	Father's country of birth (open-ended question) [2]	1=Australia 2=Western country, e.g. England, Italy 3=Eastern/Asian country, e.g. India, Turkey 4=China
	Mother's country of birth (open-ended question) [2]	1=Australia 2=Western country, e.g. England, Italy 3=Eastern/Asian country, e.g. India, Turkey 4=China
Language	Language spoken at home (various categories)[2]	1=Only English 2=English and other Western language, e.g. French 3= Chinese, Cantonese and other Chinese dialects as well as English 4=Only Chinese, and/or Cantonese, other Chinese dialects
	Spoken English proficiency[4]	1=Very well 2=Well 3=Not well 4=Not at all
Religion	Religious affiliation	1=Australia-born and are Protestant, Catholic (or other

	(various categories) [2]	Western religions) 2=Australia-born and practise Chinese beliefs like Buddhism, Taoism 3=China-born and are Protestant, Catholic (or other Western religions) 4=China-born and practise Chinese beliefs like Buddhism, Taoism
Food	Food preference[3]	1=Western food only 2=Mostly Western food 3= Mostly Chinese food 4=Chinese food only
Festivals	Participated in Australian cultural activities[4]	1=Very regularly 2=Sometimes 3=Rarely 4=Not at all
	Participated in Australian community activities[4]	
Social interaction	Visit local library[4]	1=Very regularly 2=Sometimes 3=Rarely 4=Not at all
	Participated in local environmental activities[4]	
Cultural identity	Relate to Australian culture and society[4]	1= Strongly agree 2=Somewhat agree 3=Somewhat disagree 4=Strongly disagree

Note: 1. The CALD Index is calculated based on the summation of scores of the seven components. A high score reflects a stronger connectedness between China-born residents and their ethnic identity than there is to their host culture; a low score reflects a stronger connection with the host society. The continuum therefore ranges from a possible minimum score of '12' to a maximum of '48'. Reliability analysis of CALD Index shows a Cronbach alpha of 0.91. The Cronbach alpha is above 0.70, which is the agreed upon lower limit for most types of statistical analyses (Hair et al. 1995).

2. The categories were reclassified manually into four codes.

3. Diet of China-born participants was calculated based on the number of Chinese meals cooked at home out of the total number of meals in a week. Food preference of Australia-born participants was calculated based on the types of cuisine they consumed in a week.

4. There were four categories.

Source: Ting (2015)

The discovery in Ting's research (2015) that culture as an enabler plays a central role in the pursuit of sustainable living aligns with the UN's Secretary General, Ban Ki-Moon's (2013) call that '(t)o mobilise people, we need to understand and embrace their culture'. In order to mobilise individuals, there is thus a need to recognise cultural differences and their influence on population groups, how individuals can contribute to sustainable development, and their capacity to adapt to environmental change (World Population Program (IIASA) and Wittgenstein Centre for Demography and Global Human Capital, 2012). For the EU countries whose population structures are influenced by immigration, it is critical to develop an understanding of the consumption behaviours of population groups that are interspersed with migrant groups.

Migration and the EU's sustainable development

Made up of 28 member countries, the EU has a diverse population. The EU's approach to sustainable development means not only taking into consideration its diverse demographics, but also the changes in the population structure due to migration – both within and outside of the EU. Large waves of immigration occurred in the first decade of the 21st century. In 2008, 3.8 million people migrated to and between the EU-27 Member States, with 1.8 million of these being non-EU citizens (European Commission, 2013). Table 2 shows the top 10 countries of birth of immigrants, showing the diverse population groups coming from countries that are English-speaking (United States), European-language-speaking (Brazil) and non-English-speaking such as China and India.

Table 2: Top 10 countries of birth of immigrants to EU-27 Member States, 2008

Country of birth	**(1 000)**	**% (total immigrants)**
Morocco	157	8.7
China	97	5.4
India	93	5.2
Albania	81	4.4
Ukraine	80	4.4
Brazil	62	3.4
United States	61	3.4
Turkey	51	2.8
Russian Federation	50	2.8
Colombia	49	2.7

Source: Adapted from European Commission 2013

The population dynamism within the EU has added another layer of complexity to the building of sustainable societies. The EU's attempts to integrate non-EU citizens within EU societies also has to take into account the enabling of these citizens to actively participate and contribute to the EU's sustainability, as culture 'must be an overarching principle for all development efforts' (Ban 2013).

Influence of migrants' and host cultures on consumption

To promote sustainable development, it is therefore necessary for the EU to recognise differences in cultural practices between migrants and host societies alongside the conventional factors that influence individual consumption. The influence of culture on consumption was a significant finding in Ting's (2015) research in Melbourne, Australia of 133 participants – 61 China-born and 72 Australia-born. Multi-variate analyses were applied, with 14 determinants comprising 13 conventional factors and the CALD Index as independent variables, with individuals' total ecological footprint and the four component footprints (Carbon, Housing, Food and Goods and Services) as dependent variables. The results of analysis showed that participants who had large Carbon and Housing footprints and strong connectedness with Chinese culture also had less environmental awareness and less adoption of resource-efficient technologies. In addition, those with large Goods and Services footprints and strong connections with the Australian culture also had less environmental awareness. From the analysis, cultural context and environmental awareness are two significant factors.

The analysis thus found that the Australia-born group's environmental awareness was related to their high adoption of resource-efficient technologies, and to their smaller footprints, than the China-born migrants. Ting's research found that China-born migrants, who showed strong retention of Chinese culture, had large post-migration footprints due to their adoption of the Australia's high resource-intensive lifestyles. For example, some participants indicated that their homes are bigger and contain more appliances in Melbourne than when they were living in China. They also referred to their choice to drive a car rather than taking public transport as they did when travelling in China. These findings show that their increased consumption level was due to possessions acquired upon settlement in Australia, such as large dwellings and cars. These resource-intensive possessions are overt displays of migrants' success and their 'keeping up with the Joneses' in the host society. These symbolic displays are a reflection of their retention of '*mien-tzŭ*' (face), which is a Confucian concept that refers to 'a reputation achieved through getting on in life, through success and ostentation' (Hu, 1944; Zhang and Baker, 2008). These findings of Chinese and the host culture's influence on China-born migrants also illustrates the migrants' bicultural consumerism.

Current research shows that motivations for migrants' consumption behaviours in the host society vary. Ting's (2015) study shows that China-born migrants' frugality motivates them to reduce resources use at home in Australia. Research by Maller (2011) also found that a Sri Lankan migrant in Australia practised frugality through conservation behaviours. Other migrants indicated their preference to hang washing on outdoor clothes lines and in the garage rather than use an energy-intensive dryer (Maller 2011). In Sekhon's (2007) study of Indian families in Britain, Indian culture was a motivating factor. Sekhon (2007, p. 164) found that owning a BMW car reflected conspicuous consumption to express that this was "*all part of being Asian*" and also their success as migrants. For these Indians, "*(i)mmigration has meant that consumption is about achievement, symbolic possessions and status within the community*" and the host society (Sekhon, 2007, p. 166). Ting's (2015) finding thus echoes that of Sekhon (2007): that migrants retain aspects of ethnic culture while simultaneously adopting aspects of the host society. Both studies show that for migrants who moved from developing to developed countries, the factors influencing their consumption behaviours are not only conventional factors such as income, but importantly, they are also influenced by their culture. Host countries thus need to understand and identify aspects of ethnic culture that motivate or hinder migrant groups in their approach to sustainable living and resource consumption. This knowledge will better inform and enable communication and engagement by governments to encourage changes in behaviour directed towards low-carbon and low-resource consumption that aligns with the country's sustainable development framework.

Ting's (2015) research has highlighted two points: firstly, the need to increase migrants' environmental awareness of the host society and its policies and regulations towards sustainable living; and secondly, the retention of migrants' culture, which influences their post-migration consumption levels. The need to increase migrants' environmental awareness could well be due to the differences between the host's structures and lifestyles and those in the migrants' country of origin. These differences will limit migrants' choices towards alternative lower carbon and resource lifestyles (Ting, 2015). However, these dissimilarities could be overcome by exposing migrants to the host society's environment and approach to sustainable living through communications by governments, service providers and councils. This could be in the form of community education, information booklets in various languages, and continuous communication through newsletters and advertisements (Boroondara Council; Moreland Energy Foundation, 2009, 2010). In addition, the influence of culture must be part of the initiative to address migrants' consumption behaviour. Investigation is thus required to ascertain the extent of the influence of certain aspects of their culture, which may act as motivators and barriers towards sustainability attitudes and actions. By taking these two points into consideration, the move towards a dynamic and sustainable society is enabled.

The CALD Index in the context of the EU

The success of the CALD Index as a quantifiable measure in Ting's (2015) research resulted in the realisation of Jasti, Siega-Riz and Bentley's (2003, p. 2012s) proposal that "*one challenge is how to transform a cultural belief into a quantifiable variable and go beyond descriptive or ethnographic data*". The CALD Index as an effective means of gaining deeper insights into cultural influences on consumption shows the potential of its applicability across multi-cultural societies. This applicability is relevant to the EU because of its culturally-diverse population and migrant groups, who have come from European and non-European countries. Therefore, for governments within the EU to alleviate migrants' environmental impact, there is a need to target specific migrant groups, and to investigate the extent of the influence of ethnic culture on their consumption behaviours. The CALD Index can be applied for such investigations. The method by which the seven determinants of the CALD Index were derived allows the

Index to be adapted easily and applied to any migrant group, and to enable comparison with a host society. For instance, to apply the CALD Index in the context of Portugal and China-born migrants, the categories in the determinant 'ethnicity' can be altered from Australia-born to Portugal-born, while retaining the migrant's country of birth as China. In terms of language spoken, proficiency in Portuguese is used as it is the host country's national language, and for the migrants, Chinese is selected as their spoken language at home. These examples are illustrated in Table 3.

This illustration demonstrates the flexibility and adaptability of the CALD Index in measuring individuals' strength of connectedness to the ethnic culture of a migrant group in a host country within the EU. The CALD Index could thus be applied in future studies that investigate differences in consumption behaviours between a specific migrant group and a host society in the context of sustainable living. This could mobilise people from different cultures towards achieving the SDGs and sustainable development among EU member countries.

Table 3: Example of adaptability of the CALD Index to Portugal context

Component	Determinant	Code
Ethnicity	Country of birth	1=Portugal 2=China-born and baby migrant 3=China-born and adolescent migrant 4=China-born and adult migrant
	Father's country of birth	1=Portugal 2=Western country, e.g. England, Italy 3=Eastern/Asian country, e.g. India, Turkey 4=China
	Mother's country of birth	1=Portugal 2=Western country, e.g. England, Italy 3=Eastern/Asian country, e.g. India, Turkey 4=China
Language	Language spoken at home	1=Only Portuguese 2= Portuguese and other Western language, e.g. French 3= Chinese, Cantonese and other Chinese dialects as well as English 4=Only Chinese, and/or Cantonese, other Chinese dialects
	Spoken Portuguese proficiency	1=Very well 2=Well 3=Not well 4=Not at all

Source: Adapted from Ting (2015)

Conclusion

The aim of this paper was to demonstrate the importance of understanding cultural influence on consumption among the EU's diverse population. Past research has shown that migrants' consumption behaviours do not entirely reflect that of the host society. Though migrants adopt aspects of the host culture, their ethnic culture plays a critical role in influencing the dissimilarities in their consumption behaviours from those of the host society. For each EU member country to fully realise its sustainable development and the SDGs, it is important to understand the extent of the cultural influence of each migrant group. Aspects of culture can be motivators and barriers, which are challenges not only for governments to achieve sustainable development, but also for each specific migrant group in their attainment of sustainable living at household and individual levels. With these understandings, the target of the Sustainable Development Goal of 'responsible consumption and production, that "*people everywhere (to) have the relevant information and awareness for sustainable development and lifestyles in harmony with nature*" (United Nations, 2015) can be effected within the contexts of EU countries.

References

BAN K-M. (2013), « Secretary-General's remarks at General Assembly thematic debate on culture and sustainable development ». New York: Statement at General Assembly of United Nation.

BARR S. (2004), « What we buy, what we throw away and how we use our voice », Sustainable household waste management in the UK. *Sustainable Development*, 12, p. 32-44.

BERRY J. (2006), « Acculturation: A conceptual overview » in Bornstein M. and Cote L. (eds) *Acculturation and Parent-Child Relationships: Measurement and Development.* New Jersey: Laurence Erlbaum Associates Publishers, p. 13-30.

BHAWUK DPS., LANDIS D., MUNUSAMY VP. (2009), « Understanding the basics of culture» in Moodian MA. (ed) *Contemporary Leadership and Intercultural Competence: Exploring the Cross-Cultural Dynamics Within Organisations.* Thousand Oaks, California: SAGE Publications, Inc., p. 7-17.

BIESIOT W., NOORMAN KJ. (1999), « Energy requirements of household consumption: a case study of The Netherlands », *Ecological Economics* 28, p. 367-383.

BOROONDARA COUNCIL, Available at: https://www.boroondara.vic.gov.au/.

BRANDON G., LEWIS A. (1999), « Reducing household energy consumption: A qualitative and quantitative field study », *Journal of Environmental Psychology*, 19, p. 75-85.

CARLSSON-KANYAMA A., LINDEN A-L, THELANDER A. (1999), « Insights and applications gender differences in environmental impacts from patterns of transportation - A case study from Sweden », *Society & Natural Resources*, 12, p. 355-369.

CULLEN JB., PARBOTEEAH PK. (2008), *Multinational management: A strategic approach,* Mason, Ohio Thomson/South-Western.

DAHLSTRAND U., BIEL A. (1997), « Pro-environmental habits: Propensity levels in behavioral change », *Journal of Applied Social Psychology*, 27, p. 588-601.

DEY C., BERGER C., FORAN B, FORAN M., JOSKE R., LENZEN M, WOOD R. (2007), « Household environmental pressure from consumption: An Australian environmental atlas » in Birch G. (ed) *Water, wind, art and debate: How environmental concerns impact on disciplinary research*, Sydney University Press, p.280-315.

EUROPEAN COMMISSION (2013), *Statistics Explained Archive*, Luxembourg: Publications Office of the European Union.

GREGORY GD., Di LEO M. (2003) « Repeated behavior and environmental psychology: The role of personal involvement and habit formation in explaining water consumption », *Journal of Applied Social Psychology*, 33, p.1261-1296.

HAMILTON C., DENNISS R., BAKER D. (2005), *Wasteful consumption in Australia*, The Australia Institute.

HØYER KG., HOLDEN E. (2001), « Housing as basis for sustainable consumption », *International Journal of Sustainable Development*, 4, p.48-58.

HU HC. (1944), « The Chinese concepts of "Face" », *American Anthropologist*, 46, p. 45-64.

IEA (1997), *The link between energy and human activity*, International Energy Agency.

IPCC (2013), *Climate change 2013: The physical science basis. Fifth Assessment Report*, Geneva: Intergovernmental Panel on Climate Change.

JASTI S., SIEGA-RIZ AM., BENTLEY ME (2003), « Dietary supplement use in the context of health disparities: Cultural, ethnic and demographic determinants of use », *The journal of Nutrition*, 133, p. 2010S-2013S.

KARLIN B., FORD R., FRANTZ CM. (2015), « Exploring Deep Savings: A toolkit for assessing behavior-based energy interventions », *2015 Energy Program Evaluation Conference*, Long beach.

LUTZENHISER L. (1997), « Social structure, culture, and technology: Modeling the driving forces of household energy consumption » in Stern PC., Dietz T., Ruttan VW., Socolow RH. And Sweeney JL. (eds) *Environmentally significant consumption: Research directions.* Washington: National Academy Press, p. 77-91.

MALLER C. (2011), « Practices involving energy and water consumption in migrant households » in Newton PW (ed), *Urban Consumption*, p. 237-250.

MARKOWITZ EM., DOPPELT B. (2009), *Reducing greenhouse gas emissions through behavioral change*, Eugene: Climate Leadership Initiative.

MORELAND ENERGY FOUDATION(2009), *A pratical guide to reducing your carbon emissions*.

MORELAND ENERGY FOUDATION (2010), *Zero Carbon Moreland*. Available at: http://www.mefl.com.au

NEWTON PW., MEYER D. (2012), « The determinants of urban resource consumption », *Environment and Behavior*, 44, p. 107-135.

NEWTON PW. and NEWMAN P. (2013), « The Geography of solar photovoltaics (pv) and a new Low Carbon Urban Transition Theory », *Sustainability*, 5, p. 2537-2556.

NSW DEPARTMENT OF TRANSPORT (2001), *Household travel survey summary report 2001: Sydney Statistical Division*. Available at: http://www.transport.nsw.gov.au/.

OECD (2010), « Taking the car? A survey », *OECD Observer.*

OECD (2011), *Greening household behaviour: The role of public policy*, OECD.

OECD (2012), « Compact City Policies: A Comparative Assessment », in *OECD Green Growth Studies*, Paris: OECD Publishing.

PHINNEY JS., BERRY JW., VEDDER P., LIEBKIND K. (2006), « The acculturation experience: Attitudes, identities, and behaviors of immigrant youth » in Berry JW., Phinney JS., Sam DL., and Vedder P. (eds), *Immigrant youth cultural transition: Acculturation, identity, and adaptation across national contexts.* New Jersey: Lawrence Erlbaum Associates, Inc., p. 71-116.

REUSSWIG F., LOTZE-CAMPEN H., GERLINGER K. (2003), *Changing global lifestyle and consumption patterns: The case of energy and food*, Potsdam Institute for Climate Impact Research (PIK).

SEKHON YK. (2007), « 'From saris to sarongs' ethnicity and intergenerational influences on consumption among Asian Indians in the UK », *International Journal of Consumer Studies*, 31, p. 160-167.

SHOVE E., LUTZENHISER L., GUY S., HACKETT B., WILHITE H. (1998), « Energy and social systems » in Rayner S. and Malone EL. (eds), *Human Choices and Climate Change.* Columbus, Ohio: Battelle Memorial Institute, p. 291-325.

SIMPSON GG., GERARD RW., GOODENOUGH WH, INKELES A. (1961), « Comments on cultural evolution », *Daedalus*, 90, p. 514-533.

SYME GJ., NANCARROW BE., SELIGMAN C. (2000), « The evaluation of information campaigns to promote voluntary household water conservation », *Evaluation Review*, 24, p. 539-578.

TING CYP. (2015), *Towards sustainable living in Australia's multicultural society: An exploration of cultural differences in attitudes to environment and consumption,Swinburne Institute for Social Research.* Melbourne: Swinburne University of Technology.

UNFCCC (2009,) *Copenhagen Accord*.

UNITED NATIONS (2015), *Sustainable Development Goals*. Available at: https://sustainabledevelopment.un.org/sdgs

WILHITE H. and LING R. (1995), « Measured energy savings from a more informative energy bill », *Energy and Buildings*, 22, p. 145-155.

WORLD POPULATION PROGRAM (IIASA) and WITTENGENSTEIN CENTRE for DEMOGRAPHY and GLOBAL HUMAN CAPITAL. (2012), « Demographic challenges for sustainable development » In Lutz W and Butz W (eds). Wittgenstein Centre, International Institute for Applied Systems Analysis (IIASA), Austria.

ZHANG H. , BAKER G. (2008), *Think like Chinese,* Sydney: The Federation Press.

Psycho-social risks in the European policy of sustainable development

Besma HARGUEM, Habib HADJ-MABROUK

Higher Institute of Arts and Crafts of Kairouan, Tunisia
French Institute of Science and Technology of Transport, Spatial Planning, Development and Networks IFSTTAR, France

The risk management remains an essential necessity for the sustainable development of any organization. The implementation of a management system is based essentially on the identification of potential hazards, the investigation of the causes and associated hazardous elements in order to assess the level of risk and thus propose preventive measures and / or protection measures that can minimize and mitigate the consequences of a socio-economic system. In this context, and in order to ensure their current development, without compromising their future or that of individuals or local authorities, companies are now obliged to implement a comprehensive and sustainable approach to the prevention of all types of risks, technical risks, economic risks, environmental risks and occupational risks.

In the context of occupational risks, psychosocial risks (PSR) are now recognized as major subjects of occupational health within organizations. In the face of increasing psychosocial risks at work, such as burnout, bullying, or moral violence, and the associated costs, mental health problems have become a priority for organization due to the serious economic and social consequences. The organization must therefore implement appropriate health and safety prevention measures in order to maintain a satisfactory working environment. Thus, occupational health must be more than ever a social responsibility of the organization. Reducing the risks to which its employees are exposed, amounts to adding a psychosocial dimension to the conventional approach of sustainable development of organizations. Taking into account the prevention of psychosocial risks is therefore one of the pillars of Sustainable Development by considering all the social, economic and environmental dimensions in a joint and complementary way.

Psychosocial risks: the challenge of sustainable development in Europe

According to Cooper (Cooper, 2006), PSR are become a major issue for businesses due to their dramatic impact on increase in the rate of absenteeism and low employees yield. Thus, a company committed to a prevention strategy invests not only in the well-being of its employees, but also in its productivity and reputation. This new direction goes far beyond the issue of the management of PSR and the associated costs. This leads to the recognition of the crucial importance of prevention of PSR, which has negative consequences for employees but also for the entire society (Remoussenard & Ansiau, 2013). Despite the negative consequences of the PSR on health, work and the environment, which are pillars of sustainable development (Caillard, 2010), the approaches implemented are still far from being adapted to the reality on the ground (Van Wasssenhove , 2014).

In order to reinforce and rationalize the usual approaches and thus guarantee a sustainable future for organizations and individuals, it is therefore essential to revise the strategies implemented in companies through the introduction of a sustainable prevention approach in the field of occupational health (Gilles, 2014) and (Rouat & Sarnin, 2013). To reduce the costs of health insurance and prevent professional wear and tear, companies must ensure employability, promote professional equality, combat discrimination, consolidate social cohesion and participate in local development (Chopin, Deluzet & Godino, 2012).

Mrad (2013) considers that it is essential that companies evolve their management methods in terms of prevention of PSR while respecting social concerns and adopting levers of actions in a perspective of sustainable development.

According to Pigeyre (2012), in addition to the company's operating methods, strategic management must take into account how to consider the human capital of the company. Companies must therefore review their operating methods by considering employees, who may be exposed to stress and pressure at work, as the first stakeholders. Consequently, the revalorization of employees is an interesting orientation because it leads to a more humane management mode and a more sustainable economy.

This verdict, which encourages the integration of the prevention of PSR at work in the company's sustainable development strategy, was also approached in Picard's work (2006). In effect, the promotion of mental health at work and sustainable development encompass common characteristics, such as the principles of sustainability, transparency, solidarity, prevention, partnership and participation, enacted at the Rio Convention in 1992 and reaffirmed in 2002 at the Johannesburg Conference. In France, the principles of sustainability, participation and solidarity are clearly reflected in the National Agreement of 19 February 2013 on occupational health and psychosocial risks. Article 6.2 of this Agreement states that a complete and sustainable approach to developing a health and safety culture in the company, an awareness of the need for action on organizational and psychosocial and/or relational factors, information and staff participation are sought by the employer in collaboration with its partners (ANI, 2013).

Furthermore, the principles of participation and solidarity correspond, in our context, to the involvement of all stakeholders in the construction of a sustainable policy psychic health for employees (Picard, 2006). Since the French law on social modernization of 17 January 2002, mobilization and accountability of all actors in occupational health are strongly recommended. Moreover, the Agreement of 29 February 2008 on occupational health specifies that an approach to assessment and prevention of occupational risks and the monitoring of its implementation must implicate all actors in occupational health. This approach must also involve employee participation in order to achieve at a precise analysis of the risks, working conditions and constraints confronted by employees (ANI, 2008).

So as to concretize these national agreements, the National Agency for the Improvement of Working Conditions (ANACT) proposes a prevention approach based on the factors of constraints and resources to reduce the tension between the requirements of the company and those of the employees. The challenge of this approach is to explicitly engage the actors in the construction of a sustainable prevention policy, which takes into account both the health of employees and the performance of the organization (Douillet, 2013). The objective is therefore to integrate durably mental health problems in the strategic management of the company.

Concerning the principle of transparency in sustainable development, it has limitations when it is implemented in the management of mental health at work. In France, the assessment of PSR should be noted in a Single Document. Within the company, this Single Document is devoted only to Occupational Health and Safety Committee and the occupational physician. Outside the company, this document must be made available to the labor inspector, social security and external service providers specializing in occupational health and safety. The communication of this single document is thus limited only to certain actors.

However, the 3rd Occupational Health Plan 2015-2019 (PST3) encourages the collection and putting into perspective of occupational health data in order to produce an information system that is readable and accessible by all the actors involved in the implementation of an approach to preventing PSR.This analysis showed that the principles related to the prevention of PSR at work are intimately linked to certain principles of sustainable development. It is a new perspective that requires the implementation of long-term actions in a broader framework of human, social and economic goals, which allows all the actors involved to cooperate and act on the modes of operation of the company in order to meet not only the needs of the company in terms of performance but also those of individuals in terms of well-being at work. As a result, prevention of PSR is a set of concrete human investment measures for the benefit of individuals, organizations and therefore society. Occupational safety and health, and in particular psychosocial risks (PSR), are thus becoming increasingly widespread to the point where they become a problem of sustainable development not only in France but also at the level of the European Union and all its member states. In order to renew their commitment to global sustainable development policy, the European Union (EU) and its Member States underlined their commitment to work collectively to reach the 17 objectives set by the United Nations Sustainable Development By 2030, whose objective 8.8 is to ensure the protection of all workers and thus promote safety at work (United Nations, 2015).

The European Union's contribution to this Sustainable Development Program was defined by the European Commission Communication "A decent life for all: from vision to collective action", published in June 2014. Among the main challenges of this program is the quality of formal and informal employment, which includes, in particular, working conditions and health and safety at work.

In June 2014, the European Commission set out an EU strategic framework for occupational health and safety for the period 2014-2020, with three main challenges to overcome: (1) effective application of the legislation in the Member States, (2) improving the prevention of work-related diseases and (3) coping with demographic change (European Commission, 2014). In April 2016, in order to meet these challenges, the European Commission and the European Agency for Safety and Health at Work (EU-OSHA) launched a European campaign 2016-2017, entitled "Being well in the workplace Regardless of age."

The objectives of the campaign are to promote sustainable work and healthy aging, to prevent occupational diseases in a sustainable manner and thus to endow employers and workers means to manage occupational safety and health, while encouraging the exchange of information and know-how.These findings make it possible to conclude that Health and Safety at Work (HSW) is now one of the priority areas of the Community's Sustainable Development Policy of the European Union.

Psychosocial risks in the European strategy

As we have shown, in recent years there has been an important concern for occupational safety and health (OSH) and in particular the psychosocial risks in European policy. The following paragraphs describe the evolution of regulatory texts as well as OSH practices at the European Union and its Member States levels.

At European Union level

In 1989 the European Council adopted Framework Directive 89/391 on the implementation of measures to promote the improvement of the health and safety of employees at work. Since then, several Directives have been adopted by the European Union in this field and especially:

- Directive 93/104 / EC concerning certain aspects of the organization of working time;
- Directive 2000/78 / EC on equal treatment in employment and occupation;
- Directive 2002/14 / EC on the right to information and consultation of workers in the EU;

- Directive 2006/54 / EC on equal treatment for women and men in employment and occupation.

Since 2004, special attention has been paid to psychosocial risks (PSR). Two agreements have been adopted by the European Union, namely:
- European framework agreement on work-related stress of 8 October 2004, transposed in France by the National Inter-professional Agreement (NIA) of 2 July 2008 (ANI, 2008);

- European framework agreement on harassment and violence at work of 26 April 2007 transposed in France by the National Inter-professional Agreement (NIA) of 26 March 2010 (ANI, 2010).

Concepts related to occupational psychosocial risks were taken up by the first Community strategy on OSH for the period 2002-2006, which aimed at a global approach to wellbeing at work and improving of quality of work, a culture of risk prevention and building partnerships between all health and safety actors.

For the period 2007 - 2012, the Community strategy set six objectives: to put in place a modern and effective legislative framework; encourage the development and implementation of national strategies; encourage changes in behavior; face new risks; improve the monitoring of progress achieved and promote international safety and health.

To concretize these objectives, in 2009, the European Agency for Safety and Health at Work (EU-OSHA) realized out an extensive survey of companies on new and emerging risks in the public and private sectors in the 27 Member States of The European Union (ESENER, 2009).

With regard to the 3rd Community strategy on health and safety at work, in June 2014, the European Commission set out a strategic framework for the period 2014-2020, by setting several objectives, including better enforcement of legislation in the Member States and improved prevention of work-related diseases.

To this end, in October 2014 a report was produced by the European Agency for Safety and Health at Work (EU-OSHA) and the European Foundation for the Improvement of Living and Working Conditions (EUROFOUND) on the working conditions of Europeans and the prevalence of psychosocial risks at work (EU-OSHA - Eurofound, 2014). The report also analyzed the policies pursued by the Member States to combat these risks. This is the subject of the next paragraph.

At Member States levels

The EU Member States are required to transpose the European Directives into their legislative and regulatory texts. The above-mentioned 1989 Directive fixed down minimum rules for the improvement of health and safety at work, but each Member State must adapt the Community strategy to its situation.

In France

In France, the employer is subject to an obligation of safety of result concerning the physical and mental health of its workers. This is a legal obligation imposed on the employer and the general principles of which are set out in the Labor Code. Nevertheless, this legal framework is not yet stable, due to very evolving jurisprudence and still unclear regulatory provisions.

In effect, the RPS is a phenomenon still unclear (Nasse and Légeron, 2008) and yet presents everywhere, except in the Labor Code. The latter only addresses the issue of PSR in a restricted manner, either by prohibiting acts of moral harassment (Article L.1152-1 of the Labor Code) under the French Social Modernization law of 17 January 2002, either by imposing the principle of obligation of security of result of the employer (Article L. 4121-1 of the Labor Code).

However, since 2007, the prevention of occupational risks, and in particular psychosocial risks (PSR) in the workplace, has been the subject of numerous important initiatives by the public authorities as well as by employers 'and workers' organizations.

In effect, several reports were produced following the request of the public authorities and in particular:

- A report on the identification, measurement and follow-up of psychosocial risks at work was carried out at the request of the Minister of Labor (Nasse and Légeron, 2008);
- A Senate information report was produced on behalf of the Information Mission on ill-being in the Workplace and the Committee on Social Affairs (Dériot, 2010);
- An information report of the National Assembly analyzed the problem of psychosocial risks at work (Lefrand, 2011);

- A report on well-being in the workplace was produced with a view to improving psychological health conditions at work, following a request by the Prime Minister (Lachmann and al., 2010);

- A report of the college of experts on the statistical monitoring of PSR was prepared, following the recommendations of the Minister of Labor (Gollac and Bodier, 2011);

- An opinion of the Economic, Social and Environmental Council (ESEC) was drawn up by a public rapporteur on psychosocial risks (Brunet, 2013).

Furthermore, concerns about PSR are particularly strong for employers 'and workers' organizations. In effect, on 2, July 2008, the social partners signed a National Inter-professional Agreement on Stress at Work (NIA, 2008).

This agreement was complemented by an agreement on harassment and violence at work on 26 March 2010 (ANI, 2010). The extension of these two agreements was concretized by a National Inter-professional Agreement (NIA) on Quality of Working Life and Professional Equality on 19 June 2013 (NIA, 2013).

In January 2015, a framework agreement project was established on Quality of Working Life in the Public Service, which has never seen the light of day because of the refusal of the trade unions organizations to sign it with the government.

In practice, three Occupational Health Plans have been implemented since 2005. The aim of the Occupational Health Plan 2005-2009 (OHP1) was to initiate a new dynamic in order to improve the prevention of occupational risks for long-term and to encourage the diffusion of a genuine prevention culture in companies.

The Second Plan of Health at Work 2010-2014 (OHP2) underlined the need for a strong mobilization of all actors, in order to put these risks in a sustainable prevention approach in companies.

The 3rd Occupational Health Plan 2015-2019 (OHP3) advocated improving the operational complementarity of occupational health actors so as to enhance the effectiveness of public and private action in this area.

Despite the increasing willingness of public authorities and social partners to implement an effective PSR prevention strategy, the results achieved remain relatively unsatisfactory.

This has been confirmed by the opinion of the Economic, Social and Environmental Council (ESEC) on psychosocial risks, which makes it clear that the various initiatives of the public authorities and the social partners in the prevention" are slow to produce their effects and remain insufficient" (Brunet, 2013).

In Belgium

In Belgium, the Belgian law of 4 August 1996 on the well-being of imposes an obligation on the employer to take account of psychosocial problems in preventive measures implemented (Belgian Law, 1996).

Since then, several national agreements have been signed, in particular the 1999 Inter-professional Agreement, the second part of which deals with specific matters relating to the policy on working conditions.

In 2002, Belgian law imposed specific rules to prevent and combat violence and moral or sexual harassment in the workplace pursuant to the law of 11 June 2002 on violence and moral and sexual harassment (Belgian Law, 2002).

Following the European framework agreement on stress in 2004, Belgium introduced the notion of "psychosocial burden occasioned by work" in the Royal Decree of 17 May 2007 on the prevention of the psychosocial burden caused by Including violence, moral or sexual harassment at work (Royal Decree, 2007).

This Royal Decree of 17 May 2007 was replaced by the Royal Decree of 10 April 2014 related to the prevention of psychosocial risks at work. It henceforth imposes dispositions on risk analysis and preventive measures, the procedures to be followed by employees who feel they are suffering harm as a result of their exposure to psychosocial risks at work.

Recently two new laws of 28 February 2014 and 28 March 2014 were adopted, radically reforming the dispositions of the law of 4 August 1996 on the well-being of workers in the exercise of their functions.

The latter law henceforth sets out a more general framework for the prevention of PSR at work, whereas previously it only addresses PSR in a restricted way by condemning violence and moral or sexual harassment at work.

In Belgium, these new dispositions delimit the scope of PSR by integrating them into the risk analysis in general and specifying the roles and obligations of the actors of prevention in the company.

In Sweden and Denmark

Sweden, like several other countries, had adopted specific legislation on violence, and in particular the 1993 Decree on reprisals at work.

Moreover, the Swedish Work Environment Act of 1 July 1978 had the objective and content of guaranteeing "a safe and healthy working environment which must at all times be in conformity with the technical and social status of society "(Swedish Work Environment Act, 1978).

The Work Environment Act was reformed in 2009 and henceforth stipulates that employers have a legal obligation to make written assessments of work-related risks and must therefore prevent undue physical and psychological prejudice resulting from nervous tension excessive.

Nevertheless, the social partners have estimated that the Work Environment Act was too general and did not formally define the responsibilities of the employer. To this effect, they proposed a draft “*guidelines*” (Swedish Work Environment Act), which ultimately did not come about because of lack of agreement.

In Denmark, the Swedish Working Environment Act of 1 July 1978 is considered to be the reference text of occupational health and safety law.

In reality, the system evolves only on the basis of the supervisory institutions, in particular the labor inspectorate, which plays a predominant role in Denmark. Thus, the labor inspectorate has the power to classify companies according to their level of commitment to safety and health.

During the years 1995-2005, the Labor Inspectorate took several initiatives, including inspection campaigns on the psychosocial work environment. Since 2006, a new reform has now required labor inspectorates to regularly and systematically monitor the psychosocial work environment.

In Denmark, the labor inspectorate is a supervisory authority which can authorize psychologists to intervene in the workplace in order to observe and evaluate the psychosocial environment.

To do so, a questionnaire called "Copenhagen" was designed by the National Research Center for the Working Environment to assess stress at work.

In addition, the social partners have developed a "stress barometer" which has been made available to government institutions, including labor inspection, in order to assess the level of stress among employees (DGAFP, 2010)

In Germany

Occupational health and stress in Germany has evolved since the introduction of the European directive in 1989 and the adoption of the law on occupational health in 1996.

In 2012, following a report on stress at work entitled "Stress report Deutschland" carried out by the Federal Institute for Occupational Safety and Health (BAuA), psychosocial risk has become the main problematic of the occupational health in Germany.

To cope with these new risks, the government, the insurance companies and the social partners have defined a *"Common German Occupational Health and Safety Strategy"* (GDA), which is articulated in three principal objectives consists in renewing preventive practices and attitudes (MSE program), improving labor protection structures (ORGA program), and to develop techniques for screening for diseases resulting from stress (PSYCHE program) in enterprises that was launched in 2015 (ILO, 2016). In September 2013, after several negotiations, the social partners signed a "joint declaration on mental health in the workplace", which constitutes a reference document producing measures and rules for the prevention of PSR.

Other Member States: the Netherlands, Ireland and Austria

In the Netherlands, a Working Conditions Act was adopted in 1994. On 1 January 2007, the same law was replaced by a new Working Conditions Act (Arbowet), which Employers the obligation to prevent aggression, violence and harassment. Employers must regularly evaluate the working conditions of employees (EUROGIP, 2010).

In Ireland, a Safety, Health and Welfare at Work Act was adopted in 1989 and reformed in 2005. The concepts related to PSR do not appear to (EUROGIP, 2010), it nevertheless contains rules of application and codes of practice relating to violence, aggression and harassment, which were also revised in 2007.

In Austria, the occupational health and safety law reformed in 2002 requires the employer to take into account the mental health of employees. Employers must conduct an on-going assessment of all risks, including PSR, in accordance with the guidelines imposed on them, being given than the regulations do not specify how to assess these risks (OECD, 2012).

Other Member States have decided not to address the concepts related to PSR and have merely transposed the 1989 framework directive into their regulatory texts, such as Luxembourg, Poland, Romania, Slovenia and Spain.

This inventory found that the strategies implemented to prevent PSR clearly vary from one member of the European Union to another. Nevertheless, the majority of the legislative and regulatory texts applied in the Member States are inspired from the directives.

On this regulatory plan, there is no one way to address psychosocial risks. Some countries have introduced the need to prevent PSR in their regulatory texts such as the case of Austria, Denmark, France and Sweden.

Other countries such as Belgium, Denmark and France place the fight against PSR among their strategic priorities. Some member countries have introduced the obligation to assess PSR, such as the case of Belgium, Germany, the Netherlands and Austria.

Conclusion

This work apprehended psychosocial risks (PSR) as a major sustainable development issue at the level of the European Union and particularly at the level of its member states. In effect, the implementation of a genuine policy of prevention of PSR has become not only the key to occupational health but also an essential investment for the improvement of the financial health of the company and to ensure Thus its economic stability and its capacity to consider human capital as a factor of added value and a fundamental source of growth. This perspective inevitably leads to admit that psychosocial risks have human, organizational and economic consequences that are detrimental to the sustainability of company as well as repercussion on the whole of society. It is therefore essential that every company must have a management system taking into account in a more formal way the human component in the same way as the technological and economic components and consequently consider the employees exposed, possibly, to the psychosocial tensions at work, as the first stakeholders.

References

ANI (2013), *Accord national du 19 février 2013 relatif à la santé au travail et aux risques psychosociaux*.

ANI (2008), *Accord du 29 février 2008 relatif à la santé au travail*.

ANI (2010), Accord sur le harcèlement et la violence au travail du 26 mars 2010.

ROYAL DECREE (2007), *Arrêté royal du 17 mai 2007*. Source : https://www.ulb.ac.be/scppt/docs/ARHarcelement2007.pdf

BELGIAN LAW (1996), *Loi du 4 août 1996 relative au bien être des travailleurs lors de l'exécution de leur travail*. Source : http://www.meta.fgov.be

BELGIAN LAW (2002), *Loi du 11 juin 2002 sur la violence et le harcèlement moral et sexuel*. Source : http://igvm-iefh.belgium.be/sites/default/files/downloads/11_juin_2002.pdf

BRUNET S. (2013), « L'avis du Conseil Economique, Social et Environnemental (CESE) sur les risques psychosociaux », *Journal Officiel*, mai, 154 p.

CAILLARD J. F. (2010), « Les services de santé au travail au service du développement durable en France : protéger la santé », *3e colloque de la Chaire Développement durable. Revisiter la prévention des risques professionnels : un enjeu de développement durable*, p. 42-47.

CHOPIN D., DELUZET M., GODINO R. (2012), *La grande transformation de l'entreprise. Travail, sens et compétitivité*. Editions de l'Atelier.

EUROPEAN COMMISSION (2014), *Communication de la commission au parlement européen, au conseil, au comité économique et social européen et au comité des régions relative à un cadre stratégique de l'union européenne en matière de santé et de sécurité au travail (2014-2020),* 6 juin, 18 p.

COOPER C. (2006), "The challenge of HRM in managing employee stress and improving well-being. In R.J Burke & C.L Cooper", *The human resources revolution*. Elsevier, p. 139-146.

DERIOT G. (2010), « Rapport d'information fait au nom de la Commission des affaires sociales par la Mission d'information sur le mal-être au travail », *Sénat de la République Françai*se, 127 p.

DGAFP (2010), Pratiques européennes pour lutter contre le stress au travail dans les administrations. *Direction générale de l'administration et de la fonction publique.*

DOUILLET P. (2013), « Prévenir les risques psychosociaux : outil et méthodes pour réguler le travail », *Agence nationale pour l'amélioration des conditions de travail ANACT.*

EUROGIP (2010), « Risques psychosociaux au travail : une problématique européenne », Note thématique, Janvier*, Eurogip*-47/ F.

ESENER (2009), "European survey of enterprises on new and emerging risks", *European Agency for Safety and Health at Work (EU-OSHA).*

EU-OSHA – Eurofound. (2014), Psychosocial risks in Europe: Prevalence and strategies for prevention, *European Foundation for the Improvement of Living and Working Conditions (EU-OSHA) and the European Agency for Safety and Health at Work (Eurofound)*, 106 p.

GILLES M. (2014), « Transformer les capacités de connaissance et d'action sur les contextes de travail. Les objets intermédiaires dans les processus d'amélioration des conditions de travail », *Revue des conditions de travail, n°1. Agence nationale pour l'amélioration des conditions de travail ANAC*T, p. 134-142.

GOLLAC M., BODIER M. (2011), « Mesurer les facteurs psychosociaux de risque au travail pour les maîtriser », *Rapport du Collège d'expertise sur le suivi des risques psychosociaux au travail, avril,* 223 p.

LACHMANN H. and al (2010), *Bien être et efficacité au travail*, février 2010.

LEFRAND G. (2011), « Les risques psychosociaux au travail », *Rapport d'information N° 3457 de l'Assemblée Nationale*, 25 mai, 79 p.

SWEDISH WORK ENVIRONMENT ACT (1978), *Loi suédoise sur l'environnement de travail*. Source : http://www.senat.fr/rap/r11-591/r11-5919.html

MRAD M. (2013), *Organisations hautement durables : Gouvernance, risques et critères d'apprentissage.* 2e Editions Lavoisier.

NASSE P., LEGERON P. (2008), « Rapport sur la mesure et le suivi des risques psychosociaux au travail », *Rapport au Ministre du Travail, des Relations sociales et de la solidarité*, 12 mars.

UNITED NATIONS (2015), *Programme de Développement Durable des Nations Unis à l'horizon 2030*, 21 octobre, 38 p.

OECD (2012), Santé mentale et emploi Mal-être au travail ? Mythes et réalités sur la santé mentale et l'emploi : Mythes et réalités sur la santé mentale et l'emploi. *OECD Publishing*, 9 mars, 225 p.

ILO (2016), *Journée Mondiale De La Sécurité Et De La Santé Au Travail 28 Avril 2016*. OIT Organisation internationale du Travail.

PICARD D. (2006), Vers une promotion durable de la santé psychique au travail ? *1er Congrès du Réseau International de Recherche sur les Organisations et le Développement Durable (RIODD*). France, Créteil, 7 et 8 décembre.

PIGEYRE F. (2012), *La responsabilité sociale des entreprises, défis, risques et nouvelles pratiques*. Sous la direction de Jaques Igalens. Editions Eyrolles.

REMOUSSENARD C., ANSIAU D. (2013), « Bien être émotionnel au travail et changement organisationnel », *Revue Perspectives interdisciplinaire sur le travail et la santé (PISTES),* 15 p.

ROUAT S., SARNIN P. (2013), « Prévention des risques psychosociaux au travail et dynamique de maturation : le processus d'intervention comme opérateur de la transformation et du développement de la coopération », *Revue Activités*, volume 10, n°1, p. 58-72.

VAN WASSENHOVE W. (2014), « Les obstacles à la gestion des Risques Psycho-sociaux. Gérer et Comprendre. Annales des Mines », *Les Annales des Mines*, p. 30 à 40.

Civil Society between Void and Action – The Case of Refugee Support on Lesvos[1]

Andrea CEDERQUIST

Christian-Albrechts-Universität zu Kiel, Department of Geography, Kiel School of Sustainability, Germany

While the drivers behind forced migration can be found on the dark side of globalization, its effects are being felt on a local level. However, the narrative of refugees and migration is only uncovering the long-neglected debate of what kind of society do we want to live in, and what the public values at stake are. Geuijen et al. (2016) examined if public value theory could be useful in suggesting solutions with respect to global wicked issues like forced migration. The conclusions were that it is, however, without giving an answer how the "muddling through" to create public value can be dealt with in a practical situation. This paper gives a rough overview of what happened on Lesvos in 2015 and 2016, and will use Public Value (PV) theory as a frame. The key question is: what are the tools that can be used to understand the situation and that also can be used to help to deal with conflicts in a situation of institutional void (relating to the reception of refugees on Lesvos)? The paper will examine if a system thinking approach can be a useful supplement to traditional PV. Developing and sharing a rational diagnosis of the situation is a key element for coping, it is, however, according Kahane (2012) not enough for transformational change to happen. The paper will try to identify some of the missing elements.

Methodology

The motivation behind this research was to understand and describe the situation on Lesvos while identifying options for action. The research is based on qualitative semi-structured interviews with people from the civil society of the island, all of which had been engaged in the reception of forced migrants on the island in one way or another, as well as the author's own observations. With civil society, I mean the "*third sector*" of society. It comprises different types of civil society organizations; from formal Non-Governmental Organizations (NGOs) and humanitarian agencies to informal groups and individual volunteers and citizens.

[1] That article received the *Jean Monnet Prize* in october 2016 (Clermont-Ferrand, France).

The approach positions the paper in the context of action research relating to the territorial area and development of Lesvos. According to Greenwood & Levin (2007), the central duality in action research is a pair of goals, one to create social developmental processes aiming to solve pertinent local problems, which in this case are the wicked migration issue unfolding on Lesvos, and at the same time, contribute to the body of scientific knowledge. The approach used is to causally reflect on the input given by the interviewees (underpinned by a constructivist epistemology that seeks to elicit and develop the "*perspectives of participants and social actors*" (Carr, 2006), my own experiences and a critical realist ontology).

To be able to intervene, first, a causal and dynamic understanding of the problem must exist, so that any intervention does not lead to unintended consequences. Second, points of intervention, i.e. those points in a system where with relatively little impact good (in the applied ethics sense) and lasting solutions can be achieved, need to be identified. Third, the problem and its suggested solutions need to be communicated simply and convincingly (Stroh, 2015). This approach is building on Crinson (2001), who stressed the need to go beyond the micro-interactions of social agents and "*towards an explanation of the way in which social discourses arise out of the interaction between agency and structure in a particular material context*". And on Archer (1995), who argues that both agency and structure are both causes and effects. This apparent contradiction is resolved once time is introduced. Agents act within the constraints of structure. As they act, time passes and their behaviour, purposefully or not, changes the structure in which they can act. The newly changed structure creates different constraints (and opportunities) later on to act. As they act, again time passes and their behaviour again changes the structure in which they can act. And so on. A never-ending causal loop (see also Abbott 2001). The three tasks specified at the beginning of the paragraph can be met by accepting that there is a reality, which can be described understood and intervened in. Thus, to reach a casual understanding of the situation on Lesvos (and identify intervention points) a system thinking approach will be used as an ontological and epistemological framework, thus extending the traditional PV approach, that can model causal relationships (see Mingers 2011).

In turn, to obtain the key variables and their causal relationships, this paper will use the Public Value (PV) theory as a guide, building on the PV concept by Mark Moore (1995). Both Moore and Bozeman (2007) favour a normative approach in the public value debate. However, this is not sufficient for understanding the role of civil society as an actor for change, as Meynhardt (2009) emphasizes. He argues in his non-normative approach that PV is created in every societal exchange. Every process that is shaping individual experiences concerning a relationship to the "public" is, according to Meynhardt, public value creation. Personally, I think PV creation has a normative factor, as, for example, non-democratic beliefs, while creating "value" for those participating but not for society, should not be categorized as "*public value* *creation*". One consequence of my view is that public value theory needs to address the difference between facts, the interpretation and evaluation of those facts by individuals and their interactions.

For this paper, I conducted fifteen semi-structured interviews in the summer of 2016 with individuals from civil society on the island of Lesvos. All interviewees had been engaged in helping, and were affected by, the influx of refugees and forced migrants on the island. The qualitative interviews were recorded, transcribed and then analysed with MAXQDA®. The coding of the data was used to identify the causal relationships that make up the models described in Figure 2 and 3. Vensim® provided the graphical modelling interface for the causal loop diagrams. The extended conceptual public value framework introduced (Figure 2) was applied to the question of how to cope in the current situation (Figure 3).

The situation on Lesvos

Lesvos has a rich history, and its geographical location has made it a target for the powers since early antiquity. Refugees and migrants have been arriving on the island, in different intensities. The last peak was during the Greco-Turkish War (1919-22), when thousands of Anatolian Greeks were forced to leave Turkey, but the influx the island faced last year, was far beyond any previous dimension. By the end of December 2015 more than 500.000 refugees/migrants had arrived on Lesvos. Almost all of which were arriving on the Northern Shores between the villages of Mithymna (Molyvos), a tourist destination, and Skala Sikamineas, a small fishing village, where they completely dwarfed the local resident population of approx. 150 inhabitants.

Phase 1 (Human solidarity: July/August 2015)

In 2015 there had be a steady rise in refugees arriving to the island. In the first phase, it was mainly Syrians fleeing their country's civil war, as well as Afghans and Iraqis fleeing conflict and repression, all looking for a better and safer life in Europe. While the number of refugees arriving on the island was steadily growing during the spring and early summer in 2015, there was no central co-ordination, logistical or infrastructural support provided by the authorities; with respect to the influx, a situation of institutional void. When in July/August of 2015 the number of refugees started to peak, without any formal institutional capacities to deal with the situation, addressing the immediate needs such as giving water, food, dry clothes, blankets etc., of those arriving was mostly done by individuals, local citizens and tourists. These ad-hoc initiatives were independent and uncoordinated. The forced migrants arriving wanted to leave the island as fast as possible, to continue to their ultimate desired destinations, mainly Germany or Sweden. On the island, anti-human-trafficking laws prevented taxis and commercial buses from transporting the newly arrived refugees. It was also forbidden for private individuals to drive asylum seekers (Greece later altered the law), so people helping refugees by giving them a lift in their car were breeching laws in the name of humanity. Thus, despite significant media attention, the Greek government, except for a handful of overwhelmed Coast Guards, the European Union and international Non-Governmental Organizations (INGOs) were conspicuous by their absence on the front-line response. *"This is what was more devastating than anything else. The realization that you are alone. The realization that the police is not here to protect you, the doctors are not here to help you because they cannot. They are so overwhelmed with all the things that are happening and the coast guard as well. They are understaffed. They cannot meet your needs, which in any civilized country, you would expect that there's enough personnel to fulfil these needs. We would call the police, and the police would say, I'm by myself. I can't come help you. So, deal with it by yourself. How do you deal with it by yourself? So, you do what you think is right. I don't know how many laws we broke. I know for sure by just transporting them we broke a big law, but we were by ourselves. What are we going to do?"* (Resident of Lesvos, september 2016).

Phase 2 (Exodus: Sept/Nov.2015)

During this phase, the number of arrivals peaked at over 10,000 a day. The volunteer-led response of July and August 2015 formalized steadily over the subsequent fall. Many individuals began establishing organizations, such as the Starfish foundation in Molyvos or the "*Dirty Girls of Lesvos*", to better fund-raise and recruit more volunteers in order to provide a more comprehensive humanitarian response both on the shores as well as it the transition camps. Individual hotel owners tried to juggle the business of running a holiday hotel with the challenges of bringing refugees ashore. International initiatives like the Swedish,"*Vi gör vad vi kan*" (In English: we do what we can), the Spanish initiative "Proactiva Open Arms", or the Swiss/Greek "*Save Assist Outreach (SAO)"* are only a tiny fraction of the many bottom-up initiatives which were initiated to help on the island. *"To leave your country, to come and volunteer and to drop everything and to come on your own expense. Or even raise money from your friends to come to help out is something that not everyone does. A lot of people received a lot of much-needed help, especially at a time when there were so many refugees here. If there weren't so many volunteers and NGOs and whoever else was involved in the system, I don't know what would have happened. I think it would have been extremely difficult. Each person played a part in this, and that was before the borders closed "* (Resident on Lesvos, 2016). The ability to quickly animate the informal networks was crucial; and was enabled through social-media tools such as Facebook and WhatsApp. Different initiatives and organisations not only provided different "services", they also distinguished themselves through their motivational and political approach: between humanitarian action and solidary support (Papada 2016).

Kara Tepe was the camp for the Syrians. All other nationalities had to remain at Moria, which was a former military camp, operated by the Greek police, run with the help of large INGOs such as United Nations High Commission on Refugees (UNHCR). In October 2015 Moria was designated a EU "*hotspot*". The "*hotspot approach*" was instituted by the European Commission in May 2015, in its European Agenda on Migration. The hotspot approach was meant to ensure a better coordination between national authorities and European agencies (European Asylum Support Office, Frontex, and Europol) to enable the registration of incoming refugees and migrants. The hotspot approach, both as a method of management and as type of infrastructure has been heavily disputed (Papada 2016). Also in Moria, was strongly criticized, due to its cramped and inhumane conditions. The local situation on the North Shore in Mithymna (Molyvos) and Skala Sikamineas was chaotic and there was no infrastructure to deal with the thousands of people arriving. Inflows of people increased steadily as refugees were trying to beat the onset of winter, crossing on overcrowded small boats, with deadly incidents mounting. The sheer number of new arrivals and the insufficient registration capacity resulted in the number of asylum seekers being stuck on the island growing daily. Since most of the people arriving lacked papers, registration was even more impeded. Conflicts broke out and with crowds fighting for access to food and to the registration centre, parents and pregnant mothers feared for their own safety and that of their children.

Phase 3 (Under siege: Dec. 2015 – March 2016)

The situation was beyond endurance, both for the refugees, volunteers, the Greek authorities and the local citizens having been deprived of their normal life. Still, many people from the community continued to help, while trying to cope with the situation, and looking for some kind of "*normality*", which is impossible with more than 300,000 people over the year passing through a village such as Skala Sikamineas with 150 inhabitants. It was becoming clear that it wasn't only a crisis for the refugees, but also a crisis for the local communities on the island.

By wintertime, there was a plethora of small and large initiatives, and by January 2016 there were more than 80 NGOs and informal groups operating on the island. More and more, there had been a transition from the volunteer-led response to a more official, professional operation by major organizations, such as the International Rescue Committee (IRC) and UNHCR. But tensions arose when professional providers began running programs in areas that until then had largely been the province of volunteers, and some interviewees doubted if the efficiency of the NGOs and the amount of money spent was justified in relation to what volunteer organizations had provided or could have provided. The tension between local residents and NGOs grew steadily, especially as many locals felt that some of the INGOs operating on the island didn't take into consideration what the local people were going through, and how the situation affected their lives, mentality and businesses. That some of the volunteers from the outside came with arrogance and an attitude that the locals found hard to tolerate, didn't help. Some interviewees expressed the feeling that while some volunteers were sincere, others only were in it for fundraising or feeling good about themselves. Another issue raised was the intransparency of NGOs. *"They are nongovernmental organizations and that gives them the license more or less to do whatever they want outside of any law. They have a lot of money and that gives them a lot of power especially since the authorities are not present. They're not even there to say no. They're not there to say yes, they're not there to say no. That leaves a big gap that people can actually do whatever they want and there is a need because there is a humanitarian disaster going on, so there is a need for somebody to do something. So, in the name of humanity you can do actually whatever you want and nobody stop you even though it's illegal. If you point out that it's illegal, what is illegal? Who gets to choose the fine lines in this, the grey zones; like, "Yes, okay. It's illegal to transfer the refugees but if we don't, it's horror so we do." It's also illegal to actually help them upon arrival but if you don't -- so we do it.*

In this phase, tensions grew:

- between local villagers who saw the need for help and those who felt that helping only fuelled more trafficking;
- between Greek authorities (who now required all organizations who wanted to help to register before they could do so), Frontex, the European border agency, and those organizations who judged the increased emphasis on security undermining the humane and solidary approach to the refugee reception;
- between local residents and international NGOs and volunteers;
- and finally, between formal NGOs, humanitarian agencies and informal groups operating on the island.

Phase 4 (Limbo: March-Sept. 2016)

The situation changed again in the beginning of 2016 with declining number of refugees arriving: The rescuing at sea and the reception was now handled by the Greek coast guard and Frontex. The involvement of the NGOs was restricted. March 2016 was also the time the EU-Turkey deal (the "Deal") took effect, changing the situation once more in a fundamental way. The "*Deal" made Turkey legally into "a safe country*" for refugees, which many of the interviewees disputed, as did Doctors Without Borders (Médecins Sans Frontières 2016), and the Greek authorities (Gerovasili, 2016). The trust in the "Deal" and that Turkey is a reliable humanitarian partner was, and still is, heavily questioned in Greece, also by the Greek national government. Hence, as Greece, until now, has not accepted Turkey to be a save country, the "Deal" has not led to refugees having been sent back. With people being trapped on the island, the situation on Lesvos and the other Aegean Islands was becoming explosive, especially in the camps. Although the number of arrivals of refugees went back dramatically in 2016, there were still daily arrivals, increasing again after the failed coup in Turkey on July 15th 2016. Additionally, there was, and still is, the uncertainty if the "Deal" will last or not, the "Deal" being entirely in the benevolence of the Turkish government. The borders closing in Europe, the detention of the refugees in the camp of Moria (in the context of the implementation of the EU-Turkey agreement, Moria was converted from an open to a "*closed facility*" or prison), the slow processing of cases and the comparably small but increasing influx of new refugees were all bringing the situation in Moria to the verge of collapse. *"Again, I'm saying that their mentality was different when they were arriving. The way of them looking at us was totally different than as compared to now. Now, there's disappointment. There's anger, and it's not directed personally to you or to me. In general, it's directed to whoever comes their way first, because they're stuck here, and they're not being provided—when they come out of the boats, they're not being provided with warm clothes and soup and tea and sandwiches to eat. They're just put into a bus and taken immediately to Moria. Then, in Moria, I don't know how the situation is now. I know Kara Tepe, it's much better than in Moria, but in any place, living in an army camp for months on end must be strenuous"* (Resident of Lesvos, September 2016).

There is also a fear that the island will become like Nauru for Australia, the refugee island of the EU and in parallel, many islanders are worried on the impact on their lives. *"Why Lesvos? That's the whole point. Why Lesvos? Why Kos? I remember in the summertime when the boats were coming over and over and over again and we were watching it and we were asking for help but nothing was happening. I remember we'd joke sarcastically about it, saying, you know what? I bet you a million dollars they have agreed already to turn Lesvos into the refugee camp of the E.U. What a better place than to put the Eastern Aegean islands? Because it's an island. They are not even on the mainland of Greece, and people will be caught there. It's only 90,000 people. Well, someone has to pay the price, and that's going to be you. And that's what we talked about. I still believe it."* (Resident of Lesvos, September 2016).

What comes next?

The tourism industry, the economic backbone of the islanders, had declined. According to the Regional Authorities of the North Aegean Islands, 75% of international charter flights and 35% of domestic flights were cancelled in 2016. And according to the Lesvos Hoteliers Association room bookings were down 90% in some places on the island (GTP, 2016). Even today it is not clear what impacts the refugee crises will have on the overall economies of the island. Of course, NGOs, volunteers and refugees also have had positive impacts on some businesses, such as smaller and bigger hotels, mini-markets, car rentals and cafe-restaurants in some parts of the island. Opportunities arising out of the new situation, such as ideas to reinvent tourism on the island to get rid of the dependence on tour operators, were identified in the interviews. Tech initiatives to create employment opportunities for both locals and refugees/migrants were also mentioned. However, this needs trust, energy and support for the local communities. In a situation where Greek unemployment in 2016 stands at 23 percent – the highest in Europe, and the financial crisis already having had its toll on the islanders, it is not understandable that there has been no real support from the Greek government nor from the EU for the people on the island to cope with the situation. There has been no tax-reliefs, nor support to those who can't pay their health insurances, and no incentives to improve the situation in the schools. The overall economic crisis has reduced the ability of the Greek authorities to function.

Interviewees also raised the concern around the conflicting messaging about the island in 2016 when a narrative dominated that caused the whole island to be considered a crisis zone. It surely was for refugees stuck in the miserable conditions of the detention centres, which must not to become forgotten. On the other hand, there was the dire need for the islanders to bring back their livelihoods, which for a tourist destination is tourism. And Lesvos in the summer of 2016 was an island where in the tourist areas one didn't see any refugees coming ashore, no suffering people walking on the streets, but blue seas and beaches virtually deserted of both tourists and refugees.

There is a plethora of positive stories on Lesvos, but people do not have the strength (or will) to tell them jointly. But that is precisely what would be needed to counter the negative stories told by media, and to create a counter narrative to the "*Drama story*". The more you write and communicate the "crises" and limbo situation, the more you are hurting the locals. Their livelihoods are destroyed and you are fuelling the tensions on the island between the refugees and islanders. Locals who helped and saved thousands of refugees, may, because of politics on various levels become economic migrants themselves. There is a growing tension that refugees and local communities are in "competition" regarding their needs. The key question is how to structure a process that engages refugees, volunteers, authorities and local people to jointly develop new economic opportunities and engage in sustainable community action. The current situation is the result of a development which we are facing not just on Lesvos. In all European countries, there are no easy solutions. However, looking away and letting the inhabitants of Lesvos, and elsewhere, on one hand and the refugees on the other pay the price of inaction alone, is neither a humanitarian nor a long-lasting solution. It might function for some time, but in the long run, it will only make the problems more explosive when they eventually do surface. Therefore, an effective response will need to be grounded in an understanding of the root causes of the problem. There seems to be so many ad hoc policies relating to the refugee crises which are not thought through. There is the real danger that these are becoming "*fixes that backfire*" (Stroh, 2015). Therefore, it's crucial to develop, through a deliberate debate (process), a joint understanding of what the public value at stake (outcome) is, and what the causal connections in the system are. This needs to be done by the people affected.

The concept(s) of Public Value and the need for extending them with systems concepts

"War, human rights violations, underdevelopment, climate change and natural disasters are leading more people to leave their homes than at any time since we have had reliable data. More than 60 million people — half of them children — have fled violence or persecution and are now refugees and internally displaced persons. An additional 225 million are migrants who have left their countries in search of better opportunities or simply for survival" (Ki-moon 2016). The complexity of the situation on Lesvos qualifies it to be called a wicked problem. Why? Wicked problems are complex; they often have multiple causes but no single solution or quick fix. They are unstable and social by nature, involving many different individuals and agencies, range across organisational boundaries, national borders and social divides. In wicked problems, there is significant political conflict over the values at stake and the very definition of the problem at hand; there is an absence of any institution, structure or process that provides a natural social or political location in which the problem can be nominated for attention, sized up in a process of deliberation and design, and used as the platform for directing coordinated action across many different independent organizations (Geuijen et al. 2016). The forced migration situation on Lesvos is just like this: It is difficult to define; there is juridical overlap between international laws such as the United Nations Convention on the Law of the Sea (UNCLOS) and International Convention for the Safety of Life at Sea (SOLAS) and national boarder protection; conflicts between EU-Immigration laws vs. the UN Human declaration of law; historical, political and military tensions between Greece and Turkey ; the weakening of the Greek state due to the financial crises; the extraordinary numbers of forced migrants arriving on a small island with no structural facilities to handle such an influx of people; the dependence of tourism for the island; tensions between political powers on the island; the conflicting needs of people affected – refugees, migrants, locals and tourist; media and celebrities touching down and using the situation for their own ends.

"Even some of the media that I talked to, they kept asking me, "But is it worse for you or is it worse for the refugees?" And they kept asking the same question, I said, "I cannot answer this question. That is not the deal here. It is not who is it worse for, it is could we please try and find a solution where we could get through this all of us? Because it's not just about them or us but there was a lot of pressure on trying to make it them or us. And for those who then felt very intimidated or sacred for what was going on in their homes because this is our home and people seem to have forgotten that there are people living here. This is our home. Of

course, with that fear that would come out sometimes in anger and frustration, like it has done everywhere else in Europe, there are people reacting to this negatively and it actually has nothing to do with the refugees, that's what I believe "(Resident of Lesvos, September 2016).

To do nothing in such a situation is not an option ("*you help because it's the human thing to do*"), so the questions is what are the tools we can use to understand and then to help set in motion change that has a lasting benefit to all concerned. As identified by Geuijen et al. (2016), Public Value Theory can help frame global wicked problems for effective social action. *"When we discuss these issues, it's not a competition between who is in a worse situation than the other. There's no competition there. It's one thing and there are two parallel problems that coexist because of the same cause, and they need to be look at: The war, the terrorism, money, and petroleum, and other things. Gas. Other things are behind this. You have two separate problems coexisting because of the same thing, and it's not a competition, but it doesn't mean that the one problem diminishes the necessity and the problems of the other. It should not be looked upon that way, because that's when conflict begins"* (Resident of Lesvos, September 2016).

The PV concept goes back to Mark Moore (1995) and was developed to help public managers carry out their numerous, and often conflicting, obligations (Bryson et al. 2015) As a visual shorthand, Moore introduced the concept of the strategic triangle (see Figure 1). Benington (2012) notes that the academic debate about public value has moved well beyond the fields of public administration and strategic management, and has reached a debate about the roles, means and ends of government within a rapidly changing ecological, political-economic and social context; about the changing relationships between state, market, civil society and the ecosphere, and about the nature of the contract being renegotiated between citizens, communities and governments. Bozeman (2007) focuses on the policy and societal level and Meynhardt (2009, 2012) argues that when we explore PV processes, it is key to understand the different motivations that cause different actors to act. Drawing on Epstein (1993) he distinguishes moral-ethical, political-social, utilitarian-instrumental, and hedonistic-aesthetical motivational dimensions. Unlike other authors (e.g. Bryson et al., 2015), Meynhardt pays little attention to institutions and supra-individual processes involved in Public Value creation. But institutionalization, and the process through which institutions are established, survive and decay, is key for both the *creation* of lasting public value, as well as the *efficient delivery* of public value when many actors with different agendas and motivation are all rushing to do so.

To be able to create and deliver Public Value (PV outcome) three different aspects are necessary:

1) An *agreement* amongst those who want to create PV and are impacted by its creation on *what* to create and *how* to do so, especially, but not only, in situations

of institutional voids. Hence, even if situations are not as desperate as they were on Lesvos, creating agreements, and re-legitimizing such agreements is fundamental. The agreement is needed for a shared sense of direction.

2) *Operating capacity* to deliver value both in the short and in the long term, in order to acknowledge, use and influence the development of the intervention to create public value *over time* – recall the four very distinct phases on Lesvos described above.

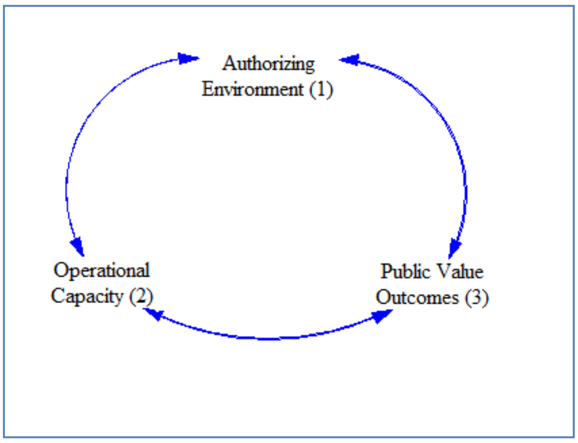
3) A well understood *authorizing environment* that legitimizes the activities undertaken to create PV, to evaluate both the intended and the unintended causal consequences of the intervention.

Extending the concept of Public Value and testing the extensions

The strategic triangle

The central tool Moore introduced was the "strategic triangle", indicating that public value is created when a given strategy or action has democratic legitimacy (e.g., the community supports it) and the support of the authorizing environment, and when a government has the operational capacity to implement the strategy or action effectively. According to Kavanagh (2014), as indicated (in Figure 1), there is a feedback system in place, so that when public value is created, legitimacy and support increases (e.g., citizens and elected officials have greater trust in the government), and operational capacity is increased (e.g., financial and other resources could be easier to obtain). In short, success begets success (and failure begets failure).

Figure 1 : The strategic triangle of public value



Source : Moore (2011)

The "agreement" is in Moore's understanding imbedded in the term "authorizing environment". It is not a standalone feature of Moore's strategic triangle. This can be explained by Moore's assumption of a "*functioning democratic state*". Such a functioning democratic state subsumes the existence of inclusive, legitimate and legal processes to reach agreements, e.g. elections. However, especially in situations of institutional voids it is necessary to reach an agreement in the first place. In my view, agreements can be reached if two conditions are met:

1) a thorough, non-judgmental and causal understanding of the motivation of all people engaged in creating PV and by people affected by that creation (Meynhardt & Bartholomes, 2011),

2) and an inclusive, inductive and respectful process of arriving at the agreement.

Motivations and process to reach an agreement

The importance of motivations has been highlighted by Meynhardt (2009, 2012) and Schwartz (2006). To operationalize their approach, Meynhardt & Bartholomes (2011) created a scorecard. This scorecard can be used in two ways: to evaluate the PV outcome, or it can be used to understand the motivational drivers of people for creating the PV outcome. Motivations are especially important to understand when one aims for long-lasting solutions, when one engages in a deliberative conversation to create the PV agreement (see later section), and when working with a large number of people engaged in PV creation. In the latter case to align the actions (Rose 2011). After understanding the motivations, one needs a *process* to reach agreement (Holmes 2011). The key requirement for such a process is that it allows all affected parties to have their voices heard. This is best achieved in a deliberate discourse, which can handle even many conflicting positions.

A systems approach to public value

Intervening in a wicked problem as it exists on Lesvos is fraught with danger. As most people think in linear and mono causal, i.e. non-feedback, terms (Forrester 1982), there is a high likelihood that any intervention leads to unintended consequences. To minimize that danger, we need to acknowledge that we live in a complex web of nested feedback loops (cf. the definition of a wicked problem above). Feedback loops are the structures within which all changes occur.

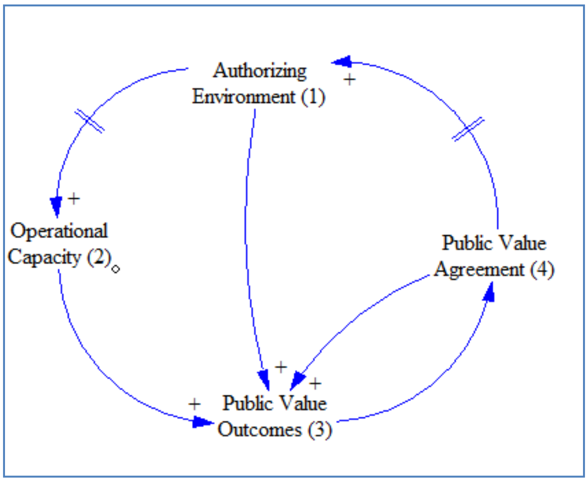
Systems, or feedback, thinking makes three main assumptions:

- Loops are causal (arrows have a meaning).
- Time is the intervening variable between agency and structure.

- There are no independent variables (in a causal loop everything is dependent or independent, but you a free to choose a variable where you start the story).

If these considerations are applied to the strategic triangle of Moore, the graphic below emerges (Figure 2).

Figure 2 : The PV Agreement approach



First, the public value agreement has entered the triangle as an explicit fourth variable. Second, all variables are connected by arrows. They are causal and the causality works like this: Each arrow has at its head a plus sign. This is shorthand for the following: if the variable at the tail of the arrow *increases*, that causes an *increase* in the variable at the head of the arrow. Or, if the variable at the tail of the arrow *decreases*, that causes a *decrease* in the variable at the head of the arrow. In other words, the causality between tail and head works in the *same* direction. Third, two dashed lines across an arrow mean that any change in the variable at the tail of the arrow will take a long time to cause an effect in the variable at the head of the arrow.

If one starts with the public value agreement (4) and assumes that it increases, i.e. it becomes stronger, clearer, then this causes an increase in the public value outcomes (3) – all else being equal. Similarly, an increase in the public value outcomes (3) will cause an increase, i.e. strengthen, any public value agreement (4).

This is what Kavanagh (2014) meant when he looked at Moore's strategic triangle. A structure formed by two variables connected by two causal arrows that each transmits their causal effects in the same direction creates a *self-reinforcing* loop. Here it means that once one gets an agreement, public value outcomes emerge, which make it easier to get a better agreement later on, which then in turn create better or more public value outcomes. This is a *virtuous* cycle. Additionally, a time dimension has been introduced, because for the effects to take place, time needs to pass.

One can read more from Figure 2. It also states that to create public value outcomes one must have both authorizing environments (1) and operating capacity (2). Most likely, these three influences are multiplicative, meaning that if any one of those three is missing, nothing will happen. You can have all the authority in the world, and you can have the most superb organizational capacity, if there is no agreement on what public value to create and on how to best do so, you may very well have incredible activity, but you will not create any lasting public value. In my mind, this is the situation in phase 4, the 'limbo' phase, described earlier.

Furthermore, figure 2 implies that out of public value agreements after some time an authorizing environment can emerge. And it suggests that you need *only* agreements to achieve legitimacy. Would there be an agreement among the groups involved, the authorizing environment would come out of that agreement.

However, reaching the agreement (and its formalisation to a certain extend) needs to include the ones engaged in and affected by the public value being created, which is a complex endeavour in a wicked situation. The agreement would be a joint sense for direction, where the plurality and multifaceted initiatives of civil society drive the struggle for an agreement.

In figure 2 all causes are acting in the same direction. Thus, besides the self-reinforcing loop already mentioned, there is also a self-reinforcing loop running through public value agreement (4), authorizing environment (1) and public value outcome (3), and a third one running through public value agreement (4), authorizing environment (1), operational capacity (2), public value outcomes (3) back to the public value agreement (4).

These loops are *virtual* cycles, but there is a dark side to them. If, for any reason, any one of the variables *decreases*, this leads inevitably after some time to the *decrease* in all the other variables. Things collapse and the cycles are no longer virtuous, they are *vicious*. Agreements are no longer honoured, fragmentation occurs, disputes arise, resulting in violence and destruction.

Finally, it is also possible to use figure 2 to explain the various phases of the refugee crisis described earlier. As an example, recall phase I. With respect to the dramatic influx of refugees on the island, dwarfing the number of local inhabitants and tourists many, many times over, there was in phase I neither an operating capacity of any kind, nor an authorizing environment. Yet people arrived and needed help. So, the public value agreement that formed spontaneously was a deep human instinct in all of us, and especially in the people who happened to be on Lesvos at that time, namely that when a fellow human being needs help and you happen to be there, you just help.

Out of that humane instinct sprang a locally initiated, highly distributed, highly individual capacity to help. Similar to the first moments after an earthquake, long before professional help has had a chance to be flown in, if one is there, one simply helps by looking for survivors and attending to their needs. Hence, the authorizing environment in phase I also sprang from a deep need for immediate help. *"For me personally I got a little bit scared for how far are they (NGOs) willing to go and what are going to be the consequences for us here? Again we have a neighbour which is Turkey and we got so many warnings. Because the volunteers went out with our boats and they crossed the borders. And when we are kindly asking to not cross that border because we're going to be in trouble. They didn't respect it. There is also a very fine line when there are no authorities about when are you a humanitarian and when are you a smuggler?" (*Resident on Lesvos, 2016).

Definition of Public Value - in the "PV Agreement" approach

Public value is created when people reach an agreement (AG) of what public value they concretely want to create (outcome), when operating capacity (OC) exists to deliver the value and an authorizing environment (AE) legitimizes the creation. Public value creation is a process that unfolds over time. All four are connected through causal influences.

- The agreement must be reached by all, those who want to create the value and those who are impacted by the creation. It is a continuum, from an informal look into the other's eye and a nod, via handshakes, informal agreements on what is the right thing to do, onto contracts, laws, constitutions to universal rights. With time, there must be a deliberate discourse about the agreement.
- Operating capacity is the ability to cope, to deliver the value set out in the agreement. It has material and immaterial aspects and varies over time.

An authorizing environment draws its legitimacy from the agreement, it is the formalization of the agreement. In situations of institutional voids, public value creation usually starts with an informal agreement.

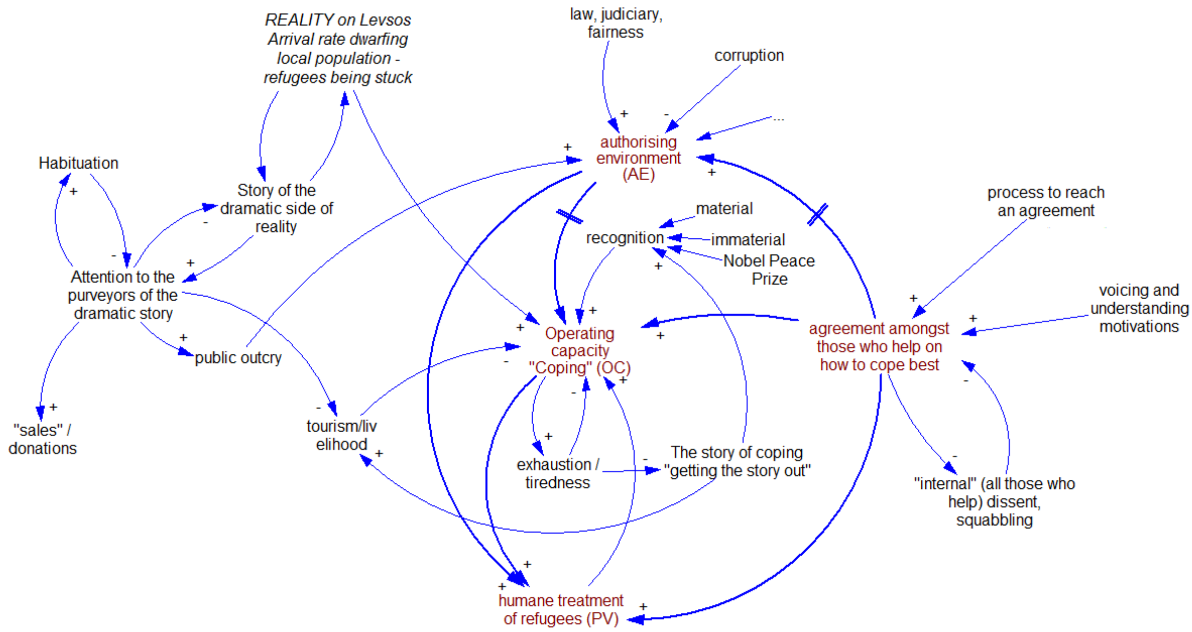
Giving Operating Capacity and Authorizing Environment a time dimension and embedding them in causality

To operationalize the conceptual framework introduced above, and to apply it to the question of how to cope in the current situation, I make use of the system thinking frame mentioned at the beginning. It can be most parsimoniously visualized through the causal loop diagram below (figure 3). It contains all public value concepts introduced so far and is tied together with some more detail with a focus on the stories being told. These two stories are used as an example of how causal thinking can disentangle an otherwise confusing situation.

A systems approach to understand the differing stories about Levsos

Reading about, or actually experiencing the situation described above, there is a tremendous danger of being overwhelmed by the complexity of the situation, and the question of what to do. Starting with figure 2, I have extended the causal map of figure 2 with input from the different semi-structured interviews conducted (in the summer of 2016) with people from the island who have been engaged in the refugee reception. This was done to understand the two different stories that can be, and are being, told about Lesvos in 2016 in causally stringent way, so that intervention points can be identified: (1) The first story is actually being told and it is dominating what people outside of Lesvos see and hear. It is carried predominantly by international media. It is the *story of drama*, disaster, and tragedy. It is part of the truth, but is not the whole story and certainly not true for all time. (2) The second story that could be told, but isn't so far, is the story of how everybody involved coped with the dramatic situation, and how the situation changed over time. This is the *story of coping*, or to use the terminology of public value, the story of operating capacity.

Figure 3 : Lesvos causal diagram: The extended version of Moore's strategic triangle is embedded and adjusted in the diagram.



The challenge in describing the situation based on causal loops is that they need to be rich enough to capture underlying mechanisms and tell a story, precise enough to spot leverage, but also simple enough so that most important dynamics clearly stand out (Vermaak 2016). To recall, all causal arrows are hypotheses, and in this example, are based on qualitative analyses of the interviews conducted and the causal connections retrieved from this information. Figure 2 is part of this larger diagram (figure 3). Its variables are written in bold and the causal arrows are slightly thicker than the rest. In Figure 3, there is no direct connection between the agreement and the public value outcome, as the agreement is still missing in reality. Instead there is a new arrow from the agreement to the operating capacity. Note the following:

a) The public value outcome has become specific. In the case of Lesvos, the public value in question suggests itself as the humane treatment of refugees. However, the public value to be created is a *choice*. At times, as is the case on Lesvos, the public value needed (in the first phases) is obvious because the situation is so dire and catastrophic that one does not need long and complicated deliberative processes to arrive at a concrete manifestation of the particular public value that needs to be created. In other situations, this may well not be the case. Furthermore, the public value to be created may be refined or extended (cf. the situation on Lesvos where it over time is changing to *both* secure a humane treatment of refugees *and* also enabling locals to cope with the situation).

b) The need for public value creation, i.e. the humane treatment of refugees, exists because there is an *objective* reality – namely the dramatic increase in the arrival rate of refugees on the island. There had been earlier initiatives on the island, such as the "Village of Altogether" created in 2012 and others to engage with refugees coming to the island, but these alone were by no means able to cope with the sheer number of refugees arriving in 2015.

The reality in 2015 can be told in two ways.

Lesvos: the story of tragedy

Direct your attention to the left third of Figure 3. What happened, and is still happening, on Lesvos can be told in a dramatic fashion. People fleeing in unprecedented numbers, people dying, people rising to the challenge and finding strength and kindness, and also people failing, being mean-spirited, racists and violent. These are precisely the ingredients of a drama story for international media, who are in a constant battle for the precious moment of attention from their readers, viewers and "likers". This is also a story for some of the organisations who need to fundraise on the story for their existence - a double edged sword. *"Drama is what sells. You have these impressive titles, but behind the impressive titles, it's not that dramatic. The media has played a serious role. Not only has the media, even the people, even volunteered who have been here. They are doing this because they're trying to secure funds to keep them here so that they can support the system and help out. They're doing this to help, but at the end of the day, they don't really realize that actually, to some extent they're also really harming the island when you are posting pictures from last year of boats arriving and you're saying, we want to help refugees in Moria."* (Resident of Lesvos, September 2016).

In causal diagram language, the dramatic story increases the attention both to the story itself and the provider of that story. Hopefully, it will lead to a public outcry – which may trigger a political reaction, but unfortunately, there's more to the story.

Namely, that as attention is drawn to the dramatic side of reality one tends to get used to drama, and when we get used to something, attention drops. When attention drops, an even more dramatic version of the story is being told. This is captured by the variable called *habituation*, which, once you are used to the drama, makes your attention drop (Beck 1976; Sokolov 1963). *"And they were asking if I wanted to talk about how wonderful it is here now. Then again focus is; now the refugees are not here now the tourists can come. Why? What is wrong with refugees? They are people and it is not the refugees who caused the problems in this place. It was the trash. It was the journey. It was what they left behind because they did not get help. It was not the people. This constantly turning things up against each other, where human life and reality it gets a little bit lost in those stories. The media they're only interested in those kinds of stories because we contacted a lot of them. "Will you please tell our story?" But it's not interesting, our story is not interesting"* (Resident of Lesvos, September 2016). The ever-increasing dramatic depiction of the situation on Lesvos has two consequences. Both of them have a strong impact on the ability of the public to create value. The first is a public outcry. Seen very vividly after the refugee camp in Moria on the island burned in September 2016. Days later the Greek government, part of the authorizing environment to use public value terminology, announced that it was moving the refugees from the island to the mainland in significant numbers to improve the situation and reduce the tension. But the unbearable situation in the camps was not solved, and the stockpiling of refugees and migrants in Moria under dire conditions, has continued. *"There is a face of Europe that is very human and it's amazing, where there is solidarity. I think it's a very simple human thing we have to do, and if we do it things can be very different. Solidarity saved lives here. But solidarity is not enough. There should be political decisions so that we won't experience this again. The policies now are cruel, and there is a face of Europe that is very ugly and that scares me"* (Resident of Lesvos, september 2016).

The second consequence of the dramatic story impacts negatively on the tourism of the island. And since tourism is the main income generator for people living there, it does not just impact tourism, it really impacts the livelihood of many of the locals, with far reaching consequences. *"Generally, it's like being in a void right now because we've had a tough year. Greece itself we've had some tough years and we topped it off with the refugee influx that was coming through this island last year. Right now it could like everything is as it used to be 10 years ago but under the surface, it is not. It just looks that way and that's confusing. What worries me is – maybe not as much the fact that a lot of us won't be able to feed our families this winter, or more people will end up in the street. There's no social security and we have to help each other more otherwise, we're not going to make it. What worries me more is what comes out of that. It's the polarization of the people, the tensions. The tensions: Yes, the tensions that comes up when people are squeezed so hard because it brings up a lot of people's primitive behaviour, and people are scared. When people are scared they don't act as rational and intellectual as they would have done"* (Resident of Lesvos, September 2016).

Lesvos: the story of coping

There is a second reality, and the story of that reality has so far not been told, but for lasting public value to be created, is absolutely essential. This second story of Lesvos is that of truly unbelievable coping. On the diagram, it starts with the same variable called *reality* but leads directly to the operating capacity necessary to deal humanely with this extraordinary influx of refugees on the island. Picture the situation as it currently exists where local people, with help from international volunteers, have helped hundreds of thousands of refugees and in the process have also saved thousands of lives. People have coped, and by doing so have enabled the humane treatment of refugees – the public value we had identified earlier as the one that matters. But if you look closely at the causal diagram you also see a causal connection between operating capacity and *exhaustion and tiredness*. The more you cope, the more tired you get; and the more tired you are, the less you can cope. The ability to help that existed in phase I essentially as the outpouring of basic humanity is getting smaller, not because of some mean-spiritedness, but because of people simply being physically and emotionally worn out. This loop is our strategy to survive. We adjust our operating capacity to what we can deliver. And as we tire, we reduce our activities. One of the first victims of a *community's* exhaustion is that you are no longer willing, nor capable of telling the story of your previous coping. If the story is not being told, it certainly does not get out and the recognition that you deserve is not forthcoming. This matters crucially, because *being recognized* is one of the ways in which a community's operating capacity could be built up. That recognition could be both material or immaterial.

There are initiatives to create a bridge between local community and the refugees. To create these humane spaces is a way to work against the decline in the ability to cope. For example, Lesvos Solidarity, the "*Village of Altogether*", which is an open refugee camp based in the Pikpa camp in Mytilene. Approximately 30,000 refugees have been supported at Pipka since 2012. Another example is the Mosaik support centre, which opened in September 2016 offering educational courses such as adult language lessons for classes of mixed migrant nationalities and locals in an effort of inclusion. Members from both the refugee and local Mytilene communities are engaged as translators, legal advisors, language teachers, etc. The Starfish foundation, which is a local NGO from Molyvos, having had more than 1500 international and local volunteers helping refugees arriving on the island, is now dedicating itself to also help the local communities. "Caring Lesvos", initiated by individuals in Molyvos is trying to show another picture of Lesvos than the dramatic pictures in the media. Other examples are the Symbiosis Lesvos Art Festival or the Vision2 Venture project. *"Yes, and then the fear of, if we now at this point start saying that we need help. What if all those NGOs they start turning their attention on us? Are we going to be in their powers? Because again it's a non-democratic way of doing things. Because there are some* *organizations that they started handing out food and clothes to the locals or heaters. Who are they to decide who needs it and what about those of us who never got considered? Why did we not get considered because we didn't know the right people or we haven't behaved accordingly to what they wanted us to do?". "They should maybe have targeted more bringing people together than to tear them apart. Because with their actions they have become a part of tearing people apart here. It would have been on a longer term for me, a lot more productive if they had wanted to do the heavy work of starting communication and a dialogue, bringing people more together. Because then in the end it doesn't matter if my neighbour is the one getting the help because she already knows that I need it too and she will share with me "* (Resident of Lesvos, September 2016).

The two stories could be reconciled through an agreement

Lesvos is a stark example of having to create public value within an institutional void (relating to the reception of forced migrants). There is a general lesson because even though Lesvos is a special case, it is not unique. The challenges of Lesvos, and of wicked problems in general, shifts from using *existing* authorizing environments and operational capacities to create public value to bringing forth authorizing environments in the first place. Figure 3 above hypothesizes that authorizing environments emerge over time from agreements, formal or informal, made by those wishing to create public value. This has actually happened time and time again. The founding story of just about any democratic country in the world begins with an assembly to reach agreement. Whether that is a meeting in Philadelphia at the beginning of the United States of America, whether that is the evolution of what we now call the European Union which started in the 1950s with an agreement among six nations to pool their coal and steel resources, or whether it is the Magna Carta agreed upon in 1215 by King John of England and a group of rebel barons, all authorizing environments can trace their roots back to a group of people wishing to create public value.

While democratic authorizing environments depend on more influences than just an agreement – for example laws, which are built on human rights, respect for these laws, a sense of fairness, a judiciary seen to be dispensing fair judgments, an absence of corruption, a public capable of voicing its opinion about what is right or wrong, and many other influences too numerous to mention – the agreement is the keystone. In order to create public value in situations of institutional voids one must sooner, rather than later, address the question of how to create such an agreement. As we have seen on Lesvos, it is possible even in the formal absence of both an authorizing environment and any kind of operating capacity for public value to be created. On Lesvos, it was the basic human decency that is to a larger or smaller extent part of every one of us, that spontaneously in phase I created the capacity to operate and was its own authorizing environment. However, as we are seeing in the current phase IV, the continued absence of a more formal agreement indicative of a joint sense of direction has begun to undermine the efforts to create lasting public value. Hence the establishment and the legitimacy (and re-affirmation) of such an agreement is crucial to ensure long lasting sustainable public value creation.

Conclusion

In order to create lasting public value, I have proposed that one needs a causal and dynamic understanding of the aspects of creating public value – the operating capacity (OC) in public value terminology, the capacity to cope in more psychosocial language – as well as of the aspects of legitimacy – the authorizing environment (AE) in public value terminology – and finally all the aspects of how to reach an agreement on which public value we want to create, and how best to do so.

1. The first two, the authorizing environment (AE) and the operating capacity (OC), are well discussed in the literature on public value. The original contribution of this paper is to set the two concepts into a dynamic and causal, i.e. systemic, frame, thus offering

   a) an efficient vehicle to further, together with others, the understanding of complicated issues,

   b) an explicit treatment of time in the creation and during the deployment of the public value intervention, and

   c) a systems perspective which leads to a deeper as well as a more differentiated understanding of causes, effects, motivations as well as pointing to the leverage points in the system where one can achieve large impacts with relatively little input.

2. This paper adds to the two PV concepts (AE and OC) a third one as being absolutely necessary for the creation of public value, namely the *agreement*, i.e. a sense of direction amongst the actors involved. Especially in situations of institutional voids, or institutional unclarity, the absence of such an agreement leading to fragmentation and conflicts are a real danger.

Besides giving theoretical arguments for the papers contribution I have tested these theoretical concepts within the setting of a real case, the extraordinary influx of refugees on the island of Lesvos.

References

ABBOT A. (2001), Time Matters: On Theory and Method, University of Chicago Press, Chicago, IL, United States

ARCHER M.S. (1995), *Realist Social Theory: The Morphogenetic Approach*, Cambridge: Cambridge University Press, 1995.

BECK H. (1976), "Neuropsychological servosystems, consciousness, and the problem of embodiment", *Behavioral Science*, 21, p. 139-160.

BENINGTON J. (2011), *From private choice to public value. In: Public value: Theory and Practice*, Macmillan Education.

BENINGTON J., MOORE M.H (2011), *Public value: theory and practice*, Palgrave Macmillan, Basingstoke.

BOZEMAN B. (2007), *Public values and public interest: counterbalancing economic individualism*, Georgetown University Press, Washington, D.C.

BRYSON J. M., CROSBY B. C., BLOOMBERG L. (2015), *Creating public value in practice : advancing the common good in a multi-sector, shared-power, no-one-wholly-in-charge world*, CRC Press, Taylor & Francis Group, Boca Raton.

CAIRNS G., SLIWA G., WRIGHT G. (2010), "Problematizing international business futures through a 'critical scenario method", Futures, 42, p. 971-979.

CHERMACK T.J., LYNHAM S.A (2004), "Scenario planning in critical science research", *Futures research quarterly*, http://www.thomaschermack.com/Thomas_Chermack_Scenario_Planning /Research_files/Chermack(2004) SceninCrit.pdf, retrieved 07.10.16.

CRINSON I. (2001), "A realist approach to the analysis of focus group data", *5th Annual IACR Conference*, Denmark, 17-19 August.

EPSTEIN S. (1993), *Emotion and self-theory. In: Handbook of emotion* in Lewis M. and Haviland J. M. (Eds.), Guilford Press, New York.

EUROPEAN COMMISSION (2015), *European Agenda for Migration*, https://ec. europa.eu/home-affairs/sites/homeaffairs/files/what-we-do/policies/european-agenda-migration/background-information/docs/communication_on_the_european_agenda_on_migration_en.pdf, retrieved 09.11.16.

FORRESTER J.J (1968), *Principles of systems*, MIT Press, 1982.

GEROASILI O. (2016), *Olga Gerovasili Government Spokeswoman*, september 14, Athens. https://gerovasili.wordpress.com/2016/03/22/η-ενημέρωση-των-πολιτικών-συντακτών-α-4/, retrieved 08.11.16

GEUIJEN K., MOORE M., CEDERQUIST A., RONNING R., VAN TWIST M. (2016), "Creating public value in global wicked problems", *Public Management Review*, doi: 10.1080/14719037.2016.1192163, 2016. p. 1-19.

GREENWOOD D.J, LEVIN M. (2007), *Introduction to action research, social research for social change.* Thousand Oaks, CA: Sage. 2nd Ed.

GTP (2016), *Greece Hoteliers Up in Arms Over Cancellations Due to Refugee Crisis,* http://news.gtp.gr/2016/02/29/greece-hoteliers-cancellations-refugee-crisis/, retrieved 07.09.2016.

HERNANDEZ J. (2016), *Refugee Flows to Lesvos: Evolution of a Humanitarian Response*. http://www.migrationpolicy.org/article/refugee-flows-lesvos-evolution-humanitarian-response

HOLMES B. (2011), *Citizens' engagement in policymaking and the design of public services*. Services, (Ed.), Canberra, http://www.aph.gov.au/About_Parliament/ Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1112/12rp01#_ftn10

KAHANE A. (2012), *Transformative scenario planning: working together to change the future*, Berrett-Koehler Publishers, San Francisco.

KAVANAGH S. (2014), *Defining and Creating Value for the Public*, Government Finance Officers Association of the United States and Canada, http://www.gfoa.org/sites/default/files/GFROct1457_0.pdf

KI-MOON B. (2016), "Refugges and migrants: a crisis of solidarity", *Huffington post*, http://www.huffingtonpost.com/ban-kimoon/refugees-and-migrants-a c_b_9871290.html , retrieved 08.10.16

MATZIARAKI D. (2016), 4.1 Miles. http://www.nytimes.com/2016/09/28/ opinion/4-1-miles.html?_r=0, retrieved 11.10.16)

MEYNHARDT T. (2012), *Public Value - Turning a Conceptual Framework into a Scorecard, Creating Public Value in a Multi-Sector*, Shared-Power World, Minneapolis, 23.

MEYNHARDT T. (2009), "Public Value Inside: What is Public Value Creation?" *International Journal of Public Administration*, 32, p. 192-219.

MEYNHARDT T., BARTHOLOMES S. (2011), "(De)Composing Public Value: In Search of Basic Dimensions and Common Ground", *International Public Management Journal*, 14, p. 284-308.

MOORE M. H. (1995), *Creating public value: strategic management in government*, Harvard University Press, Cambridge, Mass.; London.

MEDECINS SANS FRONTIERES (2016), *The EU-Turkey Deal: A False Solution, An Evasion of Responsibility,* http://www.doctorswithoutborders.org/article/eu-turkey-deal-false-solution-evasion-responsibility, retrieved 09.10.16.

PAPADA E. (2016), *Humanitarian space and border management in Lesbos, Open Democracy*, https://www.opendemocracy.net/mediterranean-journeys-in-hope/evie-papada/humanitarian-space-and-border-management-in-lesbos, retrieved 11.10.16

ROSE C. (2011), *What makes people tick: the three hidden worlds of settlers, prospectors and pioneers*, Matador, Kibworth Beauchamp.

SCHWARTZ S. (2006), "A Theory of Cultural Value Orientations: Explication and Applications", *Comparative Sociology*, 5, p. 137-182.

SOKOLOV E. N (1963), *Perception and the conditioned reflex*, Pergamon Press, Oxford, New York.

STROH D. P. (2015), *Systems thinking for social change: a practical guide to solving complex problems, avoiding unintended consequences, and achieving lasting results,* Chelsea Green Publishing, White River Junction, Vermont.

TARDE G., HAMMER H. (1908), *Die sozialen Gesetze: Skizze zu einer Soziologie*, Klinkhardt, Leipzig, van der Heijden, K.: Scenarios: *The Art of Strategic Conversation*, 2nd Edition, John Wiley, New York, 2004.

Vermaak, H. (2016), *Using casual loop diagrams to deal with complex issues: mastering an instrucment for systemic and interactive change*, Published in D.W. Jamieson, R.C. Barnett & A.F. Buono (Eds.), Consultation for organizational change revisited, Research in Management Consulting, vol 23, p. 231-254. Charlotte, NC: Information Age Publishing. https://hansvermaak.com/wp-content/uploads/Vermaal-Causal-Loop-Diagrams-Shareversion.pdf

DIFFERENT CHALLENGES FOR SUSTAINABILITY IN EUROPE

A functional approach of ecosystems for a sustainable management of coastal wetlands in the Gironde Estuary region (France)

Sylvie FERRARI, Sébastien LAVAUD, Jean-Christophe PEREAU[1]

GREThA, UMR CNRS 5113, Bordeaux University

The analysis of the complex interactions between wetlands and economic activities which are leading to irreversible damages in the functioning of these ecosystems is closely linked to the issue of sustainable development through a major concept: critical natural capital (CNC hereafter). Within a strong sustainability perspective, there is a complementary relationship between man-made capital and natural capital which is usually defined as a heterogeneous stock of renewable as well as non-renewable resources including the provision of ecosystem services and life-support functions (De Groot, 1992; MacDonald et al, 1999; Daly et Farley, 2004). The preservation objective of these natural components is then at the core of the CNC concept according to which some elements of natural capital cannot be declining or deteriorated as they are unique and irreplaceable. According to (Brand, 2009), CNC "ought to be maintained in any circumstances in favour of present and future generations". Given the role devoted to natural capital in the strong sustainability approach, we might assume that a specific functioning of the ecosystems under study underlies the latter, according to which the various components of CNC involved, contribute to the provision of environmental services while qualitative changes may occur due to the impact of economic activities.

This chapter precisely aims at providing an analytical framework that develops such a functional approach of natural capital to address sustainability issues arising in the functioning of various ecosystems[2]. In what follows, a simple model is built whereby the usual analysis of CNC is extended through the taking into account of core ecological features that underlie that functioning. The ensuing framework explicitly links natural capital components, functionalities and ecological services provided by the ecosystem.

---

[1] The authors would like to acknowledge R. Cairns (McGill University) for his insightful comments on earlier drafts of our work. A special thanks to G. Gaudet and P. Lasserre (Montréal University), P. Schembri (Saint-Quentin-en-Yvelines University) and M-A. Sénégas (Bordeaux University). This work was supported by the ANR (French National Agency for Research) through ADAPT'EAU program and the MEDD (French Ministry of Sustainable Development and Ecology) through MARGO program.

[2] For more details, see (Ferrari et al., 2012).

Moreover, it accounts for the way the system may react to economic pressures affecting natural capital and may adapt to them, that property being usually addressed in the literature by the concept of ecological resilience (Holling, 1973). In our framework, the resilience property underlies the fulfilment of criticality conditions by the natural capital components. With such a representation at hand, we also aim at providing an operational framework for investigating the sustainability of ecosystems. Such a framework is then applied to the case of a specific ecosystem, namely wetlands. Wetlands seem to be a relevant case study regarding the issues at hand, insofar as they perform many ecological functions (water and climate regulation, wildlife habitat, nutrient cycles...) and provide also a large set of services and goods to the society such as recreational services, fishing, buffer zone against flood risk, water provision (EEA, 2016; Verhoeven, 2014; MEA, 2005; TEEB, 2008). However, those services are threatened by economic activities in many countries in Europe while wetlands are delivering very important ecosystems services at multiple scales - global, regional and national – (Blackwell and Pilgrim, 2011; Finlayson and Spiers, 1999). Those evolutions appear all the more damageable as the functioning of that kind of ecosystem rests upon the use of specific renewable resources for which there is no substitute (notably, biodiversity, water…).

We proceed as follows. Section 1 presents and discusses the functional approach of CNC, shedding light on its main features and how it relates to and extends the standard approach to that concept. Section 2 deals with the building of a modelling framework of the ecosystem functioning based on the functional approach of CNC. Section 3 applies the latter framework to the analysis of the case of wetlands in the Gironde Estuary region. Section 4 concludes.

Critical natural capital and ecological resilience

In that section, we develop a functional approach of natural capital so as to address the functioning of ecosystem. On that basis, a simple model is built whose features draw from that functional approach.

A functional approach of critical natural capital

Despite its various meanings in the literature, the concept of CNC hereafter has been always closely linked to the issue of sustainable development (Chiesura and De Groot, 2003; De Groot et al., 2003; MacDonald et al., 1999). Indeed, an important challenge for the conservation of natural resources relies on the fact that some components of natural capital have to be maintained because they are of critical importance for the preservation of life and ecosystems survival. That challenge is, in turn, acute as economic activities have a more and more increasing impact on nature and are likely to bring irreversible damages both directly and on the long run. In the EU-funded project on strong sustainability - CRITINC-, CNC is the "*set of* *environmental resources which performs important functions and for which no substitutes in terms of human, manufactured, or other natural capital currently exist*" (Ekins et al, 2003). In such a context, thresholds and management rules are needed to avoid the decrease of the resources (stock) provided by the ecosystem.

Generally, definitions of CNC emphasize the essential role of the ecological functions that ecosystems components (plants, animals...) and processes (biogeochemical cycles) fulfil as well as the extent to which economic activities may impinge on that role, thus affecting the whole quality of the ecosystems under concern.

Different kinds of functions have been emphasized in the literature with respect to which the features of CNC are usually identified. Pearce and Turner (1990) provide one classification exemplifying the source, sink, life-support and well-being functions. The source function is related to the productive area (harvesting) and depends on various uses. The sink function refers to the assimilative capacity of ecosystems to deal with waste and pollutions. The life-support function is based on the regulation capacity of natural processes (local and global levels). The well-being function addresses the quality of life (to which natural capital contributes) and its determinants -use and non-use values of the resources- which may refer to socio-economic issues.

De Groot et al. (2002) suggest another (albeit closely related) group of functions to classify the ecosystems as well as the services and goods they provide, and thus another grounding for identifying CNC. According to De Groot (1992), those four environmental functions (regulation, habitat, production and information functions) capture "*the capacity of natural processes and components to provide goods and services that satisfy human needs directly or indirectly*". Regulation functions relate to the capacity of ecosystems to regulate ecological processes and life support systems (climate regulation, waste treatment, water regulation...).

Habitat functions refer to conservation of biological and genetic diversity. Production functions concern the provision of natural resources for populations (food, raw materials, energy resources, genetic materials...). The information function exemplifies the contribution of ecosystems to support cognitive development of human (recreation and cultural experiments...). The first two functions are essential for human survival and, as such, dominate the last two ones.

In those circumstances, we might conclude that there is not a unique measure for criticality of natural capital, depending on the functions that are emphasized. Furthermore, such a measure cannot be rooted on a direct monetary valuation process as for a significant part of the components it refers to, CNC appears to be non monetary valuable asset (Azqueta et Sotelsek, 2007).

The assessment of the criticality of natural capital has instead much to do with ecological relationships and indicators (number of species, links between various species living within the system...) and, as such, should rely upon a biophysical evaluation process in the first hand (MacDonald et al., 1999).

A first way to assess the criticality in that 'ecological' perspective, focuses on the importance of the functions that have to be fulfilled by the ecosystem and the degree of threat that hangs over natural capital in that respect (De Groot et al., 2003).

Such an approach requires that both the importance of the functions and the degree of threat could be identified in order to assess the degree of criticality of natural capital. For example, Turner (1993) emphasizes the regulation functions of ecosystems as being essential for human activities and human life: they are '*the primary values of ecosystems for general biospheric functioning*'. On his side, Ten Brink (2000) assessed the importance dimension through a large number of criteria drawing on ecological, socio-cultural and economic functions fulfilled by the ecosystem studied.

The "threat" dimension whose measurement is based on both quantitative and qualitative aspects which are embedded in a natural capital index. Basically, the index is defined by combining indicators of size and quality of the ecosystem (for instance, the quality is defined as the ratio between the current state and a postulated baseline state).

A second way to assess the criticality of natural capital would go through defining some thresholds, beyond which some components of that capital have to be maintained in order to avoid the decrease in the provision of the related services (Pearce and Turner, 1990). Those conditions may be called criticality conditions. For instance, regulation function (climatic function) associated with a particular ecosystem (tropical forests) is to be operational only if the size of such an ecosystem is maintained over a minimal critical level, otherwise the function will not run in a proper way and impede any provision of environmental services.

The two assessment methods of criticality can in principle be linked together as one relationship can in general be established between the degree of threat and the fulfilment of the criticality condition applied to one given natural capital component. The more acute is the degree of threat hanging over the latter, the more likely the threshold (or the criticality condition) associated with that component is to be attained.

While referring to different aspects of the functioning of the ecosystems, the two aforementioned methods do not however make the criticality assessment based on an explicit and consistent representation of that functioning.

Towards a qualitative approach of critical natural capital: the ecological resilience

The functional approach of natural capital has to be complemented by an analysis of the properties of the ecosystem if we want to use the former to analyse the performances of the latter. Such performances may be tackled through the concept of ecological resilience. Since the seminal paper of Holling in 1973 (Holling, 1973), numerous definitions of resilience are present in various disciplines (Folke, 2006; Brand and Jax, 2007; Brand, 2009; Hein, 2010) but they can be broadly grouped together under two approaches.

The first one, called by Holling himself "*engineering resilience*", refers to the speed with which a system returns to some equilibrium state after a small disturbance. This definition has been mainly applied for the analysis of ecosystem stability near an equilibrium steady state. The second one, which we refer to as the Holling approach, deals with the ability for a system to maintain its structure and functions after facing one or many disturbances. By the same token, it refers to the capacity of the system to bring into motion specific mechanisms so as to adapt itself to the disturbance and reorganise accordingly. Thus, while the engineering resilience definition is suitable with respect to a system facing small perturbations and/or gradual changes, the Holling approach seems rather to apply to systems that are subject to multiple states and thresholds (Hein, 2010).

Insofar as we analyse ecosystems by focusing on the criticality of natural capital, it appears relevant to adopt the Holling resilience approach for addressing the properties that the functioning of such systems exhibit[3]. An application of that approach to resilience which may be of interest for us in that perspective has been notably suggested by Brand (2009) and by Deutsch et al. (2003). In those studies, ecosystems are defined as complex dynamic systems: the dynamics relies on an organizational and temporal complexity, while the links between the ecosystems and the social systems may be addressed with the concept of resilience. In that respect, Brand furthermore mentions that "*an ecosystem amount of ecological resilience is directly linked to the degree of threat this ecosystem may face*" (Brand, 2009) suggesting that the ecological resilience concept is able to tackle the impact of economic activities on the quality of ecological services provided by the ecosystem. However, ecological resilience cannot be observed and measured directly (Mäler, 2008). Brand (2009) has nevertheless shown that it can be estimated *via* the distance between the current value taken by a slow moving variable which characterizes the state of the ecosystem at one point in time on the one hand and the predicted value of the related ecological threshold (critical level) on the other hand.

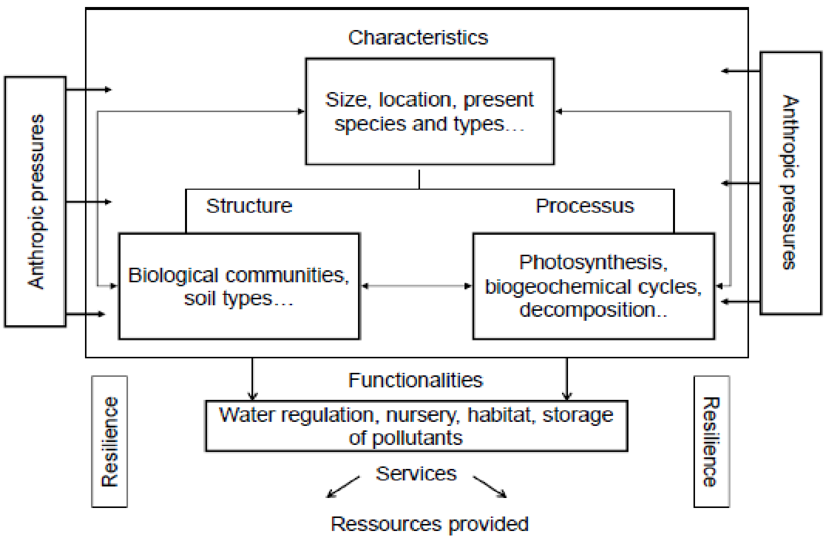
---

[3] Moreover and more generally, according to Arrow et al. (1995), ecological resilience is a necessary condition for the sustainability of economic activities: Those are 'sustainable only if the life-support ecosystems upon which they depend are resilient'.

Implicitly, the slow variable refers to the set of components of the natural capital involved in the ecosystem under study. As an example of a slow variable, we may consider the current value of nutrient concentration - such as phosphate - for a shallow lake, or the abundance of woody plants in rangelands[4].

On the whole, ecological resilience appears to be an important device to apprehend the quality of the functioning of any ecosystem. Indeed, this property allows connecting the provision of services, the environmental functions fulfilled within the ecosystem and the pressures that anthropic activities can exert on the natural capital components involved (Figure 1). It shows how the ecological resilience property may be called upon within that approach so as to provide a qualitative assessment of the performances of the ecosystem.

Figure 1: The functional approach of an ecosystem



Drawing from the study of Turner et al. (2000) which pertains more particularly to the case of wetlands (accordingly, we will use again that analysis in our case study of estuarine wetlands developed in section 4), the functioning of any ecosystem embeds three types of elements: characteristics, structure and processes. Those elements reflect both the interactions between the natural capital components and the mechanisms involved as well as between the functionalities they activate. Characteristics are descriptive properties which include the biological, chemical and physical aspects such as present species, size, soil properties, and vegetation. The structure refers to the existence of communities of plants and animals, and is closely related to the existence of biotic and abiotic webs (interactions between vegetation,

[4] It must be noted however, the threshold method can be used as such only if the ecosystems under study can shift between different stable states and if their dynamics can be accounted for by a small number of variables (Deutsch et al., 2003).

soil types, living species, biomass...). The processes operating within the ecosystem are referring to the dynamics of transformations involving energy and matter flows (photosynthesis, biogeochemical cycles...). Based on this functional approach, it is then possible to investigate how the components of natural capital activate specific ecological functions that are, in turn, at the source of the environmental services provided to the society. As we have mentioned, some functions may play a more important role than others as their activation is essential for the maintenance of the integrity of the system. In that respect, two functions are generally favoured: the regulation and the habitat functions (De Groot, 1992). For those functions, the criticality conditions that pertain to the natural capital components have to be fulfilled if we want the system to be sustainable.

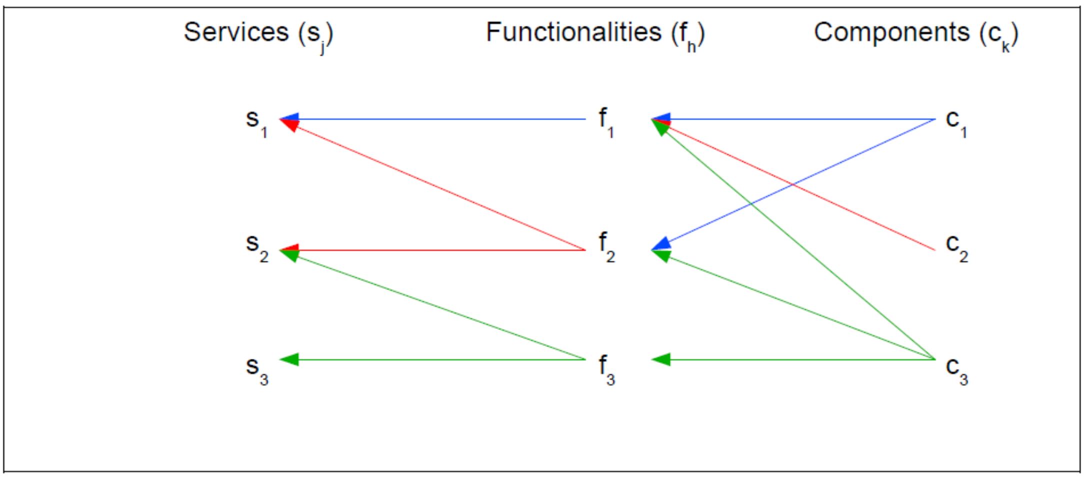
Accounting for CNC and ecological resilience in a simple economic model

Following the previous methodological discussions, we provide in this section a simple model of the functioning of an ecosystem which embeds a functional approach of CNC and accounts for the ecological resilience property. With those features at hand, the model can be used as framework to address some economic issues raised by this functioning (sustainability and optimal management issues). We proceed according to three main steps.

Components, functionalities and services

This first step consists in considering the main elements that frame the functioning of the ecosystem *i* under concern. The analysis we have conducted so far suggests three cornerstones in this respect (figure 2).

Figure 2 : The main elements of the ecosystem functioning



(1) The components of natural capital that are used within the ecosystem. Those components may be tackled through state variables. Those variables may be associated with stocks of resources or as binary indicators which reflect specific qualitative attributes of the components or aspects of natural capital (soil types, hydrological features…). In the following, we note by C^i the whole set of the p components that are involved in the functioning of the ecosystem i such that $C^i = \{c_k^i;\ \ k = 1,..., p\}$.

(2) The functionalities that refer to the ecological functions that are fulfilled by the ecosystem. The activation of those functionalities is performed through different mechanisms (biological, chemical, physical…) that play in interaction and, more importantly do involve and combine different natural capital components. In this respect, a given component may be necessary for the activation of several functionalities or may be functionality-specific. In the following, we assume that the functioning of the ecosystem i may be tackled through one set of m functionalities noted as F^i such that $F^i = \{f_h^i;\ \ h = 1,..., m\}$.

(3) The services that are provided by the ecosystem. This provision rests upon the activation of the functionalities. We may suppose at this stage that all the ecosystem services may be valued from an economic viewpoint so that maintaining this set of services does not imply favouring economic services at the expense of other ones. Lastly, as for the natural capital components that are used by the functionalities, the provision of different services may call upon the activation of common functionalities while some functionalities may be univocally involved in the provision of certain services. We note by S^i the whole set of the l services (of interest) which are provided by the ecosystem so that $S^i = \{s_j^i;\ \ j = 1,..., l\}$.

A specific representation of ecosystem functioning

This second step consists in drawing a specific representation of the functioning of the ecosystem given the three core elements that characterize it (natural capital components, functionalities, services). We may consider several ways to proceed in this respect which may be ranked by order of complexity depending on the objective we assign to this representation.

At this stage, we will only require that the representation tackles the state of the functioning of the ecosystem at a given time period. This state of functioning may be directly measured through the provision of the services (and this is why this indicator would be probably favoured from an economic viewpoint). Depending on how this provision has been contemplated in the first step of our approach, however, it is clear that this state of functioning does more fundamentally relate to the functionalities that have been activated and to the natural capital components that are involved in this process.

Moreover, even if we base the measure of the state of functioning on the provision of services, this provision may be assessed through two different but complementary dimensions: the number of services and the quantity of services which are provided. In our framework, we only focus on the former dimension meaning that we look at the effective delivery of the service through an indicator value (1 or 0).

The important feature we want to emphasize *via* that representation is the following:, we apprehend the state of functioning of the ecosystem *via conditional* relationships that link together the provision of services with the activation of the functionalities as well as the use of the natural capital components. In other terms, observing a given *number* of services implies that a given set of functionalities have been activated and that some natural capital components have been used. It suggests the following (reverse) causality sequence, where the backward arrow ← indicates "caused by" or "resulting from":

$$S^i \leftarrow F^i \leftarrow C^i \quad (1)$$

We might go further by making explicit the relationships between the elements under concern, drawing, from example, on the analytical insights of some ecological models[5]. Here, we stick to one simple and static setting in as much as the former rests upon the conditional relationships considered *supra*.

Ecological resilience and sustainability of the ecosystem

The final step consists in addressing the issue of ecological resilience in this representation and in investigating the different uses we may draw from such a property when providing an economic analysis of the ecosystem and its functioning. Ecological resilience puts a direct qualification on the functioning of the ecosystem as it aims at tackling its capacity to adapt to different pressures that affect the natural capital components. Addressing this property within the representation we may consider implies addressing two elements at least. First, there is the question of how the pressures may be taken into account in the representation. One answer would go through the introduction of a set of conditions put on the different components of natural capital. We could then assume that, depending on the kind of pressures under concern and on their intensity, the conditions may be or may be not fulfilled by the components. Accordingly, the level of pressures would then determine a *resilience potential* which could be measured as the number of conditions which are satisfied (with respect to the whole number of components involved in the ecosystem). We may model that set of conditions as[6]:

[5] We may also adopt a dynamic approach of this functioning allowing for feedbacks between the provision of services and the evolution of the natural capital components. Those extensions are left for further research however.

[6] When the natural capital component reflects a categorical variable (e.g. a kind of landscape), the criticality condition could take the form of a required category so that only if the component belongs to that category, then the functionality can be activated.

$$c_k \geq \underline{c}_k \ \forall \ k = 1, 2, ..., p \qquad (2)$$

This set of conditions (2) may be introduced beforehand, the fulfilment of which depending on the presence and intensity of the pressures. In this case, those conditions can be interpreted as *criticality* conditions (with respect to the functioning of the ecosystem), as the pressures would then imply one threat to the mere existence of the ecosystem (or at least the provision of the services).

The threshold ($\underline{c}_k$) may be interpreted differently depending on the nature of the component that is considered. For example, it can pertain to the disappearing of one component ($\underline{c}_k = 0$) or more generally to a minimal value above which the component should be maintained[7].

Secondly, the capacity of the ecosystem to adapt would *de facto* be conditioned by its resilience potential and the way the conditional relationships may interact with it. Indeed, depending on whether the whole (or part of the) set of the criticality conditions are satisfied or not, the ecosystem would be put in a different state of functioning, as the way the functionalities are activated would then be affected as well as, in turn, the provision of ecosystem services.

Sustainability concerns suggest considering the maintenance of a given number of services by the ecosystem in order to ensure the satisfaction of human needs. This sustainability condition can be written as[8]: $Card(S) \geq S_{\min}$ with $S_{\min}$ the number of services set by a regulator. Backward reasoning implies, in this case, that we search for the resilience potential(s) which would comply with this given level of sustainability[9].

Sustainability concerns may also be combined with the quest for an optimal management of the ecosystem. In that respect, it would be interesting to look at the minimum level of the resilience potential ensuring the maximal number of services provided by the ecosystem.

To solve those two problems, we need to introduce additional notations. Let $c_{h,k}$ be one of the *k* components that is required to activate the functionality *h*, and $C_h = \{c_{h,k}\}$ the set comprising all of these necessary components (for the functionality *h*). In the same way, let define $f_{j,h}$ one the *h* functionalities which are necessary to ensure the provision of the service *j* and $F_j = \{f_{j,h}\}$ the set comprising all of these necessary functionalities (for the service *j*) .

---

[7] One aspect we do not address at this stage is the fact that the fulfilment of the criticality conditions may be endogenously determined: the reaction of the ecosystem to the pressures may indeed feedback on the dynamics of the natural capital components.
[8] The notation *Card(S)* refers to the number of elements included in the set *S*.
[9] There can be several resilience potentials that can be solution of the previous problem, depending on the kind of services that are included in the sustainability condition.

We also need to reconsider the case for the criticality conditions which have been defined with respect to the c_k's. Looking at the $c_{h,k}$'s imply that the criticality conditions should now be contemplated in terms of these necessary components. In this case we will consider:

$$c_{h,k} \geq \underline{c}_{h,k} \qquad (3)$$

When several components are involved in the activation of several functionalities, they can be subject to different threshold values depending on the functionalities at stake. When the threshold values are consistent with each other, we consider that $\underline{c}_k = \max_k \{\underline{c}_{h,k}\}$. However when those values are conflicting, we have to distinguish for each critical component (that associated with each functionality). Looking first at the resilience potential(s) that would comply with a given level of sustainability, we then note that the problem amounts to search for the whole set of the $c_{h,k}$ which fulfil the *criticality* conditions $c_{h,k} \geq \underline{c}_{h,k}$ while ensuring $Card(S) \geq S_{\min}$. Searching for the minimum level of the resilience potential ensuring the maximal number of services provided by the ecosystem implies to solve the following program:

$$\begin{aligned} &\max_j Card(s_j) = \max_h \min_k \cup_h \cup_k c_{h,k} \\ &s.t. \quad c_{h,k} \geq \underline{c}_{h,k} \end{aligned} \qquad (4)$$

Assessing the sustainability of wetlands with a functional approach of natural capital

In what follows, we draw from the framework we have developed so far to analyse wetlands' functioning and sustainability. We notably try to adopt an operational approach allowing for providing data-based indicators of ecological resilience potentials as well as of sustainability of these ecosystems.

Wetlands as ecosystems

Several classifications of wetland types can be found in the literature (Blackwell and Pilgrim, 2011; Gosselink and Mitsch, 2007). That plurality is probably due to the diversity in wetlands' types we observe in the nature (Okruszko and al., 2011). One common feature shared by those ecosystems is a predominance of water during some period of time and, accordingly, that the structure of this ecosystem is mainly influenced by the hydrologic regime (Fossey and Rousseau, 2016; Turner et al., 2000). In that respect, wetlands constitute a composite group of ecosystems which have been defined by the Ramsar Convention in 1975 as "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters*".

On the basis of that agreement, wetlands are usually classified under three categories[10]:

(1) marine and coastal wetlands including estuaries, lagoons, inter tidal marshes, coral reefs…, (2) inland wetlands such as lakes and rivers, waterfalls, marshes, peatland or flooded meadows, (3) artificial or man-made wetlands, e.g. canals, ponds, water storage or wastewater treatment areas.

Under the Ramsar Convention, the Global Review of Wetland Resources and Priorities for Wetland Inventory (GroWI) conducted by Finlayson & Spiers (1999) assessed and compiled wetlands inventories at multiple scale (global, regional, supra-national and national). The estimated extend of wetland at the global scale range from 1 275 to 1279 millions ha. Although this figure sounds highly significant, it is still regarded as an underestimate due to partial cover of national wetland resources at the national scale or to coarse focus on major or remarkable wetlands. As an update of GroWI, Nivet & Frazier (2004) published a Pan-European Wetland Inventory (PEWI) based on national datasets stressing out their limitations - wetland cover underestimated -. At the same period, the Global Lakes and Wetlands Database (GLWD) (Lehner and Döll, 2004) assessed the extent of European wetlands at 26 millions ha, whereas Nivet and Frazier estimates for inland wetlands stand for 248 millions ha. More recently, the Mapping and Assessment of Ecosystems and their Services (initiative conducted by the European Commission, the European Environment Agency and the Member States, defines two types of wetlands: inland wetlands, and marine inlets and transitional waters (EEA, 2016). Inland wetlands stands for 8 millions ha (at the EU 28 scale) accounting for 1,8% of the EU area. According to the latest version of Ramsar database, the total area of European inland wetlands stands for 25 millions ha.

Table 1 : Assessment of inland wetlands area at regional scale

Inventory / Assessment	Date	Nb of Countries	Area (ha)
GroWi	1999	48	227 millions
PEWI	2004	47	248 millions
GLWD	2004	n.a.	26 millions
MAES	2013	EU 28	8 millions
RAMSAR database	2015	47	25 millions ha

It is clearly acknowledged that the two main reasons explaining such discrepancies between those area estimates, is the lack of a standardized definition of wetlands, and the scale of the analyse. As stated by Schleupner & Schneider (2012), European wetlands are «often fragmented ecosystems of small extent», many of them are

[10] A perhaps more functional classification of wetlands may be drawn from the study of Pearce and Turner (1990) which distinguish four basic types of wetland (according to their localisation): floodplains, coastal wetlands, wet meadows and peatlands.

smaller than 1 km². Thus, any coarse assessment tends to underestimate the total area. Comprehensive and accurate wetlands delineation still remains a taxing exercice as any even minor, changes in hydrological regimes may have a direct impact on the determination of their boundaries especially for seasonal and intermittently flooding wetlands. From a functional viewpoint, the functioning of wetlands, Turner et al (2000) note '*the interaction among wetland hydrology and geomorphology, saturated soil and vegetation more or less determine the general characteristics and the significance of the processes that occur in any given wetland. These processes also enable the development and maintenance of the wetland structure which in turn is a key to the continuing provision of goods and services.*'

As such wetlands may be considered as complex, adaptive ecosystems with a strong multidimensional nature that is supported by their relationships among groundwater, surface water and vegetation type (Klove and al., 2011; Plummer and Armitage, 2007). Following our methodological approach in the case of coastal wetlands, the functioning rests upon three main elements. The characteristics refer to the number and the types of species, water depth, the size and the shape of the wetlands, the soil properties and hydrological conditions. The structure refers to the communities of plants and animals of which the wetland is composed. In this respect, the focus may be put on the existence of biotic and abiotic webs such as trophic system and to the existence of biological communities (interactions between vegetation, soil types, living species, biomass...). Lastly, concerning the different processes involved, those concern the transformation of energy and matter at different levels such as the photosynthesis, biogeochemical cycling, transpiration, decomposition. The ecological functions that wetlands perform may be taken into account in many ways. In what follows, we refer ourselves to the classification that is adopted in the study of Van der Perk and De Groot (2000) for coastal wetlands[11]. The four following functions are considered: regulation functions (climate regulation, water regulation, protection against erosion, waste treatment by purification and filtering, biological control), habitat functions (nursery function, refuge function), production functions (food production and production of raw materials -fish, worms, shellfish, shrimp-), information functions (aesthetic information, recreation/tourism...).

Building the criticality and resilience potential indicators for Gironde estuarine wetlands

Among European estuarine areas, the Gironde estuary is probably the most ecologically unspoiled while being at the same time the less economically exploited zone of estuarine wetlands.

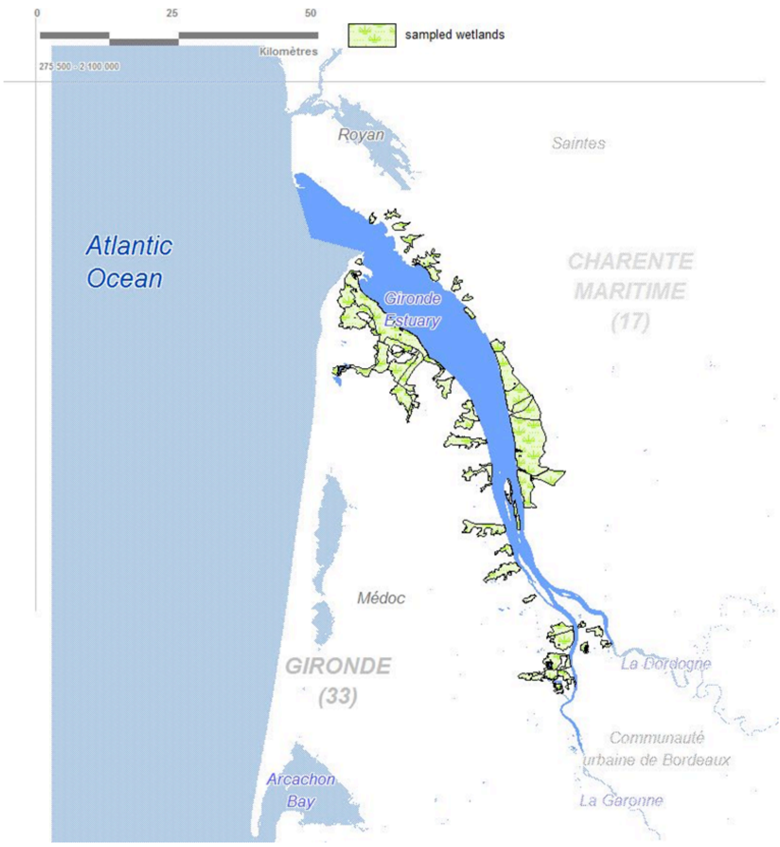
[11] Note that this classification is based on the aforementioned typology developed by De Groot et al. (2002)

But this large area experienced since years some decreases in its global environmental quality. Important factors of degradation are coming from industrial, agricultural, fishing and urban pressures. Thereafter, data-based indicators of ecological resilience potentials as well as of sustainability of the ecosystems under study are provided and discussed.

Operational framework and data collection

In the geographical zone we focus on[12], three types of wetlands are encompassed: estuary, salty marshes and inland meadows. The spatial distribution of those wetlands is illustrated on map 1.

Map 1: Distribution of the studied wetlands – Gironde Estuary



Source: Lavaud (2011)

For conducting our case study, we use an operational framework (given by Figure 3) that directly stems from the model we built in section 3. The collection of the related data-based indicators stems from several sources, ranging from scientists or local manager interviews to network river sampling stations. We selected the most

[12] The perimeter of that zone is defined on the basis of the Gironde Estuary SAGE (Water Development and Management scheme), cf. *infra*.

suitable indicator variables to get a comprehensive data set for 54 wetlands managed by local landowners. The choice of those wetlands accounts for the management that is operated at a local level and encompasses different actors: mainly Associations Syndicales Autorisées (Local Landowners Associations), local (town council, Gironde department, port authority, environmental association) and national (Conservatoire du Littoral) authorities. Table 2 summarizes the data and their sources.

Table 2 : Data description

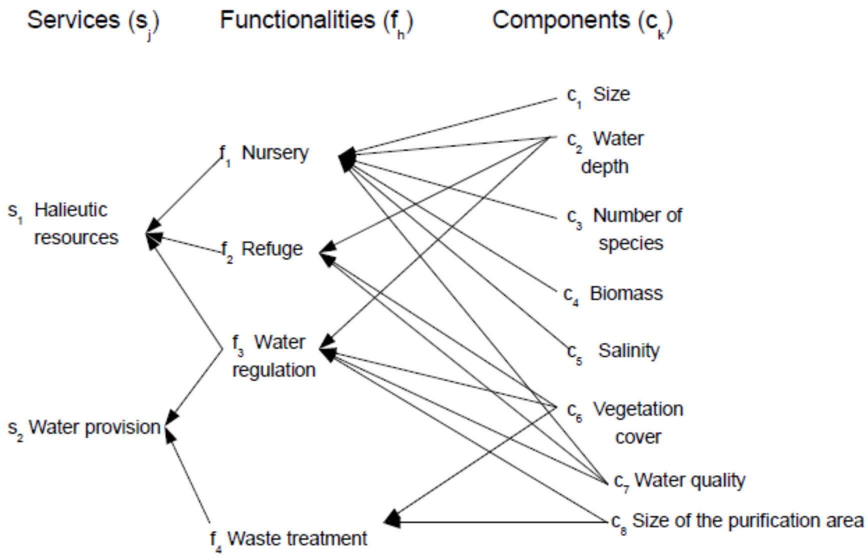
Component	Description	Unit / class	Data sources
c_1: Size	Area of the studied unit	km²	GRETHA
c_2: Water Depth	Proportion of area under the 6 meter tidal range	%	GRETHA, GIS simulation
c_3: Number of species	Fish density	Number of fishes per 1000 m², 3 average values(1): 22 (polyhaline area); 36 (oligohaline area); 64 (mesohaline area).	(Nicolas, 2010)
c_4: Biomass	Macrobenthos density	ind/m²	Agence de l'eau Adour Garonne (1992)
c_5: Salinity	salinity classes	3 classes: oligohaline; mesohaline; polyhaline.	(Nicolas, 2010)
c_6: Vegetation cover	Main vegetation type based on a 15 class vegetation cover typology	15 classes: 1:thickets; 2: humid grasslands; tall herbs; 3: humid grassland; short grass; 4: fens and bogs; 5: coastal salt meadows; 6: brackish or saline water bodies; 7: standing freshwater bodies; 8: riparian swamp forests and brush; 9:forests; 10: poplar plantations; 11: groves and tree plantations; 12: orchards; 13: field crops, horticulture; 14: vineyards;15: man-made landscape	SIMETHIS-SYMBIOSE, GRETHA & GEREA
c_7: Water Quality	TSS concentration	3 classes of average values in mg/l (2): $[89_{surface}, 204_{depth}]$; $[292_{surface}, 835_{depth}]$; $[398_{surface}, 1151_{depth}]$	SOMLIT
c_8: Size of the purification area	Proportion of available purification area	%	GRETHA, GIS

(1): Those values correspond to average densities which have been computed on the basis of samplings that have been implemented on 31 European estuarine areas and have been distinguished from each other according to three salinity classes (polyhaline, oligohaline and mesohaline).
(2): Those classes are computed as follows. Three sampling loci are considered along the estuarine area (those loci correspond to three different salinity zones). On each of those loci, one sampling is made on the surface (1 meter deep) and one is made on the depth (8 meters deep), both samplings being made at low and high tide, thus generating two values for the concentration each. The average values for the bounds of the ranges are computed on the basis of a moving average of the monthly samplings at those loci (the period sample goes from January 2007 to December 2010). The first value corresponds to the average of the concentration measures observed in the surface, while the second refers to the average of the measures observed in the depth.

As Figure 3 illustrates, the model we use to analyse the functioning of a representative wetland focuses on two core functions, namely habitat and regulation functions. The first function is associated with the nursery and refuge functionalities whereas the second function rests upon water regulation and waste treatment functionalities. The activation of those functionalities is in turn related to the provision of two main services: halieutic resources (s_1) and water provision (s_2).

Concerning the choice of the components and the elaboration of the related indicators, we proceed as follows. The first component (c_1) is the area of the wetland ranging from less than 1km² to 60 km² with an average area of 7,2 km².

Figure 3 : The functioning of Gironde Estuary Wetlands



Assessing the water depth (c_2) of each wetland unit within the study perimeter is an arduous task without any thorough knowledge on every drainage basin hydrology. GIS simulations have been required to determine the wetland proportion that lies under a six meters tidal range as the Gironde estuary is macrotidal. This raw assessment focuses on topographic variables (altitude, distance to the shore), regardless of any other elements as tidal cycle, flow or climatic conditions. The choice of an abundance index (fish density) has been made for (c_3) that is intended to measure the number of species. Few fish species are effectively able to live in the estuarine mesohaline parts as those areas are highly changing environments (Nicolas, 2010). At the same time however, the low level of competition between those species is likely to bring about a high abundance of fishes. Therefore, even if the diversity in the number of species is low, we might expect a rather important number of fishes (per specie). Macrobenthos (component (c_4)) - mainly found on riparian mudflats -, is a component of the estuarine biomass that is strongly related to the salinity gradient - component (c_5)-. Data come from four sampling stations based on the left bank of the Garonne river and Gironde estuary and are expressed in density (ind/m²). The role of vegetation (c_6) as natural component is encompassed by a 15 class based typology, ranging from thickets (class 1) to man-made landscape (class 15). The dominant type of each wetland area has been chosen to characterize each unit.

Among the indicators of water quality (that is captured by (c_7)), the total suspended solids (TSS) concentration –or turbidity - is a relevant indicator for our study as TSS results from both anthropic and natural actions and contribute to biological water quality degradation[13]. We define three classes of average values based on data coming from three different sampling points, related to three salinity classes. High TSS concentration can increase sediment production, and therefore the constitution of a pollution stock. This can lower the photosynthesis impacting oxygen availability for living organisms. However, TSS can contribute to the refuge functionality (f_2) as high TSS concentration implies high turbidity which reduces the predation risk.

To assess the available purification area (c_8) for each unit we removed any forms of man-made landscape (for instance roads, buildings, embankments, leisure ground…) by crossing Corine Land Cover database and our vegetation cover layers to obtain the part of unspoiled or natural purification potential stating that farmed land can activate the purification functionality called here "waste treatment".

Results and discussion

On the basis of the operational framework we have proposed so far, our approach aims at assessing the resilience potentials of the wetlands that are covered in our case study and, in turn, the sustainability of the management of the latter. Those assessments require beforehand to identify a set of criticality conditions on the natural capital components and related threshold values as the measure of the resilience potential is based on the number of criticality conditions to be fulfilled.

In what follows, we focus on the resilience potential(s) complying with the provision of one service only. Our operational framework leads to the determination of 2 solution sets, depending on the service considered[14].

Based on Figure 4 it appears that service 1 requires three functionalities, thus $F_1=(f_1, f_2, f_3)$, while service 2 requires 2 functionalities (so that $F_2=(f_3, f_4)$). In terms of required components, the activation of f_1 is associated with $C_1=\{c_{1,1}, c_{1,2}, c_{1,3}, c_{1,4}, c_{1,5}, c_{1,7}\}$, that of f_2 with $C_2=\{c_{2,2}, c_{2,6}, c_{2,7}\}$, that of f_3 with $C_3=\{c_{3,2}, c_{3,6}, c_{3,7}, c_{3,8}\}$ and that of f_4 $C_4\{c_{4,6},c_{4,8}\}$. Hence, the provision of service 1 is associated with the set $C_1 \cup C_2 \cup C_3$ while service 2 with the set $C_3 \cup C_4$.

The related resilience potentials can be identified on the basis of the previous sets and by taking additionally into account the criticality conditions that pertain to the natural capital components involved per functionality.

[13] The water quality component can also be taken into account via the accumulated quantity of sediments and organic matter that can interrupt water flows and eventually decrease the duration of flooding.
[14] By contrast, the provision of the whole set of services (s_1, s_2) requires the fulfilment of all the criticality conditions (involving all the components). In what follows, we focus in the least stringent case that is the one-service provision case.

The threshold values (or required categories) corresponding to those criticality conditions are given in table 3.

They have been determined, using the empirical evidence obtained for the wetlands that are part of our case study and by drawing from the criticality criteria used in the study of Van der Perk and De Groot (2000) on coastal wetlands. Some criticality conditions are more difficult to measure than others. In particular, addressing the resilience property would require to identify the slow controlling variables that make up ecosystem configuration (types of habitats, biophysical features -soil structure, geomorphology..., relationships between components, diversity -biological and functional-), and the faster variables which are operating at small spatial and temporal scales (Plummer and Armitage, 2007).

In addition, it may be noted that, in most cases, it is not the number of species per se that can allow for an ecosystem to be maintained in a particular state but rather the existence of species groupings or functional groups (predators, pollinators, herbivores, nutrient transporters, water flow modifiers... with overlapping characteristics anchored in physical processes) (Folke, 2006). That point underlines the fact that some species that can be redundant for ensuring the ecosystem functioning during some particular stages of the ecosystem development, may become of a great importance when the systems needs to regenerate after a disturbance.

Table 3 : Threshold values (T) or required categories (RC) (according to the components and the functionalities)

	$C_{h,1}$	$C_{h,2}$	$C_{h,3}$	$C_{h,4}$	$C_{h,5}$	$C_{h,6}$	$C_{h,7}$	$C_{h,8}$
f_1	(T) : 1 km²	(T): 50%	(RC): 64 ind/m²	(T): 27000 ind/m²	(RC): mesohaline		(RC): [$89_{surface}$,204_{depth}] or [$292_{surface}$,835_{depth}]	
f_2		(T): 50%				(RC): humid grasslands, tall herbs or humid grassland, short grass	(RC) : [$292_{surface}$,835_{depth}] or [$398_{surface}$,1151_{depth}]	
f_3		(T): 50%				(RC): humid grasslands, tall herbs or humid grassland, short grass or field crops, horticulture	(RC) : [$89_{surface}$,204_{depth}] or [$292_{surface}$,835_{depth}]	(T): 98%
f_4						(RC): humid grasslands, tall herbsor humid grassland, short grass or Forest		(T): 98%

Note: index h refers to the functionality. The gray area indicates a no relevant case (the component is not involved in the activation of the functionality).

Considering the ensuing criticality conditions and matching them with the set of natural components that are involved in the provision of services 1 and 2, leads to the determination of the resilience potentials that are associated with each service provision[15]. Service s_1 rests on the fulfilment of 8 critical conditions while 4 critical conditions are needed to provide service s_2.

[15] In Table 2, we observe that for some components, the criticality conditions are the same whatever the functionalities considered. In the case they differ, and unless they are not consistent with each

We now perform a detailed analysis regarding each service provision. We start with service s_2 whose provision requires less natural components; we look then at service (s_1) for which all the components have to be activated. Water provision (s_2) rests upon the activation of the waste treatment (f_4) and the water regulation (f_3) functionalities. Waste treatment in turn involves two natural components: the vegetation cover (c_6) and the size of the purification area (c_8)[16]. The critical condition pertaining to the vegetation cover is expressed in terms of the presence of either one of the three dominant vegetation types (forests; humid grasslands, tall herbs; humid grasslands, small grass) that are required to activate f_4. Regarding the critical value concerning (c_8), we use as the minimal proportion needed to achieve the functionality f_4, the average available purification area of our sample that rises up to 98%. Considering both criticality conditions, the waste treatment functionality can be activated in 39 wetlands representing 59% of whole area covered in our sample.

Wetland is also a transitional area where water can be both stored and released. Focusing on water regulation (f_3), the activation of that functionality implies the use of the following components: the water depth (c_2), the vegetation cover (c_6), the size of the purification area (c_8) and the water quality (c_7). Some assumptions have been made on the minimal levels (or required categories) concerning the natural components involved:

- For (c_2), as at least 50% of the wetlands area covered in the sample is below the 6 meters tidal range, we consider this value as being critical to ensure a minimal flooding capacity.
- For (c_6): we consider field crops or horticulture as a dominant vegetation type to be included in the required categories since we suppose that farmers seek for water proximity to improve their irrigation scheme,
- (c_7): a 850 mg/l maximum value for TSS concentration is required to lessen sedimentation[17].

Given those criticality conditions, the water regulation functionality can be offered in 25 wetlands corresponding to 51% of the whole area covered in the sample.

Further investigation could be performed however with respect to that result by notably including another component expressing the hydraulic connectivity which can be assessed by the canals maintenance cost[18].

other, the determination of the resilience potential goes through taking the most stringent of them (for a given component).

[16] We omit the first subscript referring to the functionality when it is not necessary.

[17] Thus, note that the involvement of the natural component (c_7) may be associated with different threshold values (or required categories) ($\underline{c}_{2,7}$) and ($\underline{c}_{3,7}$) depending on the functionality considered. But let note that $\underline{c}_{3,7} = \underline{c}_{1,7}$)

[18] Assessing canals maintenance costs requires a comprehensive set of monetary data by gathering data from local managers account books. In that respect, the availability of a partial set of monetary data would have probably restrained the scope of our wetlands sample.

Combining the previous outcomes, the result is the following: the resilience potential for the water provision service (s_2) is satisfied by 16 wetlands standing for 37% of the total area covered in the sample which means that the included ecosystems are able to sustain conjointly water regulation (f_3) and waste treatment (f_4) functionalities.

Now consider the halieutic resource core service (s_1) whose provision requires the activation of all the components. In particular, for that service to be provided the refuge functionality (f_2) has to be activated which is possible when the water turbidity is relatively high. A sufficient level of permanent or temporary water can allow fish movement and therefore prevent any predation from limicolous bird. Accordingly, the criticality condition reads in that case as a relatively high range in which the concentration level of TSS must establish itself. We set that range at [398_{surface}; 1151_{depth}] mg/l. The role of vegetation cover (captured by component (c_6)) is less direct but is relevant as it seems that long stemmed vegetation can contribute to shelter some fish species. Thus we consider only one category satisfying with the criticality condition, namely humid grasslands and tall herbs. While water depth - component (c_2) –is involved in the activation of the refuge functionality, the optimal water level required in that respect is difficult to identify (30 to 50 cm according to experts). We retain the same critical level as for the activation of the water regulation functionality.

Given those criticality conditions, the refuge functionality (f_2) can be activated within two wetlands of our sample case only. Enlarging the range for the required level of water turbidity, to include the range [$292_{\text{surface;}}$ 835_{depth}] mg/l concentration level does lead only to another one candidate to emerge. It turns out that the most stringent condition pertains to the vegetation cover type. Loosening the criticality condition on that component implies a larger number of candidates to prevail. On the whole, we obtain 17 humid grasslands, tall herbs *or* short grass (23% of the total wetlands area under concern) that can activate the refuge functionality.

According to our operational framework, the nursery functionality (f_1) seems to be the more challenging regarding the requirement in terms of natural capital components. Among them, the salinity gradient can affect the species richness but, as mentioned earlier, it has been decided to choose for the latter component an abundance index stating that a high fish density (regardless of the diversity in the fish species it might be associated with) involved, would have a positive impact on nursery functionality. The salinity gradient does also strongly influences the range of values taken by the indicators of other natural capital component such as biomass and water quality. Thus, focusing on a single salinity class as a critical category, (mesohaline) entails implicit levels concerning the number of species (c_3), the biomass (c_4) and the water quality (c_7). Others components involved are the size of the wetland (c_1) and water depth (c_2). Regarding the size, every area of wetland smaller than 1km² cannot be considered for the activation of the functionality under concern.

Fulfilling the whole set of critical conditions restricts the set of wetlands that may activate the nursery functionality to 18 candidates corresponding to 53% of the whole area covered in the sample. Let note that the functionality (f_3) - water regulation – is also involved in the provision of s_1, so that competing criticality conditions can occur with respect to TSS concentration (water quality). As we have just seen, the refuge functionality indeed requires a high level of TSS concentration in order to be activated, while water regulation rests upon a low level of turbidity. As a consequence, that conflict could impede the provision of the halieutic resources, except if some relevant range for the TSS concentration level could be found to allow both criticality conditions to be fulfilled. In that respect we could consider such a range by assuming that the turbidity could stand in a blurry area ranging around 800 and 1200 mg/l (for the highest concentration level), what would amount to loosening the criticality condition on TSS required for activating f_3. Doing so would allow 8 wetlands (corresponding to 13% of the area covered in our sample) to be associated with the provision of the halieutic resource service (s_1). Finally, considering the empirical threshold values and required categories needed to activate the four functionalities, the joint provision of the two services would concern only one specific wetland whose vegetation type would be mainly humid grasslands, tall herbs. Including the humid grasslands, short grass type in the vegetation cover (c_6) required categories would allow 8 wetlands (13% of the studied area) to ensure a joint provision of the two services.

Criticality indicators and local management tools for wetlands: extending the "SAGE" (Water Development and Management Scheme) scope

Given the increasing and multiple threats hanging over estuarine wetland areas, policy tools have been notably carried out by the water agencies in France to prevent further or heavier environmental damage on that kind of ecosystems. At the Gironde Estuary level, the water management is organized around a local planning tool: called 'SAGE' that provides guidelines about quality goals, protection rules, usage regulation etc…[19]. The SAGE is also intended to improve collective management of water resource, by implicating all the stakeholders that are involved at different levels. As long as one of its major goals is the wetland preservation, the kind of exercise we have performed in the latter subsection could well take place within the SAGE portfolio activities as it could be based in the first place on indicators that could be directly provided within the implementation of the SAGE. It may be noted however that the local management policy which is embedded in the SAGE does refer only to a functional approach of natural capital involved in the functioning of the wetlands considered in the "Gironde Estuary" SAGE.

[19] Within the SAGE perimeter, the major types of wetlands are estuary (10% of total surface), floodplains and marshes (SAGE, 2010).

No mention is made to criticality conditions or to the ecological resilience properties of those ecosystems within that local tool. The determination of those indicators would thus have to be added in the activities of the SAGE, should an investigation about the sustainability of wetlands be implemented within such a management scheme.

Conclusion

From a functional approach of natural capital which leads linking natural capital components, functionalities and ecological services, we have built a methodological framework of the functioning of an ecosystem able to account for its ecological resilience property (that tackles the role of economic pressures). We also linked the ecological resilience and the sustainability of the ecosystem: the latter depends on the way the criticality conditions associated with natural capital components are satisfied, involving in turn the activation of one or more ecological functionalities. The application to the case of a specific ecosystem such as Gironde estuarine wetlands has brought some useful insights for the connection between services and components of natural capital, and for the regulation of ecological services facing economic pressures.

First, after a typology of wetlands has been identified, some indicators for the criticality and the resilience potentials of the wetlands covered in our study have been discussed. For all the natural capital components involved, we have been able to determine empirically the critical values. Then, we have established the link between the provision of services and those critical conditions. We have shown that sixteen wetlands under study can implement the water provision service while the halieutic resources service is provided by eight of those ecosystems. However both services can only be provided by one specific wetland, under the most stringent conditions.

A first extension of our work could be to leave the static approach and build a dynamic framework for analysing feedback effects and links between the components for a better and more complex understanding of the relationships between components, functionalities and services. Viability methods could be a relevant framework to deal with such an issue (De Lara and Doyen, 2008; Baumgärtner and Quaas, 2009).

Second, those preliminary results suggest that the design of public policies could be different according the solution set of services that has to be satisfied. In our study, no use conflicts have been considered between the different functionalities or services, so that both the water provision service and the halieutic resources service could be satisfied jointly. But, if it is not the case, then the services provided by wetlands are no longer complement but substitutes. Another aspect of this problem can be identified when several functionalities are interacting with each other. Our methodological framework could be extended to the analysis of a set of wetlands in order to define the resilience potential at a broader local scale. In such a situation, it could be interesting to study how various wetlands could be complements or substitutes for the provision of a given service depending on whether their functionalities and/or their natural components are matching or not. Another point of interest could be to determine if the spatial closeness of several wetlands of small size is a limiting factor for the resilience of the set of wetlands and in that case to define the design of a public policy which aims to maintain embankments for economic activities.

References

ARROW K., BOLIN B., COSTANZA R., DASGUPTA P., FOLKE C., HOLLING C.S., JANSSON B-O., LEVIN S., MÄLER K-G., PERRINGS C., PIMENTEL D. (1995), “Economic growth, carrying capacity and the environment”, *Ecological Economics,* 15, p. 91-95.

AZQUETA D., SOTELSEK D. (2007), “Valuing nature: From environmental impacts to natural capital”, *Ecological Economics,* 63, p. 22-30.

BAUMGÄRTNER S., QUAAS M. (2009), “Ecological-economic viability as a criterion of strong sustainability under uncertainty”, *Ecological Economics*, 68, p. 2008-2020.

BRAND F.S. (2009), “Critical natural capital revisited: ecological resilience and sustainable development”, *Ecological Economics*, 68, p. 605-612.

BRAND F.S., JAX K. (2007), “Focusing the meaning(s) of resilience: resilience as a descriptive concept and a boundary object”, *Ecology and Society*, 12(1).

CHIESURA A., DE GROOT R. (2003), “Critical natural capital: a socio-cultural perspective”, *Ecological Economics*, 44, p. 219-231.

DALY H. E., FARLEY J. (2004), *Ecological economics. Principles and applications*, Island Press, Washington DC.

DEUTSCH L., FOLKE C., SKANBERG K. (2003), “The critical natural capital of ecosystem performance as insurance for human well-being”, *Ecological Economics,* 44, p. 205-217.

DE GROOT R.S. (1992), *Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision Making*, Wolters-Noordhoff, Groningen.

DE GROOT R.S, WILSON M. A., BOUMANS R. M. J. (2002), “A typology for the classification, description and valuation of ecosystem functions, goods and services”, *Ecological Economics*, 41, p. 393-408.

DE GROOT R., VAN DER PERK J., CHIESURA A., VAN VLIET A. (2003), "Importance and threat as determining factors for criticality of natural capital", *Ecological Economics*, 44, p. 187-204.

DE LARA M, DOYEN L. (2008), *Sustainable Management of Natural Resources: Mathematical models and Methods*, Springer, Berlin.

EKINS, P., SIMON, S., DEUTSCH, L., FOLKE, C., DE GROOT, R. (2003), "A framework for the practical application of the concepts of critical natural capital and strong sustainability", *Ecological Economics*, 44, p.165-185.

European Environment Agency (EEA) (2016), *Mapping and assessing the condition of Europe's ecosystems: progress and challenges, EEA contribution to the implementation of the EU Biodiversity Strategy to 2020*, Report No 3/2016, 148 p.

FERRARI S., LAVAUD S., PEREAU J-C. (2012), *Critical natural capital, ecological resilience and sustainable wetland management: a French case study*, Working Paper 8, GREThA, University of Bordeaux.

FOSSEY M., ROUSSEAU A.N. (2016), "Assessing the long-term hydrological services provided by wetlands under changing climate conditions: A case study approach of a Canadian watershed", *Journal of Hydrology,* 541, p. 1287–1302

FINLAYSON CM., SPIERS AG. (Eds) (1999), *Global review of wetland resources and priorities for wetland inventory*. Supervising Scientists Report 144/ Wetlands International Publication 53, Supervising Scientist, Canberra.

FOLKE C. (2006), "Resilience: the emergence of a perspective for socio-ecological systems analyses", *Global Environmental Change,* 16, p. 253-267.

GOSSELINK J.G., MITSCH W. J. (2007), *Wetlands,* Fourth Edition, John Wiley & Sons Inc, Noboken, New Jersey.

HOLLING C.S. (1973), "Resilience and stability of ecological systems", *Annual Review of Ecology and Systematics,* 4, p. 1-23.

KLÖVE B., ALLAN A., BERTRAND G., DRUZYNSKA E., ERTÜRK A., GOLDSCHEIDER N., HENRY S., KARAKAYA N., KARJALAINEN T. P., KOUNDOURI P., KUPFERSBERGER H., KUOERNER J., LUNDBERG A., MUOTKA T., PREDA E., PULIDO-VELAZQUEZ M., SCHIPPER P. (2011), "Groundwater dependent ecosystems. Part II. Ecosystem services and management in Europe under risk of climate change and land use intensification", *Environmental Science and Policy*, 14(7), p. 782-793.

LEHNER B., DÖLL P. (2004), "Development and validation of a global database of lakes, reservoirs and wetlands", *Journal of Hydrology*, 296/1–4, p.1–22.

MACDONALD D.V., HANLEY N., MOFFATT I. (1999), "Applying the concept of natural capital criticality to regional management", *Ecological Economics*, 29, p. 73-87.

MÄLER K-G. (2008), "Sustainable development and resilience in ecosystems", *Environmental and Resource Economics*, 39, p. 17-24.

MEA (Millennium Ecosystem Assessment), (2005), *Ecosystems and Human Well-being: Biodiversity Synthesis*, World Resources Institute, Washington, DC.

NIVET C., FRAZIER S. (2004), CD edition: *A Review of European Wetland Inventory Information,* Taylor, A.R.D. and VAN EERDEN, M. (eds.), Wetlands International.

NICOLAS D. (2010), *Des poissons sous influence? Une analyse à large échelle des relations entre les gradients abiotiques et l'ichtyofaune des estuaires tidaux européens,* PhD Thesis, University of Bordeaux.

OKRUSZKO T., DUEL H., ACREMAN M., GRYGORUK M., FLÖRKE M., SCHNEIDER Ch. (2011), " Broad-scale ecosystem services of European wetlands – Overview of the current situation and future perspectives under different climate and water management scenarios, *Hydrological Sciences Journal*, 56:8, p. 1501-1517.

PEARCE D., TURNER R.K. (1990), *Economics of nature resources and the environment*, Harvester Wheatsheafs, London.

PLUMMER R., ARMITAGE D. (2007), "A resilience-based framework for evaluating adaptive co-management: Linking ecology, economics and society in a complex world", *Ecological Economics*, 61, p.62-74.

SAGE (2010), *Estuaire de la Gironde et milieux associés*, Evaluation environnementale.

SCHLEUPNER C, SCHNEIDER U.A. (2012), "Gis-based estimation of wetland conservation potentials in Europe", *Applied Ecology and Environmental Research* 10(4), p. 385-403

TEEB (2008), *The economics of ecosystems and biodiversity*, An interim report, European Communities.

TEN BRINK B.J.E. (2000), *Biodiversity indicators for the OECD Environmental Outlook and Strategy: A Feasibility Study*. Report Number: 402001014, RIVM, Bilthoven.

TURNER R.K. (1993), *Sustainable Environmental Economics and Management: Principles and Practice*, Belhaven Press, New York.

TURNER R. K., VAN DEN BERGH J.C.J.M., SÖDERQVIST T., BARENDREGT A., VAN DER STRAATEN J., MALTBY E., VAN IERLAND E. C. (2000), "Ecological-economic analysis of wetlands: scientific integration for management and policy", *Ecological Economics*, 35, p. 7-23.

VAN DER PERK J.P., DE GROOT R.S. (2000), *Case Study Critical Natural Capital: Coastal Wetlands: The Dutch Wadden Sea.* Working Paper 12, Wageningen University.

VERHOEVEN J. T.A. (2014), "Wetlands in Europe: Perspectives for restoration of a lost paradise", *Ecological Engineering*, 66, p. 6-9.

Exploration of fungal biodiversity for the deconstruction of lignocellulosic biomass and the implementation of new biosynthetic pathways for green chemistry[1]

Emmanuel BERTRAND, Jean-Guy BERRIN, Christophe BOYER, Marianne DAOU, Michel DELATTRE, Elodie DRULA, Anne FAVEL, Sacha GRISEL, Mireille HAON, Isabelle HERPOEL-GIMBERT, Laurence LESAGE-MEESEN, Anne LOMASCOLO, David NAVARRO, Sana RAOUCHE, Eric RECORD, Marie-Noëlle ROSSO, Jean-Claude SIGOILLOT, Sabine TAUSSAC, Annick TURBE DOAN, Craig B. FAULDS.

Aix-Marseille Université, INRA, UMR 1163, Biodiversité et Biotechnologie Fongiques

The filamentous fungi of the Phyla Ascomycota and Basidiomycota provide a large repertoire of genes encoding a diverse combination of enzymatic mechanisms involved in the degradation of lignocellulosic biomasses. The collection of the CIRM-CF (International Centre for Microbial Resources – Filamentous Fungi, Aix-Marseille-University, Inra) hosted by the Joint Research Unit Biodiversity and Biotechnology of Fungi (UMR 1163 BBF) is responsible for the conservation and valorisation of fungal strains exhibiting selective or simultaneous degradation activities towards lignin and polysaccharides. During the last five years, several field-collecting campaigns have contributed to the development of the collection. Four were carried out over-seas and 5 on mainland France with an interest in tropical forests areas: French Guyana, French West Indies, French New Caledonia (Lechat el al 2013, 2015; Welti et al 2012). In total, 620 specimens were collected, identified by morphological criteria, cultured and added to the collection. In addition, the collection has been enriched by the deposit of strains by French or foreign mycologists. Thus, over the last five years, the collection has increased by 535 wild strains (including 38 new species that were not represented in the collection). To allow phenotype characterization and to facilitate genomic sequencing and assembly, 250 monokaryotic strains have been generated from different wild strains. This genetically stable material is used in several genome sequencing projects such as the Community Sequencing Programs at the Joint Genome

[1] https://www6.inra.fr/cirm/Champignons-Filamenteux last accessed on December 23, 2016.

Institute and were also deposited in the collection. Finally, the integration of other collections such as 377 Fusarium strains also ensure the growth of the collection. Therefore, the CIRM-CF currently includes approximately 2200 strains that have been characterized based on morphological and molecular criteria. All the strains of the collection have been authenticated by molecular methods such as ITS sequencing and phenotypic characterization is currently ongoing through research projects. All the public information and data related to the strains are available through the BRFM-DB database [1]. The collected biological material is maintained under high quality standards and has achieved ISO 9001 certification for the acquisition, authentication and distribution of fungal material since 2006. It is intended to the dissemination to the scientific community through academic and industrial projects. In 2016, within the scope of the ISO 9001:2008 certification, the CIRM-CF mission was also extended to the screening of fungal strains for targeted biological functions and white biotechnological applications.

Exploration of the fungal adaptation and their responses to lignocellulosic biomasses

The CIRM-CF collection is the starting point of comparative studies at the whole genomic level focused on the diversity of mechanisms used by the filamentous fungi to breakdown plant cell walls. One of the objective is to compare how the enzymatic systems acquired by the different types of filamentous fungi are used to cleave lignocellulosic polymers into available carbon sources. In fact, filamentous fungi can colonize plant tissues using different strategies: pathogenic, saprotrophic or symbiotic. The enzymatic systems acquired to decompose plant polymers into available molecules used as carbon sources for the fungus are compared by genomic and transcriptomic approaches. The response of the fungus to different substrates representative of model biomasses: grasses, gymnosperm, softwood and hardwood, is also evaluated by comparative transcriptomic and secretomic analyses (Couturier et al., 2015).

In particular, *Polyporales*, an order of wood-decaying fungi with applications in white and green biotechnologies and in medicinal chemistry, has been extensively studied. An open-access, user friendly, bioinformatics tool named FunGene-BD (http://www.fungene-db.org) was developed to facilitate the molecular authentication of Polyporales strains, otherwise subjected to morphological studies. This tool includes a curated database that contains Internal Transcribed Spacer (ITS) genes screened through a semi-automated pipeline from the International Nucleotide Sequence Database and the similarity search BLASTn program. (Navarro et al, 2012). The restriction of the database to one reference sequence by species allowed most of the time an unequivocal analysis. It is a promising tool for molecular authentication of the Polyporales and is useful for scientists that are not experts in mycology but need to check the identity of strains for applied microbiology.

Among the *Polyporales*, the most representative group of saprophytic homobasidiomycetes causing wood decay is the genus Pycnoporus. It is regarded as of scientific interest through the production of a full arsenal of oxidoreductases. Historically four species were defined in this genus based on their morphological features and their distribution areas, *P. cinnabarinus*, *P. sanguineus*, *P.coccineus* and *P.puniceus*. As part of the European project BIORENEW, the phylogeny of the laccase gene lac3-1 from 36 *Pycnoporus* strains within the CIRM-CF originating from different geographical areas (Central/South America, Europe, Africa, Asia and Oceania), highlighted that enzyme sequence diversity was associated with biogeographical origin. Special attention was given to the closely related species *P. sanguineus* and *P. coccineus*, which display very similar characters but are geographically discontinuous populations, indicating that biogeography has played a strong role in determining evolutionary history of species in the genus *Pycnoporus* (Lesage-Meessen et al, 2012).

In the post-genomic era, specialized databases are very useful tools to identify the full enzymatic repertoire available to a fungus necessary for it to deconstruct a plant cell wall. In a recent work in collaboration with the research unit CNRS-AFMB (www.afmb.univ-mrs.fr), the Carbohydrate-Active enZYmes database was implemented to achieve the simultaneous identification of CAZymes and oxidoreductases, especially those associated with lignin degradation (Auxiliary Activities) within a fungal genome (Levasseur et al, 2013). Forty-one available fungal genomes were initially included to study the occurrence of auxiliary activities enzymes in well-known white rot fungi (WRF), brown rot fungi (BRF) and plant pathogens from the Ascomycota (13 species) and Basidiomycota (28 species) divisions. A total of 1576 auxiliary activities were identified. All BRF strains to date lack ligninolytic AA2 enzymes whereas a single WRF strain can contain up to 26 AA2 proteins. This high prevalence of AA2 enzymes in WRF re-enforced the central role of ligninolytic class II peroxidases in wood degradation, and argues for the use of AA2 as a family “marker” for predicting the wood-decaying activities and nutritional mode of different fungal groups (White rot fungi vs Brown rot fungi).

To study the full lignocellulosic enzymatic arsenal of *P. cinnabarinus CIRM-BRFM137*, its genome was sequenced within the framework of the European project BIORENEW (Levasseur et al, 2014). CAZy analysis revealed that this genome contains all the enzymes families involved in cellulose degradation even if it presents the smallest number of glycoside hydrolases among sequenced White Rot Fungi. The number of xylan and pectin-degrading enzymes, important in the breakdown of the hemicellulosic component of the plant cell wall are also restricted and mainly represented by families GH10 and GH43. Among the predicted lignin-degrading activities, laccases (AA1_1), ligninolytic peroxidases (AA2), cellobiose dehydrogenase (AA8-AA3_1), and other auxiliary enzymes were identified. *P. cinnabarinus* contains a complete ligninolytic enzymatic spectrum and may exploit different strategies for ligninolytic breakdown compared to other White Rot Fungi.

Due to the heterogeneity of lignocellulosic substrates, many enzymes with different characteristics are required to convert lignocellulose into fermentable sugar monomers. Natural fungal diversity in wood-decaying species within the CIRM-CF collected in temperate and tropical forests or recovered from international collections was explored for biomass deconstruction using wheat straw as a model lignocellosic biomasses. Following the production of fungal secretomes (the proteins that are secreted by the fungus in its environment and that are found in the culture supernatant) under inductive conditions from 19 species, the capacity of these secretomes to supplement a commercial *Trichoderma reesei* cellulase cocktail for the improved release of soluble sugars from the wheat straw was assessed using the automatic platform developed in our unit (Navarro et al, 2010). This led to an improvement in biomass conversion into fermentable sugar yield of at least 23% as measured by the dinitrosalicylic colorimetric assay (Berrin et al, 2012). Among the isolates, the *Trametes gibbosa* secretome performed best, with an 60% improved conversion, a feature that was not universal to the Trametes and related genera. Enzymatic characterization of the *T. gibbosa* secretome revealed an unexpected high activity on crystalline cellulose, higher than that of the *T. reesei* cellulase cocktail. These investigations highlight the interest in a systematic high-throughput assessment of fungal biodiversity within collections to improve the enzymatic conversion of lignocellulosic biomass. It enabled the unbiased identification of new fungal strains issued from biodiversity with high biotechnological potential. Proteomic analysis of the best-performing secretomes (i.e. from *Fusarium verticillioides*, *Trametes gibbosa*, *Ustilago maydis*, *Podospora anserina*), performed in collaboration with the PAPPSO INRA platform in Jouy en Josas (http://pappso.inra.fr/), allowed the identification of a number of plant cell wall-degrading enzymes that may be potentially useful to improve the industrial lignocellulose bioconversion process (Berrin et al, 2012; Couturier et al, 2012; Ravalason et al, 2012; Poidevin et al, 2014). The most promising results obtained using fungal secretomes were patented in the framework of the Futurol and ANR E-TriCel projects (Sigoillot et al., 2013; Poidevin et al., 2013; Berrin et al., 2014). Furthermore, an analysis of the *Ascomycota P. anserina* secretomes produced during growth on Avicel and sugarbeet pulp (SBP) revealed a large array of CAZymes with a high number of GH6 and GH7 cellulases, CE1 esterases, GH43 arabinofuranosidases, and AA1 laccase-like multicopper oxidases. Moreover, a preponderance of lytic polysaccharide monooxygenases (LPMOs) was exclusively produced under the SBP condition. This study brought new insights into the *P. anserina* enzymatic machinery. Furthermore, global transcriptomic and secretomic analyses revealed that within the fungal taxa the Basidiomycete *Laetisaria arvalis* produces a unique repertoire of carbohydrate-active enzymes including a complete set of enzymes acting on cellulose. Temporal analyses of its secretomes indicated that the unusual degradation efficiency of *Laetisaria arvalis* is related to its early response to the carbon source, and on the finely tuned sequential secretion of several Lytic Polysaccharides Mono-Oxygenases (LPMOs) and hydrolytic enzymes targeting cellulose specifically (Navarro et al., 2014).

The mangroves wamp fungi are important actors in organic matter decomposition but little is known on the fungal diversity and community structure in this ecosystem. Using tag-encoded 454 pyrosequencing of the ITS1, ITS2, nu-ssu-V5 and nu-ssu-V7 regions, the fungal communities found on the marine and aerial parts of mangrove trees in New Caledonia were studied and compared (Arfi et al. 2012a). There was a marked zonation in species distribution. Ascomycetes were the dominant phylum (82%), Basidiomycetes were very rare (3%), and 15% of the sequences corresponds to unknown taxa. Host specificity was shown to be a key factor in the distribution of these communities, in both the aerial and intertidal parts of the trees. Microscopic observations and a metagenomic approach were used to study further the communities in the mangrove (Arfi et al. 2012b). These approaches demonstrated that fungal growth occurred under anoxic and sulfidic conditions in the mangrove. To assess the fungal diversity, a 454 pyrosequencing of the nuclear ribosomal internal transcribed spacer 1 and 2 (ITS-1 and ITS-2) was performed from mangrove soil (60 cm deep). Agaricomycetes dominate this ecosystem with 50% of the reads, but the most abundant operational taxonomic units (OTUs) were affiliated to Ascomycetes (around 80% of the ITS sequences). A Xylariale strain *Pestalotiopsis sp.* was isolated from the mangrove tree *Rhizophora stylosa* and the adaption of the strain to salinity was studied on its lignocellulolytic enzyme set (Arfi et al. 2013). Enzyme activities and proteomic analyses of the secretomes suggest that the presence of salt modifies the lignocellulolytic enzyme set with an increase in the secretion of xylanases and cellulases and an associated decrease in the production of oxidases. Thus, cellulose and hemicellulose hydrolysis is enhanced but lignin breakdown is reduced. Recently, the genome of a *Pestalotiopsis sp.* Isolated from the Baltic sea coast was sequenced (Kumar et al. 2015) and the related data allow a full access to new salt-tolerant enzymes as potentially more robust biocatalysts (Patel et al, 2016).

Degradation and valorization of complex and recalcitrant polysaccharide with fungal systems

Plant polysaccharides are the most abundant renewable carbon source on earth and are highly relevant to face tomorrow's environmental and energetic concerns. However, plant carbohydrate conversion into valuable products for energy and green chemistry that can then be transformed in the emerging second and third generation biorefineries face several challenges due to the recalcitrance of these polysaccharides to the commercially available enzymatic cocktails used for their deconstruction. Indeed, the recalcitrance of biomass to enzymatic attacks limits industrial performance. It might be interpreted as a lack of knowledge in the way we understand the relationship between the structure of biomass and the catalytic mechanisms that constitute the performance of current enzyme cocktails.

However, previous research made it possible to identify fungal oxidases and hydrolases dedicated to the degradation of polysaccharides that are currently considered as recalcitrant. The objective is to characterize and utilize these novel enzymes to unlock the degradation of these recalcitrant polysaccharides from the laboratory up to the industrial scale. For instance, the screening of fungal biodiversity allowed the identification of fungi capable of effectively supplementing the cocktail produced by *Trichoderma rees*ei traditionally used for deconstruction on an industrial scale. The correlations between omic data and markers of recalcitrance allow selection of the most promising hydrolases and oxidases. Our research has demonstrated the efficiency of fungal secretomes to improve lignocellulosic biomass conversion (Couturier et al., 2015). After screening hundreds of fungal strains obtained from the CIRM-CF collection, strains whose secreted enzymes improved significantly the glucose yield during the conversion of pretreated lignocellulosic biomass as compared to the *Trichoderma reesei* reference enzymatic cocktails used in industry were identified. This work highlighted the cooperation between fungal enzymes for enhanced degradation of complex lignocellulosic substrates. Several of the secreted enzymes were characterized, and enzymes of particular interest to biotransformation of plant biomasses have been produced on a large scale, allowing saccharification assays under industrial conditions.

More than fifteen oxidoreductases were successfully produced from 50 mg L^{-1} to 1 g L^{-1} at lab scale and at larger scale in collaboration with partners all over Europa using the host *Aspergillus* Through these collaborations, a laccase from *Phanerochaete lavido-alba* (Benghazi et al. 2013), two cellobiose dehydrogenase (CDH), a new laccase from Ascomycete origin, and the laccase of *Trichoderma reesei* were cloned and heterologously expressed (Levasseur et al. 2010). Also, more than 50 fungal CAZymes (mainly glycoside hydrolases (GH), carbohydrate esterases (CE) and auxiliary activity enzymes (AA)) have been heterologously produced in the yeast expression system *Pichia pastoris*. Due to the success of fungal enzymes being produced to high yields, the system was improved to streamline the methodology. Protocols of cloning, transformation, screening of transformants, cultures, purification of recombinant proteins were adapted in a high-throughput way (Haon et al 2015). We have used in-house genes encoding CAZymes (successfully expressed in *P. pastoris*) to establish simple standard protocols. Liquid transformation has been adapted to *P. pastoris* to avoid laborious plating of transformants. Liquid cultures have been miniaturized to 96-well plate format (deep well) and his-tagged recombinant enzymes are now purified using 96-well plates and visualized using the Caliper LabChip system (Perkin Elmer). Some of these steps (cultures, purification, etc) have been fully automated using an in-house robotic Tecan platform that will be adapted for this purpose.

(http://www.platform3pe.com/). This allowed their biochemical and enzymatic characterization with respect to their substrate specificity and optimal conditions of utilization (Couturier et al., 2011a; 2011b; 2013a; Lafond et al., 2012; Bey et al., 2013; Siguier et al., 2014; Poidevin et al., 2014; Katsimpouras et al., 2014; Puchart et al., 2015).

Fungal secretomes provide an ideal case study to identify the enzymatic and metabolic partners of LPMOs (Garajova et al, 2016) and the unit actively participates to this emerging field of research. Effort will also be focused on secreted proteins of as yet unknown function that are associated with biomass degradation markers and are candidates for the creation of new CAZyme families. Special attention is paid to new families of CAZymes (Lombard, et al., 2013), proteins of unknown function and LPMOs (Lytic Polysaccharide Monooxygenases). The works undertaken find their applications for biofuels, the production of precursor synthons of bioplastics, as well as the functionalization of oligo- and polysaccharides. Exploring fungal biodiversity has allowed the isolation and characterization of new enzymes, including oxido-reductases and carbohydrate hydrolases. A glucose dehydrogenase from the poorly characterized glucose-methanol-choline oxidoreductase family (GMCs : AA3 family) showed an ability to reduce oxidized quinones or radical intermediates, raising prospects for applying this enzyme to detoxify compounds formed during the degradation of lignins. A protein domain of unknown function identified in the coprophilic fungus *Podospora anserina* displayed yet unobserved bifunctional exo-β-(1,3)/(1,6) and endo-β-(1,4) activities toward beta-glucans. This fungal cellulase provided the basis for the definition of a new family of glycoside hydrolases, the GH131 family (Lafond et al., 2012). The structure-function analysis of hemicellulases brought to light the molecular mechanisms of substrate specificity and catalytic reactions, providing guidance for directed evolution strategies aimed at improving these biocatalysts.

CDH are extracellular glycosylated haemoflavoenzymes produced by many different wood-degrading and phytopathogenic fungi. They are involved in both the degradation of polysaccharides and lignins generating hydroxyl radicals by the Fenton reaction. The genomes from the basidiomycete *Coprinopsis cinerea* and *P. cinnabarinus*, and the ascomycete *Podospora anserina* were screened for candidate CDH genes which were successfully expressed in *P. pastoris* and *A. niger* (Bey et al., 2011; Turbe-Doan et al. 2012). CDHs kinetic constants were determined for several carbohydrates including β-1,4-linked di- and oligosaccharides. The effect of CDHs on saccharification of micronized wheat straw by an industrial secretome was studied. X-ray crystallography has been used to solve the structures of the most promising enzymes and unveil functional residues involved in the catalytic mechanism/molecular interaction. X-ray diffraction data sets have been collected at the ESRF (Grenoble) and SOLEIL (Paris) synchrotrons. Over the past four years, we have been very successful in getting the crystal structures of several fungal CAZymes expressed in *P. pastoris* (Couturier et al., 2013; Lafond et al., 2015; Siguier et al., 2014). The use of ionic chromatography and mass spectrometry allowed us to gain complementary insights into the specificities and the mode of action of these enzymes.

In the framework of the Futurol project, we have focused on two fungal endo-mannanases from the coprophilous ascomycete *Podospora anserina*, which belong to the families GH5 and GH26. These enzymes improved significantly the conversion of softwood for the second-generation bioethanol production (Couturier et al., 2011b). These mannanases were further subjected to detailed comparative analysis of their substrate specificities and active site organization. Although the GH5 enzyme displays a classical mode of action, the GH26 enzyme revealed an atypical hydrolysis pattern resulting from a predominant binding mode involving the - 4 subsite. The crystal structures of the two enzymes were solved at 1.4 and 2.85 Å resolution, respectively. Analysis of the GH26 enzyme crystal structure supported strong interaction with substrate at the - 4 subsite mediated by two aromatic residues (Couturier et al., 2013a). More recently, we provided deep insights into their binding mode with manno-oligosaccharides at the molecular level using NMR spectroscopic techniques (Marchetti et al., 2015). A strategy of molecular engineering in the yeast *Yarrowia lipolytica* was further implemented in collaboration with the ICEO platform in Toulouse (bioinfo.genotoul.fr) to improve the specific activity of the GH5 and GH26 (Couturier et al., 2013b). Following random mutagenesis and two steps of high-throughput enzymatic screening, we identified several mutants that displayed improved kinetic constants for the hydrolysis of galactomannan. Examination of their three-dimensional structures revealed which of the mutated residues were potentially important for enzyme function. Among them, a single mutation displayed an impressive 8.2-fold increase in the catalytic efficiency due to a significant improvement of the affinity for the substrate.

Although plant biomass degradation has been studied extensively, our knowledge of the enzyme systems used to degrade cellulose has changed dramatically in the last five years. Indeed, a new class of secreted enzymes known as LPMOs has revolutionized our view on how cellulose is degraded. In contrast to typical cellulases, which are hydrolytic enzymes, LPMOs degrade cellulose by a mechanism involving molecular oxygen and redox-active molecules acting as electron donors (ascorbate or cellobiose dehydrogenase). LPMO-catalysed cleavage leads to oxidation of one of the carbons in the scissile β-1,4-glycosidic bonds leading to keto and carboxylic acid functions at the surface of cellulose. These oxidases are considered as a breakthrough in the enzymatic degradation of biomass because they cleave glycosidic linkages. These LPMOs are considered as a major advance in the understanding of biomass degradation mechanisms because their oxidative cleavages of the glycosidic bonds allow a facilitated hydrolysis of the recalcitrant regions by the cellulases. The use of complementary approaches (biochemistry, biophysics, crystallography and inorganic biochemistry) makes it possible to untangle their functions and mechanisms of action (Bennati-Granier et al., 2015). LPMOs are unique since their mechanism of action requires electrons that can be provided by co-secreted enzymes i.e., sugar oxido-reductases and ligninases and small reductant molecules originating from fungal and or plant metabolites (Garajova et al., 2016). The AA9 family of LPMOs is widely distributed in the genomes of most ascomycetes and basidiomycetes. A high number of AA9 LPMOs are frequently encountered in fungal secretomes under lignocellulolytic conditions but the functional relevance of this redundancy is not fully understood. Enzyme activity of recombinant AA9 LPMOs were assayed on cellulose in synergy with the cellobiose dehydrogenases (Bey et al., 2013; Bennati-Granier et al., 2015). We showed that the total release of oxidized oligosaccharides from cellulose was higher for LPMOs that harbored a carbohydrate-binding module from the family CBM1. Investigation of their regioselective mode of action revealed that some oxidatively cleaved at both C1 and C4 positions while others released only C1-oxidized products. Rapid cleavage of cellulose was observed using the LPMO-H that was the most versatile in terms of substrate specificity as it also displayed activity on cello-oligosaccharides and β-(1,4)-linked hemicellulose polysaccharides (e.g., xyloglucan, glucomannan). These studies provide insights into the mode of cleavage and substrate specificities of fungal AA9 LPMOs that will facilitate their application for the development of biorefineries.

Degradation, modification and valorisation of aromatic compounds by fungal systems

Due to their aromatic and complex structures, lignins resist most of the hydrolytic treatments and contribute to the recalcitrance of lignocellulosic biomass. Specialized fungi, such as saprophytes, are able to destructure the complex lignin matrix through a combination of highly efficient enzymes, natural mediators, organic acids and auxiliary proteins. These fungi are also well known in transforming these aromatic products into secondary metabolites of industrial importance, such as vanillin, the premier food flavouring compound used in the world. Our objective is to identify and design novel enzymes for aromatic compound valorisation. In fact, Industrial lignins and other aromatic compounds present a sustainable source of a wide range of polymeric and/or monomeric molecules for manufacturing, building and green chemistry, with specific properties related to the aromatic nature of the polymers. The identification and characterization of key enzymes of saprophytic fungi capable of degrading this matrix, such as laccases, peroxidases, hydrogen peroxide-producing enzymes and novel dehydrogenase enzymes derived from the decryption of newly sequenced genomes and other enzymes involved in the specific pathways of biotransformation of aromatic compounds open up a wide range of monomers and polymers for construction and green chemistry. The functionalization of lignins and woody fibers allows the design of bio-adhesives in the design of agglomerated wood panels. The design of specific lignin-acting enzymatic cocktails will also be explored for the fragmentation of lignins leading to the release of platform molecules from lignocellulosic biomass, e.g. waste effluent or biomass treatment.

Another aspect of the research is to identify and characterize the key enzymes involved in biotransformation pathways specific to aromatics using comparative post-genomics approaches. The chemical metabolic pathway for the conversion of ferulic acid to vanillin by *P. cinnabarinus* has been previously elucidated although the enzymes involved were not identified. The bioconversion of aromatic monomers such as ferulic acid or sinapic acid allows applications in the sector of flavors, antioxidants and bioremediation. Although transformation of individual enzymes of interest is currently done in the Unit on model Ascomycetes such as *A. niger*, attempts to obtain consistent and stable transformants using the WRF *P. cinnabarinus* have failed so far. Efforts will be dedicated over the coming years with the development of new genetic tools such as the CRISPR-Cas9 system.

Expert knowledge on enzymes active on lignin has been developed that allows semi-automatic annotation of enzymes involved in lignin degradation. Integration of this knowledge to the CAZy classification in cooperation with the CNRS-AFMB allowed comparative genomics of carbohydrate- and lignin-active enzymes. This allowed the first pan-genome characterization of ligno-cellulolytic enzymes from *Pycnoporus cinnabarinus*, a white-rot fungus maintained at CIRM-CF.

From the construction of the Auxiliary Activity database within CAZy, several new enzymes were discovered and characterized. The genome analysis of P. *cinnabarinus* gives one putative glucose oxidase (GOx)-encoding gene and the corresponding protein was further studied. This enzyme was the first GOx studied in a Basidiomycete fungus. The cDNA was cloned in *A. niger* for production to achieve a yield of 640 mg L^{-1} (Piumi et al., 2014). The recombinant enzyme was purified and biochemically characterized for comparison to the ascomycete homologs. Analysis of the enzyme properties showed that it is a glucose dehydrogenase acting with alternative electron acceptor, not oxygen and that glucose is by far the preferred substrate, which constitutes an advantage over other sugar oxidases in the case of blood glucose monitoring. The substrate-binding domain of PcGDH turned out to be conserved in other glucose-methanol-choline (GMC) oxidoreductases. In addition, the ability of PcGDH to reduce oxidized quinones or radical intermediates was clearly demonstrated, which raised prospects for applying this enzyme to detoxify compounds formed during the degradation of lignin. Recently, three new dehydrogenases within the AA3 family of P. cinnabarinus were heterogously produced in *A. niger* and were fully characterized and showed to act synergistically with laccases (Mathieu et al. 2016).

Fungal pretreatment could be a low cost, environment-friendly alternative to chemical and physicochemical pretreatments commonly used in producing renewable energy (Rouches et al, 2016). In this context, a total of 176 strains from the CIRM-CF collection have been screened for their ability to grow on wheat straw and miscanthus with a low consumption of sugars for their own growth and to enhance saccharification. For this purpose, a new medium throughput multiwell plate Solid State Fermentation (SSF) method was used to select relevant fungi (Zhou et al, 2015). The six most efficient strains then underwent scaled-up SSF to perform finer investigations to select the best-adapted strain. The most effective fungus for enhancing enzymatic hydrolysis performance was *Polyporus brumalis* BRFM 985. From this work, a patent claiming this *P. brumalis* strain and the implementation process was filled (Gimbert et al, 2014). SSF operating parameters i.e. metals addition, time and temperature of culture and initial water content were optimized using response surface methodology, D-optimal design, combined with multicriteria optimization. To identify the enzymatic systems involved on the selective degradation of lignin during SSF, the genome of P. brumalis was sequenced and a time course analysis of the transcriptome and secretome during wheat straw pretreatment is currently underway

The influence of the structure of the high energy biomass, Elephant grass, and commercial sugar cane stems on the effectiveness of enzymatic deconstruction, was examined in collaboration with the Spanish laboratories of A Martinez (Madrid) and JC del Rio (Seville), and with the University of Sao Paolo (Brazil), VTT (Finland) and the University of Helsinki (Finland), and illustrated that in solid stem plant stalks, glycoside hydrolases preferentially degraded the more porous inner pith compared to the more lignified outer cortex (Perez-Boada et al, 2014; Varnai et al, 2014). The addition of a feruloyl esterase in both studies moderately improved the rate of hydrolysis, while the addition of an organic co-solvent such as DMSO to selectively remove xylan, while extensively increasing the rate of de-esterification (Faulds et al, 2011), reduced the overall enzymatic solubility of the biomass (Perez-Boada et al, 2014). These results show that the molecular rearrangement of the biomass and the extent of processing will have major influences on the overall efficiency of enzymatic deconstruction of biomass for bioenergy production.

Three high redox potential laccases from *P. coccineus* and *P. sanguineus* were tested and compared, with the commercial Suberase® as reference, for their ability to synthesize natural active oligomers from rutin (quercetin-3-rutinoside), one of the best-known naturally-occurring flavonoid glycosides. Considering that Pycnoporus fungi are listed as generally-recognized-as-safe (GRAS) microorganisms, a process in collaboration with Yves Rocher was developed with technical parameters (solvent, temperature, reaction time and raw materials) easy to scale up for industrial production and compatible with cosmetic and pharmaceutical formulation guidelines. The aqueous mixture of glycerol/ethanol/buffer met this requirement and allowed the solubilization of rutin and its oxidative bioconversion into oligomers. Four flavonoid oligomer mixtures were synthesized using laccases and identified as dimers and trimers of rutin, different from those produced from Suberase®. These oligorutins displayed significantly improved anti-oxidant, anti-inflammatory and anti-ageing activities on specific enzymatic targets such as cyclooxygenase (COX-2) and human matrix metalloproteinase 3 (Uzan et al, 2011).

A wide range of applications in the pulp and paper industry exist for the application of fungal enzymes. Paper production requires fibres to be refined, meaning mechanically treated to present sufficient bonding potential. As it is a highly energy consuming stage, cellulase addition as a pre-treatment step was investigated to reduce the energy consumption and improve paper properties. The enzyme was added during pulp slushing and conditions of treatment were chosen to be compatible with an industrial application. Results obtained after low consistency disc refining of a softwood bleached kraft pulp were compared at a given drainage index. Enzymatically-treated samples showed a better development of fibrillation leading to a stronger paper. Moreover, fibre swelling was significantly improved. Moreover, by treating pulp with cellulase, it became possible to reduce refining intensity by 33% (Lecourt et al., 2010a). Two cellulase treatments during disc refining were applied under similar conditions as usual in paper mills leading to a 20% energy saving. Water retention value, which characterizes the water absorption inside the fibre wall, was increased by the cellulase treatment. However, tear index losses were observed upon enzyme treatment due to endoglucanase activity, but was balanced by the breaking length enhancement. It can be concluded that cellulase treatment could save 20% of electrical energy needed for refining, i.e., 50 kWh t-1, giving a high paper quality with a high tensile resistance and an acceptable lowering of tear strength (Lecourt et al., 2010 b).

Low molecular weight organic acids production by filamentous fungi (e.g. citric, gluconic, malic, itaconic lactic and fumaric acids) have attracted considerable attention for their role in natural ecology and their potential industrial applications. To take advantage of the ability of filamentous fungi to degrade lignocellulosic biomass, 40 strains of Ascomycota and 26 strains of Basidiomycota from the CIRM-CF collection were screened in order to evaluate their potential for organic acid and ethanol production. Considering the pattern and the level of organic acid production, in a basal glucose liquid medium, this work illustrated the versatility in metabolites production among the fungal kingdom (Liaud et al., 2014). Furthermore, it enabled us to select *Aspergillus brasiliensis* BRFM103 to address some industrial issues regarding lignocellulosic biomass bioconversion into lactic acid. BRFM103 was successfully genetically modified by multicopy integration of a heterologous NAD-dependent lactate dehydrogenase gene to deviate the metabolic route toward lactic acid instead of ethanol (Liaud et al., 2015). Preliminary assays on complex substrates highlighted that the transformant was promising for lignocellulose bioconversion.

Laccase/mediator systems (LMS) were shown to be particularly efficient for pulp delignification. LMS have the disadvantage that the mediator is expensive and potentially toxic. N-hydroxyacetanilide in combination with laccase was shown very efficient to bleach Eucalyptus pulp and found to be a very promising alternative to 1-

hydroxybenzotriazole (HBT) which is generally used (Valls et al, 2010). Furthermore, a chimeric ligninolytic enzyme was designed by fusing laccase lac1 of *P. cinnabarinus* to the carbohydrate binding module CBM1 of *A. niger* cellobiohydrolase B and produced in *A. niger*. By conferring to the chimeric protein the ability to bind to complex lignocellulosic substrates such as paper pulps, CBM addition was shown to greatly improve the delignification capabilities of the laccase in the presence of HBT (Ravalason et al. 2012). The presence of CBM could enhance the laccase biobleaching potential of softwood kraft pulp since a decrease in the enzymatic charge and chlorine dioxide consumption, as well as an increase in pulp brightness were observed. The bleaching of softwood could also be improved by the use of mannanases to remove hemicelluloses, mainly constituted of gallactomannan in softwood.

Valorisation of agro-industrial residues using fungi

The residues of agro-industrial processes, such as vegetable oil extraction, brewing, fruit and vegetable juice production, etc., produce a low-value residue which is commonly used as an animal feed or composted. However, the potential value of some components of this material is sufficiently higher than the cost of animal feed or even for its conversion to bioenergy. The Unit has been looking at the exploitation of two high production agri-food residues, oil presscake and brewer's spent grain, and of a regionally-important crop residue (lavender), through the treatment with fungal cultures or fungal enzymes.

The Lavandula genus, which includes lavender (*Lavandula angustifolia*) and lavandin (*L. angustifolia* × *Lavandula latifolia*), is cultivated worldwide for its essential oils, which find applications in perfumes, cosmetics, food processing and, more recently, in aromatherapy products. Lavender and lavandin distilled straws (LLDS), traditionally regarded as waste after essential oil extraction, are mineral- and carbon-rich plant residues, the carbohydrates originating especially from cellulose, hemicelluloses and lignins. They contain terpenes, lactones and phenolic compounds of industrial interest (Lesage-Meessen et al 2015). Although they remain very limited (i.e. 32 000 tons/year for PACA region), preliminary work at BBF demonstrated the potential of filamentous fungi such as *T. reseei*, *P. cinnabarinus* and *P. sanguineus* for the saccharification of LLDS, the production of various cellulases, hemicellulases and oxidoreductases was demonstrated. The structure and composition of LLDS clearly opens new challenging perspectives for the use of LLDS in biotechnological processes,

Brewer's spent grain (BSG) is the most abundant side stream of the brewing industry, with between 15-20 kg being produced per hectolitre of beer. In 2010, 1.69 billion hL of beer was brewed worldwide (FAO-STAT, 2010). BSG is rich in polysaccharides (39.6% of Dry Matter), protein (18-27%) and lignin (14-26%) and we in collaboration with colleagues in VTT (Finland) have demonstrated that a combined mechanical pretreatment followed by sequential enzymatic extraction with glycoside hydrolase-rich cocktails (Forssell et al, 2011; Niemi et al, 2012a) can lead to the recovery of xylo-oligosaccharides (Forssell et al, 2011), which have a high prebiotic index, lignans (Niemi et al, 2012b), soluble protein (Niemi et al, 2013) and soluble and insoluble lignin-rich fractions which can be degraded in a human colonic model to stimulate the production of short-chain fatty acids (SCFA) and bioactive phenolic compounds which stimulate the growth of probiotic human intestinal bacteria (Niemi et al, 2013; Aura et al, 2013).

The continuous expansion of our knowledge on filamentous fungi, system biology, enzyme biochemistry and their associated metabolic pathways contributes to address societal challenges through the development of a circular bio-economy, the identification of new chains to produce value for the industry, by the valorisation of recalcitrant materials that were previously by-products or wastes from agro-industries and by the search for alternatives the processes that are not environmentally friendly with biological or bio-inspired processes.

References

ARFI Y., BUEE M., MARCHAND C., LEVASSEUR A., RECORD E. (2012a) «Multiple markers pyrosequencing reveals fungal biodiversity and host specificity in mangroves» *FEMS Microbiology Ecology*, 79, p. 433-44.

ARFI Y, MARCHAND C., WARTEL M., RECORD E. (2012b) «Fungal diversity in anoxic-sulfidic sediments in a mangrove soil» *Fungal Ecology* 5, p. 282-285.

ARFI Y., CHEVRET D., HENRISSAT B., BERRIN J.G, LEVASSEUR A., RECORD E. (2013) «Characterization of Salt-Adapted Secreted Lignocellulolytic Enzymes from the Mangrove Fungus *Pestalotiopsis Sp.* » *Nature Communications,* 1810.

AURA A.M, NIEMI P., NIEMELA K., MATTILA I., SMEDS A., TAMMINEN T., FAULDS C.B, BUCHERT J., POUTANEN K. (2013), «Release of small phenolic compounds from brewer´s spent grain and its lignin fractions by human intestinal microbiota in-vitro. » *Journal of Agricultural and Food Chemistry*, 61:9744-9753

BENGHAZI L., RECORD E., SUAREZ A., GOMEZ-VIDAL J.A, MARTINEZ J., DE LA RUBIA T. (2014), «Production of the *Phanerochaete flavido-alba* laccase in *Aspergillus niger* for synthetic dyes decolourization and biotransformation. » *World Journal of Microbiology and Biotechnology,* 30(1), p. 201-211.

BENNATI-GRANIER C., GARAJOVA S., CHAMPION C., GRIESEL S., HAON M., ZHOU S., FANUEL M., ROPARTZ D., ROGNIAUX H., HERPOEL-GIMBERT I., RECORD E., BERRIN J.G (2015), « Substrate specificity and regioselectivity of fungal AA9 lytic polysaccharide monooxygenases secreted by *Podospora anserina*. » *Biotechnology for Biofuels,* 8, p. 90.

BERRIN J-G, NAVARRO D., COUTURIER M., OLIVE C., GRISEL S., HAON M., TAUSSAC S., LECHAT C., COURTECUISSE R., FAVEL A., COUTINHO P.M, LESAGE-MEESEN L. (2012), «Exploring the Natural Fungal Biodiversity of Tropical and Temperate Forests toward Improvement of Biomass Conversion », *Applied and Environmental Microbiology,* 78, (18).

BERRIN J.G, NAVARRO D., LOPES-FERREIRA N., MARGEOT A., COUTINHO P.M, HENRISSAT B. (2014), « Préparation multi-enzymatique contenant le sécrétome d'une souche d'aspergillus japonicus» WO2014037925A1.

BERTRAND E., PRADEL M., DUSSAP C.G (2016), «Economic and Environmental Aspects of Biofuels. » In Green Fuels Technology, edited by Carlos Ricardo Soccol, Satinder Kaur Brar, Craig Faulds, and Luiz Pereira Ramos, p; 525–555.

BEY M., BERRIN J.G, POIDEVIN L., SIGOILLOT J.C (2011), «Heterologous expression of Pycnoporus cinnabarinus cellobiose dehydrogenase in Pichia pastoris and involvement in saccharification processes», *Microbial Cell Factories,* 10, p. 113.

BEY M., ZHOU S., POIDEVIN L., HENRISSAT B., COUTINHO P.M, BERRIN J.G, SIGOILLOT J.C (2013), «Cello-Oligosaccharide Oxidation Reveals Differences between Two Lytic Polysaccharide Monooxygenases (Family GH61) from Podospora anserina», *Applied and Environmental Microbiology,* 79(2), p. 488.

COUTURIER M., FELIU J., HAON M., NAVARRO D., LESAGE-MEESSEN L., COUTINHO P.M, BERRIN J.G (2011), «A thermostable GH45 endoglucanase from yeast: impact of its atypical multimodularity on activity. » *Microbial Cell Factories*, 10, p. 103.

COUTURIER M., HAON M., COUTINHO P.M, HENRISSAT B., LESAGE-MEESSEN L., BERRIN J.G (2011), «Podospora anserina hemicellulases potentiate the Trichoderma reesei secretome for saccharification of lignocellulosic biomass. » *Applied and Environmental Microbiology,* 77(1), p. 237-46.

COUTURIER M., FELIU J., BOZONNET S., ROUSSEL A., BERRIN J.G (2013), «Molecular engineering of fungal GH5 and GH26 beta-(1,4)-mannanases toward improvement of enzyme activity» *PloS ONE, 8*(11): e79800.

COUTURIER M., ROUSSEL A., ROSENGREN A., LEONE P., STALBRND H., BERRIN J.G (2013), «Structural and biochemical analyses of glycoside hydrolase families 5 and 26 beta-(1,4)-mannanases from Podospora anserina reveal differences upon manno-oligosaccharides catalysis. » *Journal of Biological Chemistry,* 288, (20), p. 14624-35.

COUTURIER M., NAVARRO D., OLIVE C., CHEVRET D., HAON M., FAVEL A., LESAGE-MEESSEN L., HENRISSAT B., COUTINHO P.M, BERRIN J.G (2012), «Post-genomic analyses of fungal lignocellulosic biomass degradation reveal the unexpected potential of the plant pathogen Ustilago maydis» *BMC Genomics*, 13, p. 57.

COUTURIER M., NAVARRO D., CHEVRET D., HENRISSAT B., PIUMI F., RUIZ-DUENAS F.J, MARTINEZ A., GRIGORIEV I.V, RILEY R., LIPZEN A., BERRIN J.G, MASTER E.R, ROSSO M.N (2015), «Enhanced degradation of softwood versus hardwood by the white-rot fungus Pycnoporus coccineus. » *Biotechnology for Biofuels*, 8, p. 216.

FAULDS C.B, PEREZ-BOADA, MARTINEZ A.T (2011), «Influence of organic co-solvents on the activity and substrate specificity of feruloyl esterases » *Bioresource Technology,* 102, p. 4962-4967.

FORSSELL P., TREIMO J., EIJSINK VGH, FAULDS C.B, COLLINS S., SCHOLS H.A, HINZ SWA., MYLLYMAKI O., TAMMINEN T., ZOLDNERS J., VILIANEN K., WALDRON K.W, BUCHERT J. (2011), «Enzyme-aided fractionation of Brewer's spent grain in pilot scale » *Journal of the American Society of Brewing Chemists,* 69, p. 91-99.

GARAJOVA S., MATHIEU Y., BECCIA M.R, BENNATI-GRANIER C., BIAO F., FANUEL M., ROPARTZ D., GUIGLIARELLI B., RECORD E., ROGNIAUX H., HENRISSAT B., BERRIN J.G (2016), « Single-Domain Flavoenzymes Trigger Lytic Polysaccharide Monooxygenases for Oxidative Degradation of Cellulose » *Scientific Reports* 6, 28276.

GIMBERT I., RAOUCHE S., ZHOU S., SIGOILLOT J.C, CARRERE H., ROUCHES E., COPINET E. (2014), «Prétraitement de biomasse lignocellulosique avec des champignons filamenteux pour la production de bioénergies » 30-10-2014 FR14/60472.

KATSIMPOURAS C., BENAROUCHE A., NAVARRO A., KARPUSAS M., DIMAROGONA M., BERRIN J.G, CHRISTAKOPOULOS P., TOPAKAS E. (2014), « Enzymatic synthesis of model substrates recognized by glucuronoyl estérases from *Podospora anserina* and *Myceliophthora thermophila.* » *Applied Microbiology and Biotechnology,* 98(12), p. 5507-16.

KUMAR A., HENRISSAT B., ARVAS M., SYED M.F, THIEME N., BENZ J.P, SORENSEN J.L, RECORD E., POGGELER S., KEMPKEN F. (2015) «De Novo Assembly and Genome Analyses of the Marine-Derived *Scopulariopsis brevicaulis* Strain LF580 Unravels Life-Style Traits and Anticancerous Scopularide Biosynthetic Gene Cluster", *PLoS One*, 10(10), e0140398.

LAFOND M., NAVARRO D., HAON M., COUTURIER M., BERRIN J.G (2012), « Characterization of a Broad-Specificity -Glucanase Acting on -(1,3)-, -(1,4)-, and -(1,6)-Glucans That Defines a New Glycoside Hydrolase Family », *Applied and Environmental Microbiology* 78, 24, p. 8540–46.

LECHAT C., HAIRAUD M., LESAGE-MEESSEN L. (2013), « *Stachybotrys oleronensis*», Fungal Planet description sheets 154-213. Persoonia, 31, p. 283.

LECHAT C., LESAGE-MEESSEN L., FAVEL A. (2015), « A new species of Ijuhya, I. fournieri, from French Guiana. » *Ascomyceteor*g, 7(3), p. 101-104.

LECOURT M., MEYER V., SIGOILLOT J.C, PETIT-CONIL M. (2010a), « Cellulase-assisted refining of softwood kraft pulp to reduce energy consumption », *Holzforschung,* 64, p. 441-447.

LECOURT M., SIGOILLOT J.C, PETIT-COLNIL M. (2010b), « Cellulase-assisted refining of chemical pulps: Impact of enzymatic charge and refining intensity on energy consumption and pulp quality», *Process Biochemistry, 45, p.* 1274-1278.

LESAGE –MEESSEN L., LOMASCOLO A., BONNIN E., THIBAULT J.F, BULEON A;, ROLLER M., ASTHER M., COLLONNA CECCALDI B. (2002), «A Biotechnological Process Involving Filamentous Fungi to Produce Natural Crystalline Vanillin from Maize Bran» *Applied Biochemistry and Biotechnology,* 102–103(1-6), p. 141–53.

LESAGE-MEESSEN L., BOU M., FAULDS C.B, SIGOILLOT J.C, LOMASCOLO A., (2015), «Essential oils and distilled straws of lavender and lavandin: A review of current use and potential application in white biotechnology », *Applied Microbiology and Biotechnology,* 99, p. 3375–3385.

LESAGE-MEESSEN L., HAON M., UZAN E., LEVASSEUR A., PIUMI F., NAVARRO D., TAUSSAC S., FAVEL A., LOMASCOLO A. (2011,) «Phylogenetic relationships in the polypore fungus *Pycnoporus* inferred from molecular data», *FEMS Microbiology Letters*, 325, p. 37-48.

LEVASSEUR A., SALOHEIMO M., NAVARRO D., ANDBERG M., PONTAROTTI P., KRUUS K., RECORD E. (2010), «Exploring laccase-like multicopper oxidase genes from the ascomycete *Trichoderma reeseï* : a functional, phylogenetic and evolutionary study» *BMC Biochemistry*, 11, p. 32.

LEVASSEUR A., DRULA E., LOMBARD V., COUTINHO P.M, BERNARD H. (2013), «Expansion of the Enzymatic Repertoire of the CAZy Database to Integrate Auxiliary Redox Enzymes», *Biotechnology for Biofuels,* 6(1), p. 41.

LEVASSEUR A., LOMASCOLO A., CHABROL O., RUIZ-DUENAS F.J, BOUKHRIS-UZA N.E, PIUMI F., KUES U., RAM A.F, MURAT C., HAON M., BENOIT I., ARFI Y., CHEVRET D., DRULA E., KWON M.J, GOURET P., LESAGE-MEESSEN L., LOMBART V., MARIETTE J., NOIROT C., PARK J., PATYSHAKULIYEVA A., SIGOILLOT J-C, WIEBENGA A., WOSTEN H.A.B, MARTIN F., COUTINHO P.M, MARTINEZ A.T, KLOPP C., PONTAROTTI P., HENRISSAT B., RECORD E. (2014) «The Genome of the White-Rot Fungus *Pycnoporus Cinnabarinus*: A Basidiomycete Model with a Versatile Arsenal for Lignocellulosic Biomass Breakdown» *BMC Genomics* 15(1).

LIAUD N., GINIES C., NAVARRO D., FABRE N., CRAPART C., HERPOEL-GIMBERT I., LEVASSEUR A., RAOUCHE S., SIGOILLOT J.C (2014), «Exploring fungal biodiversity: organic acid production by 66 strains of filamentous fungi», *Fungal Biology and Biotechnology*, vol 1, p. 1.

LIAUD N., ROSSO M.N, CRAPART C., HERPOEL-GIMBERT I., SIGOILLOT J.C, RAOUCHE S., LEVASSEUR A. (2015), «L-lactic acid production by *Aspergillus brasiliensis* overexpressing the heterologous ldha gene from *Rhizopus oryzae* », *Microbial Cell Factories*, vol 14, p. 66-74.

LOMASCOLO A., UZAN-BOUKHRIS E., SIGOILLOT J.C, FINE F. (2012), «Rapeseed and Sunflower Meal: A Review on Biotechnology Status and Challenges », *Applied Microbiology and Biotechnology,* 95(5), p. 1105–14.

LOMBARD V., GOLACONDA RAMUU H., DRULA E., COUTINHO P.M, HENRISSAT B. (2014), «The Carbohydrate-active enzymes database (CAZy) in 2013 », *Nucleic Acids Res,* 42, D490–D495.

MARCHETTI R., BERRIN J.G, COUTURIER M., QADER S.A.U, MOLINARO A., SILIPO A. (2016), «NMR analysis of the binding mode of two fungal endo β-1,4-mannanases from GH5 and GH26 families», *Organic and Biomolecular Chemistry*, 14, p. 314–322.

MATHIEU Y., PIUMI F., VALLI R., ARAMBURU R.C, FERREIRA P., FAULDS C.B, RECORD E. (2016), «Activities of Secreted Aryl Alcohol Quinone Oxidoreductases from *Pycnoporus Cinnabarinus* Provide Insights into Fungal Degradation of Plant Biomass. » *Applied and Environmental Microbiology,* 82(8), p. 2411–23.

MIYAUCHI S., NAVARRO D., GRIGORIEV I.V, LIPZEN A., RILEY R., CHEVRET D;, GRISEL S., BE M., BIGNON C. RRIN J.G, HENRISSAT B., ROSSO M.N (2016), «Visual Comparative Omics of Fungi for Plant Biomass Deconstruction », *Frontiers in Microbiology, 7.*

NAVARRO D., COUTURIER M., GHIZZI DAMASCENO DA SIVA G., BERRIN J.G, ROUAU X., ASTHER D, BIGNON C. (2010), «An automated assay for screening the enzymatic release of reducing sugars from micronized biomass». *Microbial Cell Factories,* 9, p. 58.

NAVARRO D., FAVEL A., CHABROL O., PONTAROTTI P., HAON M., LESAGE-MEESSEN L. (2012), «FunGene DB: A web-based tool for Polyporales strains authentication», *Journal of Biotechnology*, 161, p. 383-386

NAVARRO D., ROSSO M.N, HAON M., OLIVE C., BONNIN C., LESAGE-MEESSEN L., CHEVRET D., COUTINHO P.M, HENRISSAT B., BERRIN J.G (2014), «Fast solubilization of recalcitrant cellulosic biomass by the basidiomycete fungus Laetisaria arvalis involves successive secretion of oxidative and hydrolytic enzymes» *Biotechnology for Biofuels*. 7 (1), p. 143.

NIEMI P., FAULDS C.B, SIBAKOV J., HOLOPAINEN U., POUTANEN K., BUCHERT J. (2012a), «Effect of a milling pre-treatment on the enzymatic hydrolysis of carbohydrates in brewer’s spent grain», *Bioresource Technology,* 116, p. 155-160.

NIEMI P., TAMMINEN T., SMEDS A., VILIANEN K., OHRA-AHO T., HOLOPAINEN-MANTILA IEMI PU., FAULDS C.B, POUTANEN K., BUCHERT J. (2012 b), «Characterization of lipids and lignans in brewer's spent grain and it's enzymatically extracted fraction», *Journal of Agricultural and Food Chemistry,* 60(39), p. 9910-7.

NIEMI P., MARTINS D., BUCHERT J., FAULDS C.B (2013), «Pre-hydrolysis with carbohydrases facilitates the release of protein from brewer's spent grain», *Bioresource Technology,* 136, p. 529-34.

PATEL I., KRACHER D., MA S., GARAJOVA S., HAON M., FAULDS C.B, BERRIN J.G, LUDWIG R., RECORD E. (2016), «Salt-Responsive Lytic Polysaccharide Monooxygenases from the Mangrove Fungus Pestalotiopsis Sp. NCi6 », *Biotechnology for Biofuels,* 9(1).

PEREZ-BOADA M., PRIETO A., PRINSEN P., FORQUIN-GOMEZ M.P, DEL RIO J.C, GUTIERREZ A., MARTINEZ A.T, FAULDS C.B (2014), «Enzymatic degradation of Elephant grass (Pennisetum purpureum) stems: Influence of the pith and bark in the total hydrolysis», *Bioresource Technology,* vol 167C, p. 469-475.

PIUMI F., LEVASSEUR A., NAVARRO D., ZHOU S., MATHIEU Y., ROPARTZ D;, LUDWIG R., FAULDS C.B, RECORD E. (2014), «A Novel Glucose Dehydrogenase from the White-Rot Fungus Pycnoporus Cinnabarinus: Production in *Aspergillus Niger* and Physicochemical Characterization of the Recombinant Enzyme», *Applied Microbiology and Biotechnology,* 98(24).

POIDEVIN L., BERRIN J.G, BENNATI-GRANIER C., LEVASSEUR A., HERPOEL-GIMBERT I., CHEVRET D., COUTINHO P.M, HENRISSAT B., HEISS-BLANQUET S., RECORD E. (2014), «Comparative analyses of Podospora anserina secretomes reveal a large array of lignocellulose-active enzymes», *Applied Microbiology and Biotechnology*, 98(17), p. 7457-69.

POIDEVIN L., BLANQUET S., RECORD E., BERRIN J.G, COUTINHO P.M, HENRISSAT B. (2013), « Procédé de production d'alcool a partir de biomasse lignocellulosique par complementation des enzymes cellulolytiques et hemicellulolytiques de trichoderma reesei par le champignon podospora anserina», WO2013088003A1.

PUCHART V., BERRIN J.G, HAON M., BIELY P. (2015), «A unique CE16 acetyl esterase from Podospora anserina active on polymeric xylan», *Applied Microbiology and Biotechnology,* 99 (24), p. 10515-10526.

RAVALASON H., GRISEL S., CHEVRET D., FAVEL A., BERRIN J.G, SIGOILLOT J.C, HERPOEL-GIMBERT I. (2012), «Fusarium verticillioides secretome as a source of auxiliary enzymes to enhance saccharification of wheat straw», *Bioresource Technology*, 114, p. 589-596.

ROUCHES E., HERPOEL-GIMBERT I., STEYER J.P, CARRER H. (2016), «Improvement of anaerobic degradation by white-rot fungi pretreatment of lignocellulosic biomass: A review», *Renewable and Sustainable Energy Reviews*, 59, p. 179–198.

SIGUIER B., HAON M., NAHOUM V., MARCELLIN M., BURLET-SCHILTZ O., COUTINHO P.M, HENRISSAT B., MOUREY L., DONOHUE M.J, BERRIN J.G, TRANIER S., DUMON C. (2014), « First structural insights into α-L-arabinofuranosidases from the two GH62 glycoside hydrolase subfamilies», *Journal of Biological Chemistry,* 289(8), p. 5261-73.

SIGOILLOT J.C, BERRIN J.G, BEY M., LESAGE-MEESSEN L., LEVASSEUR A., LOMASCOLO A., RECORD E., UZAN-BOUKHRIS E. (2012), «Fungal Strategies for Lignin Degradation», *Advances in Botanical Research*, 61, p. 263–308.

SIGOILLOT J.C, BERRIN J.G, BEY M. (2013), «Compositions comprising cellobiose-dehydrogenase from *Pycnoporus cinnabarinus* and their use for the degradation of lignocellulosic biomass», WO2013004377A2.

TURBE-DOAN A., ARFI Y., RECORD E., ESTRADA-ALVARADO I., LEVASSEUR A. (2013), «Heterologous production of cellobiose dehydrogenases from the basidiomycete *Coprinopsis cinerea* and the ascomycete *Podospora anserina* and their effect on saccharification of wheat straw» *Applied Microbiology and Biotechnology,* 97, p. 4873–4885.

UZAN E., PORTET B., LUBRANO C., MILESI S., FAVEL A., LESAGE-MEESEN L., LOMASCOLO A. (2011), « *Pycnoporus* laccase-mediated bioconversion of rutin to oligomers suitable for biotechnology applications», *Applied Microbiology and Biotechnology*, 90, p. 97-105.

VALLS C., COLOM J.F, BAFFERT C., GIMBERT I., RONCERO M.B, SIGOILLOT J.C (2010), « Comparing the efficiency of the laccase–NHA and laccase–HBT systems in eucalyptus pulp bleaching», *Biochemical Engineering Journal,* 49, p. 401-407.

WELTI S., MOREAU PA, FAVEL A., COURTECUISSE R., HAON M., NAVARRO D., TAUSSAC S., LESAGE-MEESSEN L. (2012). «Molecular phylogeny of Trametes and related genera, and description of a new genus *Leiotrametes*», *Fungal Diversity,*55, p. 47-64.

ZHOU S., RAOUCHE S., GRISEL S., NAVARRO D., SIGOILLOT J.C, HERPOEL-GIMBERT I. (2015), « Solid-State Fermentation in Multi-Well Plates to Assess Pretreatment Efficiency of Rot Fungi on Lignocellulose Biomass», *Microbial Biotechnology* 8(6), p. 940–49.

Post harvest food wastage, causes along the supply chain and solutions for a more sustainable food production system

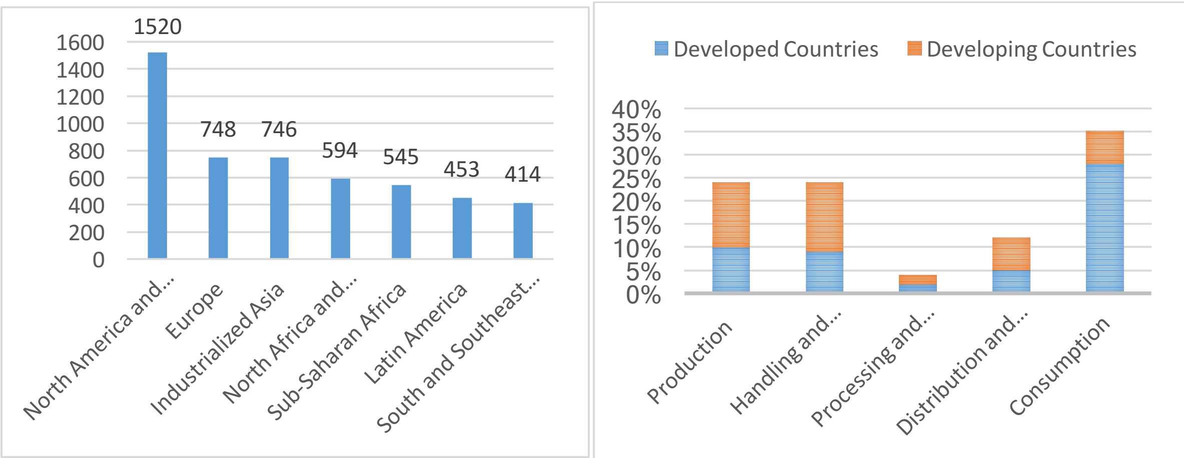
Eduard NEDELCIU[1] C., Nga NGUYEN[2], Jóhanna GISLADOTTIR[1,3]
Araj FAYEZ[4], Elena BAKHANOVA[5]

[1]*Institute of Earth Sciences, Faculty of Earth Sciences, University of Iceland*
[2]*Faculty of Geo-Information Science and Earth Observation (ITC), Geo-information Processing Department (GIP), University of Twente*
[3]*Faculty of Political Sciences, University of Iceland*
[4]*Faculty of Agriculture, Lebanese University*
[5]*Analyst, Department for Strategy and Industrial Cooperation, Skolkovo Institute of Science and Technology*

There are an estimated 570 million farms around the world spreading across 4.9 billion hectares (FAO, 2014). They produce an estimated global quantity of food amounting to almost 4 billion tonnes, of which approximately a third is wasted or lost each year (Gustavsson et al. 2011; FAO, 2016). The cost of wasted food has been estimated at approximately USD 1 trillion each year, although there is an understanding that the costs of food wastage are much higher if the socio-environmental costs are being considered (FAO 2014b). Most of the food wastage occurs in the developed countries of North America and Oceania, followed by industrialiased nations from Europe and Asia (figure1, a). Countries in Africa, Latin America and in the emerging Asian countries have the lowest rates of food wastage. The amount of food wastage in each sector, however, differs from region to region. While in developing countries most of the losses occur during production and handling and storage, in developed countries it is consumption where food is being mostly lost or wasted (figure 1, b).

In this paper, we set to review the main causes and the potential solutions for food wastage along the post-harvest food supply chain at a global level. In doing so, we will consider food wastage as referring to "*any food lost by deterioration or discard, thus [...] both food loss and food waste*" (FAO, 2013). We divide the post-harvest food supply chain in five main sectors: (i) post-harvest handling and storage; (ii) processing and manufacturing; (iii) distribution; (iv)retailing; and (v) consumption, looking into the structural causes for food wastage in each of them and reviewing solutions. Depending on the degree of food wastage in each sector and the availability of data, we focus more on high-income countries for some sectors, while for other the focus is more on low-income countries.

Figure 1: Food wastage in tons per region (a) and (b) food wastage ration at the five stages of the food supply chain



Source : Phipps et al. (2013)

Food wastage at handling and storage level

40% of the food waste in developing countries occurs at post-harvest and processing levels. In Sub-Saharan Africa and South and South-East Asia, handling and storage account for 37% of the total food wastage, compared to only 6% in the US and Canada and 12% in Europe (WRI, 2011). For instance, waste due to post-harvest storage and handling for cereals in South and South-East Asia and Sub-Saharan Africa accounts for 10% of the total food production and increases to 15% for roots and tubers (FAO, 2011). Analogously, 8-10% of the fruits and vegetables production is being wasted in Latin America, Sub-Saharan Africa and Industrialized Asia at the same food supply chain step. A similar trend is registered in all non-industrialized countries: 6-10% of the milk and dairy production is wasted or lost at the post-harvest stage (FAO, 2011). On the other hand, food wastage from harvest to processing is considered to be low and insignificant, with numbers as low as 0.07-2.81% for crops like barley in Canada (Smil, 2010). Losses of livestock at this stage usually occur from slaughter and are some of the lowest along the food supply chain, accounting for 1-2% worldwide, while fish losses between post-catch and processing are around 3-5% in industrializing regions (FAO, 2011).

Causes

Post harvest losses at the farm level are generally related to spillage and degradation during handling, storage and transportation between farm facilities (Parfitt et. al, 2010; FAO, 2011). For grains, the main factors impacting post-harvest losses up to transportation and processing/marketing are (i) moisture content; (ii) drying; (iii) cleaning; and (iv) storage. A high moisture content of grains will lead to heat build-up and will accelerate mould growth, which in turn will damage grains and potentially produce toxins. It will also cause a decrease in the nutrients stored in the grain and ultimately reduce its germination and vigour. Therefore, drying plays a central role in providing an optimal and unvarying grain moisture content, which would allow for favourable grain storage conditions. Drying at temperatures that are too high can increase grain drying rate but at the same time increase fissuring and decrease milling quality (Kirleis and Stroshine, 1990). Likewise, excessive high temperature for drying can reduce the viability and nutritional value of grains. On the other hand, drying temperatures that are too low can lead to an insufficient or too varying drying and thus make the grain susceptible to the unfavourable high moisture content processes mentioned above. In developing countries, the most common technique is sun drying, a practice which has the advantage of being low-cost but the disadvantages of being highly weather depended, labour intensive and resulting in a low quality for grain milling. Another drying technique in non-industrialized countries is field drying, where farmers leave the harvested crops to dry in the fields. The downside of this method is that it leads to a swift decrease in grain quality and can also lead to increased moisture content and mould growth. Moreover, it leaves the crops vulnerable to rodents.

In addition to drying, grains and oil seeds need to be cleaned before being stored and/or processed. Cleaning ensures that foreign materials such as dust or weed seeds are removed and at the same time, it guarantees a higher crop quality on the market. Surprisingly, the highest losses at the cleaning and separation stage are associated with mechanical processes, such as using a combine harvester, whereas losses through manual cleaning and threshing are minimal (Hassani et al., 2011). Storage is another significant food supply chain stage and in the case of developing countries, a stage at which considerable losses are incurred, particularly in developing countries. Whereas industrialized countries generally use large round metal bins and concrete silos to store crops, the most common storage structures in the industrializing countries are bags, small clay bins and baskets. The most important factor when storing crops is moisture content. A moisture content that is too high will lead to development of moulds, pests and even insect infestation. Inappropriate storage facilities will also make crops susceptible to rodents.

In terms of vegetables and fruits, most of food wastage occurs due to unsanitary storage facilities and lack of refrigeration equipment, both of which make the food products susceptible to pests (WRI, 2011). Likewise, fruits and vegetables are highly perishable products and need to either be consumed or processed fast. Other losses at this stage can result from farmers binning fruits and vegetables that do not comply with the market standards - the out grades. Fish and livestock, on the other hand, do not incur significant losses at this stage. Possible causes for losses are usually animals not being accepted at the slaughter-house or fish being spilled over after landing (WRI, 2011).

Solutions

There are a number of solutions that have been proposed in the last years for combating food wastage at a handling and storage level. On a technical level, there have been calls for more access to cost-efficient handling and storage equipment for farmers in developing countries (WRI, 2011; Kummu et al., 2012). Such equipment includes metal silos, storage bags or crates. Increased use of refrigeration technology in both developed and developing countries is often cited as a key element in preserving highly perishable foods, such as fruits and vegetables, fish or meat. More sophisticated techniques include, for instance, the use of Pulse Light (PL) to increase the life cycle of fruits as a non-thermal, residue-free storage alternative (Molina et al., 2016). Moulding, decomposition or insect infestation could also be tackled by increasing the hygiene standards of storage facilities in the case of highly perishable foods or by applying appropriate and correct drying and cleaning techniques in the case of grains and oil seeds (APO, 2011).

However, solutions are also related to socio-economic and political factors. Often, farmers lack information on appropriate handling and storage techniques and are thus not aware that a simple, cost-effective change in their techniques could drastically reduce food waste. For instance, a 1% decrease in seed moisture for grains can double their storage life (Strelec et al., 2010) but very few farmers have this knowledge. Extension services are thus needed in order to enable producers to take simple, informed decisions about the way they handle food in the farm facilities. Another structural problem is that farmers lack access to financing instruments and so incentives for investment in storage and handling technologies would enable producers to reduce food wastage at this step of the supply chain (APO, 2011). Last but not least, providing market access to farmers would enable them to sell their products at favourable times and avoid overstocking during harvest time, while simultaneously increasing the quality of their products and thus prolonging their storage life. In developed countries, on the other hand, constructing a policy environment that does not support overproduction and coupling this with financial incentives to move towards a multifunctional agriculture, would reduce the food that is otherwise lost due to a saturated market (Winders, 2014).

Food wastage in the processing and manufacturing sector

Food processing and manufacturing add substantial amount of waste to the total amount of food waste along the supply chain. More particularly, in developing countries the food losses at manufacturing and post-harvest stages can reach up to 40 %, while in developed countries this share is less significant (Gustavsson et al., 2011). Unlike much public and scientific attention to food waste in retail and consumers' sectors, food losses during manufacturing are less discussed in practice. Such situation has occurred because of several factors, including blurry definition of food loss and inaccurate (deficient) data collection (Stuart, 2009). This lead to fragmented understanding of the problem and its significance, which in turn, has its consequences on efficiency of public policy measures, business responsibility and the overall state of the problem. For instance, manufacturers could pay less attention to food waste issue and continue business as usual as long as it is economically viable since there is no direct connection between the amount of food wasted and their public image (Stuart, 2009).

Causes

The causes of food loss occurrence at manufacturing stage differ depending on the economic performance of the country, i.e. developed and developing countries. Poorly developed infrastructure is mentioned among one of the drivers for food loss in the developing countries (Gustavsson et al., 2011). Specifically, lack of refrigerators, storage facilities and improper packaging during the food processing add the most to food loss creation. Then with the increase of economic and living standards in the developing countries, the problems associated with food waste in the manufacturing stage is getting similar to the ones in developed countries. In developed countries, the driving forces mainly lie within economic and organizational levels. The behavioral aspect has also partly influenced the manufacturers in terms that some parts of food items started to be perceived as waste since the final products get more processed before being sold to the final consumers (Stuart, 2009).

Food loss at the manufacturing stage partly can be explained by inefficient quality control and manufacturing process organization, e.g. food quality loss takes place because of contamination in production process, packaging problems or inconsistency of manufacturing processes (Priefer et al., 2016). Then a more systemic problem lies within the way of how the food supply chain is organized. The amount of food loss generated at the manufacturing stage has straight connection to the demand coming from the next actor in the supply chain, i.e. retailer sector. The requirements connected with appearance, shape and size of the products lead to creating additional food waste since irregular sized or misshapen products should be trimmed to fit or rejected (Priefer et al., 2016).

Also the amount of food loss is dependent on whether the manufacturer supplies products under its own brand or produces them under retailer (supermarket) brand. According to Stuart (2009), food production under supermarket label is from 1,4 to 5 times more wasteful than under manufacturer's brand. In case when a manufacturer produces food under retailer's brand then its production process is very vulnerable to changes in orders from retailer's side. The uncertainty of demand and time delays in the supply chain can end up with a "bullwhip effect" when the manufacturer has produced much more food than was eventually shipped to the retailer (Kumar and Nigmatullin, 2011). The remaining surplus of products labeled as for particular retailer could not be sold anywhere else, and if the food is already packaged (e.g.

sandwiches), then it is complicated and costly to remanufacture or recycle it (Stuart, 2009). Such over-production creates additional amounts of food waste. 'Take-back' business practice, meaning that all unsold products are returned back to manufacturer, leads to the same result as over-production but with additional transportation expenses and possible losses during it.

Solutions

Possible solutions for decreasing food loss in manufacturing stage lay within three fields: technology, management and public policy. The technological perspective is mainly focused on recycling or material recovery out of food waste (Garrone, 2016). Plant and animal by-products can be composted or recycled in fertilizers and animal feed, while other food waste could be used as a source for energy production through anaerobic digestion technologies.

From management perspective the emphasis could be put on information exchange and increasing of transparency within food supply chain in order to overcome excessive production. As noted by Stuart (2009), on one hand, the manufacturer can not produce less food than was ordered since he might not comply with prior agreements and loose the buyer; on the other hand, in majority of the cases it is not possible to postpone production until the precise orders come because the food production might take more than 1 day and the manufacturer could not comply with delivery time deadlines. The solution in this case could be found in more flexible agreements within manufacturer-retailer relationships or in using complex forecasting and analytical software that helps to predict demand in a more precise way, e.g. vendor managed inventory system (Kulp, 2002). Additionally, special emphasis should be placed on increasing awareness regarding food loss and its influence on manufacturer financial performance (Stuart, 2009).

From public policy side the leverage point could be seen in increasing the transparency of data on food loss in the manufacturing sector and in regulating the responsibilities of food loss creation within supply chain. For example, in UK the Competition Commission tried to influence over-ordering and subsequent over-production in food sector through such mechanisms as voluntary Supermarket Code of Practice and Grocery Supply Code of Practice (Stuart, 2009).

Food wastage in the transport and distribution sector

Aghazadeh (2004) defines the effective distribution of food products as meeting the demand of supply by delivering good quality products in appropriate quantities to the right place respecting optimal path and cost. However, this definition is becoming outdated since it does not consider the environmental performance of food supply chain (Validi et al., 2014). Food distribution consumes large amounts of energy and other resources (Cuellar and Webber, 2010). It has negative green house gas (GHG) emissions from transport vehicles. Food is responsible for quarter of the distance traveled by lorries in UK, while consumers drive 12 billion miles/year to buy it (Food Ethical Council, 2008). By wasting edible food, all resources consumed in the production, processing and transporting of that food are wasted and resulted more environmental impacts (Gustavsson et al., 2011). It is essential that environmental impacts of food will be reduced while still meeting the global demand. Godfray et al. (2010) suggested minimizing the volume of food discarded. Wastage in vegetables and animal commodities in the distribution stage includes wholesale markets, supermarkets, retailers and wet markets (FAO, 2011). According to Gooch et al. (2010), the portion of food waste in distribution and transportation is estimated to not exceeding 3% in Canada. In 2013, UK estimated her wastage of food in distribution phase to be 3% also. However, the economic and environmental values of finished products from distribution and retail are high (Bond et al., 2013). FAO (2011) describes that in medium and high-income countries, food is wasted at retail, service food and household levels, while wastage is major on and near the farm in low-income countries (Escaler and Teng, 2011).

Causes

Food waste during distribution is attributed to the lack of effective distribution system. Improper handling, packaging, or damage during transport is the main cause for food wastage during the distribution phase. Products kept at improper temperatures when loading for example or while waiting at the ports for testing, reduce their shelf life (FCC/RMIF, 2005; Food Chain Centre, 2006a/2006b). Increasing the length of supply chain will raise the possibility to spoil or damage food (Verghese et al., 2013). Ineffective communication between suppliers and clients increases also food wastage during distribution (FCC/RMIF, 2005; Food Chain Centre, 2006a/2006b). Rejection of perishable food is the major wastage during distribution stage (Gunders, 2012). Gooch et al. (2010) show that food wastage at distribution centers is the result of unsatisfactory harvest, refrigeration, and handling. This is the case of fruits and vegetables. Retailers consider waste as part of doing their business. Lack of physical infrastructure is an important factor of food wastage at the level of distribution stage, especially in harsh climates. Poor storage and distribution facilities including cold-chain apparatus in developing countries are also a crucial cause (Bond et al., 2013). The poor conditions of roads and routes could influence negatively the percentage of food waste since it will increase the time of the voyage.

Solutions

Many solutions are suggested for the reduction of food wastage on the level of distribution phase. In this paper, we will be limited to those that have been discussed the most in the litterature. Companies in the food supply chain should be encouraged to implement systems to measure and monitor product wastage as a key performance indicator (Verghese et al., 2013). Packaging professionals, technologists, and designers should be trained to understand the distribution chain, the packaging performance requirements and the reverse logistics process in order to minimize food wastage (Verghesne et al. 2013). Short distance distribution should be enhanced to reduce the risk of food wastage while distributing. This will be also efficient to flourish local food economy and to reduce the need for transport demand (Food Ethical Council, 2008). In developing countries, governments should invest in domestic transport infrastructure (Food Ethical Council, 2008). As a cost saving measures, and in order to be more efficient, productive recycling or redistribution of surplus into animal feed or to produce energy and compost will be highly appreciated (Escaler and Teng, 2011; Hodges et al, 2010).

Food wastage in the retail sector

Food wastage also applies when we reach the retail stage in the supply chain and retailers are in fact somewhat responsible for bigger portion of the overall losses since they have influence on the chain both upstream and downstream (Gunders, 2012). The further down the value chain of food production we go, the greater the costs of food wastage and therefore, it is highly relevant both from a monetary as well as an environmental perspective to tackle food wastage related to this stage (Bacos et al., 2014). Consumers in Europe and North-America are expected to waste around 95-115 kg/year while data from sub-Saharan Africa and South/Southeast Asia only estimate around 6-11 kg/year waste in per capita terms. When it comes to the developing countries, more than 40% of food wastage is traced to post-harvest and processing losses while developed countries have more than 40% losses when one looks at the retail and consumption stage (Gustavsson, Cederberg, & Sonesson, 2011). In the United Kingdom alone, the retail stage produces an estimate of 1.7 million tonnes of food wastage per year and due to the costs and complexity of giving the food away, more than half of it ends up in a landfill. The retail sector in the United States is doing no better, where food wastage has been valued at $41.9 billion (Weber, Herrlein, & Hodge, 2012). Developing countries are facing challenges in their food retail sector when it comes to infrastructure regarding suitable storage and sale conditions since their market systems lack proper facilities such as for refrigeration of food products (Gustavsson et al., 2011). The main focus will be on food wastage in the retail stage in developing countries since it poses as a bigger issue there.

Causes

One of the reasons for food wastage in this stage are high appearance quality standards that supermarkets pose on farmers and manufacturers, and some even cite this as a main cause (FAO, 2013). The quality standards concern factors such as weight, shape and size of agricultural products. Since the standards are set by the supermarkets, a portion of edible crop never leaves the farm or the manufacturer, leading to food wastage (Stuart, 2009). The standards are set since consumers often base the decision of their purchase on the quality and the appeal of perishables, making retailers feel the need to have produce that is the right size, shape and color (Gunders, 2012). Furthermore, it appears that it is common among retailers to throw food away when it approaches the end of its shelf-life due to the fact that they consider it cheaper than to attempt to sell it as shelf-space is valuable. That is then done without considering the environmental and social costs occurring in the production process (FAO, 2013).

Another cause of food wastage is overproduction, which is when a manufacturer produces more quantity of a product than what the supermarket in question can sell. The waste occurs because the supermarket is able to put down a so-called "forecast order", often with a week in advance. The manufacturer or the farmer then produces and prepares the order. The supermarket is however able to confirm the order with little notice, which are often shorter than 24 hours before delivery date. If there is a discrepancy between the forecasting order and the confirmed order, which is usually the case since supermarkets tend to lower their order, the manufacturer or farmer will end up with a large quantity of fresh product without a buyer. The supermarket often forbids the manufacturers to give the surplus of products away to charities or sell it on, especially if their brand is on the label on the packaging (Stuart, 2009). It is a fact that manufacturers and farmers depend on the supermarket for income since they are their main clients, so they are obliged to comply with the rules set by them, often resulting in large amounts of food wastage (FAO, 2013).

Overstocking of food in supermarkets and other places within the retail sector is yet another cause for food wastage. It can be the result of many different issues, such as supermarkets' need for ordering a large variety of products from a producer in order to get a better deal. It also relates to supermarkets' perception regarding consumers, but they expect them to want the possibility of choosing between a wide range of products when they shop for groceries. However, the wider range of products increases the probability that some of them will reach their buy-before date before getting sold. Therefore, the supermarket will throw away more food resulting in more food wastage (Gustavsson et al., 2011). Developing countries have developed a culture of expecting large quantities of food in store displays and a variety of brands to choose from in the past two decades, which has led to increased sales. This culture does however increase the probability of food wastage since supermarkets will intentionally overstock of food and products since the consumers like to have the illusion of abundance (Stuart, 2009). Discounts for buying by quantity, such as 2-for-1 deals do also not encourage better consumer behavior so the supermarkets do have to be aware of the influence of their retail practices on food wastage (FAO, 2013). The moral arguments to the issue of consumers expecting full shelves of food when shopping, and the supermarkets' supplying it, is a complicated issue but it should still not deter people from bringing up the issue (Weber et al., 2012).

Solutions

Food wastage in the retail sector could be prevented to a great extent if there would be more awareness and knowledge on the issue, not only from the retail sector but also from consumers (Cicatiello et al. 2016). To tackle the problem, consumers need to be aware of the environmental impact of the wastage, which can be stimulated through education (Parfitt, Barthel, & Macnaughton, 2010). It has been easy for the retail sector to hide their food wastage up to this point and there is always the possibility that self-reporting of wastage data is understated (Stuart, 2009). In order to raise awareness, reliable data on the extent of the waste is needed. Policies to decrease food wastage due to aesthetic requirements for fruit and vegetables or due to overstocking of food on display in the supermarkets could include educating consumers, improving communication between stakeholders in the supply chain, and make the actors interdependent on the practices and actions of each other. Regulations on the use of the food waste supermarkets produce can represent a viable solution for solving the problem at this stage. As of 2016, supermarkets are prohibited to dump food that is still edible in France; instead, the food needs to be donated to food banks. A high tax on sending waste to landfill would also have a deterring effect on the supermarkets' decisions to throw food away (FAO, 2013). In addition to that, retailers could prevent the discrepancy between their early orders from their suppliers and their final orders, if they worked in closer collaboration with them and had tighter management as well as better forecasting (Bacos et al., 2014). When it comes to the developing countries in particular, investment in infrastructure for market facilities and better packaging of the products would go a long way (Gustavsson et al., 2011). When all comes down to it, policies directed towards limiting food wastage are dependent on education of the people all along the food supply chain.

Food wastage at consumer level

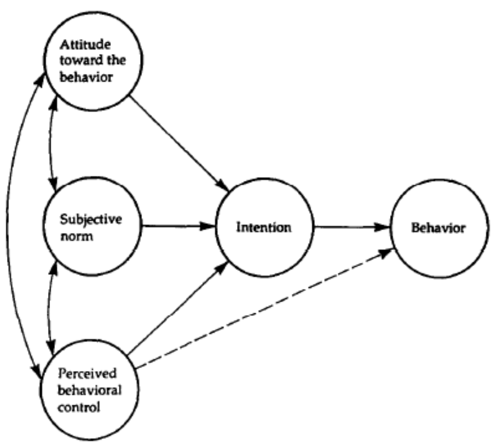
Globally, food loss and waste in the consumption stage takes up 35%, of which 7% comes from developing countries and 28% from developed countries (Gustavsson, Cederberg, & Sonesson, 2011; Lipinski et al., 2013).

Causes

According to Food-related lifestyle theory, food wastage during consumption stage happens due to: quality selection, shopping styles, cooking, and consumption arrangement (Thogersen, 2017). For example, food is wasted due to bad planning (impulse purchase, low quality that expires before consumption); prepared food are wasted due to improper cooking, bad household planning of portions or sizes; food is wasted due to improper storage, food isexpired before consumption (Cicatiello, Franco, Pancino, & Blasi, 2016; Gustavsson et al., 2011; Hoek, Pearson, James, Lawrence, & Friel, 2016; Viry, 2012). The wastage affects consumers' budget, nutrition, and subsequent social impact on environment and public health (Neff et al. 2015; Stancu et al. 2016). Thus, curving food wastage during consumption has both an individual and societal effect and is beneficial both socially, economically and environmentally (Quested & Luzecka, 2014).

In order to understand the causes and propose solutions for food wastage in the consumption stage, it is important to understand existing models framing consumers' behavior toward food consumption and food wastage. The theory of planned behavior (TPB) (Ajzen, 1991) has been applied to study behavior change in relation to food (Mondéjar-Jiménez et al., 2015; Stancu et al., 2016; Visschers et al. 2016; Wang et al. 2014). Besides TPB, there is also cognitive theory encompassing individual behavior into a social frame (Phipps et al., 2013), while others focus on the multilevel approach (Milfont & Markowitz, 2016; Thogersen, 2017; Thyberg & Tonjes, 2016), arguing that consumer behavior is part of a larger national and international scale that requires high-level policy (Eberle, Ulrike; Lorek & Reisch, 2013). However, there is no overarching theory that encompasses individual cognitive theory at a broader social level. Thus, this section explains both theories and tries to build a more comprehensive behavior model of food wastage to better understand the drivers and suggest solutions toward combating it. TPB posits that *behavior* is affected by *attitude*, which is dictated by *social norms* and *behavior intention* (here *behavior control* is used interchangeably) (Ajzen, 1991). The *behavior* of reducing food wastage is first an individual cognitive process, which is influenced by *attitude, awareness* and *preference* (Stancu et al., 2016; Thogersen, 2017; Visschers et al., 2016) toward food cost, environmental impact of food and health risk of food consumption (Hoek et al., 2016).

Figure 2 : Theory of Planned Behaviour

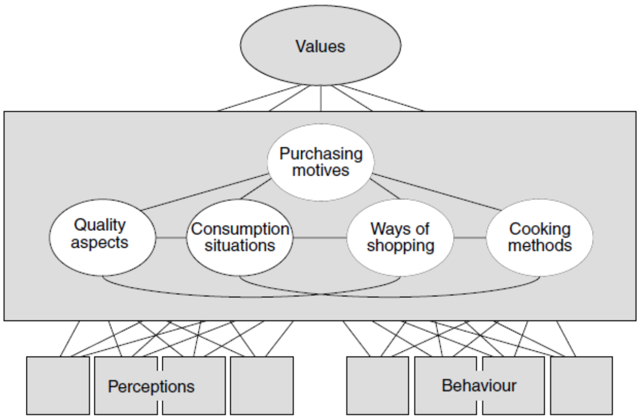


Source : Ajzen (1991)

Solutions

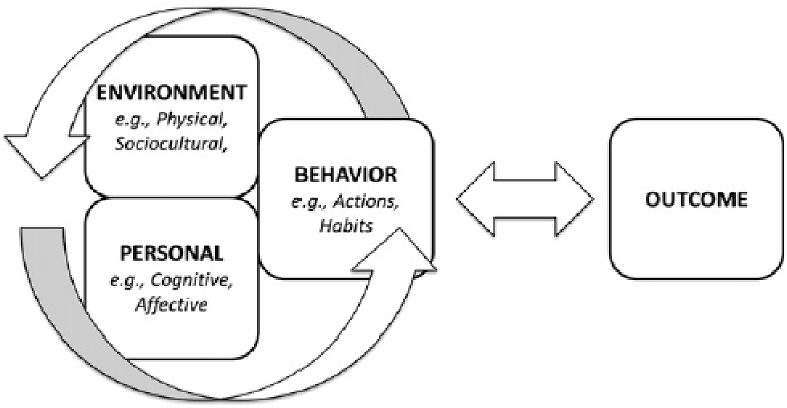
In a bigger *social (norms)* frame, individual behavior is dependent on *household behavior*, socio-cultural traditions at *national* level (Milfont & Markowitz, 2016), and *international* social norms. Within the social construct (Phipps et al., 2013) Value–Beliefs–Norms (VBN) theory argues that pro-environmental behavior (in this case reduction of food wastage) is driven by "*personal value, pro-social beliefs and personal moral norms*" (Jackson, 2005). Motivation–Opportunity–Abilities (MAO) builds on VBN and PBT, in which behavior is motivated by opportunity (infrastructure, social norms) and ability (personal attitude, awareness) (Thogersen, 2005). Building on MAO and VBN, Social Cognitive Theory (SCT) includes both Environment (opportunity and social norms), personal (ability, value, beliefs) in the causal loop that influences behavior (Phipps et al., 2013).

Figure 3 : Food-Related Lifestyle Model



Source : Grunet (2006), Thogerse (2017)

Figure 4 : Social cognitive theory and reciprocal determinism



Source : Phipps et al. (2013)

According to SCT, an individual behavior is put in a wider social environment, however, it fails to address at higher social levels that influences social norms (international agreements, wide spread media, international movement (Milfont & Markowitz, 2016; Thyberg & Tonjes, 2016), thus there is room for a more comprehensive model of consumer behavior that is both based on cognitive theories and multilevel practices. The cause for food wastage is here presented as a cognitive model based on behavior cognitive theory that transgresses multiple levels of individual and social behaviour. Based on this model, personal belief is enforced by social norms, and personal intention is restricted by social infrastructure (available food labeling, food availability). Food wastage can be understood at individual level (with different behavior patterns as categorized by (Thogersen, 2017) and (Mallinson, Russell, & Barker, 2016) and social level (as national trends shown by (Thogersen, 2017). Since food wastage happens in both dimensions of the model, solutions need to be comprehensive.

Table 1 : Solution for food wastage in consumption

INDIVIDUAL INTENTION Training on cooking Training on storing and using left-overs	INFRASTRUCTURE Better food labels Food sharing initiatives
INDIVIDUAL BELIEF Training on environmental impact of food waste Training on health risk of food	SOCIAL NORMS Changing of views on “les legumes moches” or physically inactive vegetables

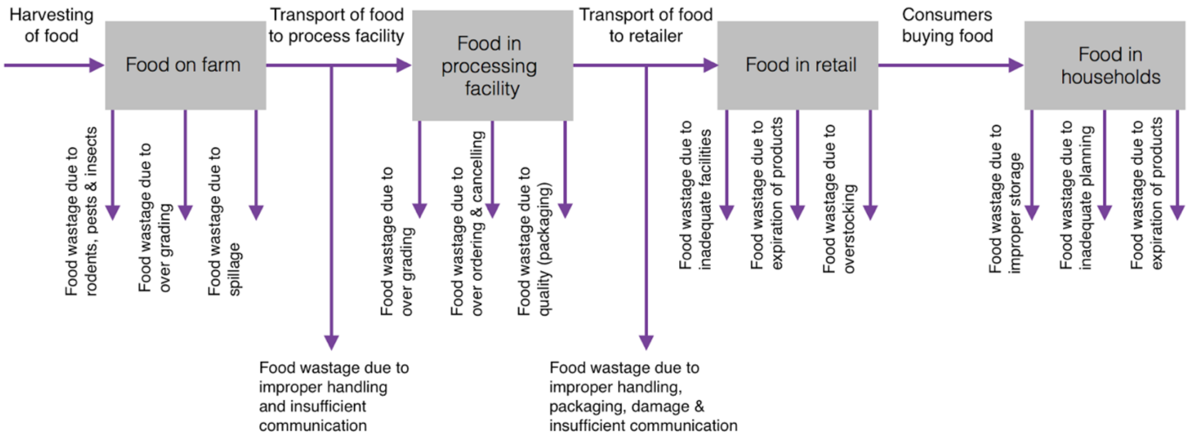
Source : Lipinski et al. (2013); Quested & Luzecka (2014); Thyberg & Tonjes (2016)

Negative footprint illusion exists (Hoek et al. 2016; Gorissen & Weijters, 2016), causing a disconnect between intention and belief (additional organic food consumption vs sustainable food consumption), thus any awareness or education effort has to be done with precaution and with reconsideration of actual values derived from the training (Quested, Luzecka, 2014).

Conclusion

Food wastage is major social, economic and environmental issue. The sheer magnitude of food waste and loss is a significant challenge to ensuring global food security and tackle worldwide hunger. It is a process that has, apart from the monetary estimations, long-term consequences and costs and will impact the integrity of our natural resources and the possibility of future generations to meet their food needs. In our review of food wastage causes along the post-harvest supply chain, which we proposed in this paper, we have shown that it is not only the lack of technology and infrastructure in developing countries that leads to high amounts of food being lost or wasted.

Figure 5: Flowchart reviewing the main causes and potential solutions identified along the post-harvest food supply chain



Food wastage is a complex socio-economic issue and it is caused by lack of information, miscommunication, cultural differences, degree of access to financing and investment, and the policy environment. In a similar fashion, food wastage in developed countries is not so much a technical issue but a human one. It is deeply embedded in unsustainable consumption behavioural patterns and a continuing incentive to have the illusion of abundance. Solutions to food wastage need to be approached from a holistic, cross-sectoral and interdisciplinary perspective, combining market and social policies with the application of food wastage reduction technologies. This is needed in the context of a growing world population and an increased pressure on our natural resources and it would impact some of the Sustainable Development Goals that the international community has agreed on, especially Goal 2: Zero Hunger.

References

AGHAZADEH S.-M. (2004), “Improving logistics operations across the food industry supply chain”, *Int. J. Contemp. Hosp. Manag,* vol 16(4), p. 263-268.

AJZEN I. (1991), "The theory of planned behavior", *Organizational Behavior and Human Decision Processes*, vol 50, p. 179–211.

BOND M., MEACHAM T., BHUNSOO R., BENTON T.G. (2013), *Food waste within global food systems*, A Global Food Security report.

BACOS J., BESWICK P., DEMEURE B., HARRISON N., SIEMSSEN S., TRENTINI R. (2014). *Reducing Food Waste: How can Retailers help?*

CICATIELLO C., FRANCO S., PANCINO B., BLASI E. (2016), « The value of food waste : An exploratory study on retailing", *Journal of Retailing and Consumer Services*, vol 30, p. 96–104.

CUELLAR A.D., WEBBER M.E. (2010), "Wasted food, wasted energy: the embedded energy in food waste in the Unites States", *Environ. Sci. Technol*, vol 44 (16), p. 6464-6469.

EBERLE U., LOREK S., REISCH L. (2013), Sustainable food consumption: an overview of contemporary issues and policies, *Sustainability : Science, Practice, & Policy*, vol 9(2), p. 7–25.

FAO (2015), *Social Protection and Agriculture: Breaking the Cycle of Rural Poverty*. The State of Food and Agriculture.

FAO (2013), *Toolkit: Reducing the Food Wastege Footprint*, State of Food and Agriculture..

FAO (2011), *Global food losses and food waste*. Extent, causes and prevention. Rome.

FCC/RMIF (2005), *Cutting Costs - Adding Value in Red Meat*. Food Chain Centre. Letchmore Heath. England.

FOOD CHAIN CENTRE (2006a), *Food Chain Centre, 2006a. Improving the Profitability of Vegetable Production: A Case Study of Fresh Leeks.* Institute of Grocery Distributors. Letchmore Heath, England.

FOOD CHAIN CENTRE (2006b), *Reducing Waste and Increasing Value: A Case Study of Fenmarcs Potato Supply Chain*. Institute of Grocery Distributors. Letchmore Heath, England.

FOOD ETHICAL COUNCIL (2008), *Food distribution. An ethical agenda*. FEC. United Kingdom.

GODFRAY H.C.J, BEDDINGTON J.R, CRUTE I.R, HADDAD L., LAWRENCE D., MUIR J.F, PRETTY J., ROBINSON S., THOMAS S.M, TOULMIN C. (2010), "Food security: the challenge feeding 9 billion people", *Science*, vol 327(5967), 812-818.

GOOCH M., FELFEL A., MARENICK N. (2010), *Food Waste in Canada*. Value Chain Management Centre, George Morris Centre.

GORISSEN K., WEIJTERS B. (2016), "The negative footprint illusion: Perceptual bias in sustainable food consumption", *Journal of Environmental Psychology*, vol 45, p. 50–65.

GUNDERS D. (2012), *Wasted: How America Is Losing Up to 40 % of Its Food from Farm to Fork to Landfill*. Natural Resources Defense Council.

GUSTAVSSON J., CEDERBERG C., SONESSON U. (2011), *Global food losses and food waste, extent, causes and prevention*. Dusseldorf, Germany.

GUSTAVSSON J., CEDERBERG C., SONESSON U., OTTERDIJK R., MEYBECK A. (2011), *Global food losses and food waste*. Food and Agriculture Organization. Rome. Italy.

GRUNERT K. G. (2006), "Future trends and consumer lifestyles with regard to meat consumption", *Meat Science*, vol 74(1), p. 149–160.

HASSANI H.S, JAFARI A. S, MOHTASEBI S., SETAYESH AM. (2011), "Investigation on grain losses of the JD 1165 combine harvester equipped with variable pully and belt for forward travel", *American Journal of Food Technology*, vol 6(4), p. 314-321.

HODGES R.J, BUZBY J.C, BENNETT B. (2011), "Postharvest Losses and Waste in Developed and Less Developed Countries: Opportunities to Improve Resource Use", *The Journal of Agricultural Science,* February, p. 37 - 45.

HOEK A. C., PEARSON D., JAMES S. W., LAWRENCE M. A., FRIEL S. (2016), "Shrinking the food-print: A qualitative study into consumer perceptions, experiences and attitudes towards healthy and environmentally friendly food behaviours", *Appetite*, vol 108, p. 117–131.

JACKSON T. (2005), *Motivating Sustainable Consumption: a review of evidence on consumer behaviour and behavioural change*. London: Policy Studies Institute.

KIRLEIS A. W., STROSHINE R. L. (1990), Effects of hardness and drying air-temperature on breakage susceptibility and dry-milling characteristics of Yellow Dent Corn", *Cereal Chemistry*, vol 67(6), p. 523–528.

KUMMU M., DE MOEL H., PORKKA M., SIEBERT S., VARIS, O., WARD P. J. (2012), "Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use", *Science of the Total Environment*, vol 438, p. 477–489.

LIPIPNSKI B., HANSON C., LOMAX J., KITINOJA L., WAITE R., SEARCHINGER T. (2013), *Reducing Food Loss and Waste*. *World Resource Institute*. Washington, DC, June, p. 1 – 40.

MALLINSON L.J, RUSSEL J.M, BARKER M.E (2016), "Attitudes and behaviour towards convenience food and food waste in the United Kingdom", *Appetite*, vol 103, p. 17–28.

MILFONT T.L, MARKOWITZ E. (2016), "Sustainable consumer behavior: A multilevel perspective", *Current Opinion in Psychology*, vol 10, p. 112–117.

MONDEJAR-JIMENEZ J. A., FERRARI G., SECONDI L., PRINCIPATO L. (2015), "From the table to waste: An exploratory study on behaviour towards food waste of Spanish and Italian youths", *Journal of Cleaner Production*, vol 138, p. 8–18.

NEFF R. A., SPIKER M. L., TRUANT P. L. (2015), "Wasted food: U.S. consumers' reported awareness, attitudes, and behaviors", *PLoS ONE*, vol 10(6), p. 1–16.

PARFITT J., BARTHEL M., MACNAUGHTON S. (2010), “Food waste within food supply chains: quantification and potential for change to 2050”, *Philosophical Transactions of the Royal Society B*, vol 365, p. 3065–3081.

PHIPPS M., OZANNE L. K., LUCHS M. G., SUBRAHMANYAN S., KAPITAN S., CATLIN J. R., … WEAVER T. (2013)," Understanding the inherent complexity of sustainable consumption: A social cognitive framework", *Journal of Business Research*, vol 66(8).

QUESTED T., LUZECKA P. (2014), *Household food and drink waste : A people focus*. Banbury, UK.

ROLLE R.S (2006), *Postharvest management of fruit and vegetables in the Asia–Pacific region*, Asian Productivity Organization (APO) and Food and Agriculture Organization of the United Nations (FAO), p. 23–31.

ROLLE R.S (2006), *Processing of Fruits and Vegetables for Reducing Postharvest Losses and Adding Value.* Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region.

STANCU V., HAUGAARD P., LAHTEENMAKI L. (2016), " Determinants of consumer food waste behaviour: Two routes to food waste", *Appetite*, vol 96, p. 7–17.

STRELEC I., SABO M. (2010), ”Influence of Temperature and Relative Humidity on Grain Moisture”, *Germination and Vigour of Three Wheat Cultivars During One Year Storage*, 2010(2), p. 20–24.

STUART (2009), *Waste - Uncovering the Global Food Scandal*. W. W. Norton.

THOGERSEN J. (2005), "How may consumer policy empower consumers for sustainable lifestyles?", *Journal of Consumer Policy*, vol 28(2), p. 143–177.

THOGERSEN J. (2017), "Sustainable food consumption in the nexus between national context and private lifestyle: A multi-level study", *Food Quality and Preference*, vol 55, p. 16–25.

THYBERG K.L, TONJES D.J h (2016), "Drivers of food waste and their implications for sustainable policy development", *Resources, Conservation and Recycling*, vol 106, p. 110–123.

VALIDI S., BHATTACHARYA A., BYRNE P.J. (2014), “*A case analysis of a sustainable food supply chain distribution system – A multi-objective approach*”, *Int. J. Production Economics*, vol 152, p. 71-87.

VERGHESE K., LEWIS H., LOCKREY S., WILLIAMS H. (2013), *The role of packaging in minimizing food waste in the supply chain of the future*. Final report. RMIT University.

VIRY G. (2012), "Residential mobility and the spatial dispersion of personal networks: Effects on social support", *Social Networks*, vol 34(1), p. 59–72.

VISSCHERS V. H. M., WICKLI N., SIEGRIST M. (2016), "Sorting out food waste behaviour: A survey on the motivators and barriers of self-reported amounts of food waste in households", *Journal of Environmental Psychology*, vol 45, p. 66–78.

WANG P., LIU Q., Qi Y. (2014), "Factors influencing sustainable consumption behaviors: A survey of the rural residents in China", *Journal of Cleaner Production*, *vol 63*, 152–165.

WEBER B., HERRLEIN S., HODGE G. (2012), *The Challenge of Food Waste: Retailers step up to the next level of inventory management*.

Climate systemic risks and financial stability

Etienne ESPAGNE

CEPII, France

Climate change impacts human societies and economies in both a non-linear and unpredictable ways. Tipping points can arise and irreversibly change both the state of the planet, and the way we live on it. They have been analyzed to arise from many sources: the natural carbon cycle itself, through the non-linear absorption rate of the ocean and the terrestrial biosphere as well as its coupling with the climate[1]; the climate system, through a fast increase in the frequency and the severity of extreme events, the melting of Greenland's ice-sheet, an abrupt change in ocean circulation, a strong increase in CO_2 and CH_4 emissions through the melting of the permafrost. Some of these changes happen slowly, accumulating unnoticed disequilibria over long periods of time; some are very sudden and unpredictable, arising at some specific point of the planet, with potentially broader contagion effects.

There is thus a high level of uncertainty on the exact timing and impact of such events, not only because of the physical processes themselves, but also because they are intimately linked with humans' reactions and policies. Weitzman (2009) summarizes this deep uncertainty with his now famous « dismal theorem »: probability distributions of many climate parameters are such that the possibility of an extreme value cannot be ruled out. Uncertainty cannot be modeled through standard Gaussian centered distributions. Fat tails are a crucial element of representation of uncertainty. Indeed, the more we fail to act against climate change, the fatter the tails. Inaction is playing as a positive feedback loop against the stability of the climate system in probabilistic terms (Perrissin et al., 2014).

In such a theoretical framework, as Weitzman goes on, climate policies should be looking more at insurance theory than at traditional externality theory. But the specifics and consequences of such an insurance approach are never fully developed, so that the final recommendation remains stuck with the usual anthem: "*Price carbon, cap the flow of emissions, there is no other way out*" (Weitzman, 2015). How can we induce from the insurance approach the definition of proper tool(s) to fight climate change? How can we insure society against an event that determines its own existence/destruction? Looking farther, is the insurance analogy sufficient to stress

[1] The standard DICE model developed by Nordhaus (Nordhaus, 1993) makes the hypothesis of a linear absorption rate of the ocean module.

out the climate change constraint? Or in financial terms, how far is climate risk hedgeable? In this paper, we try to fully appreciate the consequences of such a paradigmatic change in climate policies.

For that matter, we introduce the notion of climate systemic risk, by analogy with the notion of financial systemic risk. The notion of systemic risk, which has been widely rediscovered to analyze the fragility of the financial sector right after the 2008 financial crisis, and its policy implications in order to stabilize the system, can partly be used to tackle also climate change issues. We thus apply this concept, drawn from Keynes's radical uncertainty and Minsky's financial instability hypotheses, to climate change debates, and discuss how it could pave the way to new types of climate policies, which would crucially complement the traditional carbon pricing as well as Weitzman's insurance approach. Three fundamental reasons at least can justify the analogy of this financial concept to climate.

The structure of the paper is as follows. Section 1 briefly defines the materiality of a climate systemic risk. Section 2 emphasizes how the different dynamics of propagation of a climate systemic risk imply a fundamental change of perspective from simple carbon pricing discussions to the immersion into structural financial reforms debates. Section 3 develops the specific financial channels through which a climate systemic event can develop into a full-blown financial crisis, through circular causality effects. Section 4 proposes some policy measures to counter this outcome. It requires a safety net combining different means of action, which include but are not limited to a carbon price: insurance policies, prudential norms, information transparency, but also rules and incentives to influence the evolution of financial structures, as well as policies aimed at reducing the instability of carbon values on financial markets. Section 5 concludes on the necessary improvements of financial research on the representation of the causes and cures of climate systemic risks.

Climate and finance systemic risks: pushing the analogy

A systemic event is defined in finance by three essential elements:

- a shock, which can be a broad shock simultaneously affecting a wide range of institutions, or a limited shock followed by an important domino effect[2];
- contagion effects through a web of interrelations; and the endogenous nature of this shock, meaning that it is caused by cumulated disequilibria over time.

The possible transposition to climate change impacts on Earth, societies and their economies is striking: IPCC (2014) shows that we evidently have the possibility of a global shock through an irreversible increase in temperature levels and more

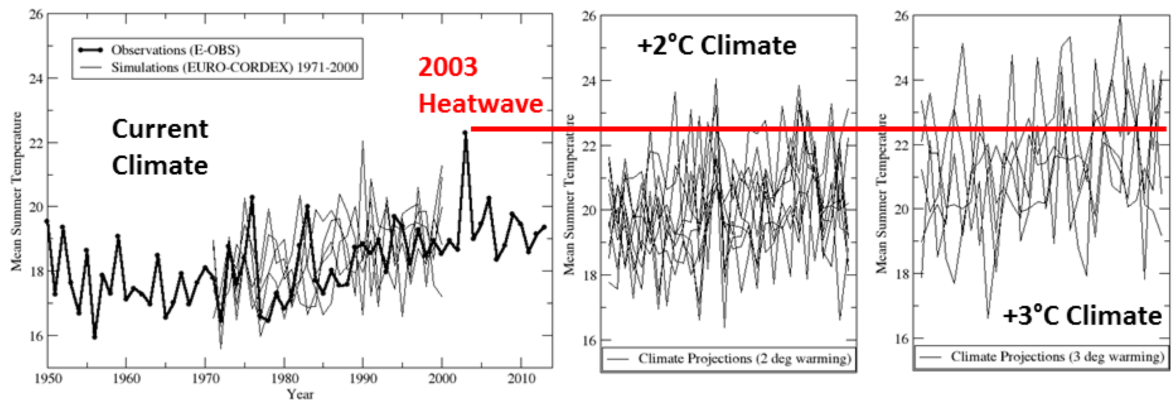
---

[2] We call a domino effect the mechanical transmission process of the initial shock. Contagion effects are supposed to arise through shifts in the expectations of economic actors, generally by means of financial markets.

localized shocks through extreme events of all sorts; most of these shocks have been proved to be caused by human action (Pachauri et al., 2014). Both types of shocks can of course be intertwined, leading to severe crises.

Idiosyncratic shocks that do not propagate widely are insurable in the sense that investors can protect themselves against them by diversification, or that society can easily pay for the incurred damages. On the contrary, systemic shocks are by definition non insurable or non diversifiable. But the limit between the two crucially depends on the possibilities of propagation. These propagation mechanisms are not directly linked to the shock itself, but are keys to determine if the initial shock will be systemic or just idiosyncratic. Three interrelated features can provide a basis for the propagation mechanisms: i) the structure of societies in relation with local risks of extreme events, i.e. their relative level of adaptation to climate change, ii) the interconnection of different societies through direct and indirect exposures, and iii) the information intensity of social, economic and financial contracts regarding emission intensity or exposure to climate damages. We detail these features in turn.

Figure 1 : Climate change



Source : IMPACT2C

Societies are currently not adapted for the projected outcomes of the current emission trajectories. Pachauri et al.(2014) for example show that global warming will very likely lead to an increased number of temperature records. As figure 2 shows, heat waves such as the one experienced by France in the summer 2003, which is believed to have killed more than 15000 persons, would happen every 3 to 4 years in a +2°C world (depending on the climate projection chosen), almost every year in a +3°C (the current optimistic evaluation of the trajectory incurred by the INDCs). Extreme rainfalls are also likely to increase (Seneviratne et al., 2012). We can give the example of a meteorological phenomenon called *épisodes cévenols*, which is defined by strong continuous rainfalls in the French region *Cévennes*. Vautard et al. (2015) show that the probability of occurrence of such events is about three times higher in a 2014 climate than it was in the 1950 climate. These examples are of course an extremely incomplete and rapid overview of what climate science can bring us in relation to the notion of climate systemic risk. It is sufficient however to understand that the structure of societies in relation with local risks of extreme events is essential to capture the potential impact of a climate change related event.

Propagation

At the same time, the interconnections have never been so high, potentially transforming a localized event into a full-blown shock. We can distinguish between physical, and financial interconnections. If trade relations have stalled a little bit in the past few years since the 2008 crisis, they still keep growing at approximately the same pace as world growth. The notion of value chains, and the related data on trade in value-added by the OECD show a level of interconnection between the different parts of the world which contribute to these intermediate inputs probably never attained before (Baldwin et al., 2015). These physical interconnections can affect the exposure to a localized extreme event. Financial relations will be dealt with in more detail in parts 4, 5 and 6, but let us just quote here the regular increase in financial transactions, and the extremely complex network of tightly linked financial institutions which constitute today's global economy (Roukny et al., 2016). Under the assumption of efficient finance, one could argue that this trend gets closer to perfect financial markets, delivering a better access to liquidity, while maintaining a low-level of financial risk. Under uncertainty, financial history has shown on the contrary that the more interconnected and unregulated is finance, the more vulnerable it is to multiple equilibria, without any hint on the way to reach the best possible outcome. Such a level of financial interconnection in a politically fragmented world can just increase the chance of sudden stops, or brutal reversals of financial expectations. Liquidity would disappear in an instant, as already happened in 2008, while central banks would have more difficulty to re-establish confidence by providing huge amounts of money. Climate damages affecting a certain asset, or a certain asset type, could generate such a shift in expectations.

Informational relations go through different channels, and act in a very similar way as financial markets, disregarding long-term trends, while suddenly affecting a high weight to little almost insignificant events. Two phenomena can contribute to the occurrence of a climate systemic event. The first is the occurrence of a signal which coordinates the expectations of the public, without being related to the full understanding of a climate event. This can translate into financial behavior (Cass and shell 1983), but also into individual or collective behaviors in the economy at large, which can increase the initial effect of the event. The second is the release of a noisy informational signal which essentially hides or distorts the information available in the scientific world, contributing to prolong the political inaction period. We certainly see this in the debate around climate-skepticism in the media (Oreskes and Conway, 2011; Pottier, 2013). This second phenomenon induces the continuous endogenous accumulation of emission disequilibria.

Endogeneity

This leads us to the endogeneity of systemic climate risk. It is now an almost certain feature displayed by climate science. Human actions are a major cause of the increase in global temperatures, through emissions. The global endogeneity of global warming cannot be put into question. By theoretical construction, all emissions have been deemed equivalent in terms of their effect on climate change. Of course, emissions are not the same once we consider other dimensions such as development, equality, … But the notion of "CO2 equivalence" epitomizes the universal source of climate changes.

However, true endogeneity implies that we are able to trace some singular events all the way through to global warming. As we have seen in the previous part, climate science has recently made progress in the attribution of extreme events to global warming, and more generally in the projection of the frequency of localized events in a world where temperatures would have increased by more than 2° (Hulme, 2014). Conversely, endogeneity could also mean that we are able to impute the costs of global warming to a specific emitter. This amounts to the possibility of liability procedures against moral, public or private actors deemed responsible of global warming. If this question has so far been put aside by most judicial courts, it is likely to arise more and more in the future (Allen, 2003; Munich Re, 2010).

So far we have developed the notion of a climate systemic event based on the three properties that any systemic event has: shock, propagation, and endogeneity. We now investigate in more details the specific policy implications of such a shift from standard externality theory.

The climate systemic risk hypothesis opens new policy perspectives

We call standard externality theory the view, derived from Coase (1960) and Pigou (1920), that climate change can be dealt with just by putting a price on emissions, either through taxes, or through a cap-and-trade system. Although these authors were mostly talking about localized external bads with mostly localized external effects, it has been supposed until today that this approach deliver the "first-best" solution for global problems also. Under this line of thought, social, technical, political or economical elements of interference with this first-best objective can be taken into account and lead to slightly under-optimal policies, also called "second-best" solutions (Lipsey, 1956). All subsequent research derived from these premises plays with these different elements in order to obtain specific "optimal" trajectories of emission reductions. This dual "first-best/second-best" approach can only move the optimal carbon price profile a little sooner or a little later depending of the chosen element of interference. The debate ends around the question of who among current

(Stern, 2007), later (Nordhaus, 1993) or intermediate generations (Chichilinsky, 1996) will be sacrificed on the altar of a stabilized climate (Espagne et al., 2012).

We argue here that the combination of increasing uncertainty on critical climate parameters with the complex political economy of climate policy action cannot be apprehended in a satisfying manner through this traditional first/second-best policy nexus. First, climate policy action cannot be separated from all social, technical, political or economical parameters. Saying that a first-best solution exists independently of all social, technical or political consideration amounts to validate the idea of a totally independent economic sphere, which can derive its own precepts. This amounts to a dogma without any scientific underpinning (Aglietta, 2016). Second, it is uncertainty, rather than risk, which drives climate change issues. In other words, it is not so much the unknowns, but more the unknown unknowns of climate parameters, which are essential to assess the potential damage incurred. Using a more probabilistic vocabulary, that is not fully appropriate to deal with uncertainty, we cannot deal with uncertain parameters by just considering their average value, we must consider the whole distribution range, which is often not Gaussian. The example of climate sensitivity, or climate damages, is striking (Weitzman, 2012). The more we fail to act, the more skewed the distribution of climate sensitivity values, and thus the higher the probability of an extremely high value. The same goes for damages. There is no optimal trajectory in concrete economies, but rather prudent policies, trying to avoid irreversible and dangerous shifts. Unknown bifurcation points totally change the whole dynamic and make the assumption of a single model of continuously evolving damages with average temperature rise worthless.

The climate systemic risk hypothesis radically departs from the premises of standard externality theory. It suggests that we might want to drastically diminish the probability of occurrence of some very bad outcomes for society, which might lead to its quasi-destruction. It is thus a collective prudential approach, which intends to act on eliminating possible future outcomes more than on internalizing an externality, because of radical uncertainty. But it also goes a crucial step farther than Weitzman, in the sense that a systemic risk approach necessarily arises in concrete economies with incomplete and imperfect markets. In concrete economies, decentralized decisions give birth to endogenous uncertainty, which paralyzes the decentralized decision framework. In such economies, the question coordinating the decisions of the economic agents becomes crucial. Markets are not the only coordination procedure for individual decisions. Individual decisions themselves echo and evolve with the immediate environment, through routines (Nelson et Winter, 1982; Nelson 1995), imitation or discussion (Kahneman, 1996; Varey et Kahneman, 1992), procedures (Conlisk, 1996). The convergence of expectations is thus a condition and a consequence of the harmonious functioning of a decentralized economy. This convergence occurs through the emergence of institutions. But institutions themselves do not emerge spontaneously. They are the product of layers of historical necessities. They are thus not well equipped for unique events such as climate change. This is an important reason why a carbon price only policy, targeted to modify individuals' behaviors only, will not be enough. In a climate systemic risk context, climate policy should specifically target these rules, habits and intermediary institutions.

Table 1 : Efficient market hypothesis vs Radical uncertainty hypothesis

	Efficient market hypothesis	*Radical uncertainty hypothesis*
Seminal works	Pigou (1920), Coase (1960)	Knight (1921), Keynes (1936)
Key concept	negative externality	systemic risk
Vision of the future	All information about future possible states is available	Unforeseen events might arise
Objective	Optimal approach	Collective insurance approach
Pivotal economic actors	Individuals	Intermediary economic and financial institutions
Coordination of expectations	Carbon market price/ Carbon tax	Social value of carbon/money
Role of carbon pricing	Internalize the climate externality	Reduce climate uncertainty

Among these intermediary institutions, money and finance are key elements. In financial capitalism financial markets act as coordinators of the expectations of economic agents. In the best case, finance deals with the constant tension between the unknowns and the unknown unknowns, between risk, which can be quantified and evaluated on the markets, and true uncertainty, which gives birth to systemic risk. But very often, financial markets are purely self-referential (Keynes, 1936; Orléan, 2011) so that they can coordinate around pretty much any value, almost independently from fundamental values. Financial regulation theoretically tries to circumvent both the possibility of too important bubbles, and the emergence of systemic events. Furthermore, finance cannot be separated from the institution of money, since in times of crisis, the two strongly interact through the elusive quest for liquidity. It is the institution of money which allows to bridge the gap between the economic sphere and the social, technical and political elements. Furthermore, by proceeding from sovereignty, money is not alike other institutions, and can deal with radical uncertainty.

As we will see in the next part, the realization of a climate systemic risk translates into potential financial turmoil and this in turn can increase the tension around the provision of the ultimate liquidity. This feature is common to any systemic financial crisis. The true difference with climate systemic risk however lies in the fact that the power of the ultimate liquidity to restore confidence into the payment system can potentially also be put into question. The reason is that the crisis not only affects a segment of the economy, the society or the financial system, but the fundamental support of life as we know it. The ethical confidence is endangered (Aglietta and Orléan, 2002). The articulation of money and finance is crucial to manage the prevention or adaptation to the realization of climate systemic risk. Carbon prices are not ruled out as efficient climate policy tools, but it is their role as coordinators of the expectations of economic agents which is now looked for, with the outspoken goal of drastically diminishing the probability of certain outcomes.

These differences of approach between the efficient market hypothesis and the radical uncertainty hypothesis are summarized in table 1. We now look into more details into this specific articulation between financial fragility and climate fragility, and show some elements of positive feedbacks between the two.

Climate and financial fragilities: a positive feedback loop?

First, climate systemic risk is a potential source of financial disruption. Climate fragilities increase financial fragilities. There is thus a strong need for the financial sector to anticipate such an outcome. This is the most largely admitted part of the loop. In his speech at Lloyd's in London on 29 September 2015, Bank of England governor Mark Carney (Carney, 2015) underlined these key channels through which climate change can affect financial stability:

- *Physical risk*: impacts on the value of financial assets of climate events such as floods, storms, *etc …* This physical risk could be better understood by taking into account the results of climate science. Knowing that climate science has a tendency of "*erring in on the side of least drama*" (Brysse et al., 2012), radical uncertainty will still remain on potential damages to financial assets.

- *Liability risk*: impacts of lawsuits by those who might have been victims of natural disasters that they would try to link to climate change, aimed at those deemed responsible for these changes. This risk currently seems to be far-fetched (Munich Re, 2010). But we can see early signals of such liability procedures from numerous NGOs and civil society, which may become a powerful political force in case of realization of a physical risk.

- *Transition risk*: the financial risk that would result from an adjustment to a decarbonized economy. Changes in policies, technologies, institutions and behaviors might lead to a new valuation of a whole set of assets once costs and benefits of climate action become more and more apparent. This shift to a "2°C portfolio" has to be managed by accompanying monetary policies.

If we wait too long, the extreme solution of geo-engineering might arise (Wagner and Weitzman, 2015). This possibility amounts to realizing these three types of risks into one single technological move. Using such a technology, physical risk is both postponed and multiplied, since stopping geo-engineering abruptly scales up the greenhouse effect, making climate sensitivity skyrocket. The liability risk can be easily targeted to the firms and States responsible for the use of this technology. The burden of the proof is much lighter since we can directly attribute climate effects to the use of such a technology. And adopting this ultimate technology represents in itself the utmost transition risk, since it is a last minute transition, when no sustainable technology can be of any use anymore. This extreme-case scenario has to be present in our climate systemic risk mapping, as it makes climate systemic risks singular among financial systemic risks.

In any case, it is the addition of new risks to an already fragile financial system, which have the potential to transform an idiosyncratic event into a financial crisis. The 2008 crisis has revealed the importance of "too-big-to-fail" institutions, a problem which does not seem to be fully solved today (Kashkari, 2016). Since then, shadow-banking has emerged as a new source of potential systemic risk (FSB, 2015), in relation with the notion of "too-connected-to-fail" institutions. In 2016, financial institutions are also experiencing a debt-overhang of oil-related debts, because of current very low oil prices. So that the current state of the financial system is admittedly highly vulnerable (Aglietta, 2016). Adding three new types of risks to this situation can only worsen financial fragilities. A true analysis of this fragility of the financial system to climate related risks requires a spatialized network approach (Battiston et al., 2016, Espagne et al., 2016).

Second, as we have only suggested so far, the financial sector might also be a powerful driver and accelerator of the realization of a climate systemic risk. Very little research tries to address this particular causality, but some sector specific studies can give us hints of an effective impact of financial misallocation on the worsening of the environment. Financial systems have undergone several hundred crises since the 1970s, the 2008 one endangering economies and societies worldwide (Reinhardt and Rogoff, 2009). The magnitude of damages on the environment, society and the economic spheres, because of acute blindness of the financial sector to external effects, only begins to be revealed: inequalities (Domansky et al., 2016), health (Karanikolos et al., 2013), the environment (Romero et al., 2012), ... In these few examples, it is the direct ignorance by the financial system (and the economic policies which follow a financial crisis) of its external impacts which generates an immense cost for everyone. Upstream, it is also the capacity of the financial system to generate sustainable investments in the long run that should be questioned. Subsequently endogenous processes arise: inequalities increase the probability of occurrence of financial crisis (Kumhof et al., 2015), deficient public health situations degrade public budgets and environmental risks generated by unsustainable investment choices are responsible for new risks looming (Carney, 2015; Espagne, 2016).

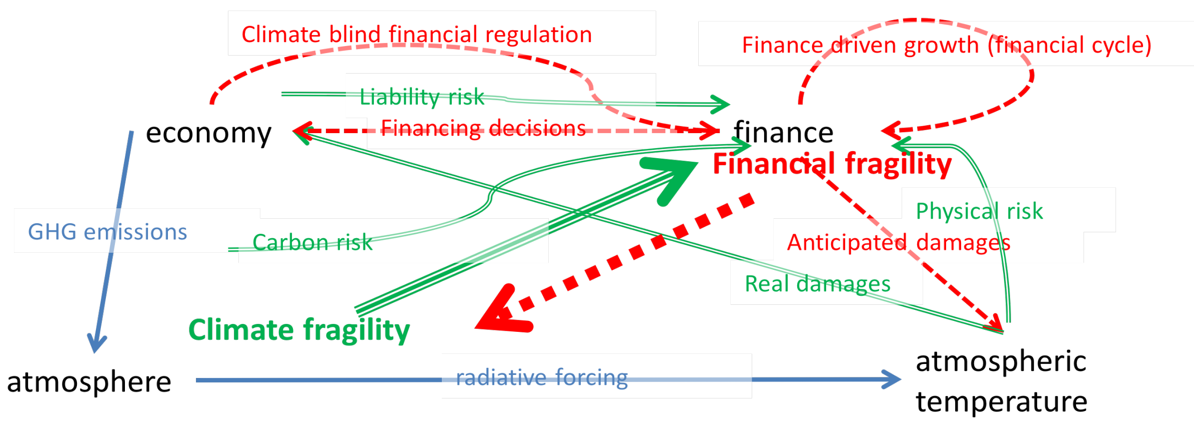
This argument of bad capital allocation by the financial system can be coupled with another more fundamental argument. We now know that since the early eighties, a singular phenomenon of financial cycles has emerged. The financial cycle lasts much longer than the more traditional business cycle, and is crucial to the growth dynamics (see figure 4). An upward oriented financial momentum brings with it high levels of growth, while the decreasing trend reveals the unsustainability of most of the previous period investment choices. The financial cycle is explained by financial variables mostly (Borio, 2014), but also by the volume of real-estate transactions. It may thus be a good proxy to estimate the specific damage incurred to the environment and indirectly to the climate by "excessive" financial developments in comparison with a sustainable growth trend. A new trend of research should look at the impact of financial globalization, and the new financial cycles, on an excessive use of environmental resources, and thus on an overshoot over sustainable emission targets. The financial bubble that accompanied shale gas development and the huge financial investment in deep sea water exploration contributed to the collapse of oil prices and subsequent financial hardship, while a substantial part of underground oil fields would admittedly be stranded if ever the 2°C objective be reached. Therefore the irrationality of present-day unbounded finance, due to the short-run horizon induced by shareholder value predominance on equity return targets, is a crucial contributor of systemic risk.

It leads to a third type of argument showing that financial fragility impacts climate fragility. It is a political economy argument. Except during the COP21 momentum, it is the financial crisis agenda which drives most of the political agenda, either to cope with the long-lasting consequences of the 2008 crisis (and its European developments), or to try to build new, more resilient and more efficient financial institutions. But could the financial system become resilient and efficient while avoiding systemic events by being isolated as an independent object of research, blind to signals given by the economy, society, and the environment? This would drive us into the equivalent of the efficient market hypothesis' mistake, implying that all the available information about pretty much everything is incorporated into prices, if these prices can be soundly established in transparent enough financial markets. Had this axiom had any bearing on real-world financial systems, systemic financial crises could not logically occurred. Indeed, the efficient market hypothesis gives rise to the Modigliani Miller theorem according to which the fundamental values of assets are independent of the financial structure and therefore equal to market prices in equilibrium. This would imply that finance could become more resilient and useful for society without considering the impact of its structure on externalities, and vice-versa that the external world could not have any role in suggesting ways or signals to shape the financial system. The still reduced, but growing, integration of non-financial criteria in financial actors' strategies shows just the opposite (Aglietta and Rigot, 2012). This political effort is thus too narrowly focused and bears the risk to miss the link with the new risks emerging from longer-term analysis, including climate changes.

Finally there is a fourth type of argument, of institutional nature. The financing of energy and primary resources is an essential part of private financial institution's activities, at least since the early seventies, if not more (Yergin, 2011). The financialization of these products is considered by Gkanoutas-Leventis and Nesvetailova (2015) to have been an essential transmission channel of the 2007 financial shock in the US to the global real economy. Institutional inertia tends to make these very same financial institutions keep financing carbon intensive industries, such as shale gas, ultra-deep-water offshore projects or arctic oil drilling. They become stuck with stranded assets (Wolf, 2016) without much intelligence on how to move away from an inconvenient position, or any willingness to do it. North (1992) argues that institutional changes are usually slow and incremental and that players will attempt more rapid institutional revisions only when they believe that they consistently lose under the existing system and when it has been such a case for a long time. Current low-growth/low-return financial situation might drive such a momentum. New types of financial institutions, which would be intrinsically responsible investors (Aglietta, 2015), would have to emerge and be seen as credible institutions for a majority of players, so that financial fragility does not accelerate climate systemic risk. Meanwhile, institutional inertia in the financial system plays in favor of more climate risks.

There are thus strong arguments defending the case that financial and climate fragilities are intertwined into positive feedback loops, as figure 5 illustrates. So that climate systemic risk also incurs financial systemic risk. We must now understand how we could break this circularity and reduce these systemic risks.

Figure 2: Financial and climate fragilities reinforce each other to generate climate systemic risks



Reducing climate systemic risk in breaking the circularity: some financial regulation options

Financial systemic risk is usually dealt with through a combination of *ex ante* and *ex post* policies. We can follow that analogy for climate[3].

Ex ante, financial regulations can try to mitigate this collective risk. This requires a combination of oversight, collateral requirements, position caps, etc…The incorporation of some kind of climate signal in monetary policy and financial stability oversight is required, not because the central banks should be a direct actor of the low-carbon transition, but as part of their financial stability mandate. They have to ensure that the financial system be resilient even when confronted with a chosen or a forced low-carbon transition, and as a facilitator of the emergence of effective financing tools. Several undertakings can be grouped into this *ex ante* approach: information sharing, specific investment tools, macro prudential instruments, and new monetary policy orientations.

The first one is fulfilled through a transparency policy, the sharing of information. It first aims at facilitating informed decisions by actors in the financial system. The voluntary disclosure of article 73 in the energy transition law of 2015 in France, or the mission given to an ad-hoc task-force by the FSB in 2016 to study the possible voluntary disclosure of the carbon content included into financial portfolios, go in this direction. But it also aims at allowing an informed supervision by the regulator, so that it can evaluate as an early signal the exposure of financial institutions to climate-related events and intervene as soon as possible before the negative financial externality has propagated. But this requires that information disclosure becomes mandatory and not simply voluntary, with clear established methodologies (Bellassen et al., 2015), and that this information is widely shared among different national financial surveillance authorities. Collective (and not just individual) stress-tests should be carried out using this particular climate-related information (Battiston et al., 2016)

The second one is more proactive. Carney's argument on the tragedy of the horizons can be understood in a minimalist way, by saying that central banks and financial regulators should encourage private finance institutions to engineer the tools required to help financial flows target specific low-carbon projects. Andersson, Bolton and Samama (2014) show that it is possible to create low-carbon financial indexes that have the same return as the "*benchmark*" index, which is indifferent to the environmental constraint. By investing in such an index, investors have at their disposal a "*free option on carbon*", which hedges its return against a possible limit on

[3] ESRB (2016) deals with the possibility of a systemic risk for the European financial system arising from the assumption of a late and sudden climate policy. We develop the concept of climate systemic risk in a more general way, even if our notion entirely includes theirs.

emissions, a non-negligible probability in the medium or long run. It is, or so it seems so far, the direction taken by the already mentioned working group commissioned by the FSB to investigate the possibility to voluntarily reveal the carbon content of financial portfolios. This approach alone however fails to recognize the collective nature of climate systemic risk.

A third (complementary) undertaking, more in line with the notion of a climate systemic risk, involves thinking on financial structural reforms. It consists in the search for better rules and better incentives to promote particular changes in the financial structure, so that a greater resilience follows. New fields of research automatically emerge: is the current globalized financial network structure fit to confront the new risks implied by climate change? What should be the size of financial institution in order to arbitrage between inside financial risks and bankruptcies? Is there an optimal level of financial concentration to deal with the efficiency/resilience dilemma? Should financial institutions hold a certain amount of "green assets" on the asset side of their balance sheet, in the same way they must meet a liquidity ratio under Basel III.? The fundamental principles of a climate-related macro-prudential policy remain to be written (ESRB, 2016).

Finally, we must consider that monetary policy should also integrate a reaction to climate-related signals and not pursue a policy exclusively oriented towards goods and services inflation. The central bank can act on the expectations of financial actors and try to align them with the long term stability of the financial system, i.e. a smooth transition out of a carbon economy. It can use several tools to reach that goal. It can lean on the announcement by EU Commission of an objective in terms of climate risk mitigation. Such a tool has been used with mixed results in the past since the 2008 financial crisis. The credibility of the announcement is key, so that it must be accompanied by possible or effective use of various instruments in order to really affect financial markets' anticipations. Such accompanying tools can be asset purchase programs, qualitative mandatory reserves at the central bank, or more direct actions on the quality of credits created by commercial banks, such as a "green funding for lending scheme" (Churm et al., 2012), or even financial repression measures (Monnet, 2015), which force commercial banks with various tools to lend to particular sectors with a high climate-related reward.

Ex post, the climate systemic risk approach becomes a crisis management issue. The central bank can have a direct role as a lender of last resort. This notion was first developed in the 19th century by the English economist Walter Bagehot (1888). It was invented to justify the temporary suspension of the payment constraint on financial markets when dangerous financial events arise by the reference to a superior level of payment. It is of course an exorbitant operation in a market economy, and it is the art of the central bank (constructive ambiguity) to reduce the risk of moral hazard which can emerge when financial actors make the implicit hypothesis that their payments will always be guaranteed. Lending in last resort is a sovereign decision, contingent to the specific situation involved and not subject to definite rules. A traditional lender of last resort action can occur either through a general monetary policy expansion or an emergency liquidity assistance targeted to individual institutions. Both methods potentially generate moral hazard issues.

In the case of a climatic systemic risk, the moral hazard issue is very different and probably less stringent than in a more traditional financial systemic risk, because much more is at stake. In Aglietta and Orléan (2002), three levels of confidence, horizontal, hierarchical or ethical, guarantee the provision of liquidity in the economy. Typical financial systemic crises affect the horizontal level of confidence when the mechanical daily payment system becomes dysfunctional (such as interbank lending in the 2008 crisis). In deflationary financial crises, whereby the rollover of debt gets frozen, the role of the central bank is to make its liabilities available to would-be solvent borrowers in the clearing settlement mechanism if enough liquidity is available. In that type of financial crisis, the *ex post* intervention of the central bank, the involvement of the hierarchical level of confidence, is enough to restore the liquidity in the system with the implicit guarantee of the central bank. In the opposite case, when the bail-out of banks and public debt becomes systematic by issuance of an unlimited amount of money, inflation can become a self-sustaining spiral, being fostered by competing private indexations. The official unit of account is not trusted anymore, meaning that the monetary order is rejected because it has degenerated. In that case ethical trust has collapsed. A drastic monetary reform, often anchored on a foreign currency, is required to restore the monetary order. This means that the principle of sovereignty itself had to be modified in order for the currency to be accepted again and the financial system to resume its function.

How can we transpose the logic of the lender of last resort to systemic climate events? It is clear that no provision of central bank liquidity can ever exactly restore the pre-crisis situation. Only the confidence in the payment system will be reestablished, and this is often sufficient to also restore the previous level of economic activity. But the provision of central bank liquidity for a systemic event linked to a physical climate damage might never be able to restore the previous level of economic activity. The implicit guarantee of the central bank cannot cover irreversible climate damages. Such damages are likely to affect the ethical level of confidence: it is the principle of sovereignty itself which is at stake if a portion of territory is irreversibly transformed due to the climate externality. Liability procedures, if they ever happen, could have such tremendous consequences for societies that they are also likely to take the form of a new social contract. So that central banks will not be the best tools to counter their effect. Moral hazard issues between financial institutions and the central bank are thus less stringent in this case also. The same kind of argument can be put to the fore for the so-called carbon risk. If a climate policy is implemented urgently and at an ambitious level (ESRB, 2016), there is only very little the central bank can do to restore confidence in the payment system. Confidence will also probably be restored first by the change in politics showing that political authorities are committed to handle the issue. So at the end, the good news is that moral hazard may not be so much of an issue in the case of a climate systemic risk; the bad news is that the central bank will be of limited power in *ex post* reactions to a climate systemic crisis. It will only be able to restore liquidity in a new adapted economy, which will have very little to do with the previous one. This fact should be internalized now by all actors in order to facilitate the implementation of *ex ante* policies. It must be underlined that the four pillars of *ex ante* mitigation of a climate systemic risk cannot be pursued separately, but rather in a combined coherent way.

The Governor of the Bank of England Mark Carney underlined in the already mentioned speech in 2015 (Carney, 2015) the great dangers looming from what he called the tragedy of the horizons: the temporal mismatch between the financial investor's agenda, the financial regulator's and the constraining physical climate change process. This seminal speech has triggered new policy initiatives for 2016: the Financial Stability Board has been tasked by the G20 in Antalya (November 2015) to study methods appraising climate risk included in financial portfolios and to propose a voluntary disclosure process to financial actors, the G20 in Shanghaï (February 2016) has given the Bank of England and the People's Bank of China the mission to investigate the reality of climate change as a financial risk, as highlighted by Mark Carney in his speech.

These results however fall short of acknowledging the full implications of climate change for societies, the economy and the financial system. New financial instruments and financial reforms to make the financial system more resilient to climate risks can build on important statements embodied in the Paris Agreement, such as carbon pricing[4], or a social, economic and environmental value of emission reductions[5], following many proposals which have popped up in the months leading to COP21 (Espagne, 2016). Paragraph 108 in particular can be regarded as important in the process of joining financial and climate policy reform agendas. The new Commission headed by Nicholas Stern and Joseph Stiglitz will pursue this idea in the spring 2017. Voluntary disclosures cannot mitigate climate risks in a reliable way, in the same way as shared public/private banking stress-tests are always inefficient in restoring confidence. Furthermore the joint realization of three highly correlated risks cannot have less than systemic consequences for the financial system. Climate change constitutes a typical example of systemic risk for societies as well as the financial system. This disclosure, as well as its policy implications, seems to have been the elephant in the room of both the UNFCCC process and the broader Paris Alliance. As a consequence, it is also the main task of climate research in all disciplines to characterize this systemic risk at all scales.

---

[4] Paragraph 136 of the Decision.
[5] Paragraph 108 of the Decision.

References

AGLIETTA M. (1991), « Le risque de système », *Revue d'économie financière*, (18), p. 61-89.

AGLIETTA M. (2003), « Le risque systémique dans la finance libéralisée », *Revue d'économie financière*, p. 33-50.

AGLIETTA M. (2015), "What is the Quality of Growth? Sustainability and Inclusiveness", *Growth is Dead, Long Live Growth*, 19.

AGLIETTA M. (2016), *Le pouvoir de la monnaie dans l'économie mondiale*. Etat du Monde 2017.

AGLIETTA M., ESPAGNE E., PERRISSIN-FABERT B. (2015), *A proposal to finance low carbon investment in Europe*, France Stratégie, Paris.

AGLIETTA M., HOURCADE J.C (2012), "Can indebted Europe afford Climate Policy? Can it bail out its debt without Climate Policy", *Intereconomics*, *3*, p. 160.

AGLIETTA M., ORLEAN A. (2002), *Monnaie (La): Entre violence et confiance*. Odile Jacob.

AGLIETTA M., RIGOT S. (2012), « Investisseurs à long terme, régulation financière et croissance soutenable », *Revue d'économie financière*, (4), p. 189-200.

AKERLOF G. (1991), "Procrastination and Obedience", *American Economic Review* , vol 81, n°3.

ALLEN M. (2003), "Liability for climate change", *Nature*, *421*(6926), p. 891-892.

ANDERSSON M., BOLTON P., SAMAMA F. (2014), "Hedging climate risk", *Columbia Business School Research Paper*, (14-44).

BAGEHOT W. (1888), *Lombard Street: A description of the money market*. Kegan, Paul & Trench.

BALDWIN R., LOPEZ-GONZALES J. (2015), "Supply-chain Trade: A Portrait of Global Patterns and Several Testable Hypotheses", *The World Economy*, *38*(11), p. 1682-1721.

BATTISTON S., MANDEL A., MONASTEROLO I., SCHETZE F., VISENTIN G. (2016), *A Climate Stress-Test of the EU Financial System*. Available at SSRN.

BELLASSEN V., STEPHAN N. (2015), *Accounting for Carbon*. Cambridge University Press.

BORIO C. (2014), "The financial cycle and macroeconomics: What have we learnt?", *Journal of Banking & Finance*, *45*, p. 182-198.

BRYSSE K., ORESKES N., O'REILLY J., OPPENHEIMER M. (2013), "Climate change prediction: Erring on the side of least drama?", *Global Environmental Change*, *23*(1), p. 327-337.

CAMPIGLIO E. (2016), "Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy", *Ecological Economics*, *121*, p. 220-230.

CARNEY M. (2015), "Breaking the Tragedy of the Horizon–climate change and financial stability", *Speech given at Lloyd's of London by the Governor of the Bank of England*, 29.

CHURM R., RADIA A., LEAKE J., SCRINIVASAN S., WHISKER R. (2012), "The funding for lending scheme", *Bank of England Quarterly Bulletin*, Q4.

CONLISK (1996), « Why Bounded Rationality? », *Journal of Economic Litterature* , vol. XXXIV, n°2, juin, p. 669-700.

DOMANSKI D., SCATIGNA M., ZABAI A. (2016), « Wealth inequality and monetary policy", *BIS Quarterly Review March*.

ESPAGNE E. (2016), "Climate Finance at COP21 and After: Lessons Learnt," *CEPII Policy Brief 2016- 09*, 2016 , CEPII.

ESPAGNE E., PERRISSIN FABERT B., POTTIER A., NADAUD F., DUMAS P. (2012), "Disentangling the Stern/Nordhaus controversy: beyond the discounting clash", *FEEM Working Papers*.

ESPAGNE E., HOURCADE J.C, FABERT B.P (2015), « La finance au secours du climat? La Nature entre prix et valeur », *Natures Sciences Sociétés*, (Supp. 3), p. 117-121.

ESPAGNE E., DRON D., GOERNER S., ULANOWICZ R. (2016), « A financial system for the age of the Commons. Using ecological principles and methods to understand and assess systemic risk in financial systems", *Working Paper*.

EUROPEAN RISK BOARD (2016), "Too late, too sudden: transition to a low carbon economy and systemic risk", *Report of the advisory scientific committee*, n°6.

FABERT B. P., POTTIER A., ESPAGNE E., DUMAS P., NADAUD F. (2014), "Why are climate policies of the present decade so crucial for keeping the 2° C target credible?", *Climatic change*, 126(3-4), p. 337-349.

FINANCIAL STABILITY BOARD (2015), *Global Shadow Banking Monitoring Report 2015*. http://www.fsb.org/wp-content/uploads/global-shadow-banking-monitoring-report-2015.pdf

FONTANA G., SAWYER M. (2016), "Towards post-Keynesian ecological macroeconomics", *Ecological Economics*, vol 121, p. 186-195.

GKANOUTAS-LEVENTIS A., NESVETAILOVA A. (2015), « Financialisation, oil and the Great Recession", *Energy Policy*, 86, p. 891-902.

HOURCADE J.C, FABERT B.P, ROZENBERG J. (2012), "Venturing into uncharted financial waters: an essay on climate-friendly finance", *International Environmental Agreements: Politics, Law and Economics*, 12(2), p. 165-186.

HULME M. (2014), "Attributing weather extremes to 'climate change': A review", *Progress in Physical Geography*, 0309133314538644.

INTERNATIONAL MONETARY FUND (2016), *Adequacy of the global financial safety net.* IMF staff report. March.

INTERNATIONAL MONETARY FUND (2016), *"The growing importance of financial spillovers from emerging market economies"*, Global Financial Stability Report, *Chap. 2.* April.

KAHNEMAN D. (1996), *New Challenges to the Rationality Assumption* in Arrow et alii (1996), p. 203-219.

KARANIKOLOS M., MLADOVSKY P., CYLUS J., THOMSON S., BASU S., STUCKLER D., McKEE M. (2013), "Financial crisis, austerity, and health in Europe", *The Lancet*, *381*(9874), p. 1323-1331.

KASHKARI N. (2016), Lessons from the Crisis: Ending Too Big to Fail. *Remarks at the Brooking Institution, Washington, D.C.,* February 16, 2016.

KEYNES J. M. (1936), *The general theory of interest, employment and money*, Palgrave Macmillan.

KNIGHT F. H. (1921), *Risk, uncertainty and profit*. New York: Hart, Schaffner and Marx.

KUMHOF M., RANCIERE R., WINANT P. (2015), "Inequality, leverage, and crises", *The American Economic Review*, *105*(3), p. 1217-1245.

MONNET E. (2014), "Monetary Policy without Interest Rates: Evidence from France's Golden Age (1948 to 1973) Using a Narrative Approach", *American Economic Journal: Macroeconomics*, *6*(4), p. 137-169.

MONNIN P. (2015), *Supporting the Energy Transition: the role of Low Interest Rates.* CEPII-France Stratégie Climate Finance Platform.

NELSON R. (1995), « Recent Evolutionary Theorizing about Economic Change », in *Journal of Economic Litterature*, Vol. XXXIII, n°1, mars, p 48-90.

NELSON R., WINTER S. (1982), *An evolutionary theory of economic change*, Harvard University Press, Cambridge, Mass.

NORDHAUS W. D. (1993), "Rolling the 'DICE': an optimal transition path for controlling greenhouse gases", *Resource and Energy Economics*, *15*(1), p. 27-50.

NORTH D. C. (1992), *Transaction costs, institutions, and economic performance* (p. 13-15). San Francisco, CA: ICS Press.

ORESKES N., CONWAY E.M (2011), *Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. Bloomsbury Publishing USA.

ORLEAN A. (2011), *L'empire de la valeur: refonder l'économie*. Seuil.

PACHAURI R. K., ALLEN M. R., BARROS V. R., BROOME J., CRAMER W., CHRIST R., DUBASH N.K (2014), *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

POTTIER A. (2013), « Le discours climato-sceptique: une rhétorique réactionnaire », *Natures Sciences Sociétés*, *21*(1), p. 105-108.

REINHART C.M, ROGOFF K. (2009), *This time is different: eight centuries of financial folly*. Princeton university press.

REZAI A., STAGL S. (2016), "Ecological Macroeconomics: Introduction and Review", *Ecological Economics*, *121*, p. 181-185.

ROMERO J., JIMENEZ F., VILLORIA M. (2012), « (Un) sustainable territories: causes of the speculative bubble in Spain (1996–2010) and its territorial, environmental, and sociopolitical consequences", *Environment and planning C: Government and policy*, *30*(3), p. 467-486.

ROUKNY T., BATTISTON S., STIGLITZ J. E. (2016), *Interconnectedness as a Source of Uncertainty in Systemic Risk*. Available at SSRN 2726631.

SCHALLER N., KAY A. L., LAMB R., MASSEY N. R., VAN OLDENBORGH G. J., OTTO F. E., BOWERY A. (2016), "Human influence on climate in the 2014 southern England winter floods and their impacts", *Nature Climate Change*.

SENEVIRATNE S. I., NICHOLLS N., EASTERLING D., GOODESS C. M., KANAE S., KOSSIN J., REICHSTEIN M. (2012)," Changes in climate extremes and their impacts on the natural physical environment", *Managing the risks of extreme events and disasters to advance climate change adaptation*, p. 109-230.

TEULINGS C., BALDWIN R. (2014), *Secular stagnation: facts, causes, and cures*, Centre for Economic Policy Research.

UNFCCC (2015), http://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_ agreement_english_.pdf

VAREY, KAHNEMAN D. (1992), « Experiences Extended Across Time: Evaluation of Moments and Episodes », *Journal of Behavioral Decision-Making*, vol. 5, p. 169-196.

VAUTARD R., YIOU P., VAN OLDENBORGH G. J., LENDERINK G., THAO S., RIBES A., SOUBEYROUX J. M. (2015), "Extreme Fall 2014 Precipitation in the

Cévennes Mountains", *Bulletin of the American Meteorological Society*, *96*(12), p. S56-S60.

VILLEROY DE GALHAU F. (2015), *Changement climatique : le secteur financier face aux trajectoires 2°C* – Discours, CEPII-France Stratégie Climate Finance Platform.

WEITZMAN M.L (2009), "On modeling and interpreting the economics of catastrophic climate change", *The Review of Economics and Statistics*, *91*(1), p. 1-19.

WEITZMAN M. L. (2012), "GHG targets as insurance against catastrophic climate damages", *Journal of Public Economic Theory*, *14*(2), p. 221-244.

WAGNER G., WEITZMAN M.L (2015). *Climate shock: the economic consequences of a hotter planet*. Princeton University Press.

WOLF M. (2016), *Fossil fuel power plants will be stranded.* Financial Time column, April 5th 2016, http://www.ft.com/intl/comment/columnists/martin-wolf.

YERGIN D. (2011), *The prize: The epic quest for oil, money & power*. Simon and Schuster.

Renewable Energy – Characteristics and representation in macroeconomic energy-climate models

Ganna GLADKYKH, Nathalie SPITTLER, Florian DIERICKX

University Clermont Auvergne, CERDI-OR2D, University of Iceland, AdaptEcon II

The current energy system, which is fossil-fuel-based, has been identified as one of the main drivers of earth system change. Although impacts of human beings are observable even earlier, none of the changes before (e.g. change in the agricultural system) caused such a significant impact on the environment as the one of the energy system (Steffen et al., 2005). Hence, it is no surprise that the energy system is also modeled as a main driver for climate change in many macroeconomic energy-climate models. One of the suggested solutions to climate change mitigation is a transition from a fossil-fuel-based energy system to a renewable-energy-based one (Edenhofer, Pichs Madruga, & Sokona, 2012; Iiasa, 2012; International Energy Agency, 2014). In the IPCC's report, renewable energy is defined as "*any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. Renewable energy is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes low-carbon technologies such as solar energy, hydropower, wind, tide and waves and ocean thermal energy, as well as renewable fuels such as biomass*" (Edenhofer et al., 2012, p. 38). It is assumed by the authors that the definitions and assumptions made for various energy sources in macroeconomic energy-climate models are affecting the modelling results depending on how the relations between climate change and the energy system are analysed. Characteristics chosen to be considered when modelling renewable energy technologies can influence modelling results. Hence, the paper deals with the following research question: How are characteristics of renewable energy represented in macroeconomic energy-climate models? To answer this question we start from the above-mentioned definition of renewable energy. Then, in a disaggregated manner, we analyse characteristics of different renewable energy technologies, relevant for the interaction between climate change and the energy system. This is followed by an overview of several macroeconomic climate-energy models including a description of their assumptions about renewable energies and a description of the connection between renewable energy and climate change. Based on the former, the differences of definitions and theories of renewables, as well as their representation in models, are discussed. A special focus will be put on the energy models used for energy scenarios and policies for the European Union (EU) PRIMES and GEM-E3.

Characteristics of renewable energies

There is no uniform definition of renewable energy. Other ways, than the above mentioned definition of renewable energy by the IPCC can be found in the literature. Some of the definitions are broad but others give a more detailed description of renewable energy or a subset of it. However, most commonly a definition of renewables similar to the one of renewable energy by the IPCC is provided. An example of this is the definition of the German Advisory Council on Global Change: "*These include the energy of the sun, water, wind, tides, modern biomass and geothermal energy. Their overall potential is in principle unlimited or renewable, and is CO2-free or -neutral*"(German Advisory Council on Global Change, 2003, p. 236). Furthermore, a definition of renewables can be distinguished between different types of renewables. The German Advisory Council on Global Change recognizes "*new renewables*" specifically, which are those that have only recently been discovered, developed and employed and therefore still bear great potential; this, for example, excludes hydropower. Another possible distinction is between combustible and non-combustible renewables. Every renewable energy source, apart from bioenergy can be considered non-combustible (Vera, Langlois, 2007). Those definitions despite not giving any more detail provide insights into the fact that renewables only in principle have unlimited renewable potential, as well as the categorizations suggest that different renewables have varying characteristics and environmental impacts. Some of these renewables cannot be seen to be 100% renewable despite the fact that the source might be constantly renewable. For example, the technology for harvesting the source might depend on scarce or critical resources (WWF 2014) and constrain the possibility to harvest a specific renewable resource at a certain point in time. Even if the energy source itself might be renewable, resource constraints with regards to harvesting it might exist and must be considered. This is in line with Garcia-Olivares argument that a future energy source "*must not depend on the exploitation and use of scarce materials*" (García-Olivares, Ballabrera-Poy, García-Ladona, Turiel, 2012).

By not including the arising constraints for renewables in macroeconomic energy-climate models, renewable energy might be represented in a way that allows for misleading conclusions based on modelling results. Table 1 displays renewable energy technologies, which from today's perspective are considered technologically and economically feasible and are commonly referred to as alternative, that can help to combat climate change (Edenhofer, Pichs Madruga, Sokona, 2012; Iiasa, 2012; International Energy Agency, 2014). Additionally, the potential of renewables in a certain location can also be impacted by climate change. Hence, this is another component that is vital for modelling renewables in macroeconomic energy-climate models, as not only the energy system impacts on climate change but also the other way around (Schaeffer et al., 2012).

Based on the above, the categories to characterize each of the renewable technologies were chosen for the following reason:

(i) Unlimited energy source: This refers to the primary energy source (e.g. sun). Due to the rate of harvesting (if the rate of harvesting exceeds the sustainable harvesting rate), some resources that are considered renewable might become non-renewable (e.g. geothermal).

(ii) Critical materials for harvesting technology: A renewable resource is only 100% renewable if harvesting does not depend on any critical or scarce resources.

(iii) Impact of climate change on energy source: Climate change itself can impact on the availability of a certain energy source and its harvesting potential. For example, does climate change heavily impact on water resources and therefore on the water available for energy generation (de Queiroz et al. 2016).

(iv) Emissions during energy production processes: These emissions refer to those occurring during the conversion of primary energy to secondary and final energy. Not all renewables are CO2-neutral or -free, to a large extent this can depend on their harvesting rate.

Table 1: Disaggregated analysis of renewable energy technologies

Technology	*Unlimited source*	*Critical materials for harvesting technology*	*Impacts of Climate Change on source*	*Emissions during energy production*
Solar PV	yes - sun	Copper, Gallium, Germanium, Indium, Selenium, Silver, Tellurium, Tin	yes	no
Solar Cells	yes - sun	-	yes	no
Concentrated Solar	yes - sun	Copper	yes	no
Hydropower Small	yes - water	-	yes	no
Hydropower Large	yes - water	-	yes	no
Geothermal	possible - earth		no	yes
Biofuels	possible - biomass	-	yes	yes
Biomass solid	possible - biomass	-	yes	yes
Wind	yes - wind	Cobalt, Copper, Manganese, Molybdenum, Nickel, Rare Earths	yes	no

Each of the above-mentioned characteristics has an implication for integrating renewables into macroeconomic energy-climate models. According to the definition of renewable energy given by the IPCC, the energy can be classified as renewable only if its harvesting rate is below the recovery rate. This is especially relevant for biomass but also for geothermal energy. With regards to critical materials for the existing harvesting solutions, especially those technologies currently receiving a lot of attention (PV, solar and wind) require a number critical and potentially scarce materials. Almost all technologies require copper (including hydropower and geothermal). However, a study by the WWF (2014) found that only the copper use of PV, wind and concentrated solar power had a significant impact on its availability. Although emissions from biofuels and solid biomass (if harvested sustainably) do not cause net emissions, there still occur emissions during the combustion of biofuels. The emissions arising at geothermal plant sites vary for different sites. The availability of all renewable energy sources, apart from geothermal, at a certain location at a certain point in time can be influenced by climate change. Those impacts vary according to the specificities of the region (e.g. change of solar radiation intensity; change in composition of crop availability due to temperature changes; less energy density in water flow due to lower precipitation) but should be considered when modelling the possible contribution of renewable energy to combating climate change on a regional and/or global scale.

In Table 1 only the interaction between renewable energy and its impacts on climate change were assessed, other environmental impacts were not taken into account. However, some of the carbon-neutral renewable energies (e.g. hydropower) do not affect climate but interfere with the proximate ecosystem, which might also lead to negative impacts on the climate in the long run. This means that even if a source is renewable it might not be fully sustainable. Other aspects that need to be considered when talking about sustainable energy are the following: spatial dependence due to environmental circumstances, resource competition with other sectors (e.g. food, transport) and global security issues. Environmental implications of building renewable energy infrastructure is another important issue. Table 1 does not take into account critical materials and emissions associated with building additional distributional infrastructure for different types of renewable energy. In case energy-climate models provide for the possibility of building up renewable energy capacities, environmental implications of such activities should be included in the models' assumptions.

Modelling renewables in the context of climate change, societal values, territory, energy security

Biophysical aspect of renewable energy, including natural resource use and emissions, is a crucial but not the only dimension which needs to be addressed when building macroeconomic energy-climate models and designing scenarios for renewable energy development. The authors believe that the issues such as geopolitical interests and financial flows are of crucial importance in renewable energy models. Modelling practice is always driven by underlying assumptions based on cultural, personal and societal values and broader regional or national geopolitical interests. However, the opposite is also true - regional or national strategies and the political climate with regards to environmental issues might be influenced by modelling results, depending on the impact of past modelling reports and their dissemination into different layers of society.

An important issue is the one of spatial scale of models, and whether they consider the renewable energy to be produced on the spatial scale of the institution issuing the model and the users using the model. For example, an issue, which is rarely explicitly mentioned in such models is whether, for example, the EU has the right to explore and exploit (renewable) energy in other countries, assuming that these other countries would accept this in a democratic way, knowing that the EU stresses fiercely its values and even tries to export them around the world. In a recently published EU guideline, it is mentioned that : "[the EU] *is at the forefront of the fight against climate change and its consequences; as it plans to keep growing, it helps neighbouring countries prepare themselves for EU membership; and it is building a common foreign policy which will do much to extend European values around the world*" (European Parliament, n.d.).

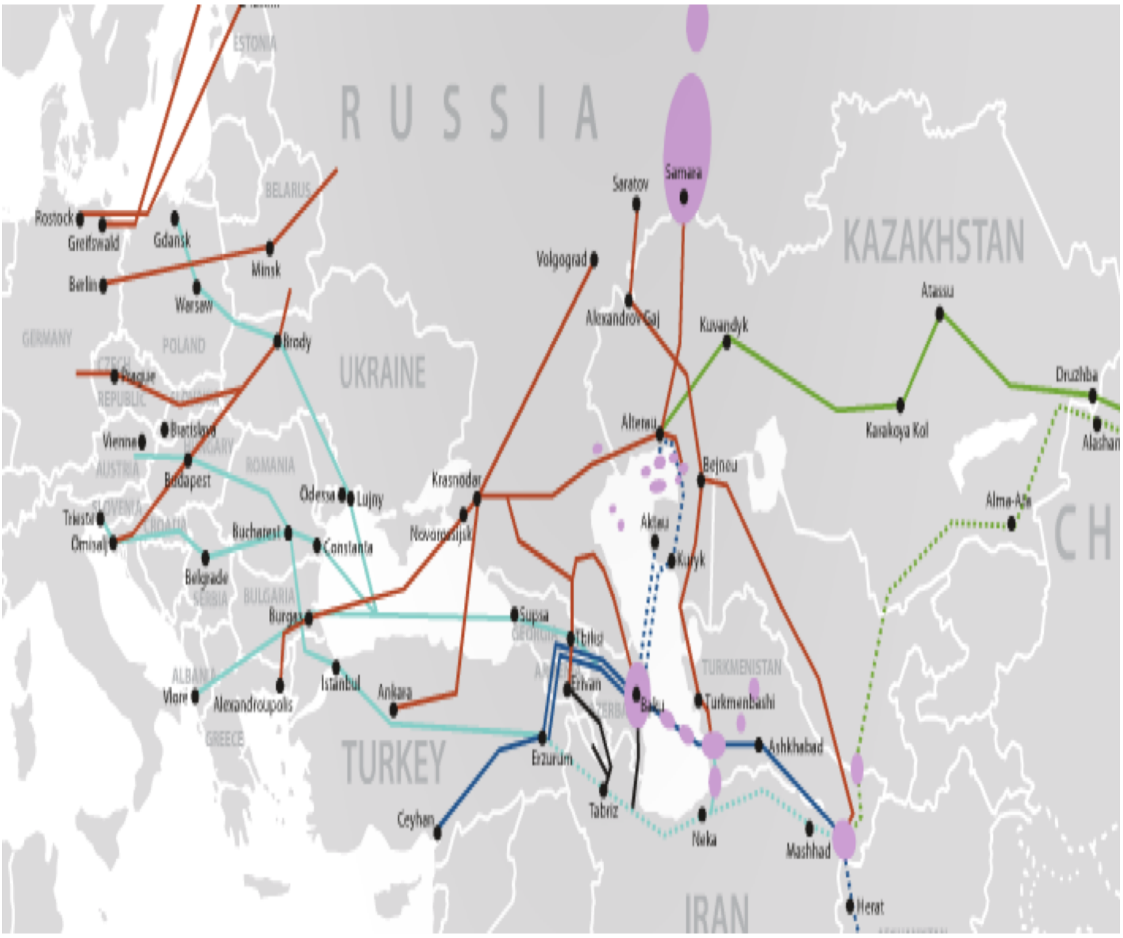
It can be interesting to know, to which extent institutions reflect on whether the values associated with large-scale renewable energy projects around the world are compatible with the values it defends on its territory. In the EU context, an example of a large-scale deployment of renewable energy is currently proposed by the DESERTEC-Atlas project, an initiative of the German Association of the Club of Rome ("DESERTEC Foundation - About," n.d.), or the Noor Ouarzazate Concentrated Solar Power Project of the World Bank (Mobarek, Sameh, 2016). When looking at the implementation plans of planned oil pipelines and planned solar energy transmission lines (figure 1, figure 2), it is clear that there is still room for reflection on the issue of scale.

On the other hand, efforts are ongoing to integrate the renewable wind energy network of the North sea (Gruenig, O'Donnell, 2016). Two examples of these are the North Seas Countries' Offshore Grid Initiative (NSCOGI) in which 10 north sea-countries collaborate to establish a common distribution grid and the Kriegers Flak project, a collaboration between Denmark, Sweden and Germany to establish a common 600 MW offshore wind grid. The NSCOGI project started with a Memorandum of Understanding in 2010 and is still in its development stage (ENTSO-E 2015) and the Kriegers Flak project is in the stage of asking funding from the European Investment Bank.

A balance should be sought on European level between energy use and supply, and the associated risk of conflicts, disturbing cultural values and reverting efforts being carried out to ensure prosperity around the world. The current Syrian war, a result of conflicts on scarce oil, might be replicated in the future in the Middle-East and Africa because of renewable energy conflicts if no answers are sought to the question of scale and territory (Figures 1 and 2). The future will determine whether the European societies will arrive to consciously assess the consequences of a consistent energy demand and balance it with potential security issues originating from foreign resource extraction, be it renewable or nonrenewable.

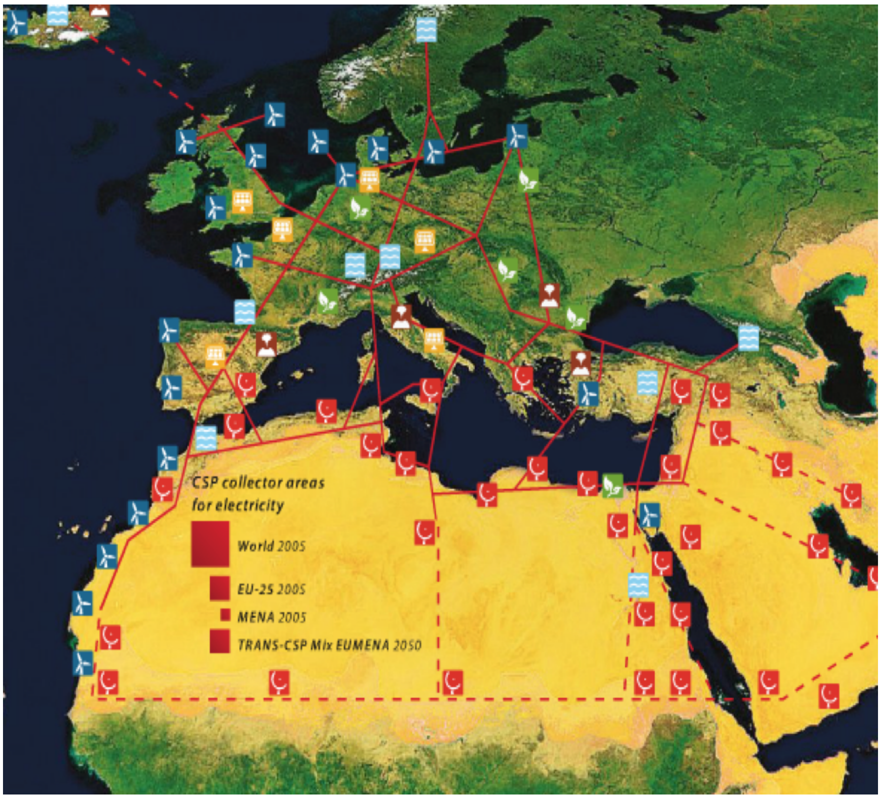
Social and geopolitical aspects discussed here, despite being very important, are not usually taken into account in macroeconomic energy-climate models. To ensure feasible modelling results, those aspects are to be discussed in the models' assumptions.

Figure 1: Planned oil pipelines in the Middle-East



Source: Desertec Foundation

Figure 2: renewable energy deployment around the equator (left)



Source: Desertec Foundation

Current macroeconomic energy-climate models

There are two main types of macroeconomic energy-climate models. The first type is represented by the models that link extensive energy and climate models but do not fully integrate them. The MESSAGE-MAGICC model used by the IPCC is an example of such models, where the energy module is connected to the climate model via its emissions part; the energy sector outcomes are used as an exogenous input for atmospheric GHG emissions change. Such models usually belong to the optimization class of models and seek for minimizing energy costs and atmospheric emissions. Another type of macroeconomic energy-climate models are integrated models, where the energy and climate sectors are connected and designed as interconnected parts of the same model's structure. Macroeconomic energy-climate models started being widely used after the year 2000. They aim at exploring energy scenarios where carbon emissions can reach the level corresponding to a 2°C atmospheric temperature increase, and where technological, resource availability and costs limitations are addressed.

Table 2 : Review of Macroeconomic Energy-Climate Models

Name of the model	*Methodology; Stand alone / Hybrid*	*Addressing resource limitations*	*Assumptions about RES*	*Addressing emissions*	*Timescale*
C-Roads (MIT)	System Dynamics Simulation model, stand alone	Only fossil fuel resources limitations are addressed	No resource limitations for RES, no connection to material requirements for RES. Renewable energy sources are seen as carbon neutral ones.	Emissions modelled as a stock. No feedback from climate change to energy resource availability.	1850-2100
MINICAM (Mini Climate Assessment Model) (Pacific Northwest National Laboratory)	Partial equilibrium model; Stand alone	Only fossil fuel and uranium resources and limitations are addressed	No resource limitations for RES. Renewable energy sources are seen as carbon neutral ones.	Emissions modelled as variables.	1990-2095
MARIA Model (Multiregional Approach for Resource and Industry Allocation)	Non-linear optimization model to assess the interrelationships among economy, energy, resources, land use and global climate change; Stand alone	Only fossil fuel resources limitations are addressed.	Renewable energy sources are seen as carbon neutral ones	Emissions modelled as variables.	1980-2060
Felix Model (Functional	System Dynamics	Only fossil fuel	Renewable energy	Climate sector and emissions	1900-2100

Enviro-economic Linkages Integrated neXus); IIASA	Model of social, economic, and environmental earth systems and their interdependencies; Stand alone	resources limitations are addressed.	sources are NOT seen as carbon neutral ones. There are CO2 emissions from RES.	in particular have the same structure as the C-ROADS Model.	
MESSAGE-MAGICC (Model for Energy Supply Energy Alternatives and Their General Environmental Impact - Model for the Assessment of Greenhouse Gas Induced Climate Change); IIASA	Hybrid model - Energy supply and energy service demand model connected to the probabilistic climate model	Only fossil fuel resources limitations are addressed.	Renewable energy sources are NOT seen as carbon neutral ones. There are carbon emissions from RES.	Climate is presented as a full-fledged model connected with the energy model via emissions part	1990-2400

None of the models analysed addresses the material resource limitations for renewable energy. Even though there are available studies addressing the problem of critical material need for renewable energy production (WWF report, 2014; Garcia-Olivares, 2011), their results are not reflected in the macroeconomic energy-climate models. Most of the models assume that renewable energy technologies are carbon neutral, and that there is no feedback from climate change effects to renewable energy resources availability. Addressing the limits of critical materials for renewable energy sources, as well as a feedback from climate change to renewable energy sources availability in energy-climate models, could help building more feasible renewable energy transition scenarios for the future and increase the accuracy of risk assessment associated with renewable energy use.

Modelling energy and climate scenarios in EU using GEM-E3 and PRIMES

A number of models used for analysing and simulating EU decarbonization pathways exist (Capros, 2014). Those models are used for informing better policy making and their modelling outputs serve as a guidance for EU policy documents. Considering the complexity policy making for the climate, it is important to be sure that such models produce feasible results and are based on realistic assumptions about economy, environment and energy systems.

GEM-E3 (Capros, 1997) and PRIMES (E3MLab, 2016) are two of the most widely used models for energy and climate change mitigation in the EU. Beyond this, together with the GAINS (Greenhouse Gas - Air Pollution Interactions and Synergies) model of the International Institute for Applied Systems Analysis (IIASA) it is possible to carry out an energy-economy-environment policy analysis in a closed-loop. The results of these models' simulations were used, in particular, for scenario analysis in the Energy Roadmap 2050 (2011) and for designing A Roadmap for Moving to a Competitive Low Carbon Economy in 2050 (2011).

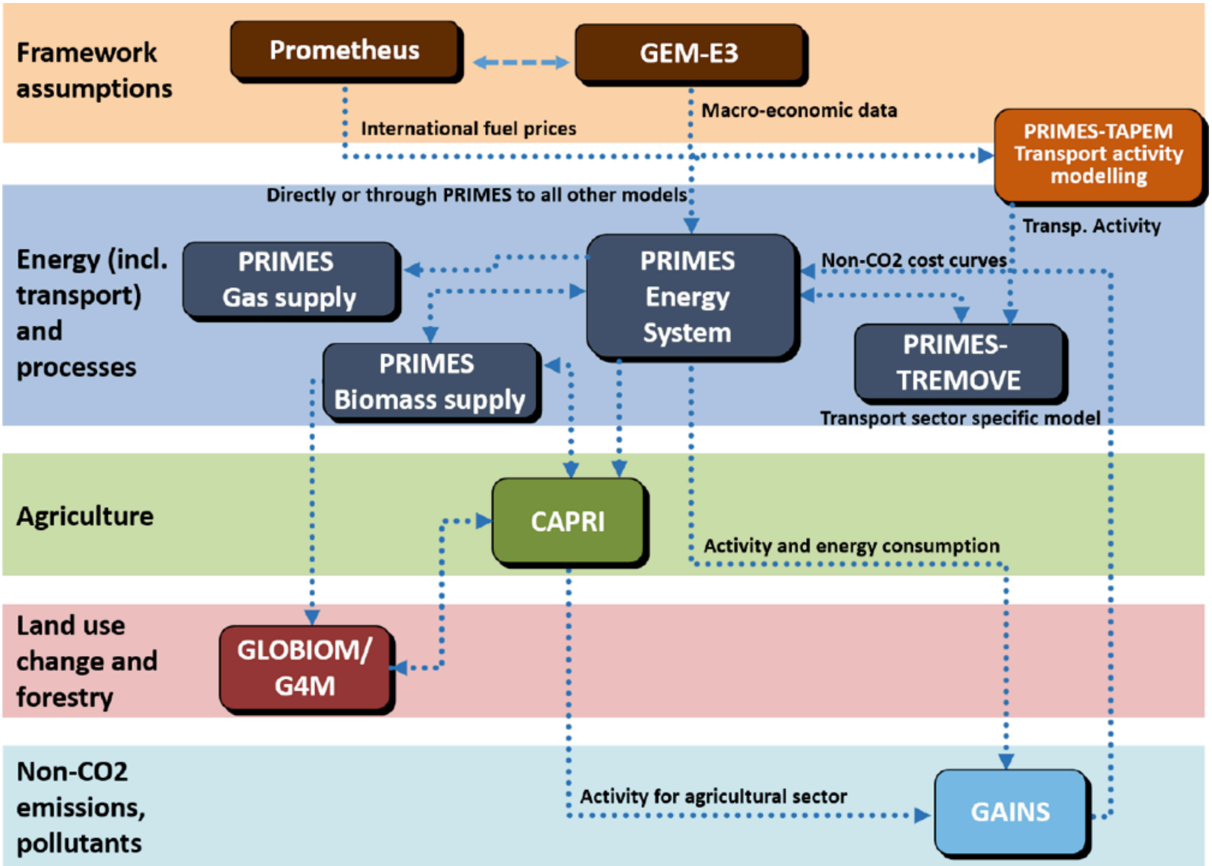
Originally GEM-E3 and PRIMES were designed as stand-alone models used for analysing the global economy and EU energy markets. For the purpose of addressing the needs for climate and energy policy making at the EU level these two models were coupled into the one hybrid structure. The intention of coupling the models aimed to support better climate and energy decisions via addressing limitations of both GEM-E3 and PRIMES (Capros,1996).

PRIMES is a partial equilibrium model which simulates equilibrium for energy supply and energy demand for all the EU member states until 2050. This model contains explicit and detailed information on energy technologies both on the supply and demand side. PRIMES is primarily directed to policy analysis in the field of security of energy supply, pricing policy, cost for climate mitigation, energy efficiency and standards on energy technologies (Capros, 2014).

GEM-E3 is a global scale multi-regional economic model which simultaneously represents 37 World regions including 24 European countries. It is a dynamic computable general equilibrium model that covers the interactions between the economy, the energy system and the environment. It provides quantitative results until 2050. Analysing global climate issues is one of the intended policy applications of GEM-E3. For this, GEM-E3 calculates and evaluates atmospheric emissions and their damage using cost-benefit analysis as the main approach for selecting the best energy and climate policy combinations.

GEM-E3 as a stand alone model cannot address technological aspects of different energy technologies which is important for assessing substitution possibilities and costs in production and consumption. At the same time PRIMES as a stand alone model lacks the interconnection between energy supply and demand and other economic sectors. Thus, GEM-E3 coupled with PRIMES performs energy-economy-environment policy analysis in a closed-loop computing energy prices in equilibrium and covering with engineering detail country-specific energy systems and the overall energy market in the EU.

Figure 3 : GEM-E3 and PRIME MODELS (2016)



Source: European Commission (2016, p. 16)

GEM-E3 and PRIMES are very oriented towards the price-driven equilibrium paradigm. They represent market clearing mechanisms and related behaviours of market agents as the main explanatory force in the models. Consequently, the assumptions of GEM-E3 and PRIMES mentioned in the models' documentation are mainly oriented at explaining market theories behind models' structures within existing technological limits.

Resulting scenarios from GEM-E3 and PRIMES simulations are focused on an energy technologies mix and a climate policy mix that would simultaneously minimize cost and atmospheric emissions. Thus, the main outputs from such scenarios are numerical parameters as energy efficiency, renewable energy sources penetration, percentage of nuclear power use, CCS deployment and transport electrification.

Since deployment of renewable energy is one of the central elements of climate and energy policy simulations, the models' assumptions of modelling renewables are of a high importance. Renewable energy technologies assumptions mentioned in PRIMES documentation allow to conclude that both nonrenewable and renewable energy technologies are modelled in a conventional way. This means that limits of resource availability are present only for fossil fuels, and none of renewable energies is associated with resource scarcities for harvesting. Feedback between climate change and renewable energy availability is also not present in the model structure. However, there are some limitations for renewable energy of a technological origin and availability present in PRIMES. They include the difficulties of getting access to resources, the availability of sites, acceptance, grid connection difficulties, and for biomass land and waste energy resource availability are considered.

Considering the arguments made in the first part of this paper, the absence of assumptions on resource limitations for harvesting some types of renewable energy and the absence of feedback between climate change and renewable energy availability can potentially lead to inaccurate modelling results, especially when it comes to long-term planning. Political aspects of energy resource availability associated with resource conflicts and additional cost could potentially have policy implications and demonstrate the need for trade-offs at both global and national levels.

Interestingly, there are studies and policy reports at the EU level, which analyse possible implications of material scarcity for harvesting renewables and potential economic and political risks associated with them. One of the elaborated reports of this kind is Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector (Moss, 2013). Integrating the findings of such reports with the assumptions of macroeconomic energy-climate models in the EU could bring new important policy insights and help better decision-making for mitigating climate change.

Conclusion

Making feasible projections on the possible impact of the employment of particular renewables to minimize effects on climate change is only possible if all factors influencing the development of renewables are treated in a heuristic way. Moreover, they should all be treated based on empirical gathered knowledge.

References

CAPROS P., PAROUSSOS L., FRAGKOS P., TSANI S., BOITIER B., WAGNER F., BOLLEN J. (2014), « Description of models and scenarios used to assess European decarbonisation pathways », *Energy Strategy Reviews*, *2*(3), p. 220-230.

CAPROS P. (1996), PRIMES and GEM-E3 Contribution to Climate Change Policy Debate. *Athens, National Technical University of Athens*.

CAPROS P.D, GEORGAKOPOULOS T., FILIPPOUPOLLITIS A., KOTSOMITI S., ATSAVES G., PROOST S., SCHMIDT T.F.N (1997). The GEM-E3 model : Reference manual. *National University of Athens, Athens*.

COMMISSIE EUROPESE (2011), A Roadmap for moving to a competitive low carbon economy in 2050, *Europese Commissie, Brussel*.

DESERTEC Foundation – About, (2016). Retrieved October 14, from http://www.desertec.org/about-desertec

E3MLAB (2016), The Primes Energy Syste Model Description, http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/The%20PRIMES%20MODEL%202016-7.pdf last accessed April 2017

EDENHOFER O., PICHS MADRUGA R., SOKONA Y. (2012), « Renewable Energy Sources and Climate Change Mitigation", *Special Report of the Intergovernmental Panel on Climate Change,* vol 6, p. 1 – 1088.

EUROPEAN PARLIAMENT (n.d.), How the European Union works - Activities of the institutions and bodies. https://doi.org/10.2775/20055

EUROPEAN COMMISSION (2016), *EU Reference Scenario 2016: Energy, transport and GHG emissions, trends for 2050,* Luxembourg, Publications Office of the European Union, 220 p.

GARCIA-OLIVARES A., BALLABRERA-POY J., GARCIA-LADONA E., TURIEL A. (2011). « A global renewable mix with proven technologies and common materials", *Energy Policy*, 41, p. 561–574.

GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE (2003), *World in Transition – Towards Sustainable Energy Systems*. Retrieved from http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/hauptgutachten/jg2003/wbgu_jg2003_engl.pdf

IIASA (2012), *Global Energy Assessment Toward a Sustainable Future*, 1884.

INTERNATIONAL ENERGY AGENCY (2014), *World Energy Outlook,* Paris.

MEADOWS D.H, MEADOWS D.L, RANDERS J., BEHRENS W.W (1972), The Limits to Growth, 1st Edition, New York, Universe Books.

MOBAREK, SAMEH I. (2016), *Morocco - MA- Noor Ouarzazate Concentrated Solar*

Power Project : P131256 - Implementation Status Results Report : Sequence 03 (No. ISR23914) (p. 1–0). The World Bank. Retrieved from http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP//

MOSS R.L, TZIMAS E., WILLIS P., ARENDORF J., THOMPSON P., CHAPMAN A., TERCERO-ESPINOZA L. (2013), « Critical metals in the path towards the decarbonisation of the EU energy sector », *Assessing rare metals as supply-chain bottlenecks in low-carbon energy technologies. JRC Report EUR*, *25994*.

ROADMAP ENERGY (2011), 2050. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Brussels*, *15*, 12.

ROTMANS J., VAN ASSELT M. (1999), "Integrated Assessment Modelling " In *Climate Change : An Integrated Perspective, edited by Pim Martens, Jan Rotmans, Darco Jansen, and Koos Vrieze,* p. 239–75. *Dordrecht: Springer Netherlands.*

SCHAEFFER R. and Al. (2012) "Energy Sector Vulnerability to Climate Change : A Review", *Energy*, vol 38, n° 1, p. 1–12.

STEFFEN W., SANDERSON A., TYSON P., JAGER J., MATSON P., MOORE III B., VERA I., LANGOIS L. (2007), "Energy indicators for sustainable development", WASSON R.J. (2005). *Global Change and the Earth System*. Berlin Heidelberg New York: Springer.

WWF (2014), *Critical materials for the transition to a 100 % sustainable energy future contents.*

Analyzing Symbiotic Relationships in Sustainable Cities - A framework

Patricia COELHO, Manuel E. MORALES, Arnaud DIEMER

Université Clermont Auvergne, France, OR2D, CONACYT, CERDI

The development of the green, ecological city or eco-city has been introduced as a means to support sustainable urban development within a social, economic, environmental and demographic context (Tsolakis, Anthopoulos, 2015). The eco-city concept was introduced by Urban Ecology, a non-profit organization founded in 1975 by Richard Register (Roseland, 1997). An eco-city ensures the well-being of its citizens via a holistic urban planning and management approach, with the aim of eliminating waste and emissions (Register, 1987). From a systemic point of view, an eco-city can be described as a set of different complex subsystems that need to be associated or reconnected in order to deliver the desired outcomes (Diemer, Morales, 2016).

In the 1990s, the term "sustainable city" replaced that of "ecological city" in response to the creation of the ICLEI (International Center of Local Environmental Initiatives) in 1990, the European Commission's so-called *Green Book* on urban environment (1990) and the Rio Conference (1992). The ICLEI was established at the World Congress of Local Governments for a Sustainable Future at the United Nations in New York. Its mission was to build and serve a worldwide movement of local governments to achieve tangible improvements in global sustainability, with a special focus on improving environmental conditions through cumulative local actions (200 local governments from 43 countries were involved). The European Commission's *Green Book* on the Urban Environment was published in June 1990… Chapter 1 focused on the future of the urban environment, Chapter 2 was titled « Towards a Community Strategy for the Urban Environment ». Dealing with the problems of the urban environment, the report addressed not just the proximate causes of environmental degradation but *examined "the social and economic choices? which are the real roots of the problems* » (1990, p. 1). Chapter 7: « Promoting Sustainable Human Settlement Development » of the Agenda 21, states that *« individual cities should participate in international city network to exchange experiences and mobilize national and international technical and financial support ».*

Emelianoff and Theys (2001) argue that the sustainable city operates a triple fracture with the ecological city: (1) Environmental concerns are no longer separated from the urban projects of economic, social or cultural policies of cities; (2) The willingness to evaluate the consequences of urban development at the global level or very long term ; (3) The city becomes a human and social environment (and not an anti-urban ecological vision). In fact, sustainable cities face the same major challenges as urban population growth in developing countries (migrations, movements from rural areas, births); aging populations in developed countries (aging populations will interact with younger populations); environmental changes including climate, vulnerability to infectious diseases, limitations in resources such as water, energy and food; governance (when a city outgrows political boundaries, its government loses the capacity to solve the problems residents face, governance starts to be shared between new entities, civil society can get more involved…).

Such challenges explain why the European Commission has recently increased its focus on urban issues and sustainable cities as a response to the fact that by 2020 it is estimated that almost 80% of EU citizens will be living in cities. The overall objective is to enhance the sustainability of EU cities by 2050 all Europeans are "*living well, within the limits of the planet*".

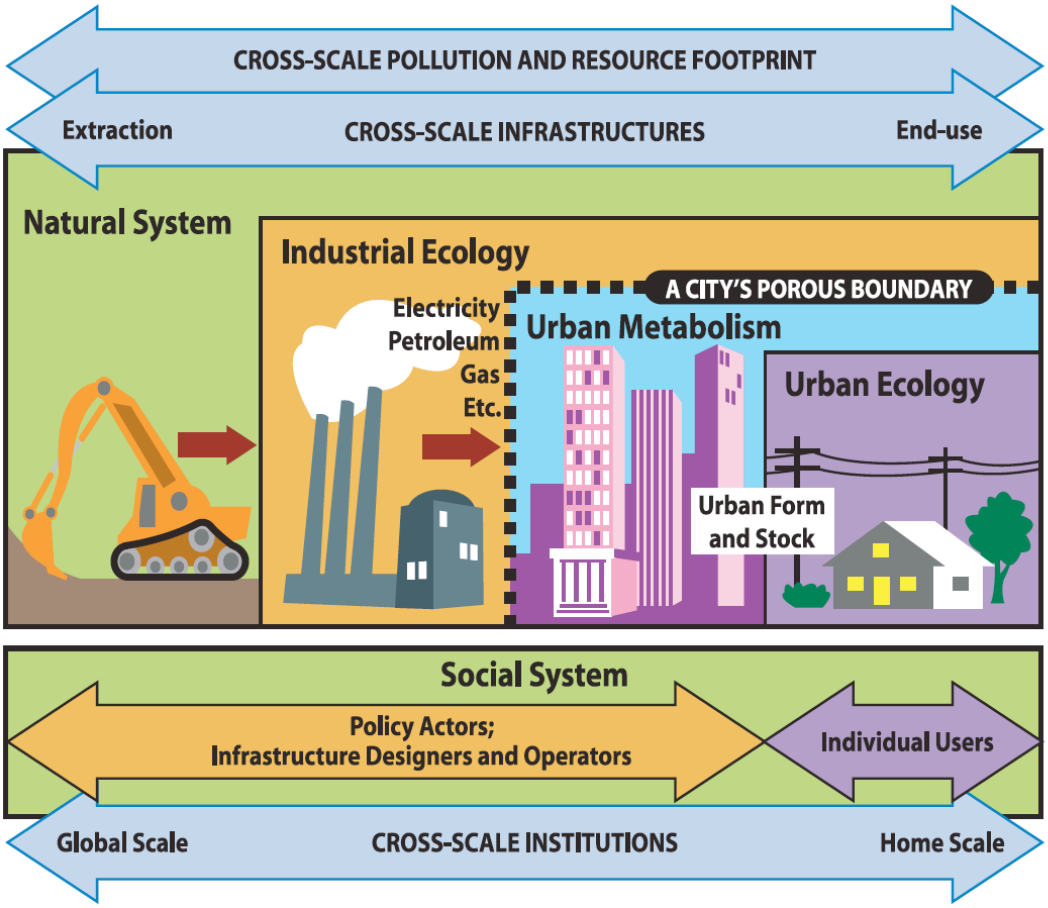
This paper offers various investigations to understand how a city becomes a sustainable city. We make the following hypothesis: a city becomes more and more sustainable as it becomes more and more able to develop and improve symbiotic relationships. In nature, a symbiotic relationship is defined as any relationship between different species where both species benefit. Thus, a symbiotic city has "*mutually beneficial relationships with its macro and micro ecosystems. It produces ecosystem services that are equal or greater than its net use of those services. The transition to a symbiotic city requires a cultural and economic recognition that we are embedded in and dependent upon our ecosystems. A symbiotic city enhances the natural environment, sustainable economic activity and quality of life*" (2012, Future Proofing Cities Working Group, July, 2012). To challenge this idea, we attempt to understand the complexity of symbiotic relationships from an interdisciplinary perspective. We then propose methods and materials (system dynamics, material flow analysis, circles of sustainability) to improve our model. Finally, we present some examples of sustainable European cities and discuss the challenges and prospects of that social innovation.

From different ecology perspectives to symbiosis: an interdisciplinary approach

It is relevant for society to understand the complexity of symbiosis from an interdisciplinary perspective (Ramaswani, Weible, Alii, 2012) to get a broader understanding of ecosystems (natural or manmade) and recognize why the symbiotic relationship is advantageous in comparison with other models available in an ecosystem (competitive, neutral or collaborative) in seeking for prospective sustainable objectives.

Over the past three decades, cities have increasingly sought to become more sustainable and to reduce their ecological footprint (Rees, 1992). It has become urgent to reduce pollution, to organize urbanization, to offer sustainable public transportation, to preserve scarce resources, and to take account of the consequences of climate change. This revolution is ecological and social (Rasmawami, Chavez, Chertow, 2012). The path toward sustainability requires a change in attitudes and new perspectives for the future. Because cities are concerned by materials, energy and human flows and stocks… the first step in this ecological and social revolution (Rasmawami, Chavez, Chertow, 2012) is to present a broad vision of sustainability (social-ecological-infrastructural systems), that takes into account the industrial character of modern societies, the social impact of development, the strength of multiculturalism and the need for a genuine political will for change (Figure 1).

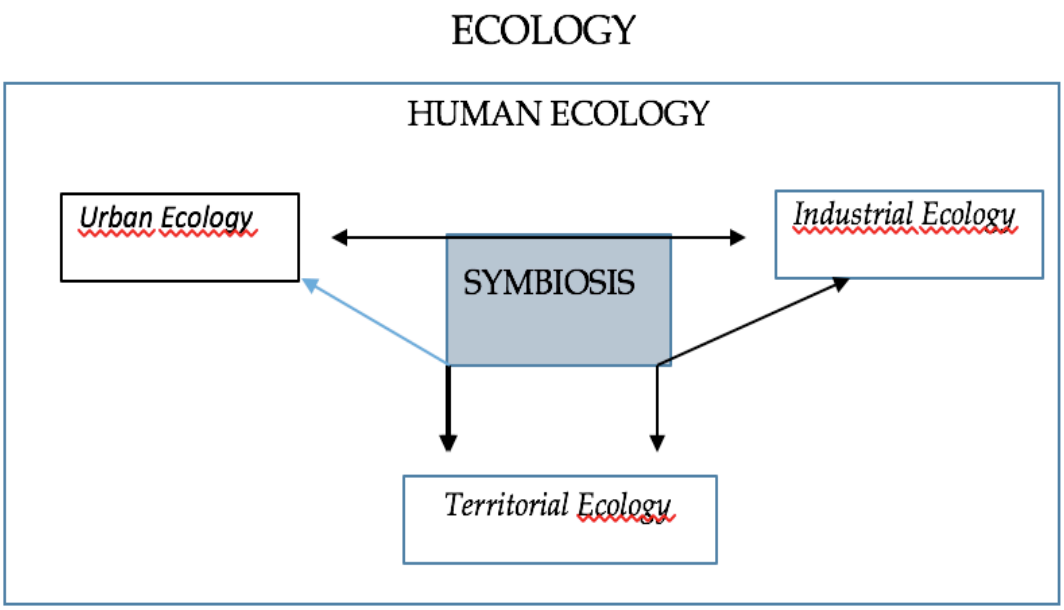
Figure 1 : Illustration of socio-ecological-infrastructural systems



Source : Ramaswami (2012, p. 803)

In what follows, we analyze symbiotic relationships in the cities in a framework that uses the following key frameworks Figure 2): industrial ecology, urban ecology and territorial ecology.

Figure 2 : Different frameworks on human ecosystem symbiosis



So

Source : Ribeyre, Gombert-Courvoisier, Sennes (2015) modified

Industrial Ecology

Industrial ecology came into being as a combination of academic and business ideas (Chertow, 2007) that argue that environmental constraints require new ways of thinking about industrial production (Frosch, Gallopoulos, 1989) highlighting the need to "mimic" in production facilities the operation of ecosystems in nature that generate no wastes because of intricate channels for reusing residuals (Duchina, Hertwich, 2003). According to Ehrenfeld (2000, 2010), natural ecosystems offer the only worldly example available to human beings' robust, resilient living system, the characteristics of which are complete models of the radical idea of sustainability. Our own human history offers no similar source for such pragmatically distinct thinking. Three collective features of stable ecosystems appear very important: connectedness, community and cooperation.

Industrial ecology is relevant to social structure, on the one hand, taken as an interdisciplinary approach linking hard, social and applied sciences is an example of its relevant contribution to identifying the drivers of a strong sustainable development model in the industrial ecosystem (Diemer, Labrune, 2007). In a previous article, we associated strong sustainability with four pillars of industrial symbiosis: eco-efficiency, resilience, cooperation and proximity (Diemer, Morales, 2016a). The technology paradigm change seems to be the key driver needed for a transition from the current industrial system to a sustainable socioeconomic reality where the industrial system can thrive. This change in the technology paradigm should highlight the relevance of a social dimension of studies related with the geographers' approach to the territorial ecology perspective (Buclet, 2011). The identification of collaborative synergies between stakeholders is presented as a way of launching social cooperation in the industrial ecosystem and helps us to understand the limits of technology. In this sense, industrial ecology attempts to reduce the idealization of technology, turned on the social relevance of the actor's geographic proximity, the optimization of flow, collaborative and resilience, interests and motivations, and providing a key role to the local authorities (Diemer, Figuiere & Pradel, 2013).

To identify the field of industrial ecology it is necessary to understand the industrial symbiosis case study at Kalundborg, Denmark (Knight, 1990, Barnes, 1992). Traditionally, industrial symbiosis separates industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and/or by-products (Chertow, 2000). Symbiotic relationships were defined because of the low availability of groundwater and the need for a surface water source which, once identified, became a key part of the resource exchange network there (Chertow, 2007).

It is fundamental that a "dedicated systems integrator" that works like a bridge for the success of industrial ecology. This bridge could be social in nature - actors with an active role - or technical - skills and know-how - (Vernay, Mulder, 2015)

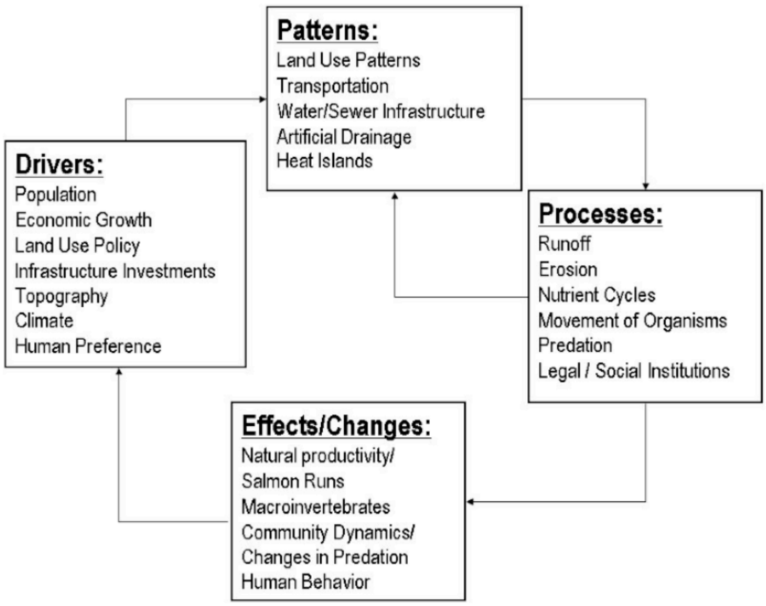
Urban Ecology

Urban ecology is the study of ecosytems that include people living in cities and urbanizing landscapes (Rebele, 1994). Urbanizing landscapes refer to environments dominated by high residential density and commercial buildings, paved surfaces, and other urban-related features that create a unique landscape dissimilar to most previously studied environments in the field of ecology (Mcintyre, Knowlees-Yanez, Hope, 2000). Urban ecology is an interdisciplinary field that aims to understand how human beings and ecological processes can coexist in human-dominated systems and helps societies with their efforts to become more sustainably. Urban ecology has deep roots in many disciplines including anthropology, climatology, ecology, economics, engineering, geography, landscape architecture, sociology, and urban planning… This is why Marzluff and al. (2000) have proposed three definitions of urban ecology as a field (Figure 3):

(1) Ecology and evolution of organisms that happen to live within city boundaries; (2) Biological, political, economic, and cultural ecology of Homo Sapiens in urban

settings; (3) Cities as emergent phenomena of coupled human and natural processes with implications for evolution and survival of our own and others species. This third view is associated with our research and allows "*various aspects of the human enterprise and nature to be seen as interacting forces that shape measurable patterns and processes*" (Marzluff and al., 2000, p. x). Thus, some key drivers cause patterns and processes that must be measured. These patterns and processes themselves affect the interactions between human and natural drivers by their effects and changes to the urban ecosystem.

Figure 3: Urban ecology, interactive forces between humans and nature



Source: Marzluff and al. (2000, p. x)

The final objective of this field is the understanding of human interactions and behaviors to fulfill human needs and improve the quality of life in an urban environment while considering the physical boundaries (Sukopp, 2000). To clarify this objective, it is important to remember that income and yield are not the only motivation of the construction of a social system; some factors such as work, entertainment, accommodation and mobility are also exceeded. In order to talk about quality of life and livability it is important to include concepts such as creativity, awareness, security, assessment, association and individual challenges that are important for every citizen of a city.

Urban ecology attempts to depict the social system structure of cities through an historical perspective to find optimal structures of social, human, biological and ecological needs satisfaction. From interdisciplinary and system dynamics, it proposes better solutions to specific and located problems, considering producers and consumers perspective, at the global and local scales (Ribeyre, Gombert-Courvoisier & Sennes, 2015).

Developing symbiosis between urban infrastructures implies that the operators of the infrastructures can align their interests (Mulder, 2016). Urban symbiosis is not a "*novelty conquering the world" but a rearrangement of actors in a specific local context*" (Vernay, Mulder, 2015).

Agreements between urban ecology, industrial ecology, family ecology and territorial ecology at the micro level are relevant for a better understanding of the social limits; furthermore, they help stakeholders to share responsibility in the process. While the micro level is comprised of physical balances for a growing number of materials and spatial units, the macro level is concerned with the formulation and evaluation of choices taken by decision makers. As in many other fields, there are substantial challenges in achieving conceptual and operational linkages between micro and macro levels. An attempt to bridge this gap takes the form of an intermediate (or meso) level of analysis represented by industrial symbiosis.

Territorial Ecology

It is difficult to separate territorial ecology from urban ecology and industrial ecology. The former is originated from the latter two, specifically the methodology of analyzing the metabolism of a territory. Human societies define their territories by interacting with their environment and other people in it. A territory is well thought of as "*a system of socio-ecological interactions*" (Buclet, 2015). Material and immaterial flows circulate within a territorial system. The socio-ecological interactions linked to the territorial system appear as dynamic interactions between self-organizing subsystems: the resource system, the user, the governance system and the infrastructure system. At the same time, territorial ecology can't be reduced to a spatial dimension; proximity focuses on the various forms of the relationship between the actors within the process of building a territory (organizational proximity and institutional proximity).

- Territorial ecology is based on analysis of territorial metabolism. The material flows analysis method applies to a territorial scale (Madelrieux, Buclet, Lescoat, Moraine, 2017). A European network has been created around two methodological guides. The principle addresses the fact that the flows come within this determined socio-ecological system and can be stored and/or pushed out, depending on the human activities which arise and communicate functional needs. These flows are mainly material flows: biomass, fossil fuels, minerals, metals, construction equipment, etc.

Table 1: Flows quantification

1. Inputs

• Local drivers

- Local extraction (used) materials, including oxygen consumed by combustion

- Unused local extraction

• Imports (from other regions and countries): raw materials, finished or semi-finished fuels

• Indirect flows associated with imports: samples taken outside a given territory? to allow imports (equivalent raw materials and unused extracted imported products)

2. Outputs

• Materials returned to nature:

- Air emissions (including water produced by combustion) and water, landfilled,

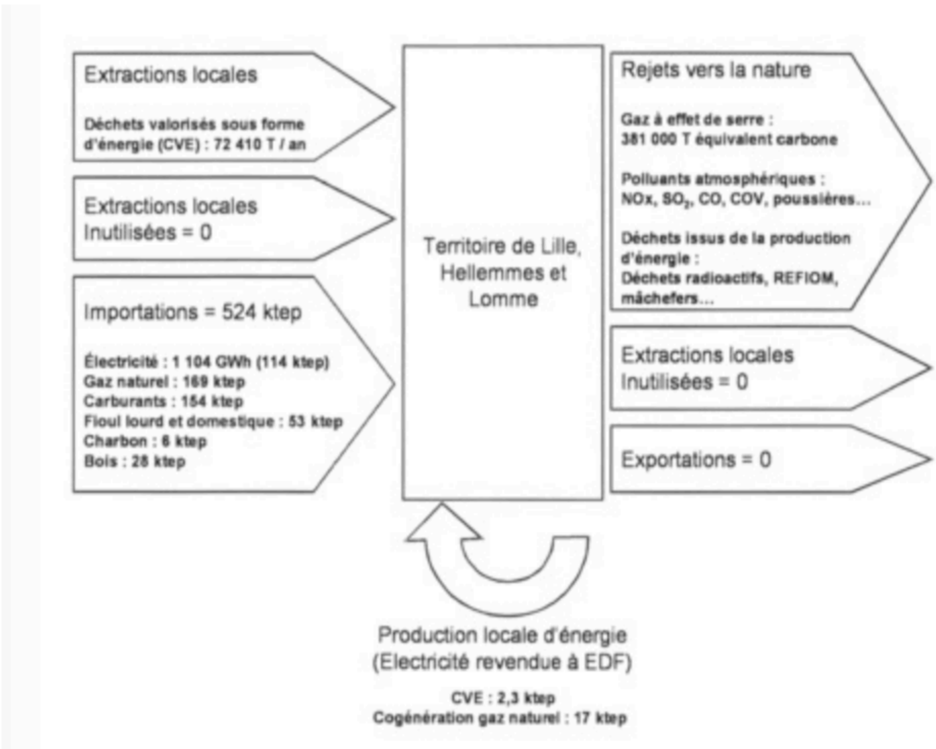
- Purposeful? and dissipative losses

• Unused local extraction

• Exports (to other regions or countries): raw materials, fuel, finished or semi-finished products, waste

• Indirect flows associated with exports: samples taken to allow exports (equivalent raw materials and unused extraction of exported products).

Figure 4: Energy accounting, city of Lille (France)



Source : Duret, Mat, Bonard, Dastrevigne, Lafragette (2007, p. 76)

Works on territorial metabolism make it possible to understand the first material flows image mobilized by a system at the macro level (type of flow, volume, structure) and therefore to characterize a territory according to these flows. The area and supply chain distances method is about defining the optimal areas from which some flows (energy, food, water) for a territory should be supplied. This method aims to characterize and measure the interdependence of a group of linked territories and identify the supply chains of a given area.

- The territorial approach invites us to consider the two essential dimensions of the implementation of an industrial ecology approach conceived as a collective action (Beaurain, Brullot, 2011) : (i) the dissemination among the actors of a set of common values which constitute the necessary conditions for coordination actors in the form of constraint and potential; (ii) the increase in interactions between firms, and between firms and other actors in the territory, reflecting the existence of collective action. These two dimensions raise the question of the nature of the project of shared territory and the mode of coordination between the actors. Thus, proximity may introduce a new corpus into industrial ecology Hence, Nicolas Buclet prefers to use the terms "*industrial and territorial ecology*") and become a new pillar of strong sustainability.

Identified urban symbiosis methodologies

Assessment of sustainable cities involves combining the result of several approaches of research. In what follows, we will refer to three approaches: (1) system dynamics developed in the 1960's by J.J Forrester (urban dynamics); (2) sustainable urban metabolism perceived as an ecosystem (mainly material and energy flow analysis and input-output assessments) and (3) the circles of sustainability approach from James (2015).

From System Dynamics to Urban Dynamics

Since the publication of *Industrial Dynamics* (Forrester, 1961), *Urban Dynamics* (Forrester, 1969), *World Dynamics* (Forrester, 1971) and The *Limits to Growth* (Meadows, 1972), there has been a long tradition of using system dynamics to study public management questions. System dynamics models cover a wide range of areas in public affairs including public health (Thomson, 2007, 2008), energy and environment (Sterman, 2008), social welfare (Zagonel, 2004), sustainable development (Mashayekhi, 1998), education (Andersen, 1990), security (Weaver and Richardson, 2006) and many other related areas. System dynamics is a form of computer simulation modeling which uses the concepts of information feedback and state variables to model social systems and to explore the link between system structure and time-evolutionary behavior (Forrester, 1968). To model the dynamic behavior of a system, Forrester (1969, p. 12) proposes recognizing four hierarchies of structure: (1) closed boundary around the system; (2) feedback loops as the basic structural elements within the boundary; (3) Level (state) variables representing accumulations within the feedback loops; (4) Rate (flow) variables representing activity within the feedback loops.

Closed System boundary: To develop a complete concept of a system, the boundary must be established within which the system interactions that give the system its characteristic behavior take place. Forrester states that "*the closed boundary does not mean that the system is unaffected by outside occurrences. But it does say that those outside occurrences can be viewed as random happenings that impinge on the system and do not themselves give the system its intrinsic growth and stability characteristics*" (ibid).

Feedback loop structure: The dynamic behavior of systems is generated within feedback loops. A feedback loop is composed of two kinds of variables, called rate and level variables. A feedback loop is a structure[1] within which a decision point – the rate equation – controls a flow or action stream. The action is integrated to generate a system level. Information about the level is the basis on which the flow rate is controlled.

The aim of system dynamics modeling is to explain behavior by providing a causal theory, and then to use that theory as the basis for designing intervention policies into the system's structure, which then attempts to change the subsequent behavior and improve performance (Lane, 2008). Each system dynamics study starts with a problematic situation and a set of assumptions that is used to describe the problematic situation. These assumptions are taken to be held in a Mental Model of a Dynamic System (MMDS).

Each causal link in a model has a polarity, the direction of effect that the influencing variable has on the influenced variable. The nature of that influence depends on the type of causal link being considered. In a system dynamics model, the polarity of each feedback loop is a crucial part of understanding the model behavior. The perturbation of a loop may result in the magnification of the original effect; this unstable response is known as a positive feedback loop polarity. Alternatively, a perturbation may be counter-acted, or resisted by the operation of the loop. This equilibrating response is known as a negative feedback loop polarity.

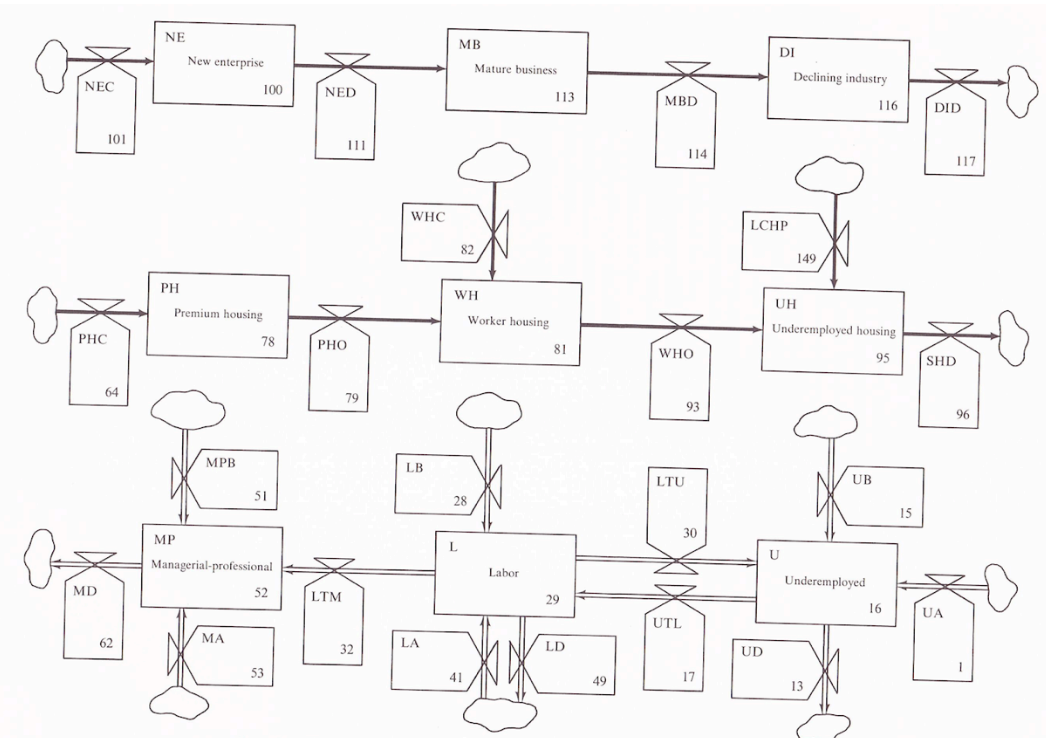
[1] "*The most important concept in establishing the structure of a system is the idea that all actions take place within feedback loops. The feedback loop is the closed path that connects an action to its effect in the surrounding conditions, and these resulting conditions in turn come back as "information" to influence further action. We often erroneously think of cause and effect as flowing in only one direction. We speak of action A causing result B. But such a perception is incomplete. Result B represents a new condition of the system that changes the future influences that affect action at A*" (1971, p. 17).

- *Role of simulation*: the interaction of these complicated relationships is almost always beyond the capability of the human mind to infer - as mental simulation is deficient. Computer simulation is therefore rigorously needed to deduce the consequences of these relationships and to reveal the counter-intuitive behavior that results from the assumptions in the model.

-*Diagramming methods*: Two diagramming methods are dominant in the system dynamics community. Broad representations of the variables and the feedback structure of a model are conveyed using Causal Loop Diagrams (CLD). In contrast, stock/flow diagrams (SFD) are more detailed, discriminating between both state and flow variables.

In *Urban Dynamics*, Forrester (1969) presents a computer simulation model of how a city first grows, then stagnates and finally decays (Figure 5). The model[2] contains the major components of the city: three classes of population (the under-employed, labor and management), three types of housing (one for each of the population classes) and three types of industry (new, mature and declining). The changes over time of each of these drivers are controlled by one or more of the 22 rate variables, which are functions of behavior characteristics, exogenously set policies, and the drivers. This is what produces people's perception of a city.

Figure 5: Structure of urban model



Source: Forrester (1969, p. 16)

[2] In fact, there are two models. One, a growth model, generates the life cycle of an urban area from its founding through growth to its arrival at a state of stagnation and decay after a period of 250 years. The other begins with the resulting depressed conditions and is used to examine various policies that would alter the conditions of the urban area over the next 50 years.

Urban Dynamics shows how urban problems such as housing shortages or unemployment are generated by internal forces and cannot be solved by attacking external symptoms. Forrester's main endeavor is the development of a tool to be used by urban policy makers.

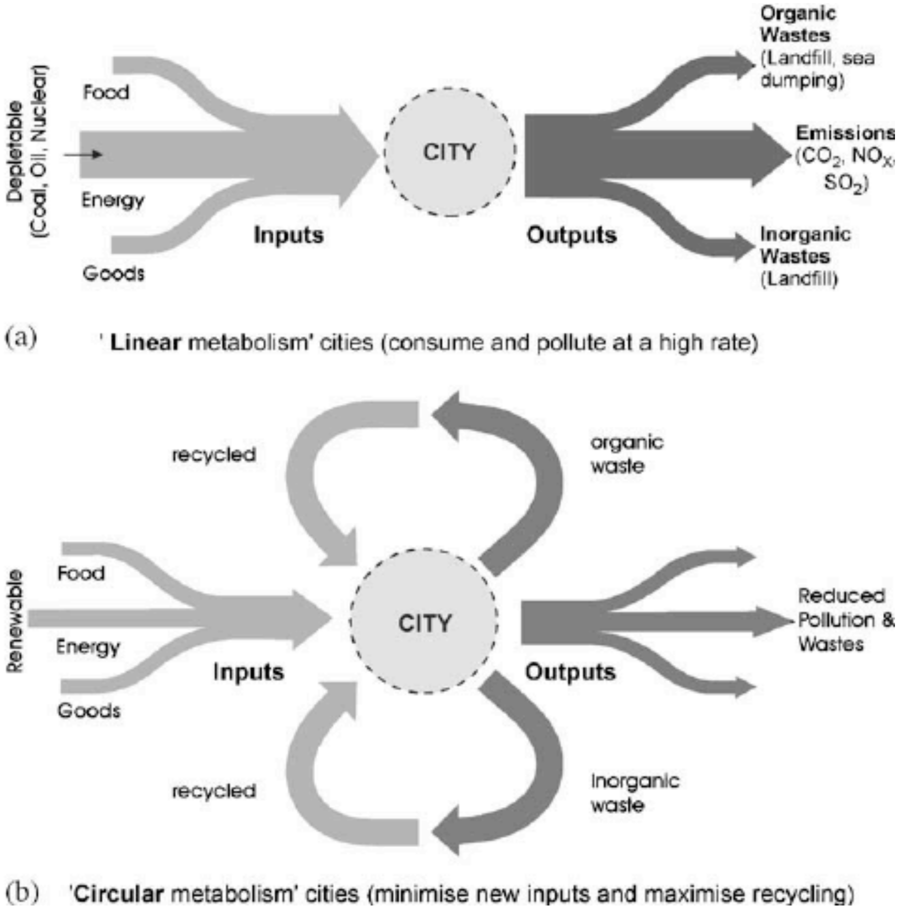
Material and Energy Flow Analysis (MEFA)

One of the underlying principles of urban metabolism is mass conservation finding ways in which to transform industrial activity from what is largely a non-sustainable system into a system that resembles more and more closely a sustainable system. "*Material and Energy Flow Analysis*" (MEFA) is the study of material and energy accounting by identifying and quantifying material and energy usages and assessing their impacts on the environment. It also aims to implement opportunities to effect environmental improvements (Graedel & Allenby, 1995). The material and energy flow (Figure 6): inputs and outputs of a city or territory are the basic features for establishing a material flow balance. Thus, it is necessary to identify the stocks and potential advantages from its operation. This metabolic level is taking into account "the required and harmful" consumption (e.g., the inevitable household expenditure) such as heat, electricity and food, considering that there is a correlation between needs and resources in order to develop the local production of these products with the corresponding benefits, in terms of local economy, employment, greenhouse gas reduction, etc. The metabolism process will gradually shift to zero waste, positive energy, and a closed water cycle.

The first and most important output of MEFA methodology is without a doubt (1) the global and interconnected dimension it puts forward the urban ecosystems theory, supplying relevant data that could be qualitative and quantitative to the decision-making process at the economic and political levels. Secondly, (2) the contribution made to the input-output theory is also important. This includes the global analysis of other sub-systems that are outside the main system but are closely linked with the system's activity working out as suppliers or consumers. The third feature is radical understanding as an alternative revolution of the broadly developed social productive system that looks for improved efficiency in the social systems based on an alternative socio-economic framework able to drive the market structure far across restricted technologically based solutions.

Urban ecology is achieving a strong sustainable approach, challenging us to think about the evolution of structures in cities. This evolution is considering relevant insights as different organization patterns that are not necessarily new. If we take a look back in history at the collaborative/cooperative social structures, for example, the kind of structure used in the past but adapted in a current social system structure could help to make the bridge between long-term political goals and short-term profits (Metereau & Figuière, 2015).

Figure 6: The metabolism of cities: towards sustainability



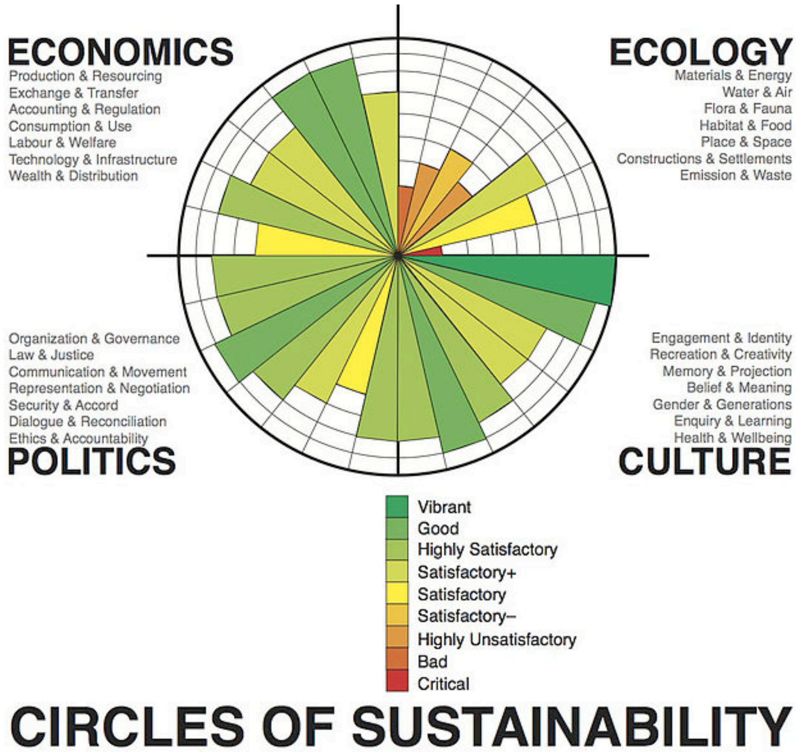
Source: Doughty & Hammond, 2004 (adapted from Girardet [3,4] and Rogers [6])

Circles of Sustainability approach

The *Circles of Sustainability* approach proposes a "*redefinition of sustainability, intersecting with other social conditions, such as resilience, liveability, adaptation, innovation and reconciliation as basic conditions of positive social life*" (James, 2015, p. XIV). This approach takes the positive intention of the "three pillars" phrase and for the first time locates that well-intentioned spirit in an integrated and generalizing framework. Circles of sustainability are intended to be flexible, modular and systematic (Figure 7). The *Circles of Sustainability approach* provides a relatively simple view of the sustainability of a particular city, urban settlement, or region. The circular figure is divided into four domains: ecology, economics, politics and culture. Each of these domains is divided into seven subdomains, with the names of each of these subdomains listed from top to bottom under each domain name. Assessment is conducted on a nine-point scale. The scale ranges from the first step: 'critical sustainability', to the ninth step: 'vibrant sustainability'.

When the figure is presented in color, it is based on a traffic-light color scheme with critical sustainability marked in red and vibrant sustainability marked in green. The center step, basic sustainability, is colored amber – with other steps ranging between amber and red or amber and green. The grey-scale used here is intended to simulate the color range.

Figure 7 : Circles of Sustainability



Source: James (2015)

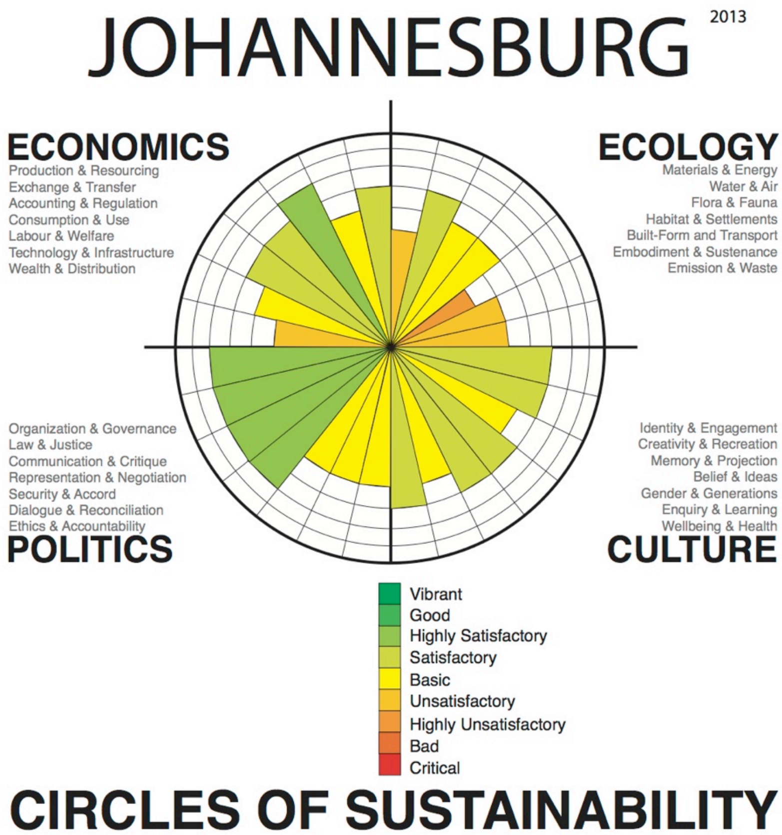
Each part of the approach has been developed so that it operates as a part of a toolbox for understanding different urban areas. More than an answer of specific issues, the Circles of Sustainability method needs to be considered in response to some fundamental social issues (wealth distribution in the city).

Sustainable cities – some examples

Many studies have been developed that consider one methodology as a framework. A relevant example is "*The Energy Consumers & Suppliers Model in Paris*" (Kim, 2015) that produces available data about the Paris's energy consumption patterns, the amount and trajectory of input and natural resources output flux. This MEFA assessment in a city is clear evidence that cities can be thought of as urban systems, and assessed with dynamic, multiscale and interconnected tools. At the same time, several cities are going beyond the analysis of urban metabolism and developing different types of environmental footprints that integrate in-boundary and trans-boundary water use, energy use, and greenhouse gases (GHGs) associated with production and consumption activities (Kennedy, Baker, Dhakal, Ramaswami, 2012).

Another good example can be illustrated with the Circles of Sustainability model. Figure 8 shows the Circles of Sustainability profile of Johannesburg, a city that began its massive development under the oppressive system of apartheid.

Figure 8: Johannesburg Circles of Sustainability



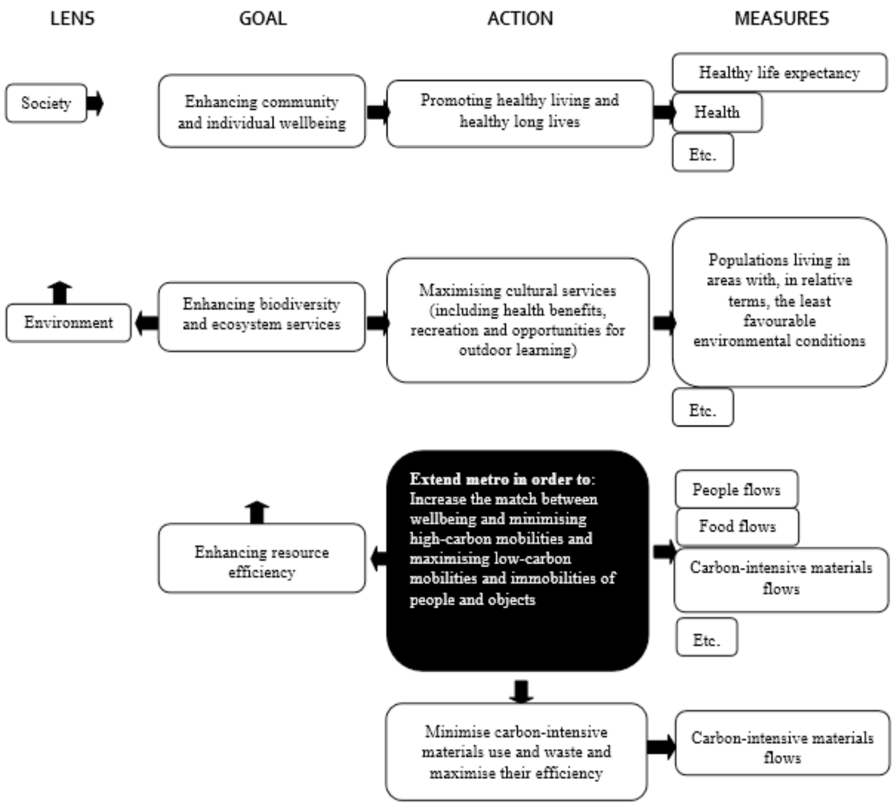
Source: James (2015)

In 1975 in Ponte City, a cylindrical skyscraper was built in the "whites' only" area of Hillbrow, making it the highest residential tower in Africa. In the same year, a freeway was completed connecting the south, including Soweto, to the city center and extending to Sandton, the wealthy northern commercial center of Johannesburg. All of these infrastructure developments became carriers of the post-apartheid spatial heritage of the city. Service jobs connected the poor south-west area and the wealthy north region. These jobs were available to those in the south who could bear the heavy peak travel times between the north and the south. Today, long after the end of apartheid and formal racially separated development, the prior configuration of stark spatial racial separation continues to confront the city. There are no walls dividing people, but the effect is no less tangible. This is the dual reality of the city. It is a metropolis with one of the highest levels of inequality in the world. Recently Johannesburg has launched a 'Growth and Development Strategy' with a long-term vision for 2040 to make "Johannesburg a world-class African city of the future — a vibrant, economically inclusive and multi-cultural African city; a city that provides real quality of life for all its citizens".

Urban methodology examples applied to sustainable cities

In order to move towards increased sustainability and liveability, it is first important to understand how cities function and how well they perform. The City Analysis Methodology (CAM) framework is an urban analysis framework for holistically measuring the performance of a city, demonstrating the need and defining the parameters for the design of city interventions (Figure 9). It is important to reiterate that the CAM is built upon international academic and practitioner literature and is practice-refined specifically for the UK (Leach et al., 2016).

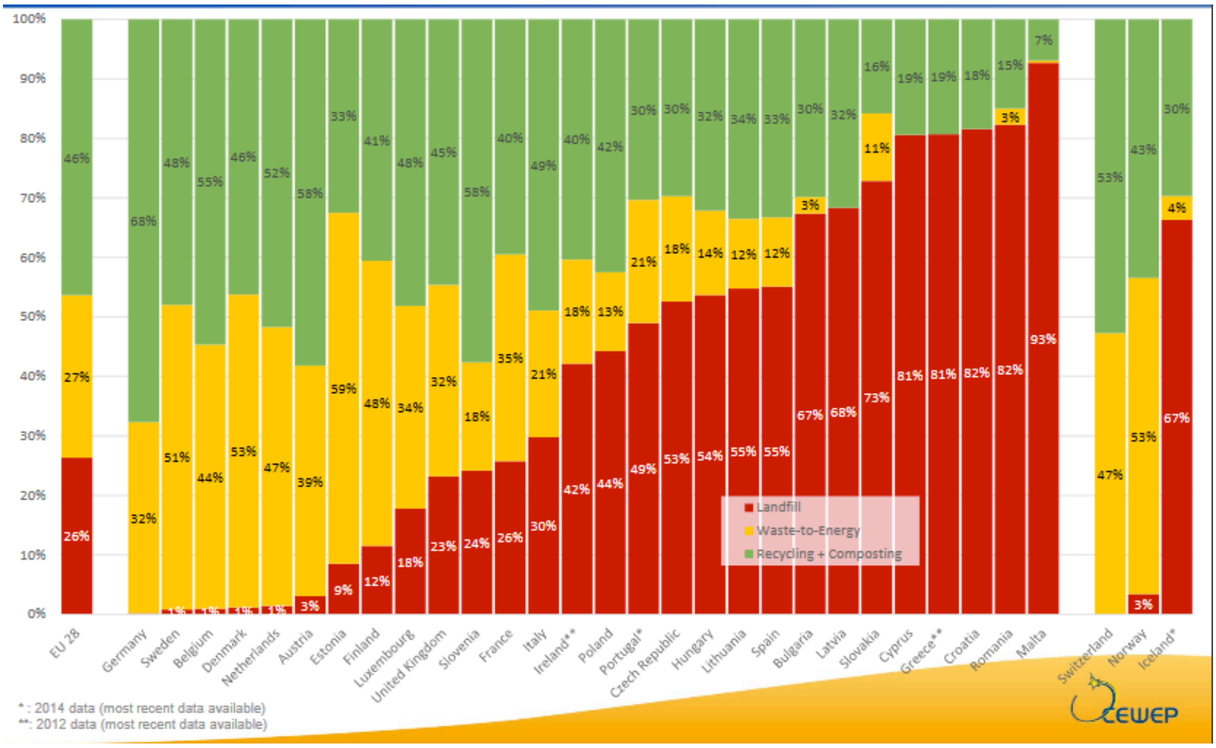
Figure 9: Interdependencies at CAM



Source: Leach et al. (2016)

Energy recovery from wastes is also an important option that should be expanded, together with material recycling and biological treatment, to support efforts in other cities to increase sustainability. The European cities that are the best urban places to live in have included waste-to-energy as one very significant method for their sustainable ways of managing wastes (Figure 10). All EU reports show that the countries which present the highest recycling rates are those that have a significant part of their waste incinerated with energy recovery. The following European cities have been identified as among the most sustainable: Vienna, Munich, Berlin, Greater Copenhagen, Malmo, Zurich, Amsterdam, Brescia, Barcelona, Mallorca; all of these cities recognized as the most sustainable use energy recovery from wastes and this is considered to be a major parameter of their achievements (Chaliki, P., Psomopoulos, C.S., Themelis, N. J., 2016).

Figure 10: Waste treatment in 2015, EU 28 + Switzerland, Norway and Iceland



Source: CEWEP, 2017.

In recent years, these cities remain among the best places to live in every ranking, or they have been included in the lists of the most sustainable cities in the world. They have reduced their carbon footprint (Ramaswami, Chavez, Chertow, 2012) and have been leaders in adopting the most advanced and sustainable solutions to improve their citizens' lives and continue to do so (Chaliki, P., Psomopoulos, C.S., Themelis, N. J., 2016). Thus, the awareness of environmental quality can be regarded as a civic value and a way to induce proactive policies leading to the implementation of alternative systems of consumption and production (Mega, 1996).

Discussion

As a matter of fact, it is the economic, social and environmental dimensions, all interconnected in a system dynamic approach, that could allow industrial ecology to dig deep into ideological structures. The understanding and sharing of ideological structures could reconnect sub-ecosystems in sustainable cities: considering symbiosis as one key of a sustainable urban ecosystem and building a new sustainable development model. At the same time, social understanding will drive society to use a shared language which might be impossible without exploring the relevance of political, cultural, ecological and economic dimensions (Metereau & Figuière, 2015).

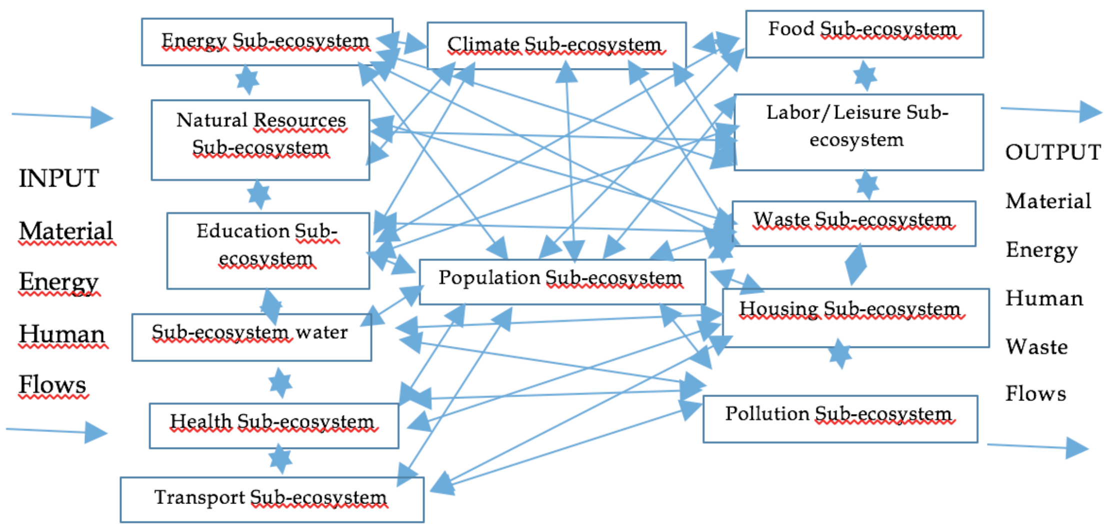
Table 2 shows that symbiotic relationship is advantageous in comparison with other different categories in a multidimensional perspective of an urban ecosystem. It generates: (1) the smallest ecological footprint, waste to energy conversion, and the lowest quantity of pollution in the environmental dimension; (2) land efficiency and blooming employment conditions in the social dimension and finally; (3) thriving flow material and energy mobility, decreasing the quantity of low materials needed in the economic dimension, all of them merged with social values and paradigm revolution and relevant proposals of shifting the mainstream system of thinking based on values such as resilience, cooperation and proximity.

Table 2: Multidimensional urban symbiosis concentric advantages

DIMENSION	ASSUMPTIONS	OBJECTIVES
Environmental	Urban Metabolism	Resilience
		Smallest ecological footprint
		Waste to energy conversion
		Lowest quantity of pollution
Social	Proximity	Resilience and social values
		Land efficiency
		Blooming employment conditions
Economic	Cooperation	Resilience and paradigms revolution
		Thriving flow material and energy mobility
		Decreasing quantity of raw materials needed

Cities that act in the short-term are trying to solve the problems they find in day to day planning and, in the best of cases, over the four to six years period that a democratically elected office allows. Like the industrial system, cities use to apply "end of pipe" solutions based on technology efficiency, they try to solve problems with short-term and short-sighted solutions. However, supplying limited resources to an exponentially growing population is completely unsustainable over the long run. The production process as we know it today is a problem in itself so we need to think about *closing loops in water, energy, material, infrastructure and non-material resources (organization, communication, mobility, know-how, technology, etc.), sustainably in* order to reduce the amount of inputs that cities require to supply their production processes. We also need to think about dematerialization, decarbonization and boosting the service economy in cities, reducing consumption among new urban structures. This process is called urban symbiosis and is illustrated below in Figure 11.

Figure 11: Urban sub-ecosystems -- understanding sustainable cities



Source : Diemer, Morales (2016)

This potential urban symbiosis must not be associated to an ideal type or perfect model - it's more one type of relationship in the ecosystem. Thus, to imagine a sustainable city we need to go beyond input and output flows (the study of metabolism) to reconnect sub-ecosystems. In fact, we do not have to create the conditions for a symbiotic relationship as these conditions exist, as well as the conditions for other types of relationships as (competitive, neutral or cooperative). We only need to reconnect the links between the sub-systems. We have identified 13 different interconnected sub-ecosystems that operate in different types of ecological relationships: energy, climate, population, health, natural resources, food, education, labor/leisure, pollution, transport, wastes, water and habitat. It's possible to identify drivers, actors and variables among the subsystems and to improve the synergies between the urban ecological subsystems. This approach studies the interactions between the different sub-ecosystems and the possibilities for fostering symbiotic relationships (symbiotic relationships are there we just need to make them visible).

Boundaries

(1) There is no difference between public and private investment

(2) The technology effect is incorporated as an external driver assumed having regular increased effects in the system.

(3) The market and the consequences of price changes on supply and demand consideration, this is assumed to be an external driver in the diagrams.

Comments

(1) Education is also considered as goods, services, energy and transportation consumption habits

(2) Resources refers to natural resources input

(3) Security is understood as medical care access.

(4) Storage in the Transport/Storage subsystem also includes parking lots and tourism accommodation.

(5) Population in the education subsystem could also be understood as family planning

(6) Public area is defined as common spaces and infrastructure for citizens (parks, hospitals, libraries, streets, ports, airports, schools, service business, etc.)

(7) Private area is designated as the places with restricted access in the city as houses, offices, industrial companies, etc.

Cities are currently spaces for the most consequential attempts at human adaptation and sustainability. The field of urban ecology is relevant, in 2014, 54% of the world's population was living in cities. Today, developed nations are about 74 percent urban, while 44 percent of residents of developing countries live in urban areas, and these numbers are rapidly growing, according to the United Nations, (United Nations, 2014). This is why cities are considered as perfect laboratories for urban symbiosis *experiments*.

Some of the barriers to urban symbiosis identified might require developing improved technology or removing institutional barriers and even of a long-term strategy in order to cope with some "locked in" infrastructures (Mulder, 2016).

Industrial symbiosis dynamics can be helpful to learn more about the emergence of interrelations. Over the last 15 years, the phenomenon of business co-location known as industrial symbiosis and discussed in the paper *"uncovering" Industrial Symbiosis* of Chertow (2007), has generated much debate and raised some questions. The tendency is to steer public and private actors to choose projects with demonstrable kernels of self-organization that can emerge more fully as viable industrial ecosystems. Industrial symbiosis' studies corroborate that "eco-industrial" projects that involve significant material and energy exchanges, have rarely come to fruition in a sustainable way. Despite the potential to create highly structured industrial processes, the literature suggests not interfering in the natural evolution of companies or supporting through public or private investment projects that have much wishful thinking but no tangible kernels or preconditions[3] for an industrial symbiotic ecosystem.

This evidence source underlines the importance of market testing to the potential recognition of industrial symbiosis in describing how different motivating forces, including the availability of specialized skills, the role of existing suppliers, scarcity conditions, and availability of natural resources, as well as chance, are involved in the success of an emerging symbiosis. However, it is important not to overestimate the relevance of economic variables up to the point of recommending zero intervention of public actors just because some evidence points out that the self-organizing symbiosis model that builds from kernels of existing cooperation and exchange tends to be more successful than a formal planning model.

Considering this logic, if society should wait until free market drivers alone allow self-organized industrial symbiosis to thrive as a strong sustainable development model, reflection about the following questions seems important: What if the emerged quantity of symbiosis is not enough? What if the industrial symbiosis never flourishes because the market drivers are mainly economic and underestimate the other dimensions, including social and environmental dimensions? The following questions seem relevant for further research: What if those assumptions we have already made are not relevant? Shall we just sit down and wait until the free market allows the urban symbiosis to begin on its own? Public actors and the community should focus on the conditions under which kernels and precursors have survived and thrived.

The public authorities and civic and private sector actors should play a lead role in the urban social system to identify and act on the balancing and reinforcing loops of the system, improving the general conditions of the social system and not just supporting specific companies or industries that seem to have synergetic potential. This is the factual link we uncover between cities and industrial symbiosis, moving forward to a multidimensional symbiotic relationship in cities where energy, water, material and people are submerged in never-ending movement, and their

[3] The preconditions and kernels of a cooperative symbiotic exchange network are usually the energy co-generation, waste or water reuse.

interactions imply a mobility request in the form of transport and storage in boundaries, relationships and behavior that can be depicted in a dynamic system?

Conclusion

In general, the methods and research outputs discussed here corroborate and expand earlier threads in the literature that find that in order to get a better understanding of symbiosis and the ecosystems where it can be developed, it is important to take a multidisciplinary approach in this complex field of study. The proposed entrance framework of study in this paper is grounded on industrial ecology, territorial ecology and urban ecology. This combination of methodologies is prescribed to encourage the uncovering of urban symbiosis as an advantageous relationship, coexisting with other relationships in the city (competitive and neutral). This combination is relevant for the emergence of sustainable cities, based on three different and successive approaches: (1) system dynamics (urban dynamics); (2) sustainable urban metabolism (mainly material and energy flow assessments) and (3) the Circles of Sustainability model from James (2015), proposed to issue the interconnection between different subsystems in the urban ecosystem. These three methodologies enable the analysis and understanding of the urban ecosystem dynamic in a territorial perspective, taking into account local stakeholders and material, energy and information exchange through a cooperative perspective allowed by the socioeconomic and political system analysis of social structures. The three methodologies are complementary because the strength(s) of one usually compensate for the weaknesses of the others.

Nevertheless, to recognize the drivers and stakeholders of the balancing and reinforcing feedback loops of the 13 identified subsystems in the urban ecosystem represents a complex problem, because the real social system cannot be depicted using only quantitative data. Therefore, we certainly need to include qualitative data and the possibility measuring it in concretely through real-life city data. This is the advantage that the Circles of Sustainability methodology offers to a social system diagnosis employed with a system dynamic perspective.

References

BEAURAIN C., BRULLOT S. (2011), "L'écologie industrielle comme processus de développement territorial : une lecture par la proximité", *Revue d'économie régionale et urbaine*, 2, p. 313 – 340.

BARLES S. (2010), “Society, Energy and Materials: The Contribution of urban metabolism studies to sustainable urban development issues”, *Journal of Environmental Planning and Management*, vol 53, (4), p. 439 – 455.

BARNES H. (1992), “Fertile Project Exploits recycled wastes. Survey on Denmark”, *The Financial Times*, 8 October, p. 5.

BRING JACOBSEN N. (2006), “Industrial Symbiosis in Kalundborg, Denmark: A Quantitative Assessment of Economic and Environmental Aspects”, *Journal of Industrial Ecology*, p. 239-255.

BUCLET N. (2015), *Essai d’écologie territoriale, l’exemple d’Auxois en Savoie*, CNRS Editions.

BUCLET N. (2011), *Ecologie industrielle et territoriale : stratégies locales pour un développement durable.* Villeneuve d'Ascq: Presses Universitaires du Septentrion.

CEWEP (2017), *Graph on European Waste Management 2015*. In www.cewep.eu/information/data/graphs/index.html

CHALIKI P., PSOMOPOULOS C. S., NICKOLAS J., THEMELIS N. J. (2016), “WTE plants installed in European Cities. A review of success stories”, *Management of Environmental Quality An International Journal* 27(5), p. 606 - 620

CHERTOW M. (2007), "Uncovering" Industrial Symbiosis, *Journal of Industrial Ecology*, 11-30.

CHERTOW M. (2004), *Encyclopedia of Energy,* Cleveland C.J: Editorial Oxford.

CHERTOW M. (2000), “Industrial symbiosis: Literature and taxonomy”, *Annual Review of Energy and Environment*, vol 25, p. 313 – 337.

CHERTOW M. (1998), “The Eco-industrial Park model Reconsidered”, *Journal of Industrial Ecology, 2*(3), p. 8-10.

CONNARD, C., NOVICK R. (1996), The Ecology of the Family: *A background Paper for a family-center approach to education and social service.* Oregon: Northwestern Regional.

DIEMER A., MORALES M. (2016a), “L’écologie industrielle et territoriale peut-elle s’affirmer comme un véritable modèle de développement durable pour les pays du Sud », *Revue Francophone du développement durable*, HS n°4, p. 52 – 71.

DIEMER A., MORALES M. (2016b), « Metabolism, System Dynamics and Circles of Sustainability : A New Paradigm for Sustainable Cities », *Symposium Europe and Sustainable Development*, October, Clermont-Ferrand, 19 p.

DIEMER A., FIGUIERE C., PRADEL M. (2013), *Ecologie Politique Vs Ecologie Industrielle: Quelles stratégies pour le développement durable?* Editions Oeconomia.

DIEMER A., LABRUNE S. (2007), « L'écologie industrielle : quand l'écosystème industriel devient un vecteur du développement durable », *Développement durable et territoires*.

DUCHINA F., HERTWICH E. (2003). Industrial Ecology. *International Society for Ecological Economics*.

DURET B., MAT N., BONARD A., DASTREVIGNE E., LAFRAGETTE A. (2007), « Ecologie territoriale : une aide à la définition d'une politique énergétique. Comprendre l'économie physique du territoire », *Les Annales de la recherche urbaine,* n°103, p. 73 – 78.

EHRENFELD J. (2010), "Ecosystem Consequences of Biological Invasions", Annual *Review of Ecology, Evolution and Systematics*, vol 41, p. 59-80.

EHRENFELD J. (2000)," Industrial ecology: Paradigm shift and normal science", *American Behavior Scientist, 44*(2), p. 229-244.

EMELIANOFF C. (2007), "La ville durable : l'hypothèse d'un tournant urbanistique en Europe », *L'information géographique*, vol 71, p. 48-65.

EMELIANOFF C., THEYS J. (2001), « Les contradictions de la ville durable », *Le Débat*, n°113, p. 122 – 135.

ERASMUS A., BOSHOFF E., ROUSSEAU G. (2001), "Consumers' decision-making models within the discipline of consumer science: a critical approach", *Journal of Family and Consumers Science*, p. 82-90.

ERKMAN S. (1997), *Vers une écologie industrielle,* Editions Charles Léopold Mayer.

FORRESTER J.J (1971), *World Dynamics*, Wright-Allen Press, Cambridge.

FORRESTER J.J (1969), *Urban Dynamics,* MIT Press, Cambridge.

FORRESTER J.J (1968), *Principles of Systems*, MIT Press, Cambridge.

FORRESTER J.J (1961), *Industrial Dynamics*, MIT Press Cambridge.

GIBBS, D., DEUTZ P., PROCTER A. (2005), "Industrial ecology and eco-industrial development: A new paradigm for local and regional development?", *Regional Studies*, 39, 2, p. 171-183. *Regional Studies, 39*(2), p. 171-183.

GIBBS D. (1994), "Towards the sustainable city, greening the local economy", *The Town Planning Review*, vol 65, n°1, p. 99-109.

GRAEDEL T., ALLENBY B. (1995), *Industrial Ecology.* New Jersey: Prentice Hall.

YOSHITSUGU H., YASUO T. (2003), "The sustainable city : Transport and Spatial Development", *Built Environment*; vol 29, n°1, p. 5 – 7.

JAMES P. (2015), *Urban Sustainability in Theory and Practice: Circles of Sustainability.* Abingdon, Oxon: Routledge.

KENNEDY C., BAKER L., DHAKAL S., RAMASWAMI A. (2012), "Sustainable Urban Systems, An integrated approach", Journal of Industrial Ecology, vol 16, n°6, p. 775 – 779.

KIM E. (2015), Etude du métabolisme urbain à long terme. Le cas de la consommation énergétique de Paris et de la région Ile-de-France, XVIIIe-XXIe siècles. In G. Junqua, & S. Brullot, *Ecologie industrielle et territoriale* (pp. 187-216). Paris: Presses des Mines.

KNIGHT P. (1990), "A rebirth of the pioneering spirit", *The Financial Times*, 14 November, p. 15.

LANE D. (2008), "The emergence and Use of Diagramming in System Dynamics: A critical Account", *Science Research and Behavioral science*, vol 25, p. 3 - 23.

LEACH J. et al. (2016), "Measuring urban sustainability and liveability performance: the city analysis methodology", *Int. J. Complexity in Applied Science and Technology*, vol. 1, n° 1, p. 86-106.

MADELRIEUX S., BUCLET N., LESCOAT P., MORAINE M. (2017), « Ecologie et économie des interactions entre filières agricoles et territoires : quels concepts et cadre d'analyse ? », *Cahiers Agricultures*, vol 26, p. 1 – 10.

MARZLUFF J.M, ENDLICHER W., ALBERTI M., BRADLEY G., RYAN C., ZUMBRUNNEN C., SIMON U. (2000), *Urban Ecology, An international perspecgive on the interaction between humans and nature*, Springer.

MCINTYRE N.E, KNOWLES-YANEZ K., HOPE D. (2000), "Urban Ecology as an Interdisciplinary field : differences in the use of urban between the social and the natural sciences", *Urban Ecosystems*, vol 4, p. 5 – 24.

MEGA V. (1996), "Towards European Sustainable Cities", *Ekistics*, vol 63, n°379, p. 273 – 288.

METEREAU R., FIGUIERE C. (2015), « Ecologie industrielle. Le secteur agroalimentaire comme point de départ pour une organisation écosystémique des activités humaines », G. Junqua, & S. Brullot, *Ecologie industrielle et territoriale COLEIT 2012* (pp. 217-232). Paris: Presses des Mines.

MULDER K. F. (2016), Urban symbiosis, a new paradigm in the shift towards post-carbon cities. Delft University of Technology – Faculty of Architecture. In *Systematic Approaches to Sustainability*, p. 16-24.

ONITA J. A. (2006), *How does industrial symbiosis influence environmental performance?* Norrköping: Linköpings Universitet.

RAMASWANI A., WEIBLE C., MAIN D., HEIKKILA T., SIDDIKI S., DUWALL A., PATTISON A., BERNARD M. (2012), "A social-ecological-infrastructural systems framework for Interdisciplinary Study of Sustainable City Systems", *Journal of Industrial Ecology*, vol 16, n°6, p. 801 – 813.

RAMASWAMI A., CHAVEZ A., CHERTOW M. (2012), « Carbon Footprinting of Cities and Implications for Analysis of Urban Material and energy flows", *Journal of Industrial Ecology*, vol 16, n°6, p. 783 – 785.

REBELE F. (1994), "Urban ecology and special features of urban ecosystems", *Global Ecology and Biogeography Letters,* 4, p. 173-187.

REES W.E (1992), "Ecological Footprints and appropriated carrying capacity : what urban economics leaves out", *Environment and Urbanization*, vol 4, n°2, p. 121 – 130.

REGISTER R. (1987), *Ecocity Berkeley: building cities for a healthy future.* North Atlantic Books.

RIBEYRE F., GOMBERT-COURVOISIER S., SENNES V. (2015), « La consommation responsable des ménages en tant qu'élément d'ancrage territorial de l'écologie industrielle ». In G. Junqua and S. Brullot, *Ecologie industrielle et territoriale - COLEIT 2012* (pp. 335-345). Paris: Presses des Mines.

SUKOPP H. (2000), "On the early history of urban ecology in Europe", in Marzluff J.M, Endlicher W., Alberti M., Bradley G., Ryan C., Zumbrunneb C., Simon U. (2000), *Urban Ecology, An international perspecgive on the interaction between humans and nature*, Springer, p. 79 – 98.

SUDHIRA H.S, HARINI N. (2013), "Local assessment of Bangalore, Graying and Greening in Bangalore, Impacts of urbanization in ecosystems, ecosystem services and Biodiversity" in *Urbanization, Biodiversity and Ecosystem Services: challenges and opportunities,* p. 75 - 91.

THEYS J. (2000), "Innover et décloisonner pour anticiper les ruptures », *Développement durable, villes et territoires*, n° 13, 128 p.

TSOLAKIS N., ANTHOPOULOS L. (2015), « Eco-cities: An integrated system dynamics framework and a concise research taxonomy", *Sustainable cities and society*, vol 17, p. 1 – 14.

UNITED NATIONS (2014), *World Urbanization Prospects: The 2014 Revision.* New York: United Nations.

VERNAY A. L., MULDER K. F. (2015), *Organising urban symbiosis projects*. ICE publishing.

Servitization tendency at Sustainable cities, the success stories of housing, energy and mobility sectors

Manuel E. MORALES[1], Marina KOVALEVA[2]

Maria FEDORUK[3], Julian TORRES[4]

OR2D-CERDI, Clermont Auvergne University
American University of Central Asia
Ukrainian National Forestry University

It's really easy to identify a non-sustainable city when you are faced with it, but not as easy to define the features that belong to them and are considered as essential to conceive it sustainable. Without a healthy environment, social cohesion and economic efficiency, the sustainable city cannot be understood. The sustainable city is a political entity that cannot be governed by the market. Long-term political goals versus short-term profits is the core element of urban policies and each city gives its own answer, based on eco-efficiency, self-efficiency and new ethics as new pillars (Mega, 1996).

This paper aims to understand the potential contribution that servitization would provide to Sustainable Cities by addressing how three sectors (housing, energy, and mobility) could get some advantages from reducing the needs for material acquisition by customers, or by replacing the products' presence altogether, evaluated by two different methods: The metabolism of Sustainable cities and the Circles of sustainability which brings the quantitative and qualitative data into the assessment equation. Service-providing practices are highlighted and analyzed as an alternative on which sustainable cities could improve resource and energy management. This is just a theoretical outlook of those 3 sectors after bibliographic analysis of different case studies, furthermore an additional research is needed to determine the qualitative and qualitative effects of the dynamic and systemic interrelations over those three areas in a city, in order to identify what are the drivers and the stakeholders taking part in the equation.

This paper is based basically on positive case studies of the service-providing practices in the economy, regardless of the negatives secondary effects, like the potential rebound effect caused by price reduction, those will be included in further researches

[1] manuel.morales@or2d.org
[2] kovaleva_m@auca.kg
[3] fedoruk.mariia@gmail.com
[4] julian.torres@live.it

where the metabolism of sustainable cities and the circles of sustainability were applied at the sustainable cities, looking forward the development of public policies and strategies, that could eventually foster social behavior changes and ongoing interrelationships.

Context and background information

Historical Sustainability conceptual evolution

To easily recognize what is a sustainable city, the historically conceptual evolution is developed here based on the concept of sustainable development, which can be traced back to 18th century forestry management in Germany (Grober, 2012), later on the Brundtland Commission starts using sustainable development as a policy term. In the report 'Our Common Future', the concept was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(Brundtland Commission, 1987). At that time the 'sustainable city' is an automatic derivative from this relating urban development.

By the 90's it was fleshed out in the Aalborg Charter (1994) by more than 700 cities worldwide, and the Melbourne Principles in Local Agenda 21 (UNEP, 2002). The sustainable city grew as a concept (Roy, 2009) and in practice became strongly intertwined with, and operationalized by, the conception of the "triple bottom line" (or "three pillars"), denoting a close interrelationship between economic, social and environmental sustainability with a combination of indicators to measure each of them.

The mindset changed at the beginning of the 21st century when Rogers (1998) conceptualized sustainable city as a place where a higher quality of life is realized in tandem with policies which effectively reduce the demand on resources (energy, materials, etc.) and drawn from the city's hinterland, becoming a more self-sufficient economic, social and environmental system.

Sustainable cities understanding

Keeping in mind the ecosystem analogy and remembering that Sustainable Cities basically reach their goals by gradual changes among different actors in an urban ecosystem, it is relevant to take into account how these interactions might change their structure as well – and not only their scope, contents or measures. One structural change we figure out at this paper is located at the economical level of interactions, pointing out the product-oriented transition into a service-oriented ones, better known as servitization (Lightfoot et al., 2013).

The sustainable city as a concept became popular in the 1990s (Roy, 2009) and in practice the sustainable city becomes a more healthy, cohesive, equitable and efficient place. Although the triple bottom line has by far become the most common view of the sustainable city, there are exceptions. Meadows (1999) and Brugmann (1999) approach the term from a more environmental angle and propose that it should include indicators for pollution and carbon emission, energy and water consumption, water quality, energy mix, waste volumes and recycling rates, green-space ratios, primary forests, and agricultural land loss. However, Rode and Burdett (2011) adopt a more socio-economic interpretation, where social equity alongside a greener living environment should be considered for the development of sustainable cities. In addition, they point out that cities should offer proximity, density and variety which would engender productivity benefits for firms, and help stimulate innovation and new job creation.

Servitization concept

The term servitization was created to describe the idea of product manufacturers, wholesalers and retailers reducing their tangible portfolio in favor of a more intangible one (Levitt 1969, Lay 2014). Currently, the application of this concept is closer to its origin in the 1980s, in which the idea was to deliver to the customers a package of services, goods, support and knowledge that altogether represent a solution, and not only a sale (Vandermerwe and Rada 1988).

Nowadays it is not difficult to be exposed to servitization since most companies adopt it either in pre-sale (e.g. trials, demonstrations and custom design), sale (e.g. installation and training) or post-sale (e.g. maintenance, support and warranty) stages (Frambach 1997, Boyt and Harvey 1997), nevertheless, actual reductions in the overall amounts of used resources and energy usually derive from services that actually replace product presence or that do not require the customer to acquire the product, but the results it delivers (e.g. leasing, renting and pooling) (Mathieu 2001, Tukker 2004).

In 2009, 84,8% of manufacturing companies offered services to support their products, being 12,1% of these directly related to the replacement of product presence or product operation by the manufacturer as service to the customer (Coombs and Miles 2000, Oliva and Kallenberg 2003). Since then, this trend has continued to grow, especially after the photocopier industry decided to lease or rent their multifunctional products to foster a *pay-per-printed-page* solution instead of a *one-photocopier-per-office* habit or tradition (Lay 2014).

Once customers began to perceive and to be attracted by direct or indirect financial benefits, this phenomenon opened the doors for discussions in all subject matters: from the potential innovations in business models to the psychology of product ownership, from unique selling propositions (USPs) to sustainable resource management (Mathieu 2001, Lay 2014).

Servitization in sustainable cities is then embodied in social and economic features: especially talking about the transition from a manufacturing-based economy associated with high emission levels to a 'cleaner' service-oriented economy, which allows social stability alongside ecological preservation throw higher eco-efficiency in the economic chain of value.

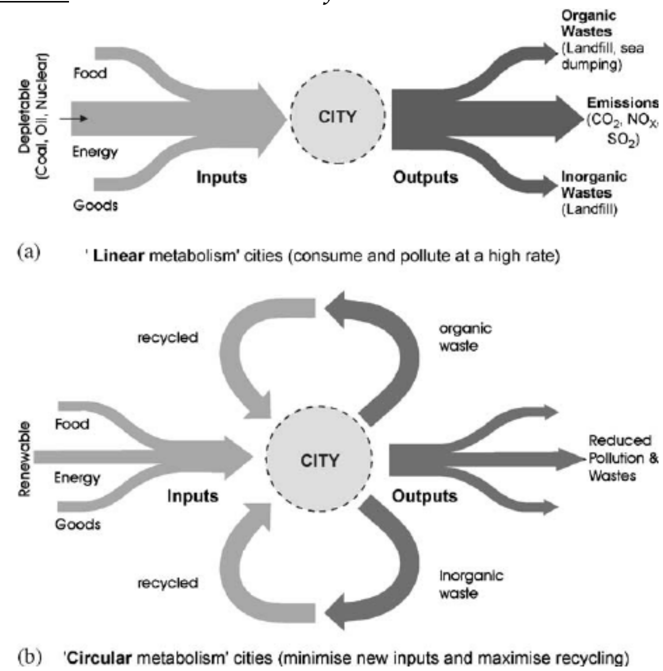
Materials and methods

Sustainable cities assessment involves combining the result of several researches. In what follows, we will refer to a two different approaches : (1) The sustainable urban Metabolism perceived as an ecosystem (mainly material and energy input-output assessments) and (2) the circles of sustainability from James (2015).

Sustainable Urban Metabolism

One of the underlying principles in Urban Metabolism is the mass conservation, toward ways in which to transform industrial activity from what is largely a non-sustainable system to resemble more and more closely a sustainable system. Once the concept sustainable systems in Urban Ecology is in hand, we move on to the first broadly and common understanding called "Material and Energy Flow Analysis" (MEFA), which is about material and energy accounting by identifying and quantifying material and energy usages and assessing their impacts on the environment; to implement opportunities to effect environmental improvements. (Graedel & Allenby, 1995).

Figure 1: The 'metabolism' of cities: towards sustainability

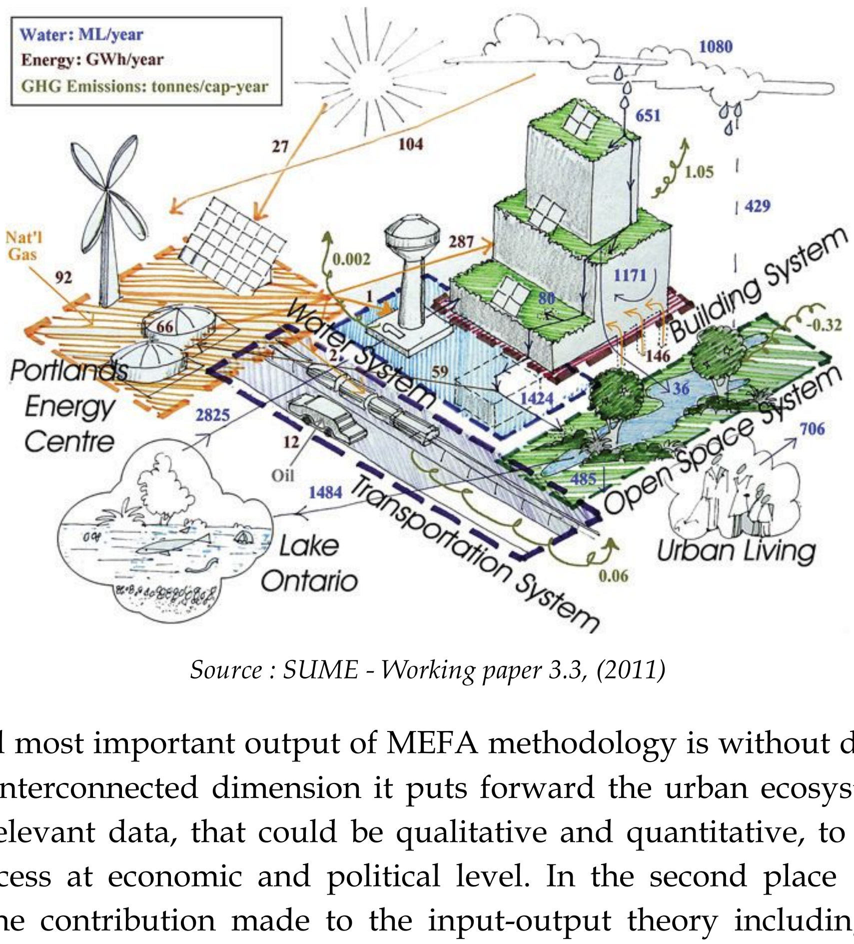


Source: Doughty & Hammond, 2004 (adapted from Girardet [3,4] and Rogers [6])

The material and energy flows: Inputs and outputs of a city or territory are the basic features for establishing a material flow balance, it is necessary to identify the stocks and the potential advantages from its operation. This metabolic level support taking into account "the required and harmful" consumption (the inevitable household expenditure) such as heat, electricity, and food, considering that there is a correlation between needs and resources to develop the local production of these products with the corresponding benefits in terms of local economy, employment, greenhouse gas reduction, etc. The metabolism process will shift gradually to: zero waste, positive energy, closed water cycle.

Many studies have been developed around the world considering this methodology as a framework, one relevant example is "The Energy consumers & suppliers model in Paris", (Kim, 2015) that produce available data about the energy consumption pattern, the amount and trajectory of input and output natural resources flux. This MEFA assessment in a city is a clear evidence that cities can be considered as urban systems, and assessed throw dynamic, multiscale and interconnected tools.

<u>Figure 2</u> : Approaches and Strategies for a Metabolically Sustainable city



Source : SUME - Working paper 3.3, (2011)

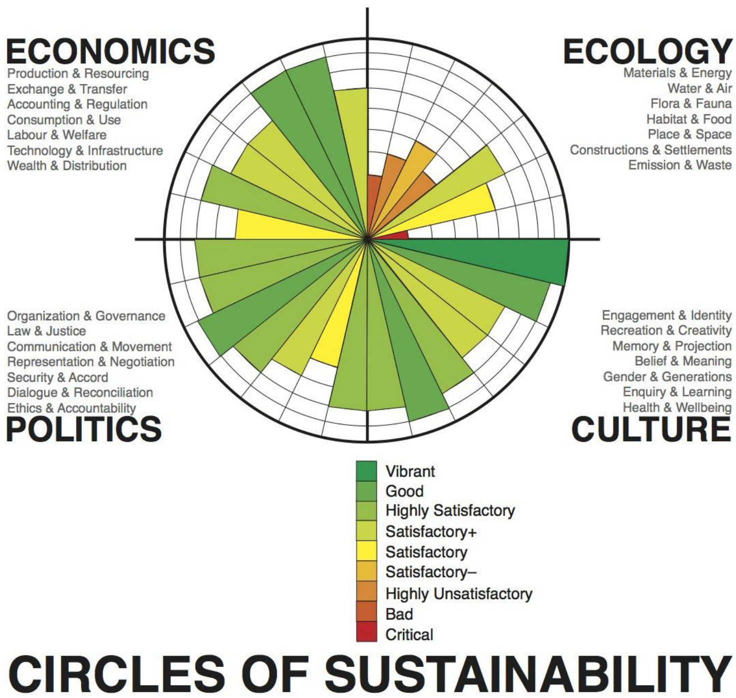
The first and most important output of MEFA methodology is without doubt (1) The global and interconnected dimension it puts forward the urban ecosystems theory, supplying relevant data, that could be qualitative and quantitative, to the decision making process at economic and political level. In the second place (2) it is also important the contribution made to the input-output theory including the global analysis of other sub-systems that are outer the main one, but are closely linked with the system's activity working out as suppliers or consumers. The third feature is the radical understanding as an alternative revolution of the social productive system, broadly developed and spread, that look for an efficiency improvement on the social systems, based on an alternative socio-economic framework able to drive the market structure far across the restricted technological based solutions.

The Urban Ecology is achieving a strong sustainable approach, challenging us to think about the structures' evolution in the cities. This evolution is figured out considering relevant insights as different organization patterns, that are not necessarily news, if we take a look backwards in the history, for example the collaborative/cooperative social structure. That kind of structures used in the past, but adapted in a current social system structure could help to make the bridge in between the long-term political goals and the short-term profits (Metereau & Figuière, 2015).

Circles of sustainability

The circles of Sustainability is a method that starts the redefinition of sustainability, intersecting with other social conditions, such as resilience, cooperation, proximity, flow optimization and reconciliation as basic conditions of positive social life. This approach takes the positive intention of the "three pillars" phrase and for the first time locates that well-intentioned spirit in an integrated and generalizing framework that provides more than high-sounding words. The Circles of Sustainability is intended to be flexible, modular and systematic. Each part of the approach has been developed so that it operates as a part of a toolbox for understanding different urban areas, a good example of the Circles of Sustainability methodology is observed in Melbourne.

Figure 3 : Circles of sustainability, Melbourne



Source : James (2015)

The Circles of Sustainability provide a relatively simple view of the sustainability of a particular city. The circular figure is divided into four domains: ecology, economics, politics and culture. Each of these domains is divided in seven subdomains. The assessment is conducted on a 9-5 points scale. The scale ranges from 'critical sustainability', the first step, to 'vibrant sustainability', the last step. When the figure is presented in color it is based on a traffic light range with critical sustainability marked in red and vibrant sustainability marked in green.

Concretely, the methodology applies non-random semi-directed interviews to key actors and stakeholders essential for city's dynamic in order to set up a strategy to identify and map the whole network of drivers and features. As this former example we can witness some other substantial efforts of urban symbiosis developments in cities like Melbourne, Australia; Papua, New Guinea; Porto Alegre, Brazil; Milwaukee, USA; New Delhi, India; and Sao Paulo, Brazil with excellent outputs, throw "The Circles of Sustainability" (James, 2015), methodological approach, that achieve rethinking paradigms in urban ecology.

Results

Servitization, eco-services and sustainable cities

To assess and analyze how to build value network and resource integration/value and co-creation, which is embedded on societal and environmental perspectives. The main theoretical and empirical challenge is to understand housing, mobility, energy and the industry of a city as based on dynamic values, which turn on eco-services features to develop and implement a feasible and proactive tool for changing the mindset.

The four analyzed areas contribute to value–based service studies in a city ecosystem by adopting a dynamic and systemic explicit tendency, better known as a servitization. These cities are in transition for a deeper structural change which is going to be built upon dynamic city networks, in order to tide the toolbox and face the structural problems we have in front upon cooperation and partnership taking long term solutions.

The main theoretical challenge proposed in this paper is to understand energy, housing and transportation as dynamics and interconnected sectors sharing values based on eco-services for sustainable cities and looking forward to implement a proactive and operational assessment tool to build sustainable plans and strategies. The paper discuss the cities experiences in an international context by embedding social and environmental perspectives, high lightening the role of cities, governmental agencies and other stakeholders in the network towards creating a sustainable city.

Energy

Energy efficiency is one of the most important requirement for a city striving to become more sustainable. Experts define Energy services as a variety of activities, such as energy analysis and audits, energy management, project design and implementation, maintenance and operation, monitoring and evaluation of savings, property management, and energy and equipment supply (Wagner, 2010). Furthermore, Energy services guarantee particular levels of service provision, such as lighting levels, room temperatures, humidity and 'comfort' In its most developed form. It also allows the client to minimize the total bill for the energy services through a single contract with an energy services provider (Sorrell, 2007).

Servitization could be seen as conjunction of energy supply and energy-related service, suggesting energy efficiency, energy savings and sustainability (Neely, 2008; Benedetti et al. 2015). The growing level of economy servitization has also significant impact on the energy sector, by changing the way in which energy is provided by Energy Service Companies (Benedetti et al. 2015). Servitization in the energy sector also refers to the outsourcing process as governance modes shift from hierarchies (in-house provision) to markets (Polzin, von Flotow, and Nolden, 2015). It might involve third-party contractors that can accelerate the commercialization and diffusion of energy efficiency technologies and help overcome overcome technological, institutional and economic barriers (Polzin, von Flotow, and Nolden, 2015).

Energy Service Provider Companies (ESPCs) are companies that provide energy services to final energy users, including the supply and installation of energy-efficient equipment, and/or building refurbishment, maintenance and operation, facility management, and the supply of energy (including heat) (Wagner, 2010). For example, a company that initially provided the city of Palermo with gas and lighting has switched to providing the "solar heat service". The company sells heat as a final product, and calculates the thermal kilowatts consumed by its clients. Buying hot water, a consumer pays for a "final result", from the installation, to the thermal-energy meters, and to the transportation of methane to the boilers as well as provided equipment maintenance (Manzini and Vezzoli, 2003).

According to Neely (2013), today the level of servitization in the energy sector significantly varies among the countries. In Brazil and China it reaches 45.45% and 45.16%, whereas in USA, France and UK 36.74%, 38.46%, 32.06%, respectively. At the same time servitization in Germany accounts only to 13.64% (Neely, 2013). Latest transformations of the energy market due to the rise of the distributed generation and use of renewable energy sources propose new understanding of the servitization paradigm. Mainly it relates to the active role of the consumer. Today, the producer of renewable energy has become the consumer itself, or a supplier for local consumers.

Thus, it makes the energy issue become more dynamic, evolving from a one direction flow to a two directions flow between utilities and consumers (Hamwi et al. 2016). The new energy market structure and new entrants have modified a widely accepted approach of servitization. Energy servitization could refer to providing technological devices and associated services for energy efficiency or for micro generation. In this case there is a reduction of energy consumption or the generation of renewable energy. Or go beyond the technological aspects and explore a consumer behaviour modification. In this case the result can be a reduction of the energy consumption or the modification of this consumption: in some cases the consumed energy amount can be constant but the time window of the consuming period may vary (Hamwi et al. 2016).

However, it is important to note that despite the prominent advantages of the servitization approach, the energy services model may only be appropriate for a subset of energy services and energy using organizations. A challenge for both business strategy and public policy is to identify those situations in which energy service contracting is most likely to be appropriate and the conditions under which it is most likely to succeed (Sorrell 2007).

Servitization business models of the energy market are considered to be emerging trends. The implementation of the new approach is still found on the initial stages and requires additional research. The new technological advancement, the literate consumer and tendency towards green energy, would bring out new forms of products and services for the new business model (Hamwi et al. 2016). It will allow the energy sector to address the efficiency, low carbon and sustainability problems in a wider manner by including all actors of the supply chain. However, it is important to note that a wholesale shift from commodity to service supply is unlikely to be either feasible or desirable. Contracting may only be appropriate for a subset of energy services within a subset of organizations, and is particularly unsuitable for final energy services at small sites and process-specific energy uses at large sites (Sorrell, 2007).

In the MEFA analysis Servitization in the energy sector will be seen as a tool that reduces "the required and harmful" consumption and shifts the metabolism process to even more positive energy.

Housing

Sustainable buildings are essential for securing transition towards sustainable cities. It has critical importance in areas such as climate change and energy security. Globally, over one-third of all final energy and half of electricity are consumed in buildings, and this consumption generates approximately one-third of global carbon emissions (IEA, 2013a).

Sustainable building is designed, constructed, operated, renovated and disposed of in accordance with ecological principles for the purposes of minimizing the environmental impact of the built environment and promoting occupant health and resource efficiency (Kibert, 2003). In addition to benefitting the environment and occupants, sustainable buildings can also produce substantial economic benefits by reducing operating expenses, enhancing building marketability and market value, improving the productivity of occupants and thus the revenue-generating ability of corporate tenants of office buildings, minimizing potential liability due to poor indoor environment, and optimizing life cycle economic performance (USGBC, 2010 and USEPA, 2012).

Although retrofit activities (i.e. the upgrading of existing buildings to improve their energy efficiency and decrease emissions of greenhouse gasses) seem to be technically viable and sometimes also economically attractive, there are multiple barriers to change that prevent the take-up of energy efficiency measures in buildings. Many governments have introduced retrofit schemes that attempt to overcome these barriers and to influence the diverse behaviors and practices that give rise to energy use in buildings.

For example, today the central role that energy plays in the emission of carbon is widely accepted by the UK Government, politicians and energy intensive businesses with energy concerns underlined on political agendas. Despite of the small size at this sector, it has developed economic infrastructure, built up around the availability of low cost energy and not considering energy concerns a threat.

The surveys indicate that property features of non-domestic ownership raise a significant barrier into the adoption of energy efficiency and conservation strategies. 50% of the sample answered that their relationship with the appartements' owners or tenant blocks changes. 36% describe their relationship as "preventive" whilst 14% says that their owners choose to not have any involvement in energy management or efficiency. Overall 43% of the sample answered that they have experienced restrictions on improving energy efficiency based on their tenancy structure.

In addition to these ownership barriers people indicate that they have also encountered financial barriers to improve energy efficiency and conservation related to buildings property. For example, 88% of the sample have encountered disincentives such as lease clauses preventing change and 79% experienced a split of financial incentives resulting from owners' decisions (Emblen-Perry, 2015). Opposite to the previous example at UK in Ukraine there is a boom of citizens' associations looking for those incentives on energy facilities and rights, specially represented by non-governmental organizations (ONG) like the association of co-owners of apartment buildings (ACAB). It means that since the creation of ACAB host and owners foresee the energy efficiency improvement as an alternative -from self-sufficiency to determine the energetic competitive index or to introduce new avant-garde clauses at contracts (Timilsina, Hochman, Fedets, 2016) for example energy saving in building. But even new form of citizens' association and private ownership does not help much to implement centralized energy saving strategies at multi-store buildings. Only a small percentage of inhabitants have taken an advantage from this right. There are a lot of social barriers: different level of income, lack of wiliness, lack of communication etc., that make this cooperation difficult.

Servitization can be a solution because the main idea indeed is to deliver to the customers a package of services, support and knowledge altogether. The servitization of sustainable housing take into account the entire life cycle of a building and the raw material origins, through use to re-use and upcycling Furthermore, the service approach requires new ways of designing, e.g. to secure the option of disassembling individual parts and components that need to be fixed or replaced. This concept of designing for disassembling opens up a large field of potential innovations within both technology and design processes. Aspects of social sustainability that relates to the use of the buildings, e.g. indoor climate, health and safety and the perceived functionality of the building, are very important for the sustainable transition of the housing sector. Not only because the productivity of e.g. employees and students is significantly affected by the indoor climate at their office or school, but also because the actual energy and water consumption often turns out to be considerable larger than expected by designing consultants (Koch-Ørvad, Thuesen, 2016). Housing service suppliers will get a great business opportunities by offering creative refurbishment proposals. Furthermore, suppliers also have to develop accessible refurbishment opportunities to low income houses. The increasing Housing services demand requires new ways of collaboration to ensure all sustainable and systemic requirements and conditions.

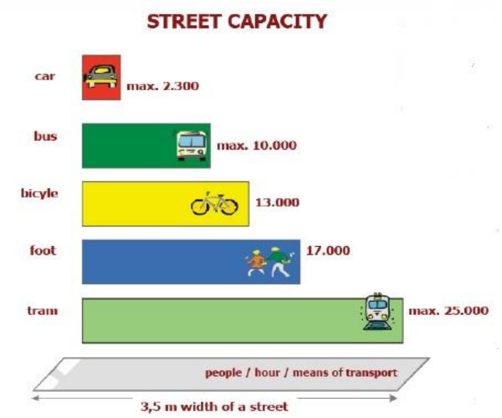
Mobility and Transport

The transport sector consumes 2.200 million tons of oil equivalent constituting about 19% of global energy supplies. Driven by increases in all travel modes, some sources expect the energy consumption of transport sector to increase by between 80% and 130% above today's level (World Energy Council, 2011). The transport sector also has the second biggest greenhouse gas emissions (GHG) in the EU, which is responsible for 24,3% of the GHG. Greenhouse gas emissions in other sectors decreased 15% between 1990 and 2007, but emissions from transport increased 36% during the same period. The main theoretical and empirical challenges are how to understand public transport as dynamic and transformative values based service eco-system for living city regions, breaking the norm of using cars in the city and to find an alternative discourse for a sustainable city to develop and implement a feasible and proactive tool for changing the mindset, which is embedded on societal and environmental perspectives.

Sustainable Combined Mobility

Sustainable Combined Mobility (SCM) is a transport model that stimulate interaction among all combined mobility actors, including public transport operators and organizing authorities. It also promotes collaboration between all stakeholders to develop a comprehensive mobility offer responding to all the needs of the users and facilitating door-to-door mobility (Cerfontaine, 2014). The SCM is a modern mobility system in servitization that combines flexibility and convenience, including all the following options of mobility without the property of the user in any of them: public-transport, car-sharing, taxis and shared taxis, bicycle and bike-sharing, car-pooling, park & ride, etc. The objective is to look deeper on how these emergent and fast growing cities are putting together the SCM for building cities for people by focusing on mobility services and not in property and ownership. The value network of SCM are integrated and co-created within the service system (Petros Sebhatu & Enquist, 2016). This paper has an explorative nature, built around the concept of Sustainable Combined Mobility (SCM) in the sustainable cities. The paper illustrates these concepts with the case of SBB and Mobility in Switzerland. It makes a contribution to the study of public transit services by explicitly linking the adoption of SCM value network at the international level, what can help us to learn and understand the challenges and opportunities of sustainable and integrated transport system based on service ecosystem economies, and resource integration/value co-creation.

Figure 5: Street capacity in a city, comparison between different transports



Source : Cerfontaine (2014)

Figure 6: Servitization at transport sector in the cities.

Source : Cerfontaine (2014)

The Swiss Mobility experience

The case study of Mobility Carsharing in Switzerland (officially Mobility Cooperative, also known as Mobility Car Sharing or simply Mobility for short) is a Swiss cooperative of car sharing. It covers almost all organized car sharing in Switzerland. Mobility offers 2.700 vehicles at 1.400 sites for private customers as well as mobility solutions for companies. The company pursues the aim of "operating vehicles of all kinds based on mutual self-help in a way which saves energy, raw materials and the environment, and to provide services in the field of mobility in Switzerland and abroad; to make vehicles of all kinds available on a fee-paying basis as an ecological and economical alternative to private ownership". The combination of public and private transportation aims to give cooperative members and other customers the opportunity to select the most suitable means of transport. One of the key considerations for Mobility's vehicle management program is sustainability: according to the company itself, its entire fleet achieves emissions averaging 95 g CO_2/km. This puts Mobility 27% below Switzerland's mandatory threshold as applicable from 2015.

According to an Interface study, 22% of private customers and 50% of business customers would buy their own car if Mobility did not exist. This would mean there would be around 27'600 more vehicles on Switzerland's roads, needing 41'400 parking spaces. The study also shows that car sharing has a positive impact on energy consumption: it leads to a reduction in CO_2 emissions of 20.500 tonnes per year. Mobility has its annual business and sustainability report audited by the Global Reporting Initiative and achieved Application Level B in 2014.

The SBB SwissPass is the key to mobility in Switzerland and also the first step in a new transition of public transport. The SwissPass gives access to partner services such as Mobility Carsharing, PubliBike or SchweizMobil as well as winter sports facilities. It manages a virtual interface that gives you instant access to your data any time with your customer account on swisspass.ch. It is really easily to manage the personal details online and keep it confidential.

Discussion and conclusion

The constantly increasing impact that a product-based economy have on the city's sustainability demonstrates that the service based economy better known as servitization should receive recognition for having brought an urban ecosystem outlook to the fore as a core concept. The need to assess sustainability in the cities requires that the key antecedents of sustainability were identified and the proper ways to define it. We provide a contribution to this line of research by offering an analysis of three successful case of studies in servitization and their contributions to the city sustainability. Reviewing the studies analyzing servitization sustainability through urban metabolism and circles of sustainability methods, we approach the sustainable cities analysis in an ecological, complex and systemic understanding. In doing so we differ from previous studies on servitization, which have mainly conceptualized the servitization advantages in terms of resource efficiency in the production process, value chain adding and profit increase in the business activity; adopting economic assessment as the cost-benefit analysis. Our conceptualization of servitization is mainly drawn from the ecological systems literature and sustainable urban metabolism. We provide a conceptualization of servitization which differs from previous ones in the literature (T.S. Baines, H.W. Lightfoot, O. Benedettini, J.M. Kay, 2009). We analyzed three different case studies. They were useful to identify the limitations and disadvantages of the linear economic indicators used at the servitization of manufacturing, and also to identify that those can fail to assess correctly the urban sustainability, because those measures cannot discriminate among different dimensions (biophysical, social and economic) and are perceived as statics measures.

In this paper, we frame the city as an ecosystem where the sub sectors (housing, energy and transport) correspond to the populations and perform specific functions to meet needs at the ecosystem. At the energy sector we can find the conjunction of energy supply and energy-related service, suggesting energy efficiency, energy savings and sustainability, taking into account the origin of the energy (renewable or non-renewable energy). In housing Servitization takes into account the entire life-cycle of a building and the raw material origins and might also create additional business opportunities services at the refurbishment sphere. In the mobility sector the concept is presented in the form of the Sustainable Combined Mobility (SCM) mobility system that combines different options of mobility without the property of the user in any of them. Many policymakers have recognized the relevance of servitization as a tool to improve some functions in those populations, introducing this discussion into their economic agenda as a tool for reaching sustainable economic development. Finally, the results of our study can be used in further researches to derive useful guidelines to the design of sustainable housing, energy and transport sectors and to improve the sustainability of the existing ones. Policymakers interested in push the servitization further into the cities should improve the number of business opportunities through a better legislation, which helps to cover some needs throw a service adding value into the chain. This study presents some limits, in particular the fact that is based on a literature review and the case studies analyzed have taken place in a specific context influenced by different cultural, social and natural variables. So it is not desirable to suggest a simple model carriage in between different contexts. But the fact of analyzing those study cases by a different systemic and complex regard helps the policymakers and scholars to get a better understanding of the servitization in those specific sectors of a city and aims to build better sustainability index in the city in further researches, using methodologies as the urban metabolism and circles of sustainability proposed in that study.

REFERENCES

BAINES T.S., LIGHTFOOT H.W., BENEDETTINI O., KAY J.M. (2009), "The servitization of manufacturing: A review of literature and reflection on future challenges", *Journal of Manufacturing Technology Management*, Vol. 20 Issue: 5, p. 547-567, DOI: 10.1108/17410380910960984

BENEDETTI M., CESAROTTI V., HOLGADO M., INTRONA V., MACCHI M. (2015), "A Proposal for Energy Services' Classification Including a Product Service Systems Perspective", *Procedia CIRP* 30. Elsevier B.V.

BOOGERT G., HAKVOORT L., HEIT R., LE FEVRE S., LEMMENS B., MANTEL B., VOERMAN R., VRIES B. (2014), *Energy Atlas Amsterdam Southeast*, City of Amsterdam.

BOYT T., HARVEY M. (1997), "Classification of industrial services – a model with strategic implications", *Industrial Marketing Management*, vol 26, p. 291-300.

CERFONTAINE C. (2014), "Combined mobility: Public transport in synergy with car-sharing, cycling, taxis, etc., a smart way forward", *5th UITP Combined Mobility Workshop*, 30. Hannover, Germany.

COOMBS R., MILES I. (2000), *Innovation, measurement and services: the new problematique*. Boston: Kluwer Academics.

DE JONG M., JOSS S., SCHRAVEN D., ZHAN C., WEIJNEN M. (2015), "Sustainable-smart-resilient-low carbon-eco-knowledge cities; making sense of a multitude of concepts promoting sustainable", *Journal of Cleaner Production*, p. 25-38.

DUVIGNEAUD P., DENAYER DE SMET S. (1977), « L'écosystème URBS, l'écosystème urbain bruxellois », *Scope*, p. 581 – 599.

EMBLEN-PERRY K. (2015), *Does tenure of business premises influence UK SMEs ' ability to benefit from energy efficient technologies ?*

EPA (2012), *Green building – basic information U.S. Environmental Protection Agency* [website accessed on 11 February 2014: http://www.epa.gov/greenbuilding /pubs/about.htm]

FRAMBACH R. T., WELS-LIPS I., GÜNDLACH A. (1997), "Proactive product service strategies – an application in the European health market", *Industrial Marketing Management*, vol 26, n°4, p. 341-352.

GRÖNROOS C. (2000), *Service management and marketing – a customer relationship management approach*. Chichester: Wiley.

HAMWI M., LIZARRALDE I., LEGARDEUR J., TECHNOPOLE I., BIRDART F. (2016), "Energy Product Service Systems as Core Element of Energy Transition in the Household Sector: The Greenplay Project", *22nd International Sustainable Development Research Society Conference*, July, 13–15.

IEA ENERGY POLICIES OF IEA COUNTRIES (2013), Germany.

JAMES P. (2015), *Circles of sustainability*, Routledge.

KIBERT C.J (2003), "Green buildings: an overview of progress", *J. Land Use Environ. Law*, vol 19, n°2, p. 491–502.

KOCH-ORVAD N., THUESEN C. (2016), "Sustainable Building in Scandinavia", *Directions of Innovations for Supporting the Transition*, 1159–1167.

LAY G. (2014), *Servitization in industry*. Switzerland: Springer.

LEED (2010), *Reference guide for green building design and construction U.S. Green Building Council*, Washington, D.C.

LEVITT T. (1969), T*he marketing mode – pathways to corporate growth*. New York: McGraw-Hill.

LIGHTFOOT H., BAINES T., SMART P. (2013), "The servitization of manufacturing: A systematic literature review of interdependent trends", *International Journal of Operations & Production Management*, vol 33, p. 1408-1434.

MATHIEU V. (2001), "Service strategies within the manufacturing sector: Benefits, costs and partnerships", *International Journal of Service Industry Management*, vol 12, n°5, p. 451-475.

MEGA V. (1996), "Towards European sustainable cities", *Athens Center of Ekistics*, p. 273-288.

MMANZINI E., VEZZOLI C. (2003), *Product-Service Systems and Sustainability. Opportunities for Sustainable Solutions*, Paris, France.

MONT O., SINGAL P., FADEEVA Z. (2006), "Chemical management services in Sweden and Europe: Lessons for the future", *Journal of Industrial Ecology*, vol 10, p. 279-292.

NEELY A. (2013), "Servitization in Germany: An International Comparison." http://cambridgeservicealliance.eng.cam.ac.uk/resources/Downloads/Monthly Papers/2013November_ServitizationinGermany.pdf.

NEELY A. (2008), "Exploring the Financial Consequences of the Servitization of Manufacturing", *Operations Management Research,* vol 1, n° 2, p. 1–50.

OLIVA R., KALLENBERG R. (2003), "Managing the transition from products to services", *International Journal of Service Industry Management*, vol 14-2, p. 160-172.

PETROS SEBHATU S., ENQUIST B. (2016), "Sustainable Public Transit Service Value Network for Building Living Cities in Emerging Economies: Multiple Case Studies from Public Transit Services", *Procedia - Social and Behavioral Science*, p. 263-268.

POLZIN F., VON FLOTOW P., NOLDEN C. (2015), "Exploring the Role of Servitization to Overcome Barriers for Innovative Energy Efficiency Technologies –

The Case of Public LED Street Lighting in German Municipalities", edited by Tommaso Ciarli and Daniele Rotolo. SWPS 2015-07. www.sussex.ac.uk/spru/.

ROTHENBERG S. (2007), "Sustainability through servicizing", *MIT Sloan Management Review,* vol 48-2, p. 82-91.

SORRELL S. (2007), "The Economics of Energy Service Contracts," *Energy Policy,* vol 35, n°1, p. 507–21.

STREMERSCH S., WUYTS S., FRAMBACH R. T. (2001), "The purchasing of full-service contracts: An exploratory study within the industrial maintenance market", *Industrial Marketing Management*, vol 30, p. 1-12.

TIMILSINA G.R, HOCHEMAN G., DEFETS I. (2016), "Understanding energy efficiency barriers in Ukraine: Insights from a survey of commercial and industrial firms", *Energy*, vol 106, p. 203–211.

TUKKER A. (2004), "Eight types of product-service system: Eight ways to sustainability? Experiences from Suspronet", *Business Strategy and the Environment*, vol 13, n°4, p. 246-260.

VANDERMERWE S., RADA J. (1988), "Servitization of business: adding value by adding services", *European Management Journal*, vol 6-4, p. 314-324.

WAGNER L. (2010), *Energy Service Companies (ESCO) Monetization of Energy Efficiency*", http://www.moraassociates.com/reports/1002 ESCO.pdf.

WU M.H, NG T.S, SKITMORE M.R (2016), "Sustainable building envelope design by considering energy cost and occupant satisfaction", *Energy for Sustainable Development*, vol 31, p. 118–129.

Industrial Symbiosis and European Policy

Arnaud DIEMER

University Clermont Auvergne – OR2D, CERDI

Since the publication of Frosch and Gallopoulos' seminal article "Strategies for Manufacturing" in *Scientific American* in 1989, has offered a new perspective on industrial development, which became the field of industrial ecology (Zhu, Lowe, Wei, Barnes, 2007). Frosch and Gallopoulos argued that industrial complexes should be designed to resemble natural ecosystems in order to use energy, water, and material resources optimally while at the same time minimizing wastes. As a part of industrial ecology, the study and promotion of industrial symbiosis has gained increasing attention in the scientific community. Building on the notion of biological symbiotic relationships in nature, industrial symbiosis consists of place-based exchanges among different entities. Chertow writes that "*Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchanges of materials, energy, water and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity*" (2004, p. 2; 2007, p. 12). Christensen considers that industrial symbiosis "*is a collaboration between different industries for mutual economic and environmental benefits*" (2006, p. 3).

By working together, businesses strive for collective benefits that are greater than the sum of individual benefits that could be achieved from acting alone. This kind of collaboration can improve social relationships among participants, which can also extend to surrounding communities. Progress toward developing industrial symbiosis programs is significantly influenced by a number of factors, including the nature of a company's operations, the history of industry in the region, the extent of peer pressure, the positioning of a coordinating body in the region, and the company's approach to awareness-raising and recruitment.

The term "industrial symbiosis" was actually coined to describe a group of interconnected industries in the Danish town of Kalundborg (Ehrenfeld, Gertler, 1997) that saw a network of by-product exchanges and other forms of collaboration evolve spontaneously over three decades (Chertow, Ehrenfeld, 2001). In general, industrial symbiosis involves three primary opportunities for resource exchange: (1) by-product reuse, (2) utility/infrastructure sharing, and (3) joint provision of services.

Our paper will seek to learn from various case studies of industrial symbiosis and is divided into three parts. In the first part, we will present the different processes which can play a role in the conceptualization of industrial symbiosis (Boons, 2011), particularly in the type of industrial symbiosis that occurred in Kalundborg. In the second part, we will highlight the key factors of success and failure of industrial symbiosis. We will show that two levels are involved in industrial symbiosis: the regional level of an industrial system and the societal level (institutional and organizational mechanisms, routines and the distribution of the symbiotic relationship). In the third part, we will introduce some case studies of industrial symbiosis to understand wheter the example of Kalundborg can readily be used as a model for industrial symbiosis initiatives at other locations. We will present the industrial symbiosis of the Guitang Group, which has developed a complex system of interactions in many industries (sugar, paper, cement, fertilizer).

The conceptualization of industrial symbiosis

If industrial ecology operates at different levels, one of them – the inter-firm level – introduces terminologies of a new model, including the industrial ecosystem (Cote, Hall, 1995), islands of sustainability (Wallner, Narodoslawsky, Moser, 1996), and eco-industrial parks (Cote, Cohen, Rosenthal, 1998). Within this framework, industrial symbiosis (IS) can be regarded as a concept of collective resource optimization based on by-product exchanges and utility sharing among different collocated facilities. A very large number of references of industrial symbiosis can be traced back to the IS complex in Kalundborg, Danemark (Ehrenfeld, Gertler, 1997; Esty, Porter, 1998; Ehrenfeld, Chertow, 2002; Brings, Jacobsen, Anderberg, 2004; Christensen, 2006…). That model can be viewed as either a paradigm or an isolated phenomenon where a number of companies were coincidentally bound together by waste, water and energy exchanges based on mutual contractual dependency.

The development of industrial symbiosis in Kalundborg has been described as an evolutionary process in which a number of independent by-product exchanges gradually evolved into a complex web of symbiotic interactions among five collocated companies and the local municipality (Ehrenfeld, Gertler, 1997). The symbiosis includes a power plant (Asnaes), an oil refinery (Statoil), a biotech and pharmaceutical company (Novo Group), a producer of plasterboard (Gyproc), and a soil remediation company (Soilrem). The various material flows among these companies are based on water, solid waste and energy exchanges. For example, the power plant produces heat for the town of Kalundborg and steam for Novo Group and the Statoil refinery. Heated cooling water comes from the Asnaes power plant and is piped off to a nearby fish farm (ensuring full scale production of the fish).

To understand the environmental and economic performance of the symbiosis of Kalundborg, Jacobsen (2006) performed a quantitative analysis of the water and steam exchanges. The environmental benefits were analyzed in terms of ability of the exchanges to reduce the intake of high quality water by means of water substitution and water cascading. From the steam/heat side, the industrial symbiosis exchanges were estimated in terms of the cogeneration effect and the net reduction of carbon dioxide, sulfur dioxide, and nitrogen oxide emissions. The economic benefits were presented as a combination of investments at the time of initiation, as direct and indirect economic savings related to upstream and downstream production related issues. The Kalundborg region has a large groundwater deficit, so a large number of private and public initiatives for saving groundwater were tested over several decades. Jacobsen (2006) identified three strategies in industrial symbiosis. One consisted in replacing groundwater with surface water in the highest water-consuming industries (1961). The second tried to optimize internal water use and diversify external water sources in these same water-consuming industries (1975). The last one looked for surface water upgraded to drinking water quality and imported groundwater to Kalundborg from adjacent regions (1997).

These different strategies created a diversified water supply system in the region, and close cooperation among the various water consuming industries. For Jacobsen, the importance of water related symbiotic flows in relation to the total water input in the different symbiotic facilities was considerable: "*More than 95% of the water input of the power plant is part of the symbiotic network, whereas 98% of the water input for the refinery is symbiotic in character, approximately 20% for the Novo facility*" (2006, p. 243). For the Asnae power plant, there are five different water sources, including a symbiotic element that forms the basis of the water supply: (i) use of surface water jointly with the refinery and the Novo facility; (ii) use of cooling water from the refinery; (iii) use of waste water from the refinery; (iv) re-use of waste water from the pharmaceutical company Novo; and (v) re-use of water from the public waste water treatment plant.

Table 1: Water consumption in thousands of cubic meters

	1991	1995	2002
Asnae Power Plant			
Groundwater	412	73	51
Surface water	87	733	686
Cooling/waste water	705	820	492
Novo Group			
Water intake	1,600	2,200	2,700
Statoil Group			
Water intake	*	1,300	1,600

Source: Jacobsen, 2006, p. 245

The Asnae power plant takes in surface water from a nearby lake jointly with the other symbiosis industries. The surface water is upgraded and made viable as boiler water for steam production. Thus, firstly, an annual saving of water (686,000 m3 in 2002) comes from the replacement of groundwater with surface water. Secondly, Asnae power plant substitutes surface water by cooling water piped from the refinery. The refinery takes surface water (which replaces groundwater) and uses the surface water as cooling water. Next, the cooling water is piped to the power plant. The Asnae plant treats and upgrades the cooling water to boiler water quality and uses the water in steam production. Thirdly, the wastewater is piped from the refinery to the power plant to partly replace the intake and cooling water (9,000 m3 in 2002).

Figure 1: The Kalundborg Symbiosis (2007)

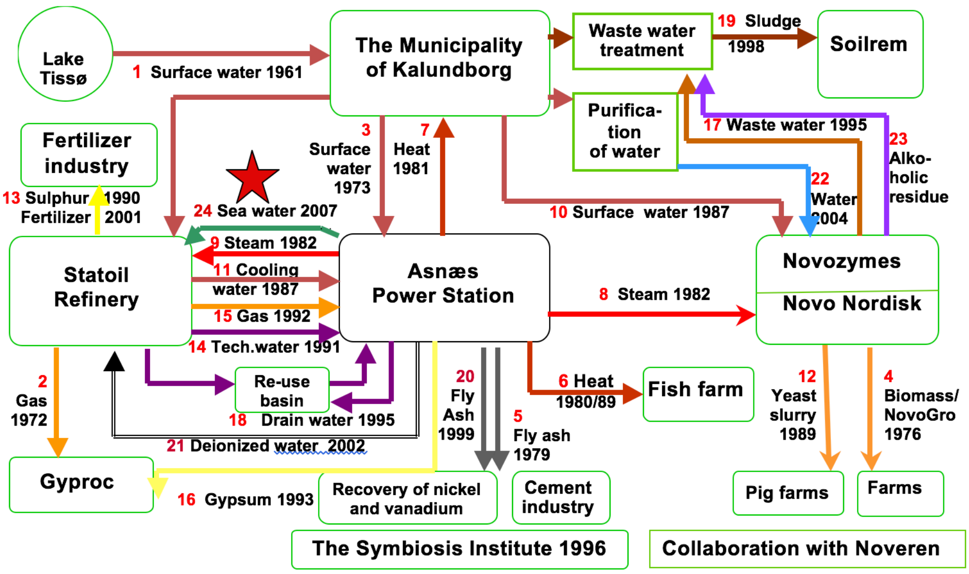
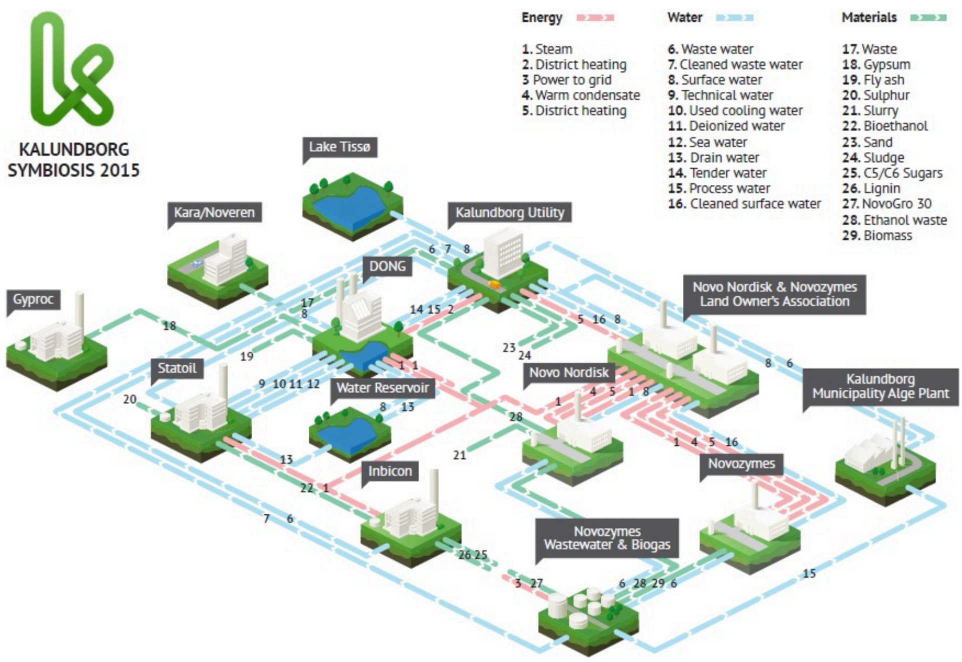


Figure 2: The Kalundborg Symbiosis (2015)



Source: Institute of industrial symbiosis (Kalundborg)

These symbiotic processes (12) involve surface water, cooling water and wastewater, but further down the supply chain the water is converted into steam (6 processes) and delivered as a high-energy product to the partners or as heat for the district heating system. Jacobsen considers that more than 50% of the Novo facility's energy input, and 4% of the refinery's energy input come from steam related symbiotic activities.

What have we learned from Kalundborg?

It seems reasonable to say that the industrial symbiosis exchanges at Kalundborg have some significant economic and environmental benefits[1], as a result of direct substitution, utility sharing and/or water/energy cascading. Beyond these benefits, it is interesting to understand and interpret the success of Kalundborg. Jorgen Christensen (2006), consultant to the Symbiosis Institute, reminds us that the success of industrial symbiosis exchanges depends greatly on the context[2] (history) and perspectives in which inter-firm arrangements are viewed. Industrial symbiosis is not regarded as an isolated environmental solution, but rather as part of a process of improving the total performance (environmental, economic, social, cultural) of individual companies as well as the collective organization.

Figure 3 : Evolution of the Kalundborg Symbiosis

Source : http://www.symbiosis.dk/en/evolution

[1] Some major benefits from exchanges of cooling water between the Asnae power plant and the refinery and some minor benefits by wastewater exchange between the same two companies.

[2] Costa and al (2010) argue that industrial symbiosis depends on an enabling context, which can be described in cognitive, structural, cultural, political, spatial and temporal embeddedness terms.

The Kalundborg Symbiosis began in 1961, when Statoil needed water for their refinery near Kalundborg. The first conduit pipes of the Kalundborg Symbiosis were laid between Statoil and the nearby lake, Tissø. In 1972, Statoil entered into an agreement with Gyproc, a local gypsum production enterprise, to supply Gyproc with excess gas from Statoil's production. Gyproc used the gas (today, natural gas) for the drying of the plasterboard produced in their ovens. The following year, 1973, Dong Energy (then, the Asnæs Plant) was connected to the Statoil water pipe, and what would later come to be known as the Kalundborg Symbiosis now had three partners. Over the years more and more businesses were became a part of the Kalundborg Symbiosis, and in 1989 the term 'industrial symbiosis' was used to describe this collaboration for the first time. If industrial symbiosis is closer to strong sustainability[3] (Diemer, Morales, 2016), its evolution evokes several questions: (i) How did this industrial symbiosis develop? (ii) Why precisely at Kalundborg? (iii) Why was the communication among actors effective?

Table 2: The reasons for the success of the Kalundborg Symbiosis

How did industrial symbiosis develop?	Why precisely at Kalundborg?	Why was communication effective among actors?	Important factors
• A "non-project" made by a "non-organization" • Not invented, but evolved over 3 decades • Not by one person, but by many • Projects were initiated independently • The name "Industrial Symbiosis" was not introduced until 1989 • After that, the "symbiotic consciousness" spread.	• The industrial potential existed : Several large industries Limited physical distances "A good fit" • The economic incentive existed • There were no legal barriers • Communication among actors was good.	• The size of the community • No competitors involved • Managers already acquainted • many in the same Rotary club • Open management style • (not secretive) • One project (steam) involved 4 partners.	• Participants must fit, but be different. • Projects voluntary plus environmentally and commercially attractive • There has to be a short physical distance between the participants. • There has to be a short mental distance between the participants. • Communication is more important than technology.

Source: Christensen (2006, p. 45-46-47-48)

[3] Lambert and Boons (2002) present two main difficulties in the development towards sustainability. First, it is relatively easy to achieve superficial, short-term social changes, but social actors have a tendency to fall back into their old patterns of behavior over the long term due to their embeddeness in an institutional context. Second, to ensure system change rather than system optimization, change needs to emerge from the existing system. Thus, all system actors need to be involved in the change process. Lambert and Boons suggest that in practice, change towards sustainability is particularly difficult to achieve in mixed industrial parks due to divergent interests of the involved actors, a lack of collective organizations and minimal experience with cooperation.

Five factors are at the origin of the success of Kalundborg: (i) the collaboration between different industries; (ii) the importance of market's solution; (iii) the short physical distance between the participants[4] (regional industrial ecology[5]); (iv) the willingness to work together and share values; (v) the good communication between the partners.

In the following pages, we will use the term "principles" to explain the success of Kalundborg. Five principles are necessary to produce a successful industrial symbiosis project: the differences principle, the economic principle[6], the geographical principle, the psychological principle and the communication principle. Beyond these principles, economic, environmental and operational facts seem to point out that the success of Kalundborg was related to a specific context. Costa and Ferrao suggest that a context favorable to the development of industrial symbiosis "*can be shaped through an interactive process wherein the government, industries and other institutions are guided towards aligning their strategies in support of collaborative business strategies in resource management*" (2010, p. 985). Domenech and Davies (2010) demonstrated that beyond the technical and economic feasibility of the exchanges in Kalundborg's model, social elements also play a crucial role in the development of an industrial symbiosis network. By social network, we mean the role of different members, the processes of information transfer, material exchange negotiation, trust building, and alliance formation (Domenech, Davies, 2009). It's also a methodology to study the patterns of relationships, interactions and social structure (Ashton, 2008). The analysis of the social structure and morphology of networks helps us to identify the conditions under which they operate and lead to reported outcomes. At Kalundborg, the industrial symbiosis network is characterized by the *type of transactions* (exchange of material waste flows, exchange of cascading water, cascading of energy, exchange of knowledge[7]), a *critical size* (six main companies), a *high degree of centralization* (a central role is played by the power plant[8] and most of the exchanges take place among centrally located actors, reducing transaction costs)

---

[4] Domenech and Davies (2010, p. 88) note that, « *The path distance is very small, which has contribued to a) reducing the transaction costs associated with the exchanges b) favouring the building of trust and commitment among members* ».

[5] Baas and Boon (2004) have developed a social science framework for investigating regional industrial ecology. A three-phase learning process is used to analyze the evolution of industrial ecology initiatives. The phases are called regional efficiency, regional learning and sustainable industrial districts. Each phase is associated with different governance mechanisms through which different types of collective competitive goods are produced.

[6] Industrial symbiosis is an expression of Business to Business. However, arrangements must be driven by both long-term and short-term direct and indirect considerations.

[7] The exchange of knowledge refers to an intangible exchange of know-how, leading to innovation. Mirata and Emtairah (2005) discuss industrial symbiosis networks from the perspective of innovation studies. They argue that industrial symbiosis networks can contribute to fostering environmental innovation at the local or regional levels by simulating the collective definition of problems, providing inter-sectoral interfaces, and promoting a culture of inter-organizational collaboration oriented towards environmental challenges.

[8] The Asnae power plant plays the greatest role of brokerage in the network.

and a *high density of linkages* (the flow of transactions contributes to an increase in the density of the network and favors the building of stronger relationships). The institutionalization of the network took place in 1996 when the different partners created the Symbiosis Institute (Christensen, 2006), a platform to share experiences and contribute to the identification of potential areas of collaboration.

We should note that all of these developments lead us to distinguish two levels of analysis of industrial symbiosis (Boons, Spekkink, Mouzakitis, 2011). First, we have the *level of the regional industrial system* which is associated with "*a more or less stable collection of firms located in proximity to one another, where firms in principle can develop social and material/energy connections as a result of that proximity*" (Boons, Spekkink, Mouzakitis, 2011, p. 907). At that level, we also find local governments and other actors (consumers, citizens, ONG…) that may become involved in efforts to increase the sustainability of the regional industrial system. Much of the industrial symbiosis literature describes, compares and analyzes cases where regional industrial systems of varying geographical sizes are either shown to develop increased connectiveness or plan to do so (Van Leeuwen and al, 2003 ; Heeres and al, 2004). Secondly, we have *the societal level*. Here we are not interested in the dynamic of the process that directly produces linkages among firms, but instead in the ways through which industrial symbiosis diffuses through the society. We refer here to institutional theory, which deals with the mechanisms that are responsible for the diffusion of a concept, innovation or idea among a set of organizations. Diffusion can be a result of transmission of a concept from one organization or individual to another, or by a process of selection through which organizations that do not use the concept are eliminated. DiMaggio and Powell (1983) distinguish a number of mechanisms of transmission, which can lead to the diffusion of organizational characteristics in an organizational field[9].

Boons, Spekkink and Mouzakitis (2011, p. 909) propose a list of transmission mechanisms : 1) *coercion* (an organization is forced to adopt a certain concept or routine by another organization that holds power over it); 2) *imitation* (organizations may adopt routines and concepts they see from similar organizations for reasons of status or because it provides a way of dealing with uncertain situations); 3) *private interest government* (a group or organizations may choose to collectively adopt a concept or routine voluntarily because of the threat of legislation if they remain inactive; 4) *demonstration projects* (policy actors may initiate experiments with new concepts and routines and actively spread the results of these under a label like 'best practice' to accelerate its diffusion; 5) *training and professionalization* (individuals may learn about new concepts and routines through education and subsequently begin to apply these in their work environment; 6) *altering boundary conditions* (actions to stimulate actors within a regional industrial system in order to self-organize). These

[9] A field is defined by the interaction among its members as a result of the fact that they mutually acknowledge being involved in similar or related activities.

mechanisms may play a role in the diffusion of industrial symbiosis concepts and routines throughout a society.

Industrial symbiosis - and more specifically these two levels, the regional industrial system and societal levels – refers to the effects of human activities on living organisms and their non-living environment (what we used to call *ecological impact*).

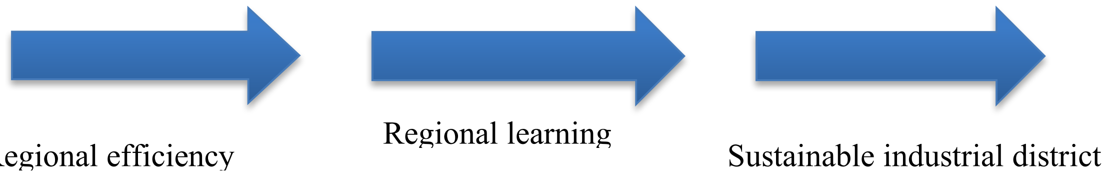
Industrial symbiosis – planned or self-organizing model?

Beyond the specificity of industrial symbiosis, an interesting question is whether industrial symbiosis exchanges can be viewed as solely market-driven arrangements that evolve spontaneously or whether the initiation of industrial symbiosis relationships requires something beyond pure market forces. In other words, does industrial symbiosis emerge spontaneously or can we plan it? Can we use the example of Kalundborg as a model for industrial symbiosis initiatives at other locations? Empirical research on industrial symbiosis seems to corroborate that attempts to plan eco-industrial parks have rarely come to fruition in a sustainable way. Gibbs (2003, 2005) studied 63 eco-industrials parks (30 in the US and 30 in Europe) and concluded that, "*Initiatives based upon the interchange of wastes and cascading of energy are few in number and difficult to organize.*" To understand this failure, Chertow (2007, p. 21) distinguished both a planned and a self-organizing model of industrial symbiosis. The planned model refers to conscious efforts to identify firms from different industries and locate them so they can share resources. Typical US planning for these systems has involved the formation of a stakeholder group of several actors to guide the process and the participation of at least one governmental or quasi-governmental agency with some powers to encourage development. A self-organizing model refers to industrial ecosystems that emerge from the decisions by private actors motivated to exchange resources for economic reasons. In the early stages there is no consciousness by participants of industrial symbiosis or inclusion in an industrial ecosystem, but this can develop over time.

Chertow argues that policy initiatives should be focused on the identification of industrial symbiosis and aid in its further development. That recommendation follows the USPCSD report's conclusions (U.S President's Council on Sustainable Development) that: "*Federal and state agencies should assist communities that want to create eco-industrial parks that cluster businesses in the same area to create new models of industrial efficiency, cooperation and environmental responsibility*" (1996, p. 104).

Boons and Berends (2001) and Baas and Boons (2004) present an important theoretical perspective suggesting how the emergence of industrial symbioses based on the exploitation of win-win situations among area firms could lead to a form of organization that embraces industrial development. Three stages are introduced. The first stage, *regional efficiency*, is described as autonomous decision-making by firms and coordination with local firms to decrease inefficiencies (utility sharing). The second stage, *regional learning*, is based on mutual recognition and trust: firms and other partners exchange knowledge and broaden the definition of sustainability on which they act. The third stage, sustainable industrial districts, shows further evolution towards a strategic vision and collaborative action rooted in sustainability.

Figure 4: Emergence of industrial symbiosis



Source: Baas and Boons (2004), Chertow (2007)

Chertow (2007, p. 23) notes that it's not clear that the third stage *sustainable industrial district* is coming any time soon nor that a strongly collective orientation will ever fully fit with the other imperatives of firms. Moreover, there have been planned developments, especially of single-industry dominated systems, that could successfully assemble core actors and organize benefits. Formal planning is much more institutionalized in countries such as China, Korea and Singapore. In the following section, we will examine the case of the Guitang Group in China.

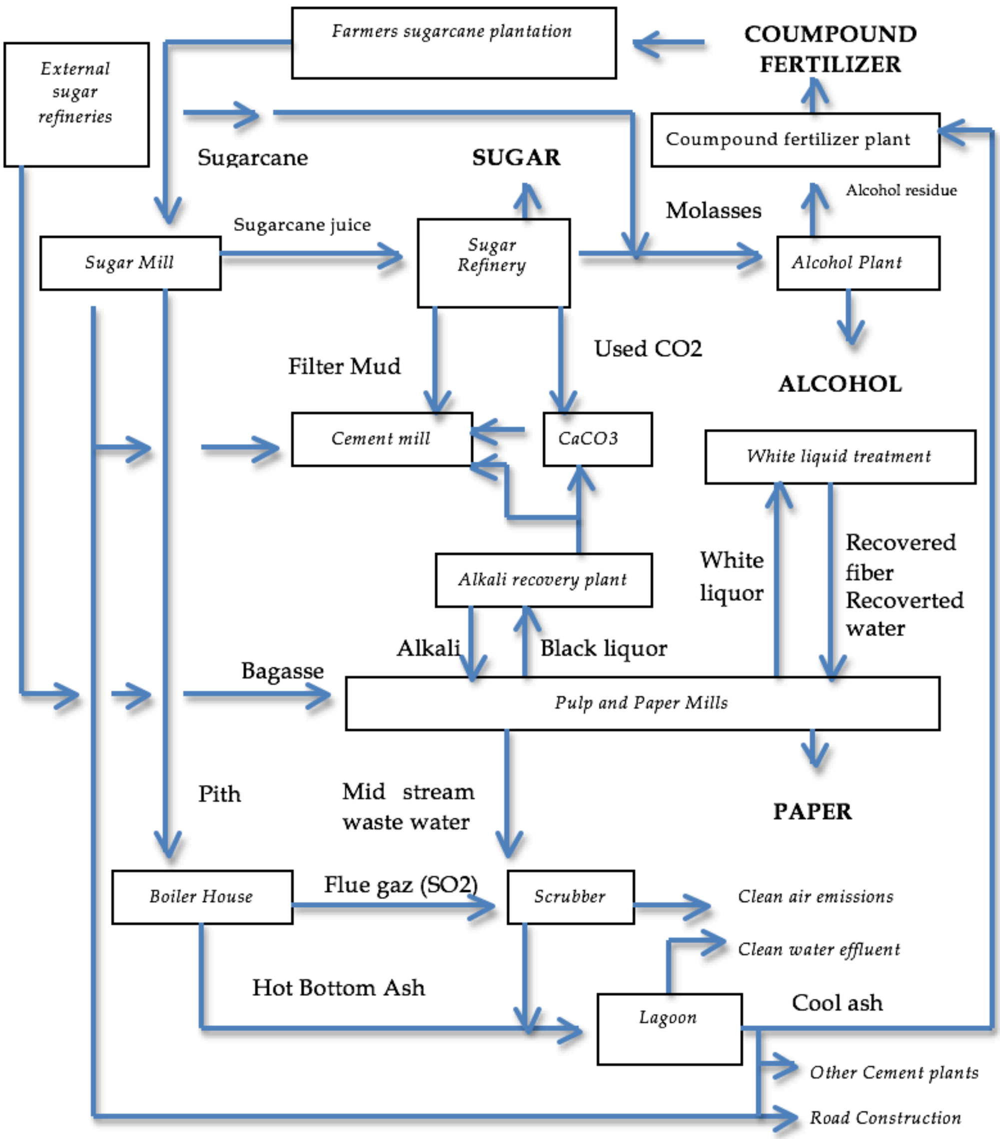
The Guitang Group is located in the Guangxi Zhuang Autonomous Region, which produces more than 50% of China's entire sugar output. Established as a State-owned company in 1956, the Guitang Group has a sugar refinery and an alcohol plant that uses molasses …. It has added three paper mills over the years, which use bagasse[10] as a raw material (Zhu, Côté, 2004). The industrial symbiosis practiced by the Guitang Group is both internal and external. The internal process can be described as follows (Zhu, Lowe, Wei, Barnes, 2007): sugarcane enters the sugar mill and is processed along one of two product chains: the sugar chain (containing the originally conceived sugar refinery and the alcohol plant) and the paper chain (containing the pulp and paper mills). The sugar chain results in the ultimate production of sugar, alcohol, cement and fertilizer. In the sugar refinery, the sugarcane juice that is released in the crushing and grinding assembly of the sugar mill is refined in a carbonation process that yields a higher-quality refined sugar. The filter mud (one of the wastes from the refining process) is used as an input for the production of compound fertilizer, which goes back to the sugarcane fields, thus closing the circle.

In addition to this internal symbiosis, the Guitang Group has built a network of external relationships including the government, customers, suppliers and competitors that affects the overall operation of the complex. The government plays an active role in the conducting of business and markets. The Guigang city government establishes a price floor that the company must agree to pay the farmers.

[10] Fiber residue from the crushing and grinding of raw sugarcane.

This direct price support provides greater incomes and security for the farmers, in line with the national policy of helping rural populations. Beyond the floor price, the city government uses other policies to manage the scale of sugarcane production and restrict the area in which the Guitang Group may buy sugarcane. The government acts as an intermediary between factories and farmers, seeking resolution of issues in matters such as price and quantity. The government also encourages local banks to provide no or low interest loans for farmers who have planted on a larger scale and provided employment opportunities to farmers whose lands have been purchased by larger scale farmers.

Figure 5: The Guitang Group's industrial symbiosis



Source : Zhu, Loe, Wei, Barnes (2007, p. 34).

All of these arrangements have set up a dynamic tension among the government, the farmers and the processers that motivates all parties to increase productivity and efficiency. Relations with customers are based on the quality of products (low levels of sulfur dioxide and color). The Guitang Group's higher quality of carbonation refined sugar, compared to competitors' sulfitation refined sugar, has enabled the Group to gain significant contracts with major soft drink companies, such as Coca-Cola and Pepsi-Cola. However, the Group's greatest market has been in paper manufacturing, which has become its major profit center. Relations with farmers are based on long-term contracts. The Guitang Group provides seeds and some organic fertilizer at a no-profit price, as well as technological support to sugarcane farmers in the area. The company helps farmers convert to organic production as a strategy for increasing competitiveness and profit margins.

In theory, industrial symbiosis should generate benefits. By choosing to approach its waste as a business opportunity, the Guitang Group has solved a traditional problem by using sludge as the calcium carbonate feedstock for a new cement plant. This new activity has allowed markets to better products that sell at a higher price and generate improved profits while reducing pollution. An investment in higher quality paper production based on bagasse and the decision to incorporate an alkali recovery plant have resulted in reduced input costs, reduced pollution and lower production costs.

Finally, Zhu, Lowe, Wei, and Barnes (2007) try to answer the question: "*Is the internal symbiotic model founded as it is on two production chains (sugar and paper) sufficiently robust to meet the challenge of sustained pressure on one or both of these chains*?" They note that the presence of two chains allows one chain (paper) to offset losses to the company if there is a downturn in the other (sugar). However, if the sugar refinery suffered a continuous loss over several years or more or if a plant met with market problems, it would be difficult to maintain the Guitang Group's overall economic performance.

Industrial symbiosis and European policy

The principle behind every example of industrial symbiosis appears to be quite simple: instead of being swept away (as pollution, contamination…), waste and surplus resources generated by an industrial process are captured and re-used as an input into/for another process (providing a mutual benefit to one or more companies or groups). Lombardi and Layborn (2012), argue that industrial symbiosis challenges the business world to operate in the same way as the natural ecosystem: "*Industrial symbiosis engages diverse organisations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes*" (Lombardi, Layborn, 2012, p. 28). We should add to that definition that industrial symbiosis becomes a strong sustainable model when it is able to manage the four following pillars: eco-efficiency, cooperation, resilience, and proximity (Diemer, Morales, 2016).

Eco-efficiency is associated with industrial metabolism. More precisely, it is a question of measuring quantitatively and qualitatively the physical dimension of economic activities, namely the flows and stocks of materials and energies inherent in all industrial activities. Within the companies themselves, this accounting is carried out by an input-output matrix (IOM) and a life-cycle analysis (LCA). These "environmental assessments" are used to control trade, and to determine the level at which they occur, how they are structured and how they destroy the environment. From an economic point of view, industrial metabolism includes all of the flows of matter and energy that enable the economic system to produce and consume.

Cooperation (and collaboration) remind us that while industrial symbiosis is linked to a market's value, it does not make competition a condition of efficiency. On the contrary, market relations within a system of symbiosis are based on synergies between the actors who prefer to foster collaboration in competition. The industrial ecosystem must draw inspiration from relationships between living beings in the natural ecosystem. The "strong" sustainability of symbiosis refers to a paradigm shift, a shift from a competitive economy to a collaborative economy. The first is an economic model based on exchange, the price value and a logic of optimization in terms of goods, services, time and knowledge between actors. The second is to design and produce solutions that integrate goods and services into two types of dynamics: (i) the shift from the sale of goods and services to genuine reflection on use-value; (ii) a systemic approach to take into account all externalities (environmental, social, political ...).

Proximity stipulates that an industrial symbiosis is predicated close to geographical nearness. The territory can be perceived as a functional space to translate local issues (waste reprocessing, water purification, de-pollution of industrial sites) and introduce the principle of proximity – space as transport cost, psychology as quality of product and subjectivity in relationships, communication as collaborative tools. The territory emphasizes the capacity of the actors to propose new forms of collaboration which can not only generate positive economic, environmental and social results, but can also, and above all, contribute to the resurgence of the collective interest among actors (Agenda 21). In a certain way, industrial symbiosis finds in territorial ecology a breeding ground capable of promoting a certain idea of sustainability (Buclet, 2016, 2011).

Resilience assumes that industrial symbiosis is part of a system of socio-ecological and socio-political interactions. Holling (1996) distinguishes two definitions of resilience (Martin, 2005). The first refers to stability close to equilibrium, resistance to disturbance, and time taken by a system to return to the neighborhood of equilibrium (Pimm, 1984). Holling (1996, p. 33) refers to this as "engineering resilience". The second definition highlights conditions far from any equilibrium in which instabilities can move the system towards another behavioral regime, that is, in another domain of stability (Holling, 1973). Resilience is measured by the maximum intensity of disturbances the system can absorb without changing structure, behavior or regulatory process. Holling refers to this as "ecological resilience ". Here, we retain this latter definition. Resilience implies analyzing the maximum disturbance an instance of symbiosis can bear without changing its operating system or organizational structure.

These four pillars (eco-efficiency, cooperation, proximity and resilience) refer directly to the interactions that develop within a symbiosis and position it within a framework of strong sustainability.

Recently, Europe developed European networks of support for industrial symbiosis and European innovation partnerships such as an international program (FISSAC) national programs (NISP in the United Kingdom), regional programs (Cleantech Östergötland in Sweden) and local programs (Dunkerque, France). The challenge is clear: the European economy requires a fundamental transformation within a generation – in energy, industry, agriculture, fisheries and transport systems, and in producer and consumer behavior.

The Europe 2020 Strategy and its flagship initiative on "A Resource Efficient Europe" have set the EU on the path toward this transformation. The flagship has called for a roadmap "to define medium and long term objectives and means needed for achieving them" (European Commission, 2011, p. 2). Industrial symbiosis is embedded "with the recommendation that opportunities to exploit resource efficiency gains through IS should be a priority for all member states" (Laybourn, Lombardi, 2012, p. 11). To boost efficient production, the European Commission considers that we could improve "*the re-use of raw materials through greater industrial symbiosis (where the waste of some firms is used as a resource for others) across the EU and could save €1.4 bn a year and generate € 1.6bn in sales"* (COM 2011, p. 6). The European Commission proposed that member *states "help companies to work together to make the best use of the waste and by-products they produce (e.g., by exploiting industrial symbiosis) (continuous)"* (ibid, p. 7).

In 2012, the European Commission's communication entitled "A Stronger European Industry for Growth and Economic Recovery" predicted that companies of tomorrow will apply highly energy and material efficient processes and increasingly adopt sustainable business models such as industrial symbiosis to recover materials, heat and energy…". It is assumed that these technologies will represent a significant business opportunity, with a global market that is expected to double in size to over €750 billion by 2020.

The European Commission's 2015 Communication "*Closing the Loop – An EU Action Plan for the Circular Economy*" was intended to promote innovative industrial processes such as industrial symbiosis: "*IS allows waste or by-products of one industry to become inputs for another. In its revised proposals on waste, the Commission proposes elements to facilitate this practice and will engage with Member States to help ensure common understanding of the rules on by-products*" (COM, 2015, p. 5). The European Union has supported such developments through its research and innovation programme Horizon 2020. Industrial symbiosis is definitely connected to the circular conomy: "*This initiative adds to a wide range of existing Horizon 2020 programmes supporting innovative projects relevant to the circular economy, in fields such as waste prevention and management, food waste, remanufacturing, the sustainable process industry, industrial symbiosis and the bioeconomy*" (COM, 2015, p. 18).

The EC's Factories of the Future (2014-2015) and "Waste: a resource to re-use, recycle and recovery raw materials" (2014-2015) calls were also focused on industrial symbiosis. In the Work Programme (2016-2017), the new "Cross Cutting Activities" focus area pushed industrial symbiosis into a priority area: (i) Systematic approaches for resource efficient water management systems in process industries (development of closed loop recycling and reuse, involving cascading of processes and industrial water symbiosis); (ii) Business models for flexible and delocalised approaches for intensified processing (deliver design constraints for new decentralised locations, which would position them, if applied, in industrial symbiosis); (iii) Sharing insights on innovative business model concepts for implementing resource and energy efficient solutions, including cradle to cradle and industrial symbiosis approaches; (iv) Assessment of standardization needs and ways to overcome regulatory bottlenecks in the process industry (IT control systems and plant monitoring systems facilitating industrial symbiosis, enabling of industrial symbiosis and better use of industrial resources); (v) Systemic, eco-innovative approaches for the circular economy (design for circular value and supply chain solutions should entail environmentally sustainable recovery, recycling and/or re-use of resources and energy flows, including by cross-sectorial symbiosis within the overall chain, from resources to marketed products).

European networks and case studies provide many examples of industrial symbiosis success stories.

The FISSAC (Fostering Industrial Symbiosis for a Sustainable Resource Intensive Industry across the extended Construction Value Chain) project[11] involves stakeholders at all levels of the construction and demolition value chain to develop a methodology and software platform to facilitate information exchange that can support industrial symbiosis networks and replicate pilot schemes at local and regional levels. The model is based on three sustainability pillars: environmental

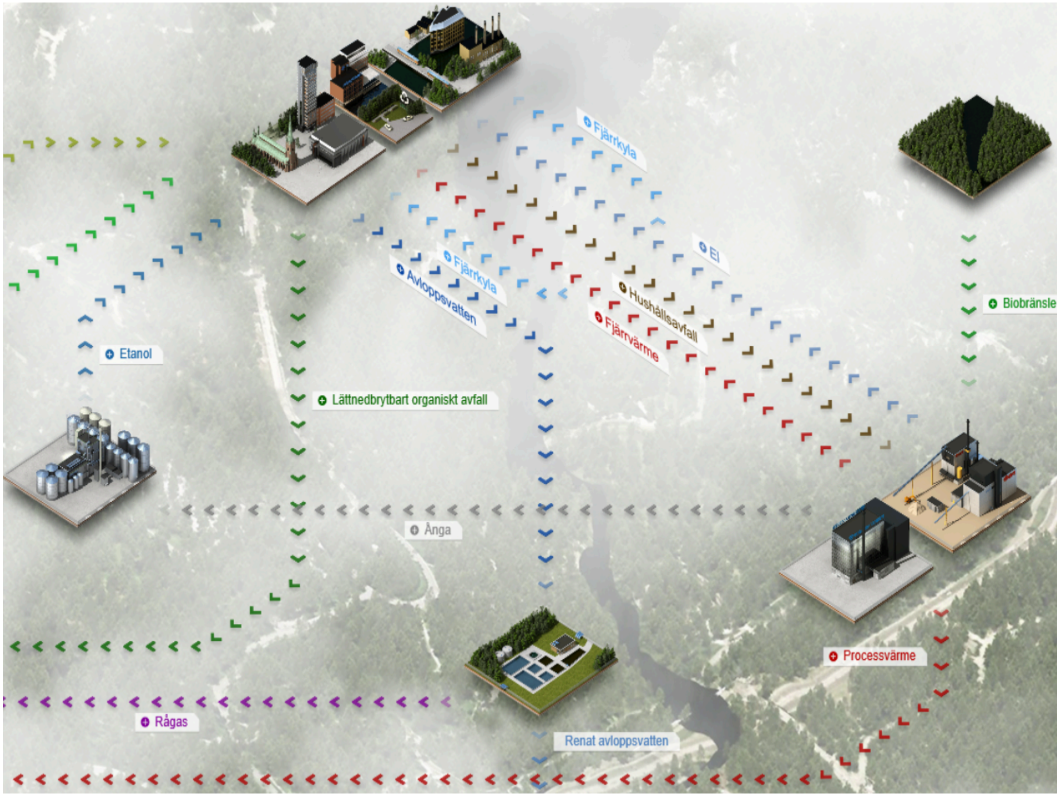
[11] The project runs from September 2015 until February 2020.

(Life Cycle Analysis, LCA), and economic and social (taking into consideration stakeholder engagement and impact on society). The FISSAC project is coordinated by *Acciona Construcción* (Spain). The consortium is composed of 26 partners from 9 countries (8 EU member states and Turkey) and includes general contractor and engineering/construction companies, non-profit research organizations, SMEs in different sustainable business fields, public authorities, manufacturing and energy intensive industry organizations, standardization and certification bodies, and local and regional sustainable resource management organizations.

In the UK, industrial symbiosis methods can identify reuse outlets for effluent or used-water supplies as well as new potential energy streams (the National Industrial Symbiosis Programme, NISP). Arla Foods, one of the UK's leading dairy producers, uses substantial volumes of water on a daily basis for washing equipment, which subsequently becomes contaminated and not fit for much. Instead of simply flushing it down the drain, Arla looked at the issue and was able to redirect the contaminated water to a nearby Severn Trent Water biogas plant where it is used as a 'new' input for the production process. In the North East of England, a nitrogen producer captures steam and CO2 generated as by-products of its manufacturing process. The steam is channeled to power a nearby vegetable plant and the CO2 reassigned and used to support the growth of fruits and vegetables within the plant.

In Sweden, Cleantech Östergötland is a non-profit organization that contributes to increased competitiveness and enhanced business opportunities for cleantech companies in Östergötland. Several companies offer products and services that contribute to a better environment, for instance by decreasing greenhouse gas emissions and emissions of nitrogen and phosphor. The proprietary, patented ORC-system (Organic Rankin Cycle) provides 20-2000 kW with short pay-back time. AQVIS Miljö AB offers products and solutions for noise barriers and surface water management, as well as landfills and management of contaminated materials. Deviaq's vehicle control system Deque creates value for customers from gathered vehicle data, providing opportunities to optimize transport flows, reduce transport costs and increase efficiency and productivity. Using eco driving, Deque reduces both CO2 emissions and fuel costs. Econova connects different actors and provides the basis for cross-industrial cooperation around flows of material and energy on a regional level. EC-Power is a consultancy company that delivers energy and high quality process solutions in the areas of engineering design, procurement, project management, surveys and energy efficiency. European Wenture Group/Miljöbolaget run environmental projects in all of Sweden focusing on sampling, water purification, decontamination of land, landfills, wet chemistry, freeze dredging, air scanning and soil treatment…

Figure 6 : Industrial symbiosis and circular flow in Östergötland



Source : http://cleantechostergotland.se/the-model/?lang=en

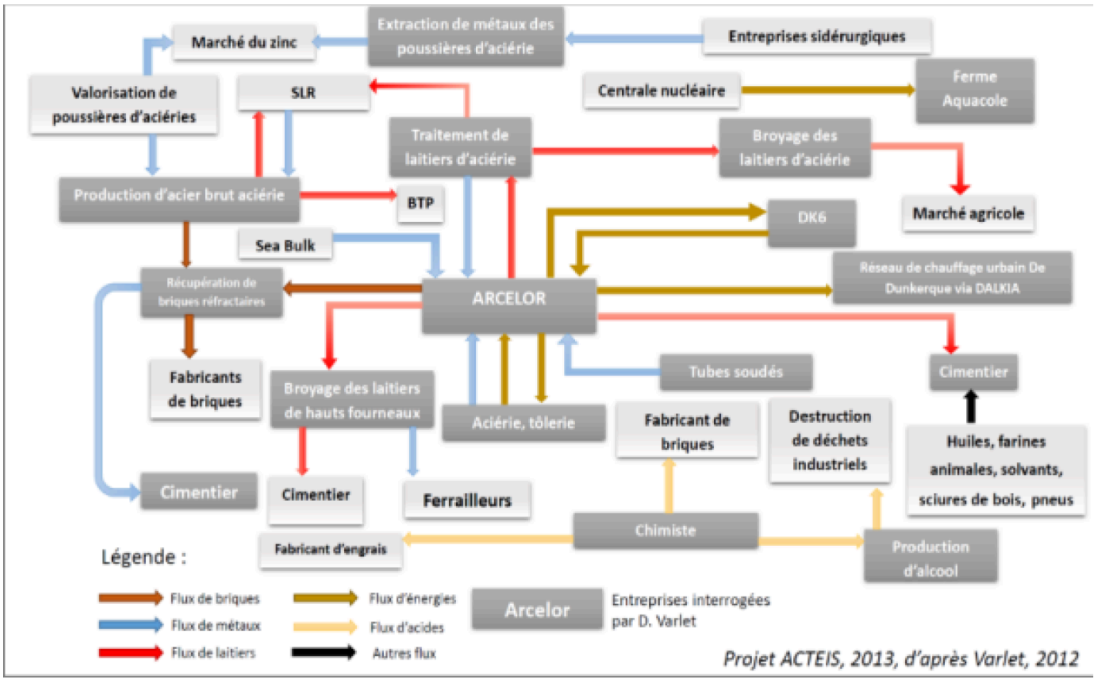
In France, industrial symbiosis is associated with the city of Dunkerque (Boutillier, Laperche, Uzunidis, 2015). Dunkerque is Europe's largest energy center, comprising the most powerful nuclear power plant in Europe (35.46 billion kWh in 2000), the gas terminal (Dunkerque Terminal DA), which exceeds Norway's equivalent of one third of the French consumption of natural gas (15 billion cubic meters per year), the largest unit of industrial gas production in France, a refining activity, the reception at the port of Dunkerque of more than 6 million tons of coal per year. DK6, the Gdf-Suez combined cycle power plant generates electricity through the recovery of ArcelorMittal's steel gases. The LNG terminal went into service at the end of 2015. In Dunkirk, there are also energy projects such as the district heating network, which makes it possible to heat public buildings through the recovery of steel gases, and The Petite Synthe Energy Improvement Center, which produces energy using household waste. The territory also hosts the Hydrogen Injection Network Management for Decarbonizing Energy (GRHYD) project, which aims to demonstrate the use of hydrogen as a mixture with natural gas for transport and buses and to provide heating for a new district of *Cappelle La Grande* (200 dwellings). The CUD is also a partner of the Innocold project, whose aim is to work on extreme cold applications (energy, naval, aeronautics, health, etc.).

Dunkerque's industrial symbiosis was born out of a joint initiative by the city of Grande Synthe and several companies located in the industrial area of Deux Synthe:

ArcelorMittal, Ascométal, and GDF. The work began with a preliminary study in 1999 on the of Grande Synthe industrial zone, which attempted to identify the interest in implementing an industrial ecology approach in the region. Following this, the Ecopal association was created. It has mainly developed mutualization synergies among companies around the collection of waste.

After several years of experience, Ecopal launched the IFIM (Inventory Study of Industrial Fluxes of Materials) project with the aim of (1) identifying the substitution and pooling flows existing in the industrial zone, (2) better understanding and quantifying these flows; (3) identifying existing good environmental practices.

Figure 7: The industrial symbiosis of Dunkerque



Source: Boutillier, Laperche, Uzunidis (2015, p. 105)

The inventory of the flows carried out on the territory of Dunkerque has made it possible to meet the expectations of the 150 companies, and industries have participated as partners in this project. Numerous axes of synergies and actions have been identified and have enabled ECOPAL to define a program of concrete and operational implementation. In 2009, a partnership project between the University of the Littoral Coast of Opal in Dunkerque (ULCO) and Ecopal was established to integrate modules of industrial ecology into initial training to develop research on the industrial environment. Figure 7 combines the existing synergies of substitution that have been established through the material flow exchanges between Dunkerque companies, namely by-products, residues, heat, brick flows, metals, slag streams, acid flows and energy flows.

All of these case studies make industrial symbiosis a more widespread commercial reality in managing the flow of material waste from different sectors and industries.

While Europe (H2020 research programs) encourages industrial innovation, numerous challenges still remain: (i) environmental and social impacts; (ii) harmonization of technologies, processes and policies; (iii) the commitment of civil society to a circular economy at the European level; (iv) information on waste resources; (v) waste treatment technologies; (vi) business models and coordination among value chain actors

Conclusion

If industrial symbiosis can recycle waste, share energy and create value, it seems that the case of Kalundborg's built on scarcity (the case of groundwater), opportunities (by-products used by new entrants), regulatory changes (reuse of organic products and the impetus to pursue flue gas desulfurization) and other locational advantages (including the port and the availability of industrial land). Two fundamental conclusions have gained acceptance concerning Kalundborg. First, the industrial symbiosis there emerged not from planning or a stakeholder process but from self-organization initiated in the private sector to achieve certain goals such as cost reduction, revenue enhancement, business expansion and securing long term access to water and energy. Symbiosis was not seen by outsiders because the exchanges emerged from the invisible hand of the market rather than through direct government policy. Second, once the revelation was made, a coordinative function was found to be helpful in organizing more exchanges and moving them forward. In Kalundborg, the Symbiosis Institute, launched in 1996, was the coordinative organization of the managers aimed at accelerating the number and complexity of exchanges. Several firms (Guitang Group in China, Kwinana in Australia) have tried to follow Kalundborg's example; however, their experiences show that it is very difficult to duplicate the pattern in other locations and achieve the same levels of environmental and economic performance.

References

ASHTON W. (2008), "Understanding the organization of industrial ecosystems", *Journal of Industrial Ecology*, vol 2, 1, p. 34-51.

AUSUBEL J.H, SLADOVICH H.E (1989), *Technology and Environment*, National Academy Press, Washington.

AYRES R.U, AYRES L.W (1996) «*Industrial Ecology: Towards Closing the Materials Cycle* » Edward Elgar.

BAAS L.W, BOONS F.A (2004), An industrial ecology project in practice: Exploring the boundaries of decision making levels in regional systems", *Journal of Cleaner Production*, 12, 8- 10, p. 1073 – 1085.

BECATTINI G. (2004), *Industrial Districts : A New Approach to Industrial Change*, Edward Elgar Publishing Williston, Vermont.

BECATTINI G., BELLANDI M., OTTATI G.D, SFORZI F. (2003), *From Industrial Districts to local Development: An Itinerary of Research*, Edward Elgar Publishing, Cheltenham.

BOONS F., SPEKKINK W., MOUZAKITIS Y. (2011), "The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review", *Journal of Cleaner Production*, vol 19, 9-10, p. 905 – 911.

BOONS F., BERENDS M. (2001), "Stretching the boundary: The possibilities of flexibility as an organisational capability in industrial ecology", *Business Strategy and the Environment,* 10, 2, p. 115-124.

BOURG D., ERKMAN S. (2003), *Perspectives on industrial Ecology*, Sheffield, Greenleaf Publishing.

BOUTILLIER S., UZINIDIS D., LAPERCHE B. (2015), *Le territoire entrepreneurial durable, Etude de cas de Dunkerque (Nord France),* Réseau de la Recherche sur l'Innovation (RRI), partie 1 et partie 2, Rapport Final.

BRINGS JACOBSEN N. (2006), « Industrial Symbiosis in Kalundborg, Denmark: A quantitative Assessment of Ecobomic and Environmental Aspects », *Journal of Industrial Ecology*, vol 10, n°1-2, p. 239 – 255.

BRINGS JACOBSEN N., ANDERBERG S. (2004), "Understanding the evolution of industrial symbiotic networks – the case of Kalundborg" in Van Den Bergh J. and Janssen M. (dir), *Economics of industrial ecology: Materials, structural change and spatial scale*, Cambridge, MIT Press.

BUCLET N. (2016), *Essai d'écologie industrielle, l'exemple d'Aussois en Savoie*, CNRS Editions.

BUCLET, N. (2011), *Ecologie industrielle et territoriale,* Septentrion.

CHERTOW, M., EHRENFELD J. (2012), « Organizing Self-Organizing Systems", *Journal of Industrial Ecology*, vol 16, 1, p. 13 – 27.

CHERTOW M.R (2007), "Uncovering Industrial Symbiosis", *Journal of Industrial Ecology*, vol 11, n°1, p. 11-30.

CHERTOW M.R (2004), "Industrial Symbiosis" in *Encyclopedia of Energy*, Cleveland C.J (ed), Oxford.

CHERTOW M.R (1999), « The Eco-industrial Park Model Reconsidered », *Journal of Industrial Ecology*, vol 2, n°3, p. 8-10.

CHRISTENSEN J. (2006), "The history of the industrial symbiosis at Kalundborg, Denmark", *IPTEH – UNIL, Workshop GSE*, Lausanne, November 30th, 49 p.

COSTA I., FERRAO P. (2010), "A case study of industrial symbiosis development using a middle-out approach", *Journal of Cleaner Production*, 18, p. 984–992.

COTE R., COHEN-ROSENTHAL E. (1998), "Designing Eco-industrial parks: A synthesis of some experiences", *Journal of Cleaner Production*, vol 6, p. 181-188.

COTE R.P., HALL J. (1995), "Industrial parks as ecosystems", *Journal of Cleaner Production, 3*, p. 41-46.

DIEMER A., MORALES M. (2016), "L'écologie industrielle et territoriale peut-elle s'affirmer comme un véritable modèle de développement durable pour les pays du Sud », *Revue Francophone du développement durable*, HS n°4, p. 52 – 71.

DIEMER A. (2016), « Les symbioses industrielles, un nouveau champ d'analyse pour l'économie industrielle », *Innovations*, n°50, p. 65 - 94.

DIEMER A., FIGUIERE C., PRADEL M. (2013). *Ecologie Politique Vs Ecologie Industrielle: Quelles stratégies pour le développement durable?* Editions Oeconomia.

DIEMER A., LABRUNE S. (2007), « L'écologie industrielle : quand l'écosystème industriel devient un vecteur du développement durable », *Développement durable et territoires*.

DOMENECH T., DAVIES M. (2010), "Structure and Morphology of Industrial Symbiosis Network: the Case of Kalundborg", *Procedia Social and Behavioral Sciences*, vol 10, p. 79 – 89.

DOMENECH T., DAVIES M. (2009), "The social aspects of industrial symbiosis: The application of social network analysis to industrial symbiosis network", *Progress in Industrial Ecology, An International Journal*, vol 6, n°1, p. 68 – 99.

EHRENFELD J.R, GERTLER N. (1997), "Industrial Ecology in Practice: The evolution of interdependence at Kalundborg", *Journal of industrial Ecology*, winter, vol 1, n°1, p. 67-79.

EHRENFELD J.R, CHERTOW M. (2002), "Industrial Symbiosis: The Legacy of Kalundborg" in R. Ayres (dir), *Handbook of Industrial Ecology*, Northampton, UK: Edward Elgar.

EHRENFELD J.R (2004), "Can Industrial Ecology be the 'Science of sustainability'?", *Journal of Industrial Ecology*, vol 8, n°1-2, p. 1-3.

EHRENFELD J.R (2005), « Eco-efficiency: Philosophy, Theory and Tools », *Journal of Industrial Ecology*, vol 9, n°4, p. 6 – 8.

ERKMAN S. (1997), «Industrial Ecology: An Historical View », *Journal of Cleaner Production*, vol 5, n°1-2, p. 1 – 10.

ERKMAN S. (2004), « *L'écologie industrielle, une stratégie de développement* », Exposé, Bruxelles, 9 p.

ESQUISSAUD P. (1997), « *Ecologie Industrielle* » Paris, Hermann.

ESTY D.C, PORTER M.E (1998), « Industrial Ecology and Competitiveness: Strategic Implications for the Firm », *Journal of Industrial Ecology*, vol 2, n°1, p. 35-43.

EUROPEAN COMMISSION (2016), *Draft Horizon 2020 Work Programme 2016 – 2017 in the area of Cross Cutting Activitie*s. Brussels, 123 p.

EUROPEAN COMMISSION (2015), Closing the loop – An EU action plan for the Circular Economy. Brussels, 2/12, COM (2015) 614 Final, 21 p.

EUROPEAN COMMISSION (2011), *Analysis associated with the Roadmap to a Resource Efficient Europe*. Brussel 20-09, SEC (2011à 1067 Final, 32 p.

EUROPEAN COMMISSION (2011), *Feuille de route pour une Europe efficace dans l'utilisation des ressources*. Bruxelles, 20/09, COM (2011), 571 Final, 31 p.

FROSCH R.A (1992), «*Industrial Ecology: A philosophical Introduction* », Proceedings of the National Academy of Sciences of the USA, vol 89, p. 800 – 803.

FROSCH R.A, GALLOPOULOS N.E (1992), « *Towards an Industrial Ecology* », p. 269 – 292, in Bradshow A.D, «The Treatment and Handling of Wastes » Chapman and Hall, London.

FROSCH R.A, GALLOPOULOS N.E (1989), «Strategies for Manufacturing », *Scientific American*, vol 261, Special Issue «Managing Planet Earth », September, p. 144 – 152). Traduction française «Des stratégies industrielles viables », *Pour la Science,* n°145, novembre 1989, p. 106 – 115.

GIBBS D.C, DEUTZ P., PROCTER A. (2005), "Industrial ecology and eco-industrial development: A new paradigm for local and regional development?", *Regional Studies*, 39, 2, p. 171-183.

GIBBS D.C (2003), "Trust and networking in interfirm relations: The case of eco-industrial development", *Local Economy,* 18, 3, p. 222-236.

HEERES R.R., VERMEULEN W.J.V., DE WALLE F.B. (2004), « Eco-industrial park initiatives in the USA and the Netherlands: first lessons", *Journal of Cleaner Production* vol 12, p. 985-995.

HOLLING C. (1996), « Engineering Resilience versus Ecological » in Schultze P. (dir), *Engineering within Ecological Constraints, National Academy of Engineering*, p. 31 – 43.

HOLLING C. (1973), « Resilience and stability of ecological systems », *Annual Review of Ecology and Systematics,* vol 4, p. 1 – 24.

KORMONDY E. J. (1969), *Concepts of Ecology*. Englewood Cliffs, N.J, Prentice-Hall, Inc.

LIFSET R. (2006), "What Next for Industrial Ecology?", *Scientific Workshop 'Frontiers of Research in Industrial Ecology'*, University of Lausanne, November 27 – December 1th, 17 p.

LOEWE E.A (2001), "Eco-industrial handbook for Asian Developing Countries", Report to the Environment Department, Asian Development Bank.

LOEWE E.A (2005), "Defining eco-industrial parks: The global context and China", *Environmental Protection Administration*, China.

LOMBARDI D.R, LAYBOURN P. (2012), « Redefining Industrial Symbiosis", *Journal of Industrial Ecology*, vol 16, p. 28 – 37.

MARSHALL A. (1919), *Industry and Trade, Mac Millan*, New York.

MARTIN S. (2005), *La résilience dans les modèles de systèmes écologiques et sociaux*, Thèse de Doctorat, Mathématiques Appliquées, Ecole Normale Supérieure de Cachan, 198 p.

MIRATA M., EMTAIRAH T. (2005), "Industrial Symbiosis Networks and the contribution to environmental innovation – the case of Landskrona industril symbiosis programme", *Journal of Cleaner Prodution*, vol 13, 10-11, p. 993 – 1002.

PECK S. (2001), "When is an Eco-Industrial Park not an Eco-Industrial Park?", *Journal of Industrial Ecology*, vol 5 , n°3, p. 3-5.

PIMM S. (1984), « The complexity and stability of ecosystems », *Nature*, vol 307, p. 321-326.

POWERS C.W., CHERTOW M.R. (1997), « Industrial Ecology », in M.R. Chertow, D.C. Esty (eds) *Thinking Ecologically*, New Haven, Yale University Press, p. 19-36.

SCHULZE P. (1996), *Engineering with Ecological Constraints*, National Academy Press.

TADDEO R., MORGANTE A., ERKMAN S. (2017), "The development of industrial symbiosis in existing contexts. Experiences from three Italian clusters", Ecological Economics, vol 139, p. 55 – 67.

THE GUITANG GROUP (2004), *Brochure of the Guitang Group*.

TILLEY D.R (2003), "Industrial Ecology and Ecological Engineering: Opportunities for Symbiosis", *Journal of Industrial Ecology*, vol 7, n° 2, p. 13-32.

USPCSD (1996), *Sustainable America: A new consensus for prosperity, opportunity, and a healthy environment for the future*, Washington, US Government.

VAN LEEUWEN M.G., VERMEULEN W.J.V, GLASBERG P. (2003), Planning eco industrial parks: an analysis of Dutch methods", *Business Strategy and the Environment* 12, p. 147-162.

WALLNER H.P, NARODOSLAWSKY M., MOSER F. (1996), "Islands of sustainability; A bottom-up approach towards sustainable development", *Environment and Planning*, Vol 28, n°10, p. 1763 – 1778.

WELLS P., ORSATO R.J (2005), "Redesigning the Industrial Ecology of the Automobile", *Journal of Industrial Ecology*, vol 9, n°3, p. 15-30.

ZHU Q., LOWE E.A, WEI Y.A, BARNES D. (2007), "Industrial Symbiosis in China", *Journal of Industrial Ecology*, vol 11, n°1, p. 31-42.

ZHU Q.H, GENG Y. (2002), "Integrating environmental issues into supplier selection and management: a study of large and medium sized state owned enterprises in China", *Greener Management International*, vol 35, p. 27 – 40.

ZHU Q.H, COTE R.P (2004), "Integrating green supply chain management into an embryonic eco-industrial development: A case of study of the Guitang Group", *Journal of Cleaner Production*, vol 12, p. 1025 – 1035.

Progress in Education for Sustainable Development: Improving Learning Using System Dynamics

Conor MEEHAN, Therese BENNICH, David COLLSTE

Loop Consulting, Dublin
Department of Physical Geography, Stockholm University
Stockholm Resilience Centre, Stockholm University

Today's society is faced with a large number of inter-related challenges, including climate change, biodiversity loss, inequality, poverty, and resource scarcity (Steffen et al., 2015; Raworth, 2012). In the process of addressing these issues, education for sustainable development has become increasingly recognized and put at the core of development agendas on global, regional and national levels (EU, 2010; UN, 2015). Education for Sustainable Development aims to provide citizens with the knowledge, values, and skills necessary to shape a more sustainable future (EU, 2010). Teaching these complex and large-scale issues may, however, be challenging. A main obstacle in the field has been to create an in-depth understanding of the integrative nature of sustainability issues, which includes both natural and social sciences. In order to educate a new generation of sustainability leaders and citizens in the EU and elsewhere, we believe there is a need to create innovative models for learning that emphasize systems thinking and the use of participatory methods.

This article presents a module for education for sustainable development, addressing common challenges faced by educators in different settings. It was developed in a collaboration between Loops Consulting and The Sustainability Laboratory, a US-based non-profit seeking to address urgent sustainability issues facing the planet. Grounded in The Sustainability Lab's Five Core Principles of Sustainability, sustainability science and systems thinking, the module makes use of tools such as System Dynamics and educational technology. System Dynamics enables the discovery and understanding of endogenous sources of complex system behaviour, which we consider useful in explaining sustainability concepts such as carrying capacity, entropy, and circular economy. The aim of the module is to provide a hands-on tool for teachers and students concerned with sustainability issues, and to make a contribution to the discussion on new models for education for sustainable development. The module was designed with third level students in mind, however we believe it is useful for anyone from secondary school and upwards seeking to learn more about sustainability concepts and System Dynamics.

Theoretical background: Sustainability Principles and System Dynamics

This part outlines the basis for the education module - The Sustainability Lab´s definition of sustainability and guiding framework, the System Dynamics methodology, and online tools used for educational purposes.

The Sustainability Lab's Sustainability Framework

To counteract what The Sustainability Lab believe is a growing ambiguity in the use of the term 'sustainable development' and 'sustainability', they offer a new and more rigorous definition of sustainability, focusing on the relationship between the population and the carrying capacity of its environment. As a means to achieve this defined state of sustainability, they also offer Five Core Principle of Sustainability, which are described in relation to five fundamental domains that are 'the primary dimensions of the population-environment interaction' (Ben-Eli, 2015). These domains are the Material Domain, the Economic Domain, the Domain of Life, the Social Domain, and the Spiritual Domain. Each domain then has a related principle, stated in a general way but intended to be operationalized in different contexts – applicable to for instance the various sectors of the economy, investment decisions, and individual decision making. We see this framework as exploratory and complementary to other definitions of sustainability and sustainable development. The Sustainability Lab's Domains and Principles are presented in Box 1.

Box 1: The Sustainability Lab's approach to Sustainability

Sustainability is defined as: "a dynamic equilibrium in the process of interaction between a population and the carrying capacity of its environment such that the population develops to express its full potential without producing irreversible, adverse effects on the carrying capacity of the environment upon which it depends".

The Five Domains and Related Principles

The Material Domain

This domain is concerned with the principles of regulating flows of materials and energy.

The First Principle

Entropy should be contained, aiming to ensure that resources are *as nearly non-declining as is permitted by physical laws*. Examples of policy implications include ensuring maximum resource productivity and closed loops of energy and matter.

The Economic Domain

This domain provides a guiding framework for how to understand, create, and manage wealth.

The Second Principle

An accounting system for the economy should be adopted, fully aligned with ecological processes. The policy and operational implications include employing a comprehensive concept of wealth, and incorporating externalities in cost and benefit accounts.

The Domain of Life

This domain relates to the guidance of interactions of different forms of life in the biosphere.

The Third Principle

All essential forms of biodiversity and life in the biosphere should be maintained. For policy, this implies conservation of the existing gene pool and enhancing biodiversity.

The Social Domain

This domain provides the basis for social interactions.

The Fourth Principle

Freedom and potential self-realization should be maximized, without any individual or group adversely affecting another. Practical implications include establishing cooperation as a basis for governing planetary commons and addressing global issues.

The Spiritual Domain
This domain focuses on ethical and attitudinal orientations.

The Fifth Principle

This principle recognizes the link of mystery, wisdom, love, energy, and matter between the biosphere, the planet, and the solar system. The principle highlights the need to embody a universal ethics, to guide human action. Operational implications include acknowledging the "transcendent mystery underlying existence", and to foster compassion.

For more information, see:

http://www.sustainabilitylabs.org/approach/

System Dynamics for Educational Purposes

A system may be described as a set of things that are interconnected in such a way that they produce their own dynamics. Although the system may be affected by the behaviours of things that are outside the system's boundaries, the system's response to these is characteristic of itself (Meadows, 2008; Forrester, 1969). System Dynamics uses maps and computer models as simplified representations of systems in order to explore and learn about real systems. The ultimate objective of a System Dynamics exercise is typically to improve system behaviour. System Dynamics has its origin in the works of Jay W. Forrester (1918-2016) and has been a very influential method in sustainability science by the Club of Rome publication of *The Limits to Growth* (Meadows et al., 1972; 2004). A significant feature of System Dynamics modelling is the focus on behavioural patterns rather than point predictions. System Dynamics modelling may have different purposes, including prediction, performance, training, entertainment, education, proof and discovery (Axelrod, 2003). Exercises may range from being very applied and practical to being more theoretical and abstract, and the use and application of data follows the purpose of the exercise.

Our purpose is to use System Dynamics to educate and present sustainability principles on a conceptual level. Thereby, there are in most of our cases no corresponding real world data – and if there were it may not have assisted in increasing the understanding of the sustainability principles. However, in more narrow and concrete real world policy making, such as in the development of government policies or business strategies, a system dynamics exercise is generally more data intensive.

Other online tools

This module is not the only example of using System Dynamics in an online context for education for sustainable development. There are several examples on the iseesystems website[1] which also unravel System Dynamics simulation models in a step-by-step manner, and many of these models are dealing with issues related to sustainability (such as ecosystem management, for example). Additionally, there are several online role-playing games that use System Dynamics models in order to simulate the impacts of certain decisions in different environments. The Fish Banks game, developed by Dennis Meadows and made available in an online format by MIT, is an example of this (Meadows et al, 2016). However, many of these games do not show the user the model that is being used to generate the outcome of their decisions. We believe this is a shortcoming in the sense that without understanding the model that produces this behaviour, students are less likely to internalise the messages found therein.

The Creative Learning Exchange has created a range of models and most recently apps that are designed to teach certain subjects, many of which are related to sustainable development. The target audience for this material is k-12 students in the United States. Additionally, System Dynamics has been used to teach sustainability topics in many areas of third level education. Universidade Nova de Lisboa in Portugal teach a module that uses System Dynamics as a medium for discussing many issues related to sustainable development. However, we are not currently aware of any education material that uses System Dynamics for third level education for sustainable development and which is freely available online. We hope that this module will fill this gap and allow third level students to develop their interest and skills in the use of modelling for education for sustainable development, no matter where they are located and what their financial situation is.

[1] http://xmile.iseesystems.com

The Result: An Online Education Module

In this section, we give a brief description of each of the eight exercises contained in the module. The module is freely available online, and can be used by anyone by using the following link:

https://loopsconsulting.kumu.io/sustainability-definition-5-core-principles

Exercise 1 serves as a brief introduction to System Dynamics, whereby the user learns about the kind of problems that system dynamics deals with, and why this particular methodology has been chosen as an aid to understanding some of the ideas found in The Sustainability Lab's framework. The exercise also allows the user to familiarise themselves with the fundamental building blocks of System Dynamics models (stocks and flows), and a simple model is built so that the user can see how the System Dynamics simulation software works.

In Exercise 2, we focus on increasing understanding of The Sustainability Lab's definition of sustainability, by demonstrating the meaning of the definition and its two clauses - namely, that the population is allowed to reach its full potential, and that it does not irreversibly harm the carrying capacity of its environment in doing so. These conditions are demonstrated through the construction and simulation of a model of an imagined population stranded on a resource constrained island. This island serves as an analogy to Earth.

Through building the model, the user is introduced to concepts such as carrying capacity, resource sufficiency (which is taken as a simple proxy for human wellbeing), and dynamic equilibriums. At the same time, the user is introduced to new System Dynamics concepts not found in Exercise 1, such as reinforcing and balancing feedback loops, and the use of equations and look-up functions to represent relationships between variables in the model.

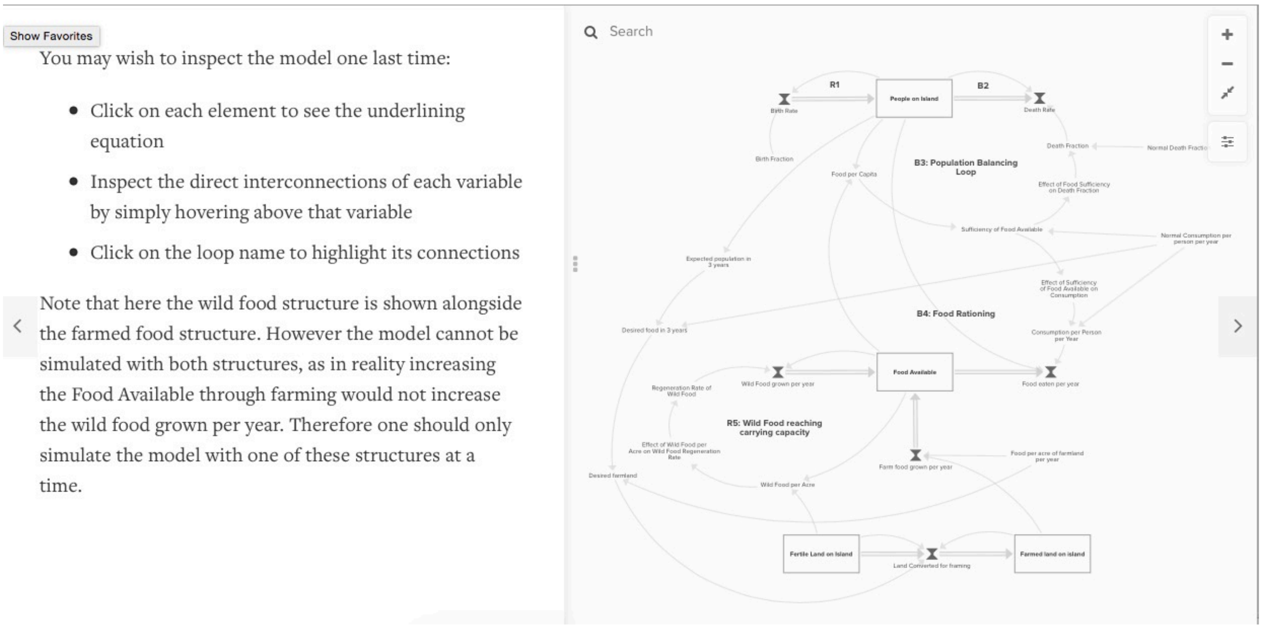
The user is brought through a step-by-step development of the model, and we simulate the model with different structures - first with no carrying capacity, then with a static carrying capacity (represented in a simplified manner by food available), then with a dynamic but self-reproducing carrying capacity (represented by wild food) and finally with a dynamic but human-controlled carrying capacity (represented by farmed food). For each simulation, the user is asked to use a pen and paper to sketch their own guess of how the population will develop over time. This is done for every simulation in the module, with the hope that it will develop the user's ability to infer dynamic behaviour arising from the structure.

An image of the model used for this exercise (taken from the module) is seen below:

Figure 1: a screenshot of a model from the module

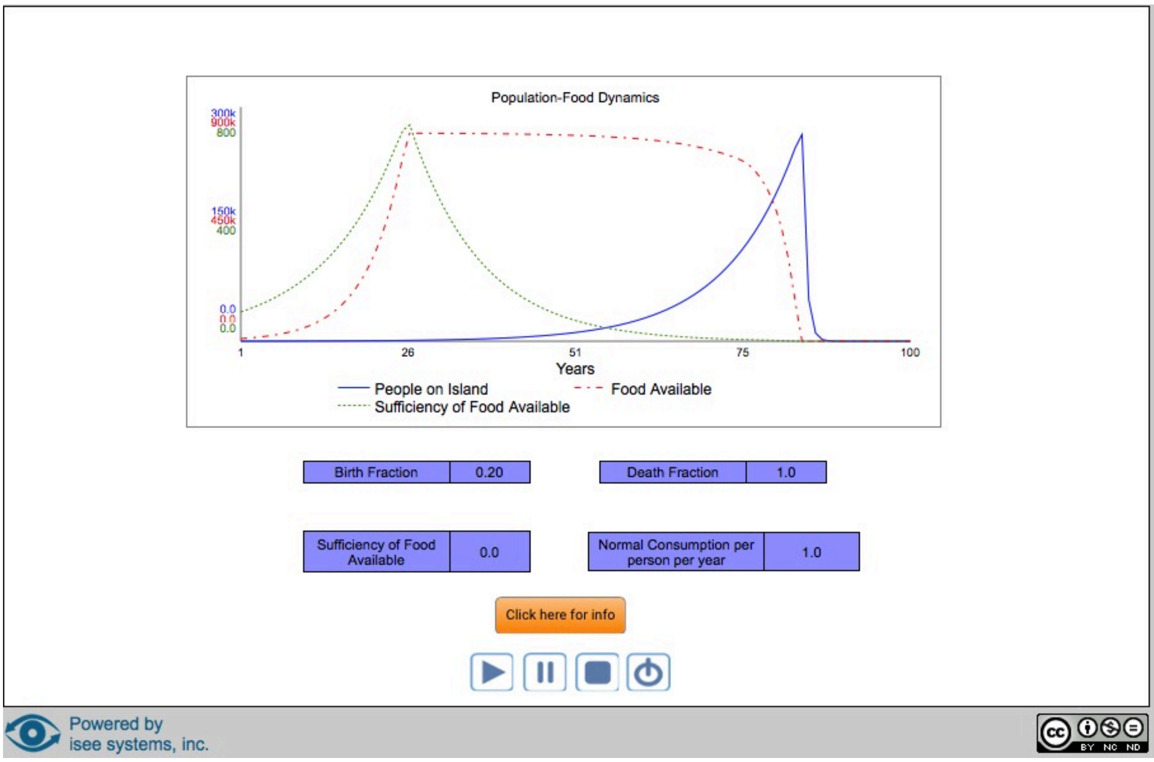
Figure 2: a screenshot of a model from the module

Figure 1 : A screenshot of a model from the module



An image of the simulation result for the self-reproducing carrying capacity structure of the model can also be seen below:

Figure 2: A screenshot of a simulation result from the module



The reasons for this result are discussed in detail, in terms of the changing dominance of different feedback loops over time.

Limitations of the model are then noted and some are justified, such as the use of arbitrary numbers and the lack of representation of any of the effects of pollution.

In the next five exercises, Exercises 3A, 3B, 3C, 3D, and 3E, we deal with the topic of The Sustainability Lab's 5 Core Principles of Sustainability. The main aim of each of these exercises is to increase understanding of each of the principles. This means both increasing understanding of the logic behind each principle (i.e. why does The Sustainability Lab have this as a principle of sustainability?), as well as increasing understanding of the operational and policy implications of each principle (i.e. what does application of this principle look like?). The ultimate aim of all of this, however, is not just an intellectual understanding of the principles. Indeed, the ultimate goal of the principles themselves is not the prescription of a set of rules to be followed, but rather to provide a systemic and rigorous framework in which people can ground their understanding of some of the most important aspects surrounding the concept of sustainability, and maintain an awareness of its interdisciplinary nature.

Exercise 3A, which deals with the principle relating to the material domain, demonstrates the laws of conservation of energy and mass, and the law of increasing entropy (such laws are also known as the first and second laws of thermodynamics) and discusses their policy implications. A small System Dynamics model is used to explain some of the concepts in this domain, although in general the System Dynamics methodology was not relied upon to the same extent as in the other exercises.

Exercise 3B deals with the principle relating to the economic domain. The main goal of this exercise is to show how alternative ways of accounting for wealth creation and incentivising the creation of wealth can lead to a more sustainable relationship between a population and its environment. In terms of accounting for wealth creation, we use a System Dynamics model to demonstrate how GDP can be very misleading in how it accounts for the creation of wealth, even in purely materialistic terms. And in terms of incentivising new ways of creating wealth, we look at how imposing a cost on natural resource depletion and environmental pollution can incentivise the use of renewable energies as well as the establishment of the circular economy and the products-as-a-service economy. Finally, we discuss the importance of incorporating a measure of wellbeing in economic calculations, and provide some examples of recent efforts to achieve this.

Exercise 3C deals with the principle relating to the domain of life. We begin by discussing the importance of nature and biodiversity for human wellbeing, in terms of direct and indirect ecosystem services that it provides, as well as its aesthetic or spiritual value. We then move on to show a less obvious benefit of biodiversity in particular - ecosystem resilience. To demonstrate this, we take an example from the coral reefs in Jamaica, where overfishing in the 1960’s eventually contributed to an algal bloom that occurred in the 1980’s. We use a System Dynamics model to demonstrate how there can be a cause and effect relationship between these two events that happened two decades apart. The overall aim of this model is to demonstrate the way in which biodiversity increases ecosystem resilience, by modelling the interdependence between organisms in a complex ecosystem. An image of the model is seen below.

The exercise also discusses the economic implications of overfishing, demonstrating the fact that sustainable fishing methods may have produced smaller catches in the short term, but allowed for much larger catches in the long term. This in turn results in greater health for coral reefs and other ecosystems, as well as greater economic wellbeing for the fishing industry and its customers over the long run. This point is driven home through a simulation of the model that tracks the total fish caught over the whole simulation period.

Exercise 4C deals with the principle relating to the social domain. This exercise discusses some of the theories that drives the logic of the principle, such as human fallibility, which implies that no one group or individual has the right to impose their beliefs on others. It also introduces the user to the use of Causal Loop Diagrams (CLDs), which are essentially the qualitative version of a System Dynamics simulation model. This type of diagrams is then put to use by constructing a CLD of the social dynamics of two individuals or groups that each seek to reach their own self-determined goal. The diagram serves to clarify the dynamics that can reinforce the desired or undesired nature of social relationships (whether those be between individuals or groups).

This exercise also discusses The Sustainability Lab’s idea of how recent studies support the hypothesis that human nature is not fixed towards any particular type of behaviour but is actually more malleable. In other words, The Sustainability Lab argues that humans can nurture a better nature.

Exercise 5C discusses the principle relating to the spiritual domain. The goal is for the user to understand the principle as a perspective proposed by The Sustainability Lab which could inspire people towards wanting to achieve a state of sustainability on the planet. The perspective also acts as a basis upon which a universal code of ethics could be formed.

In the final exercise, Exercise 4, we discuss The Sustainability Lab’s idea of how achieving sustainability requires an approach that addresses each domain simultaneously, and that each domain affects the others and is affected by each in return. In other words, we discuss how the achievement of sustainability requires a systemic approach, whereby emphasis on one domain without emphasis on the other is unlikely to achieve effective and long-lasting results.

Conclusion

We have designed an education module to create better understanding and comprehension of sustainability principles. We believe the module may assist in:

- Visualising how each part of the Earth system fits into a bigger whole. This helps us to keep the bigger picture in mind. By simulating the different model structures presented, the user gets the chance to reflect upon the relationships between the causal structure of the model and the resulting behaviour. Similarities between the model and the real world are then used to learn about sustainability in the real world.

- Thinking about the long-term implications of certain decisions and ways of living related to sustainability. The simulations help us explore the principles and their policy implications for long-term trends.

- Making theories explicit through the use of maps and simulation models. This is less ambiguous than writing about such theories.

Potential future developments include making the module more interactive, to allow students to gain further modelling skills and the ability to create System Dynamics models on their own. In order to let the users more fully develop skills in System Dynamics, the module may be complemented with other online tools such as games or exercises that assist the user in learning how to build a model from scratch. We may also facilitate web based or real life workshops with the module as a starting point, to further assist learning and explore the usefulness of System Dynamics in this context.

References

AXELROD R. (2003), "Advancing the Art of Simulation in the Social Sciences", *Japanese Journal for Management Information Systems* 12(3), p.1–19.

BEN ELI M. (2015), *Sustainability: Definition and Five Core Principles.*

EU (2010), *Council conclusions on education for sustainable development.*

FORRESTER J. W. (1969), *Urban Dynamics,* Massachusetts: Pegasus Communications.

MEADOWS D. (2008), *Thinking in Systems: A Primer,* Chelsea Green.

MEADOWS D., STERMAN J., KING A. (2016), *Fishbanks: A Renewable Resource Management Simulation*

MEADOWS D., MEADOWS D., RANDERS J., BEHRENS III W.W. (1972), *The Limits to Growth: A Report for THE CLUB OF ROME'S Project on the Predicament of Mankind*, New York: Universe Books.

MEADOWS D., MEADOWS D. and RANDERS J. (2004), *Limits to Growth: The 30-Year Update,* Chelsea Green.

RAWORTH K. (2012), "A safe and just space for humanity: can we live within the doughnut", *Oxfam Policy Pract. Clim. Change Resil.* 8, p. 1–26.

STEFFEN W., RICHARDSON K., ROCKSTRÖM J., CORNELL S.E., FETZER I., BENNETT E.M., BIGGS R., CARPENTER S.R., VRIES W. de, WIT C.A. de, FOLKE C., GERTEN D., HEINKE J., MACE G.M., PERSSON L.M, RAMANATHAN V., REYERS B., SÖRLIN S. (2015), *"Planetary boundaries: Guiding human development on a changing planet"*, Science, vol 347.

UN (2015), *Transforming our world: the 2030 Agenda for Sustainable Development.*

Role-play and the discussion of the controversial issues during teacher training: teaching practices in favor of a Sustainable Development?

Elisabete LINHARES, Pedro REIS

Instituto Politécnico de Santarém – Escola Superior de Educação, Campus Andaluz _UIDEF, Instituto de Educação, Universidade de Lisboa, Portugal.
Universidade de Lisboa, Instituto de Educação, Alameda da Universidade, 1649-013 Lisboa,

In order to respond to current challenges, typical of a society that is constantly changing and deeply marked by advances in science and technology, in the most recent curricular documents there is a philosophy that emphasises the formative and personal and social development aspects, as well as the interaction Science-Technology-Society-Environment (CTSA). In an open and democratic society, the education in sciences is particularly important in the training of citizens capable of participating actively and responsibly in the discussion or resolution of scientific and technological problems (Cachapuz, Praia, Jorge, 2004). The knowledge and understanding of science and technology and their role in our daily life enable individuals to get involved and understand the discussions about these issues, as well as their social implications. The valuation of a scientific education is evidenced in the PISA – *Programme for International Student Assessment* – study, launched by the organization for Co-operation and Economic Development (OCDE), in 1997, and whose main objective is to access the ability of 15 years old young people to use their skills (defined according to PISA) towards real life challenges. In the PISA report (OECD, 2006) special attention was given to scientific literacy. This focus on various issues related to science comes from the recognition that the individuals face daily with a large number of situations, problems and questions that require, in fact, some understanding of science and technology.

The Education in sciences also refers to the promotion of environmental values. Within the framework of the decade of Education for Sustainable Development (DEDS) (2005-2014), it is possible to affirm that Portugal as a country that has sought to stimulate participatory practices at different age levels, in order to ensure a future that guarantees sustainable development (National Commission of UNESCO-Portugal, 2006). The Sustainable Development requires an adoption of a model that is compatible with the ecosphere, less demanding in relation to natural resources and less harmful to the environment. To this end, it is essential to reduce the effects of human activity about the environment (Fernandes, Gonçalves, Pereira & Azeiteiro, 2007). Currently, the deterioration of the environment is a problem debated in the most diverse areas, from the media, to political power and the international organizations.

If the seriousness of the environmental problems and the rapid rhythm of today's society call for an intervention and awareness in the environmental area, with a view in terms of continuity of life and sustainable balance, it is essential to reach the population of which young people are part of and, consequently, it is up to the school to intervene in this direction. For Fernandes and his collaborators (2007), the school is an important place to promote the necessary change and clarification, by transmitting the environmental values in order to train more enlightened and responsible young people. The use of diverse environmental themes, whose reflections are felt and have repercussions on the lives of the people and of the planet where they live provides, therefore, diverse opportunities for approach. Due to the rapid transition to the current state of modernization, our country has difficulties in achieving a sustainable situation. The problems are diverse: the disorder of the territory and the disfigurement of the landscape; low energy efficiency and the excessive dependency of fossil fuels (and the associated problems – climate change); the accentuated degradation of natural resources; and the social asymmetries (National Commission of UNESCO-Portugal, 2006).

The discussion of controversial issues and the role-play

In all societies there are controversial issues. The basis for controversy may stem from differences in religious beliefs (such as the abortion issue), cultural beliefs (such as the links between "race" and intelligence) and moral issues (for example, related to genetic engineer) (Oulton, Day, Dillon & Grace, 2004). Controversial issues are, by definition, issues on which there are significant divergences of opinion (Bridges, 1988). Several authors defend the exploration of controversial subjects in science teaching in order to build knowledge about the contents, the history and the processes of science and the comprehension of interactions between science, technology and society (Albe, 2009; Dolan, Nichols & Zeidler, 2009; Legardez & Simonneaux, 2004; Lundström, Ekborg & Ideland, 2012; Oulton et al., 2004; Reis, 2003, 2004). The socio-environmental controversy, explored in the present study, is defined as a conflict that arises from different social interests in relation to the use or management of environmental resources (Lumerman, Psathakis & Ortiz, 2011; Manzochi, 2008).

Empirical studies developed in Portugal show that teachers and students are in favour of inserting the discussion of controversial issues in class. Some of the reasons pointed out by both educational actors are related to: a) the potentialities of this methodology in the understanding of scientific, technological and social dimensions of important issues for citizens' lives; b) the development of thinking and argumentation abilities; c) the motivation of students; d) decision-making; and e) the formulation of reasoned opinions and criticisms (Hilário, 2009; Reis, 2001, 2004, 2008). This type of educational experience is, therefore, capable of triggering an evolution in the cognitive, communicative, social and democratic processes, paving the way for scientific literacy and participatory and democratic citizenship.

However, there are many obstacles that arise and complicate the practices of teachers related to the discussion. Consequently, not all students have access to this type of educational experience. It is possible to highlight difficulties related to the educative system that, by the extension of the curricula and the use of national exams focused on memorization, make it difficult to carry out discussion activities in different educational contexts. Among teachers, the complexity of the issues in discussion, the difficulties in curriculum management and the lack of familiarity in relation to the theme and methodology in cause may also constitute strong barriers to the integration of the discussion in classes. In the students, there are problems related to their lack of experience in this type of activities and, consequently, the lack of interpersonal skills (Cowie & Rudduck, 1990; Dillon, 1994; Gall, 1985; Reis, 2001, 2004, 2008; Reis & Galvão, 2008). All of these barriers can be overcome but, for that, changes are needed which challenge the entire educational community. It is essential that teachers and their students familiarize themselves with this teaching methodology in order to overcome the difficulties they face. It is by knowing and reflecting about the potentialities and the obstacles detected in the discussion of activities centred on controversial issues that discussion activities can be fully explored and, thus, contribute to the development of diverse competences and social values. It is important to focus on an intervention that allows the promotion of skills in teachers, in the conception, implementation and evaluation of this type of activities, and in the development of skills in students, associated to a greater scientific literacy. Discussion activities can be carried out using role-playing.

In role-playing, the performance of each role gives students to opportunity to engage in discussion of distinct points of view on scientific issues (Cherif & Somervill, 1995) and about various social and environmental issues. The use of role-playing, in addition to placing the participants in certain situations, also identifies their obligations and responsibilities, thus contributing to further reflections about the consequences of their actions. The involvement of students in situations of stimulation exposes us to facts of reality that provide the activation of experiences, meanings and identities, ending up involving them in the problems where moments of sharing, experience and reflection linked to learning take place (Barab & Roth, 2006). As Colucci-Gray (2009) concludes, this whole process of sharing ideas of different characters can make students aware of how society works and of its own ways of acting and living. Osborne, Duschl and Fairbrother (2002) consider it necessary to support teachers in the implementation of this type of activities. According to these authors, the increase of effectiveness and of dynamism of role-playing may require the preparing instructions to students; encourage the adoption of a role and define appropriate times for its implementation. Depending on the characteristics of the class and objectives of the teacher, it is possible to define different approaches for the presentation of roles. The role-playing organization model proposed by Cherif and Somervill (1995) involves a component of individual work in which, starting from the electronic addresses suggested by the teacher, the elements of each group should research information that allows the construction of arguments to support the position of the character that they represent and, therefore, prepares their report. After this data collection to support the position of each character, the group meets in order to share opinions about the issue under study, according to their character. It follows the final decision of the group that will be presented to class and discussed using various arguments.

Taking into account their characteristics, the effectiveness of role-playing is reduced if there is no previous knowledge about the theme under discussion (Duveen & Solomon, 1994). In order to overcome this limitation, it is expected to explore the theme in previous classes and provide a set of sources of information that students should use to reinforce their knowledge and to produce better arguments during the discussion. The promotion of role-playing in the classroom is justified by the fact that it is possible to measure an increase in student activity and their investigative practice, a retention of the material used in the exercise for a longer time and the evidence of a greater understanding of the issues involved (Duveen & Solomon, 1994; Ments, 1990). This type of activity still produces high levels of motivation and satisfaction in the participants and, consequently, it becomes difficult to interrupt the activity. Thus, the student acquires a deeper understanding of the problem under study and develops social and communication skills (Castano, 2008; Ments, 1990). In this context, the teacher is seen more as a facilitator of the exercise than a source of knowledge (Ments, 1990; Simonneaux, 2001).

Some of the problems that the teachers face in role-playing activities are related to: a) the time and effort that this type of activity requires to succeed; b) the difficulty in creating characteristics in sufficient numbers, perspectives or sources of interest for the topic under study; and c) the use of controversial topics from the ethical, social, political and economic point of view, regarding that many teachers have never been taught to negotiate conflict in the classroom or to teach how to develop conflict resolution skills (Cherif & Somervill, 1995). Regarding the obstacles, Simonneaux (2001, 2002) highlights: a) the lack of familiarity of teachers with this methodology that prevents , most of the times, the teacher to remain neutral during a discussion; b) difficulties in promoting an attitude of respect for contrary opinions; and c) difficulty in asking questions that promote a reflexive thinking, which is responsible for raising students' awareness of the role and limits of scientific knowledge and the values that arise with the subjects under study.

Role-playing can be considered as a teaching tool that can be used to explore and promote learning on an issue or as a means of developing various skills. The skills to be developed come from a boarder understanding of learning that takes place on an ongoing and shared basis. In the current social context, where the boundaries between science and politics are less clear and where the limitations associated with scientific objectivity are recognized, it is important to think of a form of education that will redefine the power relations between science and the citizen (Colucci-Gray, 2009).

Methodology

This action-research integrates a broader study involving different types of activities to discuss controversial issues in order to provide knowledge about the factors that that may contribute to the quality of these activities. The present study contains a strong formative and reflective component, both for the students and for the teacher-researcher, and is qualitative nature. An investigation of this nature makes it possible to articulate theory and practice and, consequently, makes it possible to transform this practice (GTI, 2002), in order to change and improve a situation (Belton, Gould & Scott, 2006). The action-research is understood as a device where the process of educational action and research are produced simultaneously. The research follows the action in direction of its understanding. The resulting knowledge is reinvested in the action itself, as it aims at its transformation. Therefore, it is a process of research into action, through action and for the action, with active participation of the authors of the action (Caetano, 2004).

It is also a research that is inscribed in the critical paradigm for wanting a transformative action (that characterises this paradigm) and to involve in this action the social and educative authors (Ponte, 2008). This approach is characterised by an intervention of the teacher in his/her own context of action with a view to a change and, simultaneously, an improvement of the approach of the discussion of controversial issues in the formation of future teachers. Regarding the ideological nature of the critical paradigm, it is characterized by a more interventionist nature (Coutinho, 2011) aiming, in this study, to improve a teaching and learning situation.

This study was carried out with 67 students of two classes, working in a different regime, one during daytime and the other in the evening, attending a curricular unit of Environment and Sustainable Development. In order to evaluate the potentialities and the limitations of the discussion of controversial issues using the representation of roles in the environment classes, it was used a content analysis of the data obtained through the application of: a) a questionnaire evaluating the activity; and b) an interview with a member of each working group.

The qualitative analysis involved the classification of the registration units that constitute the texts, according to categories susceptible to introduce order in the apparent disorder of the raw data. The process of construction of categories was influenced by several aspects, such as, for example, the objectives of the study, and involved the comparison of different units of information in order to detect recurrent categories among the available data (Bardin, 2009). A quantitative analysis was also performed with the purpose of helping to know the importance of each one of the categories considered in the study.

Characterization of the didactic approach of the role-play

As suggested by Tal and Kedmi (2006), the entire didactic proposal was planned to explore a relevant issue/theme of daily life and to enable future teachers to be actively involved in decision-making processes. According to these authors, participating in decision-making processes implies "an active interaction of students with their partners, sharing and communicating identified problems, asking questions, constructing and analysing arguments, deciding on the credibility of sources, interpreting data, raise hypothesis, draw conclusions, make value judgements" (p. 617). The selection of the environment theme was based on its current and social relevance. The problem invites students to become aware of the risks and interests involved and in which different groups of society, such as scientists, environmentalists, politicians and economists, take part. In line with the National Strategy of Sustainable Development (ENDS) (Resolution of the Council of Ministers number 109/2007, 20th of August of 2007) and with regard to the area of integrated management of water from watersheds, it was considered relevant to work the issue related to the construction of dams. Portugal is a country with high water potential in which the government has bet with a view to its better use, namely, through the National Program of Dams of High Hydro-electrical Potential. This bet aims to reduce the high energy dependence of the exterior and increase the percentage of electric energy produced by renewal sources. In this context, the country justifies its commitment to the construction of dams, but does it effectively constitute a sustainable bet? We propose to discuss this controversial issue with the group of students participating in this study, promoting in them the necessary knowledge and reflection to participate in the debate about these issues and to become aware of their role in the decision-making processes of the society they live in. The performed role-playing consisted of a decision-making exercise. The students were confronted with a real situation – The Alqueva Dam – and, through this example; the students had to decide whether or not to agree with the construction of more dams, carrying out or not more of these types of projects. The simulation of certain roles encourages the students to learn a particular way of thinking instead of memorizing facts (Jenkins, Purushotma, Weigel, Clinton & Robison, 2009), which encourages the development of skills.

The elements of each group formed an Evaluation Committee with experts from various sectors of society: agricultural, energetic, touristic, environmental and social sectors. The commission was responsible for analysing the current situation of Alqueva and decide whether it would be feasible to build more projects of this type, and decide whether they are in favour or against. A favourable decision should indicate some conditions and make some recommendations.

Each member of the group represents one role, with the objective to write an individual report (with a maximum of 2 A4 pages) summarizing their substantiated opinion and their position in relation to the Dam of Alqueva and to other projects of the same nature. After discussing the arguments presented by each character, the group writes a joint reflection that bases their final decision on the feasibility and reasonability of more investments related to the construction of dams in our country and presents their conclusions to the class. The discussion of the group happens in several moments that are summarized in figure 1. In a similar way to the study developed by Simonneaux (2001), at the end of the activity each group should express their opinion on the subject under discussion – whether they are for or against the construction of more dams and the construction of more projects in this area. In case of agreement with the construction of dams, the groups specify in what circumstance they should be performed. This is, therefore, a moment of sharing with the class. This activity integrates an individual and group work component. The evaluation of this activity focuses on: a) group work; b) individual reflections; c) the quality of reflections built by the group; and d) in communicating the results to the whole class.

Figure 1 : Organizational scheme of the didactic approach performed in the role-play

	1st Phase	2nd Phase	3rd Phase
Organization	Individual work	Group work and small group discussion	Discussion in class
Task	Preparation of a report on the analysed sector	Discussion of ideas about the various studied sectors and Preparation of group reflection	Presentation and discussion of conclusions in each group

Presentation of results and discussion

Potentialities attributed to role-playing

Regarding the most relevant positive aspects pointed out by the students, they are the ones that coincide with the development of skills. The role of the teacher in the discussion was also often referred, as it can be seen in figure 2.

In the opinion of the respondents, the role-play on the problem of dam construction promoted the development: a) of substantive knowledge; b) of didactic knowledge; c) of reasoning; and d) of attitudes. A high percentage of answers pointed to scientific knowledge as the most developed aspect through role-play (98, 4%). In the opinion of the students, this activity allowed the knowledge of the operation of a dam and the advantages and disadvantages associated with its construction and operation. The fact that they have to simulate different groups of citizens involved in this issue, made the students aware of the possible impact of this type of enterprise in several areas of our society. The contact with these types of groups was decisive for a deeper understanding of the theme.

Some students report that this discussion contributed to the knowledge of a current theme and the Portuguese reality:

> *I learned that the construction of dams has many positive aspects, in what refers to the evolution of tourism and of energies, because it is important to focus on the economic development and on alternative energies. However, at the social and environmental level, it presents serious problems, as the ecosystems and, villages and lives already built, will be destroyed. (Q, D13)*

> *The theme of the dams was not totally unknown, as it is a current theme in society and in Portugal. Despite this, there are aspects that I had never really thought about, especially the negative ones, because I thought that the construction of dams did not bring so many negative factors as they actually do. Having said that, after having done the work and after having had the opportunity to confront different opinions regarding the construction of dams, I had the opportunity to reflect on my opinion about the subject (…). (Q, PL11).*

Figure 2 : The knowledge that students consider to have taken place as a consequence of the activity of discussion about the construction of dams and the case of Alqueva

Category	Subcategory	N	%
Development of Skills	Scientific knowledge	63	98,4
	Communication	15	24,2
	Reasoning	9	14,1
	Attitudes	5	7,8
	Didactic knowledge	2	3,6
Teacher	Conception, management and evaluation of discussion	43	69,4
	Total students	**62**	

Subtitle: N – number of students who mentioned a certain aspect; % - according to the total number of students who answered the question.

The planning of the activity predicted the necessary research of information by the students in an autonomous way, in order to substantiate their role and, therefore, form a reasoned opinion about the issue under study, contributing to the development of their reasoning (14,1%) and communication (24,2%). The reasoning of the opinion itself develops in students the argumentative capacity. This context of discussion promotes the expression of ideas by the sharing of opinions, both at the level of the group and of the class:

> *Once again, this activity served to deepen and improve the argumentative capacity of all members of the class. (Q, D24)*

> *It helped me to be in a situation of debate and manage the will to confront ideas with the defended ones. It has helped me to strengthen my power to defend something that does not represent my real opinion. (Q, PL12)*

> *Being able to listen to other opinions and build a more informed idea, about this subject. (Q, D13)*

The students also considered that this activity had an impact on the attitudes (7,8%) resulting in an improvement in interpersonal relationships. Greater familiarity with this type of activity may have led to an increase in respect for the opinions of the others:

> *In this activity, as in the previous one, I learned to respect both my classmates and the class in general. (Q, D41)*

> *This activity reinforced the dynamics practiced in the last group discussion and helped me to better understand certain opinions, as well as to accept them more easily, I feel that with the passage of time I am more receptive to different opinions. (Q, D39)*

Behavioural improvements were referred, mainly, by the students in the daytime class. This fact may be indicative of the occurrence of interpersonal problems during discussion in class. Through the analysis presented by the students, it can be seen that the acquired knowledge, in terms of skills, correspond to those that are mostly identified and discussed in the literature in the use of role-playing (Castano, 2008; Colucci-Gray, 2009; Cudworth, 1995; Duveen and Solomon, 1994; Hilário, 2009; Ments, 1990): a greater understanding of the issues under study and an improvement in the ability to argue, together with the development of social and communication skills. Two answers showed the development of the didactic knowledge (3,6%). These participants valued the opportunity to develop knowledge related to the accomplishment of discussions involving role-playing, emphasising the importance of this knowledge for their future professional practice. These data indicate the recognition of this type of activities and suggest their use in the teaching practices of these future teachers /educators:

> *This activity was an added value, for my future professional practice. (Q, D17)*

> *I acquired knowledge (a lot!) related to this specific theme, and also at the level of research in role-playing. This knowledge enables students to feel more integrated in the community and to be aware of the development. This activity enables us to learn to*

> *research in order to ground our statements and to develop the capacity for argumentation, as we defend a perspective. It is a very important tool for life because in any subject we always have to defend our opinion. It's learning to research in order to ground our statements. (Q, D37)*

According to several participating students, the conception, management and evaluation of the discussion by the teacher constitutes a strong point of the activity of role-playing (69,4%, Q). From a set of focused points, the division of the theme by sectors (different roles) helped to deepen the subject and, as all elements of the group has a sector to work, everyone had to work hard and be involved in the task. In role playing, the discussion in group is essential so all group members get to know the sectors under study and form a deeper global view of the theme. Then, the group can be prepared to discuss their ideas with the class. The orientation of this activity followed some of the suggestions presented by Cherif and Somerville (1995) and Duveen and Solomon (1994), in order to provide accountability for all elements of the group, which seemed to really have happened.

During the interviews, among a set of references favourable to the planning of activity, the most valued aspect consisted in a set of guiding questions for each character that the teacher made available to the students. According to the interviewees, those questions enabled the guidance of the research process and gathering information, helping to select the meaningful information for each sector. This procedure seems to be most appropriate for groups of students with little experience in the discussion (Cherif & Somerville, 1995) as it ensures the research of the essential aspects to the discussion. Ensuring that everyone has prior knowledge of the theme is essential so that the discussion with role-playing is effective (Duveen & Solomon, 1994).

On the other hand, the fact that all groups have the same characters to represent and, therefore, the same questions of orientation, enabled a richer and more concordant exchange of ideas between the groups, since all worked from the same points of analysis. The attribution of different sectors to each group is considered positive because it allowed initially the development of an individual and more exhaustive research on each of the sectors involved in the theme. This individual exploration of a sector gave each element of the group a deeper knowledge about the dimension studied. Posteriorly, all groups had to meet in order to discuss the information related to each sector and all elements of the group were informed of the overall theme.

> *ENT – (…) What is your opinion about providing some guiding questions to the representative of each sector? (…)*
>
> *D30 – I think it is good because it gives us clues about the path we have to follow, it does not mean that we have to limit ourselves to those points but it gives us an orientation of the essential points that we should study and work. (Ent, D30, p. 5)*

Some students refer, for instance:

> *The whole process of accomplishment of this activity was very positive, as it enabled us to form and ground our knowledge, which is not always verified with the performance of exams, because the information provided by the teachers is memorized in order to be used later. (Q, PL13)*

At the same time, it was proved that the theme was also a favourable factor for the discussion, due to its social relevance and because it is a current theme with future repercussions, functioning as a precondition for the success of the activity:

> *I really enjoyed doing this activity, I think the discussion in class was very enlightening; many important aspects were focused and developed, in all aspects. In all themes, it was verified that each one complemented the idea of the other (…). These are themes that we do not think about every day, and after this kind of work we become more attentive. (Q2, PL17)*

In summary, the participants recognised that the role-play allowed the performance of many skills, mainly, the substantive knowledge.

Negative aspects of role-playing activity

As it can be seen in figure 3, in the questionnaire answers the students also identified weaknesses in the way the teacher managed the discussion (45,8%). It is interesting to notice that, if for some students the division of the theme by sectors was positive, for others it was a negative aspect of this activity. According to these respondents, the fact that they worked individually one sector enabled them to dominate it better than the others, compromising the global understanding of the theme. This situation is surprising, as the meeting in group work in order to discuss the ideas and information about each sector aimed to overcome this eventual limitation. It was intended that this group meeting would provide clarification and information sharing among the various elements so that all would take the different perspectives under study. Probably, this situation was related to the fact that the students were overly focused on their role and on their arguments and, consequently, did not pay enough attention to their classmates:

> *The fact that each element only develops one sector, I think that it could have been a group work because, there will be some gaps to fill in other sectors. (Q, D24)*

Figure 3 : Negative aspects attributed by the students to the discussion activity using in the role-play

Category	Subcategory	N	%
Students	Communication skills and group wok skills	13	22
	Reasoning	2	3,4
Teacher	Conception, management and evaluation of discussion	27	45,8
There are no negative aspects		26	44,1
	Total students	59	

Subtitle: N – number of students the referred a certain aspect; % - according to the total number of students that answered the question.

The intervention of each group in the discussion was organized so that the discussion process occurs after the presentation of the work of all groups and it was not possible to intervene individually before that. In the opinion of some students, this process has resulted positively as it allows everyone to present the group's opinion but, for others it would have been detrimental to the rhythm of the discussion:

> *In my opinion, (…) the negative aspects of these activities are final discussions. This is because we cannot intervene as soon as the speech of the classmates happens. And I think that only opposing all opinions when everybody has exposed their points of view; loses a bit of the impact. (Q, D33)*

Time management proved to be an inherent peculiarity of the nyght class. For some of the respondents of this class, the available time for the performance of the activity was not enough, namely, the period of time that happened between the delivery of the individual report and the subsequent positioning of the group. The explanation presented by the students relates to the lack of time for a better preparation of each moment of the activity. The reason why this factor is referred only by the class of after labour regime may be due to the fact that the students are mostly student-workers (TE) and have a family life (married and with children) that fills their availability. This situation conditions the working group meetings for the performance of tasks:

> *The negative aspects were lack of time and of availability for group work. (Q, PL27)*

According to the questionnaire answers of some students, the communication and group work skills (22%) and reasoning skills (3,4%) were the most negative aspects of this activity. In the opinion of some of them, the problems of disrespect towards the opinions of others seem to remain during the discussion in class. They also suggest the lack of "knowing how to be" in group and the non-compliance with the rules established by certain elements. The negative cases identified in the study of Colucci-Gray (2009) also point to problems related to the ways of working in group and between groups, when the opinions of the others are not respected and valued. The author also focuses on leadership situations whose focus is on individual performance without appreciation of the contributions of all.

According to a small number of students, the reasoning was the skill where they face greater obstacles because they had difficulties in summarizing the researched information and in reaching conclusions about the subject in questions. These data demonstrate how decision-making about controversial issues can be difficult:

> *In this activity, I think there was a not good aspect, which consisted in the great concentration of information, in relation to this theme. This large information that was available, mostly on the internet, made the process of information selection difficult, as there was a great controversy regarding this theme. (Q, D17)*

During the interviews, the weaknesses associated with role-playing also focused problems related to the teacher's and student's action. In addition to mentioning as weak point the division of the theme by sectors, they allude to an insufficient introduction made by the teacher in this activity. They confess that the difficulties involved focused on the contextualization of the theme and on the points to be addressed, possibly due to the reduced knowledge about the theme under study – the dams. Thus, they present some suggestions to overcome this problem, such as the teacher making news or articles available for analysis at an initial moment and, later, start an activity.

Conclusion

The activity of role-playing allowed the development of great learning, namely, skills related to scientific knowledge, the communication, the reasoning and the attitudes. The references related to the development of didactic skills are highlighted. The participation in the role-playing activity gave the students the opportunity to contact with this type of discussion. From this contact, the students considered the use of this activity in their future professional practise. The simulation of different sectors seems to have enabled the students to understand the impact that the construction of dams can have on society. Therefore, they became aware of the mutual differences between science and technology and their impact on society and on the environment.

The learning carried out by the students during the role-play was notorious. Similar to what was verified in other studies (Barolli, Farias, & Levi, 2006; Freitas, Villani, Zuin, Reis & Oliveira, 2006; Galvão & Reis, 2008) the knowledge of the students about the theme under study was little or none at the beginning of the activity, ignoring in general some of the implications of the construction of dams. Due to the lack of knowledge about the theme, some students lacked a more consistent and deep theoretical approach to facilitate the initial understanding of the theme, even suggesting the provision of articles /texts about the subject in order to overcome this problem. This suggestion was pertinent as the contact with newspaper articles from the media promote a better understanding of the parties and interests involved in this issue. However, this prior exploration was planned immediately after the introduction of the theme, through the researches and analysis of several documents, among them the *Bioquest* resource. At the end of the activity, it was found that the students were able to consider the involvement of various interests and relationships at the CTSA level and develop an environmental awareness for the sustainable development of the society in which they live.

Due to the specificity of this activity represented by several sectors, the students considered to be important the discussion that happened within the group so that everyone becomes aware of the other sectors worked by the different elements of the group. On the other hand, this division by sectors allowed a deeper study of the subject and everyone had to get involved in the work. The division of tasks seems to create a cooperation and accountability of all. The selected theme was considered pertinent because it has social relevance and is controversial. Still in relation to the planning of the activity, the supply of guiding questions for each role to be represented was received positively by the participants. This procedure seems to have been more suitable regarding the reduced experience of the students in the discussion and to think that, in this way, they would be more easily oriented in the information selection process. The fact that the guiding questions are the same among the groups; ensured that all groups explored the aspects that are considered essential in each dimension under analysis, allowing later a richer and more common exchange of ideas.

For students in the evening class regime, the time available for the activity was not enough for a better preparation and development of the theme. They recognize that this problem only arises because they are student worker and they have little availability to invest in research or to meet with group colleagues. Regarding this limitation, more classroom sessions may be introduced and during them the groups may, effectively, meet to carry out their work.

According to the conclusions of Lewis and Leach (2006), it is considered that a school curriculum that integrates the understanding of scientific concepts, of ideas about the nature of science, promotes ethical reasoning and the abilities of argumentation, will give more opportunities to be applied in the daily life of the students. Consequently, the students become better prepared to deal with social issues arising from the application of science and technology. Giving students the skills to solve the problems they face in their daily life in an autonomous and responsible way is, one of the possible implications that are expected to be achieved with this study.

It is known how difficult it is to develop an environment conducive to the teaching and learning process, but this is where the challenge of each education professional is centred, the constant search for improvement of the pedagogical contexts in which it intervenes, in order to provide the development of essential skills in the students to face the constant challenges of their daily life. It seems that, through the study promoted here, discussion (using role-play) is one of the promising methodologies in the formation of citizens capable of dealing with the diverse demands and changes of the current society, since it allows the aggregation of several favourable factors for the development of skills, as presented and discussed in the results.

However, it is known how it is not easy to implement despite the recommendations that may exist regarding its conduction in educational context. As Hughes (2000) and Martins (2002) mention, it is not enough to introduce references to an approach to content through controversial issues in the curriculum or programs so that this one is carried out. Thus, the recommendations that are left can be a contribution to a path to be adopted by professionals who want the introduction of other approaches and the innovation of their practices.

References

ALBE V. (2009), *Enseigner des controverses*, Rennes: Presses Universitaires de Rennes.

BARAB S. S., ROTH W. M. (2006), « Curriculum-based ecosystems: supporting knowing from an ecological perspective », *Educational Researcher,* 3, 5, p. 3-13.

BARDIN L. (2009), « Análise de conteúdo », Lisboa: Edições 70.

BAROLLI E., FARIAS C. R. O., LEVI, E. (2006), « *O Potencial de assuntos controversos para a educação em uma perspectiva CTS* », Comunicação apresentada no III Colóquio Luso-Brasileiro sobre Questões Curriculares, Braga, Portugal.

BELTON V., GOULD H. T., SCOTT J. L. (2006), « Developing the reflective practitioner - Designing an undergraduate class », *Interfaces*, 36, 2, p. 150–164.

BRIDGES D. (1988), *Education, democracy & discussion*, Lanham: University Press of America.

CACHAPUZ A., PRAIA J., JORGE M. (2004), « Da educação em ciência às orientações para o ensino das ciências: um repensar epistemológico », *Ciência & Educação*, 10, 3, p. 363-381.

CAETANO A. P. (2004), «A mudança dos professores pela investigação-ação », *Revista Portuguesa de Educação*, 17, 1, p. 97-118.

CHERIF A. H., SOMERVILL C. H. (1995), « Maximizing learning: using role playing in the classroom », *The American Biology Teacher,* 57, 1, p. 28-33.

COLUCCI-GRAY L. (2009), « Role-play as a tool for learning and participation in a post-normal science framework» in Colucci-Gray G. L.; & Camino E. (Eds.), *Science, society and sustainability. education and empowerment for an uncertain world* (Vol. 27, pp. 188-211), New York: Routledge Research Series in education.

COMISSION NACIONAL POUR L´ UNESCO-PORTUGAL (2006), *Década das Nações Unidas da Educação para o Desenvolvimento Sustentável (2005-2014) - Contributos para a sua dinamização em Portugal*, Lisboa: UNESCO.

COUTINHO C. P. (2011), *Metodologia de investigação em ciências sociais e humanas: teoria e prática,* Coimbra: Almedina.

COWIE H., RUDDUCK J. (1990), « Learning through discussion » in Entwistle N. (Ed.), *Handbook of educational ideas and practices* (p. 803-812), London: Routledge.

DILLON J. (1994), *Using discussion in classroom*s, London: Open University Press.

DOLAN T. J., NICHOLS B. H., ZEIDLER D. L. (2009), « Using socioscientific issues in primary classrooms », *Journal of Elementary Science Education,* 21, 3, p. 1-12.

DUVEEN J., & SOLOMON J. (1994), « The great evolution trial: use of role-play in the classroom », *Journal of Research in Science Teaching,* 31, 5, p. 575-582.

FERNANDES A, GONÇALVES F., PEREIRA M. J., AZEITEIRO U.M. (2007), « Educação ambiental: características, conteúdos, objetivos e atividades práticas. O caso Português » in Gonçalves F., Pereira R., Manuel de M. Azeiteiro U. e Pereira M. J. V. (Eds.), *Atividades práticas em ciência e educação ambiental* (p. 11- 41), Lisboa: Instituto Piaget.

FREITAS D., VILLANI A., ZUIN V. G., REIS P., OLIVEIRA H. T. (2006), *A natureza dos argumentos na análise de temas controversos: estudo de caso na formação de pós-graduandos numa abordagem CTS,* p. 1-14.

GALL M. D. (1985), « Discussion methods of teaching » in Husen T. & Postlethwaite T. N. (Eds.), *The international encyclopedia of education: Research and studies* (p. 1423-1427), Oxford: Pergamon.

GRUPO DE TRABALHO SOBRE INVESTIGAÇÃO – GTI (2002), « Introdução » in Grupo de Trabalho sobre Investigação (Ed.), *Refletir e investigar sobre a prática profissional,* Lisboa: Associação de Professores de Matemática.

HILÁRIO T. (2009), *A discussão de controvérsisas sociocientíficas na promoção de competências de cidadania em alunos da disciplina de Biologia do 12.º ano,* Dissertação de mestrado inédita, Universidade de Lisboa, Departamento de Educação da Faculdade de Ciências.

HUGHES G. (2000), « Marginalization of socioscientific material in science–Technology–Society science curricula: some implications for gender inclusivity and curriculum reform », *Journal of Research in Science Teaching,* 37, 5, p. 426–440.

JENKINS H., PURUSHOTMA R., WEIGEL M., CLINTON K., ROBISON A. J. (2009), *Confronting the challenges of participatory culture - media education for the 21st century,* Cambridge: Mit Press.

LEGARDEZ A., SIMONNEAUX L. (2004), « Les conditions de la discussion dans l´enseignement des questions socialement vives » in Tozzi M. & Etienne R. (Eds.), *La discussion en éducation et en formation - un nouveau champ de recherches* (p. 95-119), Paris: L´Harmattan.

LEWIS J., LEACH J. (2006), « Discussion of socio-scientific issues: the role of science knowledge », *International Journal of Science Education,* 28, 11, p. 1267-1287.

LUMERMAN P., PSATHAKIS J., ORTIZ M. Á. (2011), *Climate change impacts on socio-environmental conflicts: diagnosis and challenges of the argentinean situation,* Brussels: Initiative for Peacebuilding – Early Warning Analysis to Action (IfP-EW).

LUNDSTRÖM M., EKBORG M., IDELAND M. (2012), « To vaccinate or not to vaccinate: how teenagers justified their decision », *Cultural Studies of Science Education,* 7, p. 193-221.

MANZOCHI L. H. (2008), *Educação ambiental formadora de cidadania: as contribuições dos campos teórico-metodológicos de "conflito socioambiental" e "educação moral" para a formação continuada de professores,* Tese de doutoramento inédita, Universidade Estadual Paulista, Araraquara. Faculdade de Ciências e Letras.

MARTINS I. (2002), « Problemas e perspetivas sobre a integração CTS no sistema educativo português », *Revista eletrónica de Enseñanza de las Ciencias*, 1, 1, p. 1-13.

MENTS M. V. (1990), « Simulations, games, and role-play » in Entwistle N. (Ed.), *Handbook of educational ideas and practices* (pp. 823-832), London: Routledge.

ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT - OECD (2006), *Assessing scientific, reading and mathematical literacy: A framework for PISA 2006*, Organization for Economic Co-Operation and Development. Recuperado de http://www.oecd.org/pisa/pisaproducts/pisa2006/37464175.pdf

OSBORNE J., DUSCHL R. & FAIRBROTHER R. (2002), *Breaking the mould? Teaching science for public understanding,* London: The Nuffield Foundation.

OULTON C., DAY V, DILLON J., GRACE M. (2004), « Reconceptualizing the teaching of controversial issues », *International of science Education*, 26, 4, p. 411-423.

PONTE J. P. (2008), « Investigar a nossa própria prática: uma estratégia de formação e de construção do conhecimento profissional », *PNA: Revista de investigación en Didática de la Matemática*, 2, 4, p. 153-180.

REIS P. (2001), « O ensino das ciências através da discussão de controvérsias: realidade ou ficção? » in Silva B. D. & Almeida L. S. (Org.), *Atas do VI Congresso*

Galaico-Português de Psicopedagogia (p. 367-379), Braga: Centro de Estudos em Educação e Psicologia da Universidade do Minho.

REIS P. (2003), « Os professores e a controvérsia em ciências » in Neto A., Nico J., Chouriço J.C., Costa P. & Mendes P. (Eds.), *Didáticas e metodologias da educação: percursos e desafios* (p. 723-731), Évora: Universidade de Évora, Departamento de Pedagogia e Educação.

REIS P. (2004), *Controvérsias sócio-científicas: discutir ou não discutir? – Percursos de aprendizagem na disciplina de ciências da terra e da vida,* Tese de doutoramento inédita, Universidade de Lisboa, Departamento de Educação da Faculdade de Ciências.

REIS P. (2008), *A escola e as controvérsias sociocientíficas – Perspetivas de alunos e professores,* Lisboa: Escolar Editora.

REIS P., & GALVÃO C. (2008), « Os professores de ciências naturais e a discussão de controvérsias sociocientíficas: dois casos distintos », *Revista Eletrónica de Enseñanza de las Ciencias,* 7, 3, p. 746-772.

RESOLUTION OF THE COUNCIL OF MINISTERS NUMBER 109/2007, 20th of August of 2007 (Estratégia Nacional de Desenvolvimento Sustentável e respetivo Plano de Implementação).

SIMONNEAUX L. (2001), « Role-play or debate to promote students´ argumentation and justification on an issue in animal transgenesis », *International Journal of Science Education*, 23, 9, p. 903-927.

SIMONNEAUX L. (2002), « Analysis of classroom debating strategies in the field of biotechnology », *Journal of Biological Education,* 37, 1, p. 9-12.

TAL T., KEDMI Y. (2006), « Teaching socioscientific issues: classroom culture and students´ performances », *Cultural Studies of Science Education,* 1, p. 615-644.

Order Book

Oeconomia,
3 rue Jean Giraudoux,
63000 Clermont-Ferrand, France

http://www.oeconomia.net