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# Social and economic determinants of materials recycling and circularity in Europe: an empirical investigation

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**Abstract**
The present empirical study sheds light on the role of socioeconomic characteristics toward circular economy, resulting in more sustainable production and consumption patterns. Using fixed-effects and instrumental variable fixed-effects panel approaches, we examine the role of social and economic determinants on materials recycling and circularity in the European Union (EU). Empirical results reveal that recycling and circularity rates are positively affected by factors such as economic wealth, fertility rate, the level of environmental taxes and R&D expenditures. Furthermore, urbanization also seems to have a positive, but nonlinear effect on recycling and circularity rates. Our results can be beneficial to decision makers and managers for implementing several policies aiming to increase recycling and circularity across the EU and beyond.

**JEL Classification** O13 · Q56

## 1 Introduction

The concept of "a new sustainable and" circular economy is not new as it has its roots in the post-war environmental movements (Winans et al. 2017). Economic growth was based on overconsumption of natural resources and energy, neglecting impacts on the environment and climate change (Dauvergne 2010). Professor Kenneth Boulding characterized economics as "cowboy economics," questioning the assumption that *the Earth's)* resources were unlimited. Back in 1966, he reported in his book that: "*Earth has become a single spaceship, without unlimited resources*

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*[…], therefore, man must find his place in a cyclical ecological system*" (Boulding 1966, p. 7). *He indicated that as resources are reduced so is the spaceman's life, unless methods of waste recycling and food generating were adopted.)* This *spaceship, known as Earth,* is characterized by circular relationships in which everything is an input into everything else (Pearce and Turner 1990; p. 37). That prophetic theory, at that time, has inspired economic and social sciences to reconsider the assumption that economic wealth is not exclusively synonymous with social wellbeing but should be seen as just one of the pillars of welfare. New values were introduced which were regarded as essential and vital to human wellbeing as economic wealth. A term introduced in economic literature by Prof. Boulding, was "human betterment". It is a time-variant process in which the human system is evaluated as superior or better today than yesterday. Environmental quality is a "value" of this betterment process.

The increasing number of environmental risks launched a new movement of climate activism. An urbanizing population claims public space and will consequently create air, water and soil pollution combined with an increasing amount of waste generation. In addition, the fast rate of industrialization combined with the consumption of resources follows a lineal model path, "produce-consume-dispose" that cannot perpetuate in a sustainable future. This is well captured in the words of Professor Stahel "*The 'bigger, better, faster, safer' syndrome for new goods that is the hallmark of the current industrial model won't work in an era of greater scarcity and waste accumulation"* (Lacy and Rutqvist 2016, p.17).

The recycling of materials and circularity in general can be important drivers of environmental improvement and sustainable growth. The new European circular economy action plan gives ample attention to recycling and circularity activities (Friant et al. 2020). Recycling can be achieved in several ways, such as the placement of neighborhood containers, zone containers, green points or curbside recyclable waste bins (Gonzalez-Torre et al. 2003; Keramitsoglou and Tsagarakis 2013). However, recycling may be negatively associated with households' utility maximization and positively with the quantity of goods consumed (Sterner and Bartelings 1999).

On the other hand, circularity is an inflated term often used as a synonym of sustainability (Acerbi and Taisch 2020). The main goal of materials circularity is extending the lifetime of resources by retaining them *within an economy* decelerating their replacement and making waste a new source of energy rather than a disposable material. In other words, conventional recycling under the circularity principles contributes to the achievement of zero waste by revisiting production-consumption processes (Mhatre et al. 2021). This new closed loop process of a circular economy will lead to several eventual socioeconomic, business and environmental benefits (Ellen MacArthur Foundation 2019). These benefits have been categorized based on the Triple Bottom Line—economic, environmental and social[1] (Rosa et al. 2019) that can improve the quality of human life using new

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[1] Economic benefits refer to lower overall cost, lower business cost, opening new revenue streams, improving competitiveness advantage; environmental benefits refer to complying with environmental regulations, reducing environmental effects, improving resource efficiency and supply chain sustainability; social benefits refer to enhancing reputation and brand value, reaching new markets and countries,

technology, new business models or new lifestyle models such as a sustainable manufacturing model (Garetti and Taisch 2012).

However, it is essential to highlight that this process does not only have benefits such as the creation of new jobs, saving primary materials and lowering the carbon footprint in the environment. It also has a high cost that can be mainly attributed to the use of more technical and technologically advanced equipment involving the excess use of energy. Nevertheless, even if circular economy is still being formulated (Friant et al. 2020), the approach to sustainable growth is considered a promising and ideal concept that is expected to address several environmental issues such as resource scarcity, climate change and waste disposal. For instance, waste management capacity plays a prominent role in complying with circular economy goals (Di Foggia and Beccarello 2021). Moreover, it also contributes to the optimization of energy consumption, integrating of products data and information and reducing costs both related to product and production processes (Rocca et al. 2020).

Our study used data on material recycling, circulation rates and demographic characteristic indicators covering the whole European Union. This social dimension can be an important parameter for the estimation of the performance assessment methods and indices of circular economy (Vinante et al. 2020; Sassanelli et al. 2019a,b). To the best of our knowledge, it is the first study to find exploratory variables for the circular economy indicator, a fairly recently established indicator which has only been reported by Eurostat since 2010. We performed our analysis based on demand side theory and trying to quantify associations between socioeconomic variables. Borrowing on the traditional framework of production theory (Becker 1965), we assume that consumers, public and private utilities do not demand more recycling and circularity for "direct consumption"; rather, they use them as inputs to obtain higher environmental quality and thereafter higher utility. Thus, environmental quality can be defined as a function of recycling and circularity demand that has the usual properties of curvature and differentiability. Findings could directly and positively impact on both the production process and organization (Acerbi and Taisch 2020).

Empirically, panel data better provide micro-foundations for aggregate data analysis than cross-section or time-series analysis. A possible endogeneity issue was also accounted for in the models. The main purpose of the paper is to extend our understanding on the key social and economic factors that can determine the rate of recycling and circulation processes in the European Union. Generally, the study bridges the gap in the relevant literature since empirical studies indicating microeconomic factors of materials circularity rate research are, as far as we know, rather limited (Korsunova, et al. 2021). We believe our findings will be useful for applying environmental policies at a national, European, international and global level to pursue the transition to a circular economy.

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Footnote 1 (continued)

improving health and safety in workplaces and developing innovative skills and knowledge (Rosa et al. 2019).

The rest of the paper is structured as follows. A snapshot of the interrelationship between materials recycling and circularity concepts is presented in Sect. 2. Section 3 introduces particular features of recycling and circularity rates in Europe. Section 4 presents the data used, the econometric methodology, and illustrates the empirical results. Finally, Sect. 5 discusses the concluding remarks and the possible policy implications.

## 2 Recycling and circularity

Economic growth leads to higher consumption and consequently to increased waste quantities, which subsequently are disposed into the environment. In the eight-year period ranging from 2008 to 2016, the per capita waste generation has increased by around 3% according to Eurostat (2020). This is in line with the demand for primary raw materials (minerals, fossil-based materials, and metals), which leads to the depletion of natural capital, the loss of biodiversity and climate change. Experts conclude that this situation should be reversed using several environmental policy actions which would be undertaken in a European Union wide context. Materials recycling and circularity seem to be a way to mitigate environmental degradation related to resources.

Recycling and circularity both have resources as a reference, yet they differ as concepts. Recycling can be implemented without circularity, but a circular economy cannot exist without recycling (Murray et al. 2017), even if recycling is only one of the circular strategies triggering and supporting its adoption (Acerbi and Taisch 2020). In order to shift from a linear to a circular economy, it is essential that resources are used efficiently and that they are reused and recycled. In the process termed as "industrial symbiosis," materials move from production along consumption to waste, becoming resources again for reproduction (Frosch and Gallopoulos 1989). In other words, the waste of one industry can be used as a resource for others (Lu et al. 2020; Shah et al. 2020). Alternatively, it can be said that "recycling is the reprocessing of recovered materials at the end of product life, returning them into the supply chain" (Worrell and Reuter 2014). As recycling has been placed high on the European economic agenda, consumers and households are important agents for policy interventions (Tsagarakis 2017; Onder 2018). For this reason, several empirical studies have focused on the recycling behavior of households (Jenkins et al. 2003; Sidique et al. 2010; Saphores and Nixon 2014; Lopez-Mosquera et al. 2015). Overall, it can be concluded that recycling is the most important strategy for closing the loop by returning resources into the economic system (Mhatre et al. 2021).

On the other hand, circular economy is considered an umbrella concept (Blomsma and Brennan 2017; Homrich et al. 2018; Merli et al. 2018; Rossa et al. 2019a,b; Sassanelli et al. 2019a, b; Urbinati et al. 2020) which includes smart material input with the minimum of waste generation (Ellen MacArthur Foundation 2015; Moraga et al. 2019), while positively and directly affecting both the production and organization process (Sassanelli et al. 2020; Acerbi and Taisch 2020). Regarding the definition of circular economy, there is not a commonly agreed upon term (Heck 2006; Preston 2012; Su et al. 2013; EEA 2016; Ghisellini et al. 2016; Sauve et al. 2016; Rizos et al.

2017). As there is no consensus on a definition, several studies have looked into the development of a circularity typology; however, none applies perfectly. According to some authors, the terms are either too general and do not allow for clear differentiation of its concepts or too narrow (Friant et al. 2020). Several attempts at defining a circular economy have been made (Kirchherr et al. 2017; Ghosh 2020), most of which highlight resource efficiency management, reusing and recycling, changing utilization patterns as well as sustaining the value of production systems and materials (Rizos et al. 2017; Sassanelli et al. 2020).

Friant et al. (2020) point out that the main challenges of a circular economy are grouped into five topics: (a) the systematic thinking on growth, entropy and decoupling, (b) energy, materials and biodiversity nexus, (c) the impacts of a circular economy and the rebound effect, (d) socio-political implications of circular economy and (e) alternative visions of circularity. Under a broad spectrum, based on Sanahan (2018), the discussion on circular economy can be classified in three broad categories: (a) topic specific research, which looks into the production design process (Bilitewski 2012; Bermejo 2014; Andrews 2015; Sassanelli et al. 2020), (b) research with focus on products, industries, regions or countries (Zhu et al. 2010; Hu et al. 2011; Ma et al. 2015; Lieder and Rashid 2015) and (c) strategic and policy studies with focus on business models, awareness, stakeholder involvement and circularity penetration (Geng et al. 2013; Ellen MacArthur Foundation 2015; European Commission 2020; Gregson et al. 2015; Rosa et al. 2019; Urbinati et al. 2020).

According to Johansson and Henriksson (2020), leading circular economy policies are preferred for achieving strong circularity, compared to small-scale initiatives. In their work, a macroeconomic perspective on recycling and circularity drivers is explored. It is known that several studies have endeavored to analyze the determinants of circularity in general (Ghisellini et al. 2016; Sauve et al. 2016; Geissdoerfer et al. 2017) but without considering specific socioeconomic parameters that could act as incentives or barriers to circularity. Thus, to fill this gap, we have included social and economic indicators with reflecting variables that may explain proactive consumer and industry behavior.

## 3 Research methodology

This section details the methodological approach. First, data on recycling and circularity rates (*dependent variables*) are discussed and illustrated. Then, rationale behind explanatory variable selection is provided. Finally, empirical analysis is employed using a panel dataset ranging from 2000 to 2018 for recycling and 2010–2017 for circularity, respectively.

### 3.1 Data on circularity and recycling

Macro-data on circularity span only a short period of time (2010–2017), as reported by Eurostat (2020). Suitable statistical analysis considering this type of data is collected from all EU countries as panel data. However, the short life span of this indicator might be a key reason for the scarce amount of empirical literature on the topic based on which indicators may favor or hinder the transition to a circular economy. A closely related variable, which stems from the same database but with a longer time span 2000–2018, is the recycling rate. The recycling rate can help to identify and support the empirical model for circularity as it consists of an important enabler for closing the loop of resources (Mhatre et al. 2021). Furthermore, current theory is still vague on which indicators may affect circularity, as there is no consensus on the definition of circular economy (Kirchherr et al. 2017; Korhonen et al. 2018; Prieto-Sandova et al. 2018).

Recycling and circularity indices were used for our empirical investigation as dependent variables, which are freely downloadable from the Eurostat database. Obviously, higher recycling and circularity rates correspond to higher environmental awareness and waste management efficiency in a country. The Recycling Rate of Municipal Waste measures the share of recycled municipal waste on the total municipal waste generation. On the other hand, Circular Material Use Rate measures the share of material recovered and fed back into the economy.

Our sample comprises yearly observations from the 28 EU economies over the period 2010–2017 for circularity and 2000–2018 for recycling rate based on data availability. The country sample consists of Austria, Belgium, Bulgaria, Czech Republic, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and UK. Table 1 provides information about the average circularity and recycling rates for the 28 EU countries over the periods of investigation. Also, it ranks these countries from the best performer (rank 1) to the worst.

The average rate of circularity within Europe is 8.6%, but excluding the Netherlands, which is a "positive" outlier, the average circularity rate drops to 7.9%. On the other hand, the average recycling rate is around 28% within European Economies but with high variability as can be observed in Table 1. Figure 1 provides more comparative insights for the average circularity and recycling values among the EU countries over the examined period. This group classification shows that only Benelux countries remain in the top performing for both indicators. Other top performing countries for recycling do not match their material circularity rate with it or vice versa.

### 3.2 Independent variables

In line with previous studies, we include several socioeconomic covariates in our model. *Real GDP per capita* is used as the main indicator of the level of an economy's wealth. Higher GDP is expected to be positively associated with environmental performance indicators (Guerin et al. 2001; Berglund and Soderholm 2003; Jenkins et al. 2003; Afroz et al. 2011; Kostakis et al. 2017) such as materials recycling and circularity rate.

Second, to take into account socio-demographic indicators, we used a group of variables, i.e., *fertility rate*, *education level* and *level of urbanization*. Total fertility

**Table 1** Average circularity and recycling rates for the 28 EU countries. Source: Authors' calculations based on Eurostat data

| Countries | Circularity rate | | Recycling rate | |
|---|---|---|---|---|
| | Score | Rank | Score | Rank |
| Austria | 9.2% | 11 | 59.6% | 2 |
| Belgium | 16.6% | 3 | 53.6% | 3 |
| Bulgaria | 3.0% | 23 | 23.1% | 15 |
| Czechia | 6.7% | 16 | 15.4% | 20 |
| Croatia | 3.7% | 22 | 12.9% | 23 |
| Cyprus | 2.2% | 25 | 9.1% | 26 |
| Denmark | 7.9% | 14 | 42.9% | 7 |
| Estonia | 12.4% | 7 | 19.8% | 17 |
| Finland | 9.3% | 10 | 35.4% | 8 |
| France | 17.9% | 2 | 34.4% | 9 |
| Germany | 11.0% | 8 | 61.9% | 1 |
| Greece | 2.1% | 27 | 14.5% | 22 |
| Hungary | 5.9% | 18 | 18.3% | 18 |
| Ireland | 1.8% | 28 | 30.6% | 11 |
| Italy | 15.0% | 5 | 30.0% | 13 |
| Latvia | 4.1% | 20 | 11.9% | 24 |
| Lithuania | 4.0% | 21 | 16.8% | 19 |
| Luxemburg | 14.4% | 6 | 44.8% | 6 |
| Malta | 6.6% | 17 | 7.2% | 27 |
| Netherlands | 26.9% | 1 | 48.9% | 4 |
| Poland | 10.8% | 9 | 14.6% | 21 |
| Portugal | 2.1% | 26 | 19.9% | 16 |
| Romania | 2.3% | 24 | 6.8% | 28 |
| Slovakia | 4.8% | 19 | 11.3% | 25 |
| Slovenia | 8.2% | 13 | 28.5% | 14 |
| Spain | 8.7% | 12 | 30.4% | 12 |
| Sweden | 7.1% | 15 | 45.5% | 5 |
| UK | 16.1% | 4 | 33.2% | 10 |
| Mean | 8.6% | | 28.1% | |
| St. dev. | 6.2% | | 18.2% | |

rate indicates the average number of children per woman in a country. This indicator is the main proxy variable of population growth and youth within a country. It also shows that there are more parents in the active economy and the decision-making process who can promote bequest values for their offspring (Jenkins et al. 2003; Tsagarakis et al. 2011). In addition, there is an indirect positive influence by children on their parents stemming from environmental education received at school (Evans et al. 1996; Keramitsoglou and Tsagarakis 2011).

Education level has been recognized as an important driver to environmental protection decisions (Smith 1995; Torgler and Valinas 2007; Zografakis et al. 2012; Xiao et al. 2013; Kostakis et al. 2015; Meyer 2015). We therefore assume

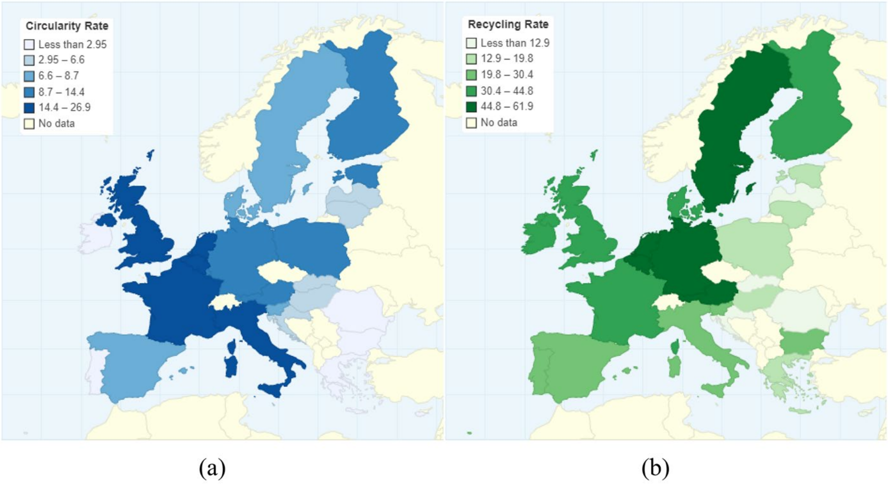

**Fig. 1** Quantile classification of EU countries based on their average annual performance on the: a. materials' circularity (2010–2017) and b. recycling rates (2000–2018)

that, as the percentage of the population who have completed tertiary education within a country increases, there will be a higher probability that this country will perform better in environmental and sustainability indicators. However, we should highlight that while materials recycling starts mainly from households, being part of a bottom-up process, circularity is a more complex procedure involving several other stakeholders in order to organize the return of these resources and become part of the production process again.

In addition, the level of urbanization is used as a proxy variable for the cost of garbage and waste collection (Berglund and Soderholm 2003; Bohm et al. 2010). Regarding recycling, it is well documented and expected that higher urbanization leads to lower collection and management costs for recycling and circularity processes like logistics, energy and transportation (Kinnaman and Fulerton 1997). However, based on the assumption of the homogeneity urbanization process, we expect that urbanization may have a nonlinear effect as there are extremely complex procedures and requirements in large cities.

An *environmental tax* variable was incorporated for assessing the legal instrument to control environmental impacts. This variable is defined as the total environmental taxes over total revenues from taxes in a year. Based on Eurostat, within the definition of an environmental tax it is stated that "*it is a tax whose tax base is a physical unit (or a proxy of a physical unit) of something that has a proven, specific negative impact on the environment*". In other words, "more waste means higher cost" as an environmental tax is levied on market activity that generates negative environmental externalities. It is obvious that a higher environmental tax should lead to lower environmental degradation since, among other beneficial outcomes, more materials are being recycled and circulated back into production. From a microeconomic perspective, an environmental tax may have several implications on households (Ekins et al. 2011). When examining environmental taxes in relation to environmental behavior, it might affect individual decisions and increase their awareness in line with the higher premium they need to pay (Hong 2001). Thus, we expect that environmental taxes will lead to both higher reuse and recycling rates and also assume higher circularity rates.

As new business models are necessary to change the flow of traditional materials in line with research and development, we have selected a relevant indicator that monitors expenditures on *research and development* (R&D). It is expected that this indicator will positively affect environmental protection strategies (Gaballah and Kanari 2001; Wang et al. 2014) and could also be related to high circularity and recycling rates. At the same time, R&D expenditures can lead to high added-value products and energy saving (Mo et al. 2009). In other words, waste management should be based on scientific R&D to minimize environmental impacts (John and Zordan 2001). Wang et al. 2014) and could also be related to high circularity and recycling rates. At the same time, R&D expenditures can lead to high added-value products and energy saving (Mo et al. 2009). In other words, waste management should be based on scientific R&D to minimize environmental impacts (John and Zordan 2001).

Based on the above discussion, Table 2 summarizes the selected variables, giving information about official definition, mean (over the study period in the sample), standard deviation (St. dev) and expected sign.

### 3.3 Model specification

This section specifies two empirical models that capture country variability in materials recycling and circularity rates. Panel fixed-effects and instrumental variable (IV) fixed-effects estimators were employed. Based on demand theory, the general econometric model has the following form:

$$y_{i,t} = \beta_0 + \beta_i x_{i,t} + \mu_\iota + e_{i,t} \tag{1}$$

where $y_{i,t}$ is the materials *circularity* and *recycling* rates, respectively, in country $i$ at time period $t$. $\beta_0$ is the constant term, $x$ is the vector of independent variables that were used in the empirical analysis, $\beta_i$ is the estimated coefficients for each variable, $\mu_\iota$ is the unobserved heterogeneity, and $e_{i,t}$ is the idiosyncratic term. The vector of independent variables that were used are as follows: $lnGDPc_{i,t}$ is the natural logarithm of real gross domestic product per capita in each country; $Fertility_{i,t}$ is the fertility rate; $Tertiary_{i,t}$ is the ratio of the population having a higher education degree; $Urbanization_{i,t}$ and $Urbanization^2{}_{i,t}$ are the urbanization rate expressed as the percentage share of the total population living in urban areas and its square term, respectively; $EnvironmentalTaxes_{i,t}$ is the total environmental taxes as a percentage of total revenues from taxes and social contributions; and $R\&D_{i,t}$ is the share of expenditures on research and development on real GDP.

Although most of the literature assumes that the fixed-effects estimator is conventionally more appropriate than a random-effects model, we performed the Hausman

**Table 2** Dependent and independent variables, mean, standard deviation and expected signs. Sources: Eurostat

| Variables | Definition | Mean | St. dev. | Expected sign |
|---|---|---|---|---|
| Circularity rate | Circular material use rate | 8.56% | 6.22% | |
| Recycling rate | Recycling rate of municipal waste | 28.11% | 18.15% | |
| GDPc | Real GDP per capita | 24,213€ | 15,804€ | + |
| Tertiary | Tertiary education (levels 5–8), Percentage of total 15–64 years old | 22.69% | 9.79% | + |
| Fertility rate | Total fertility rate, the mean number of children that would be born alive to a woman during her lifetime | 1.53 | 0.22 | + |
| Urbanization | Distribution of population by degree of urbanization, percentage of people who live in cities | 40.93% | 14.47% | ± |
| Environmental taxes | Percentage of total revenues from taxes and social contributions (including imputed social contributions) | 7.39% | 1.66% | + |
| R&D | Intramural R&D expenditure by sectors of performance, all sectors | 1.45% | 0.87% | + |

(1978) test in our analysis. The Hausman specification test basically tests whether the idiosyncratic errors ($u_{it}$) are correlated with the independent variables ($x_{it}$) $H_0 : E\left(x_{it}\right) = 0$ or $H_1 : E\left(x_{it}\right) \neq 0$. The test statistic examines whether the random-effects estimate is insignificantly different from the fixed-effects estimate. If the null hypothesis is not rejected, we may infer that individual effects are not significantly correlated with at least one regressor in the model and the random-effects model is more appropriate. Based on the results, the Hausman test clearly rejects the null hypothesis indicating that a fixed-effects model is indeed more appropriate for our empirical analysis. By doing so, the within-country variation was removed.

We also allowed correlation between the instruments and the unobserved heterogeneity, employing instrumental variables fixed-effects estimator. More specifically, we assume that the level of environmental taxes is not a strongly exogenous variable as it depends on the level of renewable energy sources that are used in the economy. Assuming that $cov\left(x_{1t}, e_{it}\right) \neq 0$ instrumental variables estimator will take place in addressing the problem of omitted variable bias:

$$y_{it} = b_0 + b_1 x_{1t} + b_2 k_{it} + \mu_i + e_{it} \tag{2}$$

$$x_{1t} = c_0 + c_1 z_{1t} + c_2 k_{it} + v_i + u_{it} \tag{3}$$

As we know, this kind of tax is implemented when a negative externality to the environment is present, whereas the use of renewable energy sources has no negative impact on the environment. Thus, it is expected that renewable energy sources affect the level of the implemented tax. At the same time, renewable energy sources do not directly affect the level of materials recycling and circularity rates. Thus, from the empirical analysis point of view, we identify the share of renewable energy sources on total energy use as a possible instrumental variable for the environmental tax level. We argue that this variable meets the three assumptions needed for an instrumental variable, which are: (a) the instrument -z- and the endogenous variable -x- are associated either as z has a causal effect on x; (b) z affects the outcome y only through x *ceteris paribus* and (c) z is not associated with uncontrolled factors that cause y. Furthermore, weak identification and overidentifying restriction tests were employed. -z- and the endogenous variable -x- are associated either as z has a causal effect on x; (b) z affects the outcome y only through x *ceteris paribus* and (c) z is not associated with uncontrolled factors that cause y. Furthermore, tests for under-identification, weak identification based and of overidentifying restrictions test were employed.

## 4 Empirical findings

Table 3 presents the empirical results of the estimated models. We estimated Eq. 1 for the full sample period and countries. In general, the results show that most independent variables are highly statistically significant with the expected sign.

Countries with higher GDP per capita perform better in recycling and circularity rates, than those with lower GDP and consequently perform environmentally better.

**Table 3** Fixed-effect and instrumental variable fixed-effects analysis

| | Circularity | | Recycling | |
|---|---|---|---|---|
| Variables | fe | fe 2sls | fe | fe 2sls |
| lnGDPc | 4.090* | 4.044* | 16.545*** | 17.301*** |
| | (2.260) | (2.270) | (4.233) | (4.318) |
| Tertiary | 0.013 | 0.013 | 1.024*** | 1.086*** |
| | (0.060) | (0.060) | (0.092) | (0.097) |
| Fertility rate | 3.507** | 3.537** | 18.242*** | 19.217*** |
| | (1.637) | (1.637) | (3.598) | (3.579) |
| R&D | 6.358*** | 6.356*** | 0.616 | 0.473 |
| | (0.790) | (0.776) | (1.425) | (1.473) |
| Environmental taxes | 0.826*** | 0.799** | 1.379*** | 1.272*** |
| | (0.267) | (0.391) | (0.397) | (0.488) |
| Urbanization | 0.432*** | 0.432*** | 0.238 | 0.200 |
| | (0.101) | (0.099) | (0.179) | (0.178) |
| Urbanization^2 | −0.005*** | −0.005*** | −0.003 | −0.002 |
| | (0.001) | (0.001) | (0.002) | (0.002) |
| Constant | −61.96*** | – | −202.67*** | – |
| | (21.727) | | (39.945) | |
| Urbanization threshold | 41.7% | 41.7% | 46.8% | 45.4% |
| Hausman | | 22.29*** | | 76.71*** |
| Anderson canon. corr. LM statistic | | 87.690*** | | 240.758*** |
| Cragg-Donald Wald F statistic | | 76.405*** | | 376.867*** |
| Sargan statistic | | 3.010* | | 13.319*** |
| Observations | 223 | 223 | 396 | 378 |
| R-squared | 0.383 | 0.383 | 0.533 | 0.554 |
| Number of countries | 28 | 28 | 28 | 28 |

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Lag of environmental tax and renewable energy sources are used as instrumental variables of the level of environmental tax within countries

The estimated elasticity is positive and statistically significant in all models. In particular, an increase in per capita GDP by 1% leads to higher recycling by around 0.17 and circularity rate by 0.04 percentage points, respectively. It can be said that motives for recycling differ between high-income and lower-income countries (Berglund and Soderholm 2003), where wealthier citizens might have a higher demand for a cleaner environment (Torgler and García-Valinas 2007). As far as the recycling rate is concerned, our empirical findings confirm several previous studies including Jenkins et al. (2003); Colesca et al. (2014) and Lopez-Mosquera et al. (2015) who concluded among others that better economic status positively predicts recycling behavior. Regarding circularity, to the best of our knowledge, no empirical studies explain the relationship between socioeconomic and macroeconomic factors with materials circularity rate.

Our model predicts, as expected, that countries with a higher level of education tend to perform environmentally better. Our finding is similar to Guerin et al. (2001), Torgler and García-Valinas (2007), Keramitsoglou and Tsagarakis (2011), Fiorillo (2013) and De Silva and Pownall (2014). All these empirical studies affirm that higher education is positively related to pro-environmental behavior for recycling. The coefficient of educational level expressed by the proportion of people who have completed a tertiary degree is positive and statistically significant at 1% in the recycling models. More specifically, the demand for recycling seems to be elastic (or at least unity elastic) and shows that an increase by 1% in the ratio of highly educated people over the total population will result in higher recycling within a country by more than one percentage points. On the other hand, educational level is positive but insignificant for materials circularity equations. This result can be explained through how differently circularity and recycling functions are organized. Materials recycling is categorized as a bottom-up process and is organized by each individual or household within a region. On the contrary, materials circularity is focused on the efficient reuse of recourses in the production process, which is competence at a government, company or industry level.

A higher fertility rate results in more people in the young cohort who consequently might be more likely to carry out pro-environmental behavior (Song et al. 2012). The positive coefficient of fertility rate indicates that a higher fertility rate can lead to an increase in recycling and circularity rates. Higher fertility suggests more young people within a country, which means twofold better environmental performance. An indirect effect of the educational school programs to parents (decision makers of the society) and higher parental environments is that they add value to the country where such programs are present. This expected positive effect is statistically supported for the estimated models.

An environmental tax is an additional cost on activities with negative environmental impacts. Although environmental taxes have been much debated (Patuelli et al. 2005), because they may have several implications on different households (Ekins et al. 2011), they might also work as an incentive for people and industries to take more actions in protecting the environment. Adding an environmental tax gives the necessary incentive to move toward using fewer polluting technologies and taking actions that protect or restore any environmental damage. This finding is supported by our analysis which shows that coefficients are positive and statistically significant at a 1% level in almost all estimated models; higher tax rates result in higher recycling and circularity rates.

Research and development programs are essential for the improvement of waste management (John and Zordan 2001). Countries with higher expenditures on research and development are more likely to adopt environmental strategies. Our empirical results show that a higher level of research and development is positively associated with material circularity activities, while it seems not to significantly affect materials recycling statistically. While recycling is a mature and established process, a circular economy is nowadays a hot issue for R&D. Materials circularity is focused on the material waste management that takes place mainly at an industry or company level. Therefore, it is expected that research and development investments play a crucial role on pursuing a circular economy.

When it comes to waste management, optimal geographical coverage is an essential step to ensure sustainability (Economopoulos 2010; Economopoulos et al. 2013). With respect to urbanization level, it was found that economies within a more densely populated region circulate more materials but with a decreasing trend. The relationship between materials circularity rate and urbanization seems to be nonlinear coming up with an inverse-U shape. In particular, as the urbanization trend takes place, it creates increasing scales of economy as the cost for circulating and recycling decreases. However, this trend declines slowly after a threshold point at around 40% for materials circularity processes and at around 45% for materials recycling, respectively. This result is expected, based on the assumption of the homogeneity urbanization process that is considered in our model, meaning that homogeneous complex procedures and requirements exist in large cities.

Finally, we consider that some explanatory variables may have different effects on recycling and circularity rates according to some other characteristics of countries, since the 28 EU are not a fully uniform group. We suggest, as plan for future work, that variables like the relative level of wealth within the EU, the early entered countries in the EU and those countries with ex-communist economic systems will have different effects on our dependent variables. With additional data, when available, more in-depth insights will be possible, considering also several additional factors, such as subjective norms and business indices or following system dynamics approaches (Guzzo et al. 2021) in the analysis.

## 5 Conclusions and policy implications

This paper empirically investigated the main socioeconomic determinants of inter-country differences in materials recycling and circularity rates in the European area. In particular, we employed a panel dataset of the 28 EU countries over the period 2000–2018 for material recycling and 2010–2017 for materials circularity. The empirical findings are presented as follows.

GDP per capita has a positive impact on both materials recycling and circularity rates within the EU, indicating, as expected, that prosperous economies are more likely to take actions toward recycling and circularity. Fertility rate as a proxy variable of population growth also positively impacts both on recycling and circularity rate. Education has a positive effect on recycling indicating that countries with a higher percentage of educated people tend to recycle more. However, the level of education seems to be insignificant regarding materials circularity rates. This result might contradict our expectations, but it can be explained since the circularity process mainly takes place at government or industry level. As the research and development expenditures are expected to benefit industries and entrepreneurship, they do matter for materials circularity, as supported by the presented empirical results. Countries with a high percent of environmental taxes perform better on materials recycling and circularity rates. However, the coefficient of environmental taxes is higher for recycling than circulating. Finally, urbanization is used as a proxy of the level of materials recycling and circulating cost. Our findings indicate a positive association between urbanization and recycling and circularity but following a nonlinear, inverse-U shape. Urbanization positively affects circularity due to economics of scale, but this is inversed after a threshold value. On the other hand, the impact of urbanization on recycling is similar but not statistically significant.

Policy decision makers and company managers may benefit from these preliminary findings to determine strategies for regions performing low in sectors related to the variables concerning circularity. For instance, financial motives for R&D expenditures toward a circular economy will result in more sustainable production and consumption patterns. It would also be beneficial to highlight the ecological values in the new products since they would improve and direct the circularity process. Policy measures concerning households and industry agents' behavior may include the systematic dissemination of information by launching educational programs for increasing environmental awareness. Waste management policies should involve urban planning optimization strategies for optimal service coverage.

Although the aforementioned results and their policy implications could be considered when implementing policy strategies, it would nevertheless be essential to carry out further research toward fostering pro-environmental strategies, including recycling and circularity transitions, in future studies. In addition, more data availability will lead to progressive methodological approaches and congruous instruments that would be advantageous in addressing possible endogeneity issues. Furthermore, new theoretical and practical contributions should be better evidenced and differentiated at the company level as the results obtained in conjunction with the analysis provided could be insightful to administration.

**Authors' contribution** I. Kostakis collected data and carried out statistical and econometric analysis. K.P. Tsagarakis formulated the research idea and provided suggestions on empirical methods. All authors read and approved the final manuscript.

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**Data availability** Data are available.

## Declarations

**Conflicts of interest** The authors declare that they have no competing financial interests or personal relationships that might influence the work reported in this paper.

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