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# Macroeconomic Influences on Recycling in Europe: An Econometric Investigation

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**Abstract**
While the circular economy has garnered significant attention over the last two decades, few studies have explored the relationship between recycling and macroeconomic conditions. This paper aims to elucidate how macroeconomic factors influence and correlate with recycling indicators, focusing on European waste management. First, we analyze how macroeconomic indicators impact key circular economy indicators related to waste management, considering 27 European countries from 2000 to 2019, categorized into Western, Southern, and Eastern Europe. An ordinary least squares model serves as a baseline for comparison with a fixed effects model and a model with regional and time dummies. As a response to Ferrante and Germani's (2020) call for more research on causal studies of this kind, we also address reverse causality both by testing for panel data Granger causality and by applying the dynamic panel data approach developed by Arellano and Bond (1991). Second, we investigate variations in circular economic performance across European regions and countries, both before and after controlling for the macroeconomic context. The empirical analysis reveals a substantial correlation between circular economy indicators and key macroeconomic conditions, but we do not find evidence supporting causal impacts from macroeconomic circumstances in the short run. Regional examinations unveil disparities in circular economic performance, with Western Europe generally surpassing Southern and Eastern Europe. However, these patterns align more closely when considering the macroeconomic context. The methodologies employed in the study may prove valuable for future research on the circular economy and its relation to macroeconomic influences.

**Keywords** Circular economy · Macroeconomic influences · Regional development · Econometric analysis · European economy · Recycling

## Introduction

Waste management constitutes a major global issue, with landfilling being the most commonly used, yet least desirable, method of waste disposal. As a response to this issue, recycling constitutes a key ingredient in the circular economy.

Extended author information available on the last page of the article

Over the past twenty years, the circular economy has garnered substantial attention in political and academic circles, particularly in Europe, where environmental issues are of major concern. In 2015 and 2020, the European Commission [2] adopted the first and second circular economy action plans [11], with gradual revisions, elaborations and implementations over the years. The related regulatory framework has also developed by several different dimensions, inter alia through the adoption of the European Green Deal in 2020 and revisions to the circular economy monitoring framework in 2022, along with different sectorial regulations and international initiatives. As the circular economy embraces the three pillars – economic, social and environmental – the indicators that best describe it should be selected by referring to the area of target, whether it is waste management, air pollution and carbon dioxide emissions, energy, material management, or economic factors [21].

Recycling plays a central role in the circular economy. As the amounts of waste are increasing annually, the importance of recycling is growing accordingly. Recycling can partly solve the problem of waste generation by various circular economic measures. First, circular economy design is applied, where product from its production is designed to be reused, recycled, or become a part of another product. Second, innovative business models enable the transition from the traditional buy-consume-dispose principle to more sustainable production. Third, reverse cycles are developed, covering logistics, collections, sorting, treatment, and segmentation, by enabling innovative systems for new or used materials to be returned to the soil or production. Fourth, a network of enablers and accelerators are established, including a wide range of relevant stakeholders (e.g., governmental institutions, clusters, partners, co-operators, investors, research centers, higher education and other institutions that could encourage shifting to the circular economy). The concept of the circular economy encompasses innovative business models that hinge on effective waste management, optimized supply and consumption chains, and the adoption of resource-efficient and energy-saving technologies. Additionally, it entails strategies such as minimizing the consumption of primary natural resources, extending the lifespan of products through closed-loop production and consumption, and promoting the recycling or cyclic utilization of materials [23].

While the literature on the circular economy has expanded, the connections between macroeconomic factors and waste management remain incompletely understood with only a few notable contributions. Even fewer studies investigate systematically the differences in characteristics of countries with high circular economic performance and how the macroeconomic context matters in this regard. Still, some notable studies address the relationship between the circular economy and macroeconomic circumstances. A key contribution is Ferrante and Germani [12]. The authors apply fixed-effect models and Granger causality tests to explore both directions of the relationship between indicators of the circular economy and social-economic variables. Their results suggest that although the relationships between the variables are not always bidirectional, the circular economy may enhance economic growth. Ferrante and Germani call for more empirical work to explore whether the correlation patterns between the circular economy indicators and the macroeconomic variables are causal, and how their development patterns interact.

According to Domenech and Bahn-Walkowiak [9], the analysis of European national policies on environmental resource efficiency reveals a complex and fragmented landscape. This landscape is marked by diverse strategies, targets, and policy instruments, which often diminish the effectiveness of resource efficiency policies and hinder the uniform implementation of circular economy action plans. By the same token, Gutberlet et al. [15] underline that the development and implementation of circular economic measures calls should take the prevailing national business system into consideration, including macroeconomic circumstances.

In this research, we consider circular economy indicators reflecting recycling efforts as kind of waste management practices. We contribute to bridging the knowledge gap on how recycling efforts depend on macroeconomic circumstances and vice versa, as pointed out by Ferrante and Germani [12]. Moreover, we seek to fill some of the gap in scientific literature when macroeconomic conditions impact the development of the circular economy. We aim to shed light on how macroeconomic circumstances influence recycling efforts, and what explains the difference between European countries. Thereby, we aim to provide new insights into how economic development specifics impact the transition of European countries toward a circular economy.

The empirical investigation undertaken in this paper focuses on the European Union-28 countries from 2000 to 2019 (except for the Czech Republic due to data shortages), exploring six circular economy indicators related to waste and six macroeconomic factors. The study employs four econometric models. This includes a linear ordinary least squares model as a baseline approach, a fixed effect model adjusting time-fixed and country-fixed effects and a model with regional time dummies, which aims to capture distinct development patterns in Western, Southern and Eastern Europe. The fourth model is the dynamic panel data model of Arellano and Bond [3], which aims to capture the dynamics of the correlations and potential bidirectional causal relations. In addition, we perform the panel data Granger causality test developed by Dumitrescu and Hurlin [10] to further check the causal relationship between the indicators for the circular economy and the macroeconomic circumstances.

When analyzing European countries, regional allows us to identify successful circular economy implementation practices through shared common characteristics. Moreover, adjustment for the macroeconomic context allows us to shed light on what explains the differences in the circular economy indicators. The proposed econometric models allow the assessment of relations between macroeconomic key variables and circular economy indicators, and the comparative development in Europe. We examine how macroeconomic conditions influence and covaries with the circular indicators and how macroeconomic circumstances contribute to explaining differences in circular economic performance across European regions and countries. The regional and country-specific investigations are suited for shedding light on differences in national practices, as requested by Domenech and Bahn-Walkowiak [9] and Gutberlet et al. [15]. The main ingredients of the empirical approach applied are- illustrated in Fig. 1.

The empirical findings of this paper suggest that while there is no clear evidence of a causal impact in the short term, a complex relationship exists. Regional analyses demonstrate differences in circular economic performance, with Western Europe consistently outperforming Southern and Eastern Europe, although growth in circular economy indicators is higher in the latter regions. The patterns remain, but they become more similar when controlled for the macroeconomic context.

Some other papers are also relevant for this study. Another article standing out is the one by Tantau, Maassen and Fratila [28]. The authors examine the relationships between circular economy indicators in the European Union using panel data regressions. Their research utilizes measures of waste management, environmental taxes, and R&D expenditure, drawing on data from 28 European Union countries between 2010 and 2014. They selected the recycling rate of municipal waste as the dependent variable, which is also one of the six circular economy indicators used as a dependent variable in our study. The ordinary least squares regression model and the non-pooled regression by Tantau, Maassen

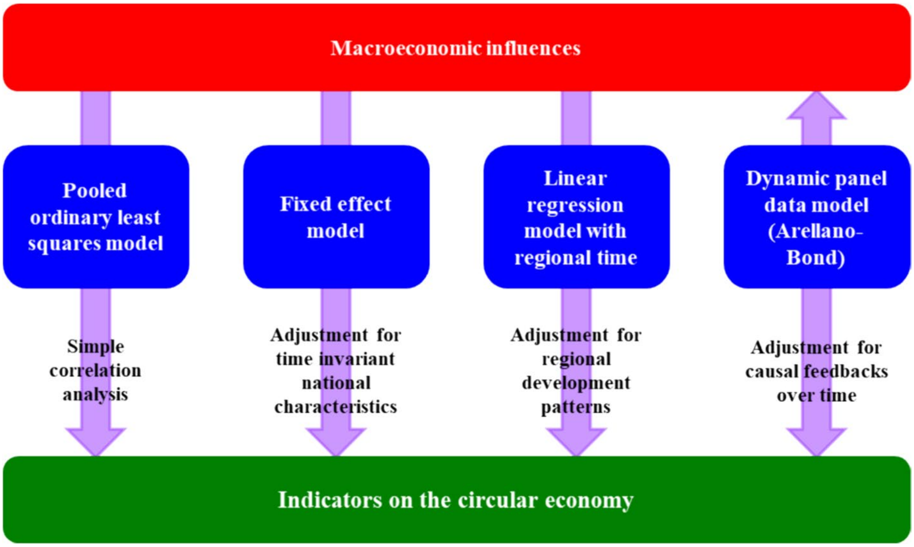



**Fig. 1** Illustration of methodological approach

and Fratila indicate that most of the selected independent variables are influenced by the dependent variable.

The literature review of Razminienė et al. [25] illustrates how scholars analyze the relationship between the circular economy and economic performance on a regional level, motivating further investigation at the European national level. The review also depicts an exponential growth in such studies. The existing literature generally find that waste management is influenced by several circumstantial factors, among them foreign direct investment flows, environmental impacts, population, pollution and spillover effects. Van Bueren et al. [29] review macro studies on the circular economy with the intention of finding the optimal regions in terms of neighborhoods and planetary boundaries, while Razminienė and Tvaronavičienė [25] review of cluster synergies in context of the circular economy.

This study investigates regional developments in the circular economy within three European regions sharing common characteristics. Regional development is also addressed in the literature concerning other parts of the world. Lu et al. [20] examines efficiency of the circular economy in Chinese provinces, applying a two-stage data envelopment analysis, accounting for spatial autocorrelation. The authors apply economic outputs, recycling outputs and undesired outputs in their production estimation. They find that high circular economic efficiency for a region is associated with proximity to similar regions, high level of economic development, openness to the outside, government regulations, industrial aggregation and low level of industrialization.

Other authors address the relationship between macroeconomic circumstances and other circular economic indicators. By applying a linear regression model to evaluate the potential correlation among European end-of-life vehicle flows in six countries, D'Adamo et al. [8] reveal correlation patterns between generated and recycled end-of-life vehicles on the one hand and gross domestic product and population on the other hand. Pham, Huynh and Nasir [22] apply a panel vector autoregressive model and a fully modified ordinary least squares model to European countries. They find that population size, urbanization, economic growth, FDI, trade and energy consumption correlate positively with carbon emissions, whereas renewable energy consumption may contribute to environmental degradation in the long run.

Another part of the literature analyzes the relationship between the circular economy and macroeconomic circumstances by model simulation. Integrating circular materials into a standard neoclassical general equilibrium model, [7] show that the optimal recycling rate depends positively on marginal pollution damage and waste content of final consumption goods. Furthermore, they show that technological improvements in recycling technology enhance total output and the circular economic activities. Higher cost of natural materials, on the other hand, diminishes output, and increases waste accumulation and recycling. Based on scenario analysis across countries, Aguilar-Hernandez, Rodrigues and Tukker [1] predict that circular economy measures may increase median figures for gross domestic product, employment and carbon dioxide emissions by 2.0 percent, 1.6 percent, and minus 24.6 percent, respectively, compared to the business-as-usual scenario.

Yet another part of the literature with relevance for this paper are carried out at micro level. Siedschlag and Yan [27] study how internal and external factors influence firms' decisions to invest in environmental protection in Ireland. They apply an instrumental variable approach with the proportion of local firms in each peer group as an instrument, exploiting that local-owned firms are more likely to invest environmental protection than foreign-owned firms. The authors find that more prominent firms tend to invest in equipment for pollution control and cleaner technologies. In a sample of more than 10,000 small and medium-sized European firms Bassi and Dias [5] find that 73.2 percent of them implement at least one circular economic activity. Green actions are positively associated with firm size and R&D intensity.

## Methodology

In this section, we describe the model and the econometric strategy employed to analyze how the macroeconomic influences and regional development patterns are associated with the circular economy.

### Macroeconomic Influences on the Circular Economy

To address how macroeconomic conditions influence and correlate with factors of the circular economy, we estimate four econometric models.

As the simplest model, we apply the linear ordinary least squares estimator. The model is cross-sectional in nature and suited to capture correlation patterns between the variables. Formally, let $y_{i,t}$ be a circular economic indicator for country $i$ at time $t$. Furthermore, $x_{i,t}$ is a vector of macroeconomic key variables (including the intercept), which possibly influences the circular economic indicator. The model becomes:

$$y_{i,t} = x'_{i,t}\beta^{OLS} + \epsilon^{OLS}_{i,t} \tag{1}$$

where is $\beta^{OLS}$ a vector of regression parameters associated with the explanatory variables and $\epsilon_{i,t}$ is an error term. Note that neither the error term nor the estimation of the coefficients' standard errors takes potential autocorrelation or heteroskedasticity into consideration.

In addition, we construct panel data models. Within these models, we let the error terms account for potential autocorrelation and heteroskedasticity, and apply robust standard errors. As it concerns the second model, we estimate a standard fixed effect model with time and country fixed effects. Here, we introduce a vector of time dummies $DT_t$ at time and a vector of country dummies$DC_i$ at country $i$:

$$y_{i,t} = x'_{i,t}\beta^{FE} + DT'_t\theta^{DT,FE} + DC'_i\theta^{DC,FE} + \epsilon^{FE}_{i,t} \tag{2}$$

where $\beta^{FE}$, $\theta^{DT,FE}$, $\theta^{DC,FE}$ are vectors of regression parameters and $\epsilon^{FE}_{i,t}$ denotes the error term.

As a third model, we apply an alternative fixed effect with regional time effects. Here, all countries are sorted into regions $r$. Compared to the standard fixed model, this model does not involve country fixed effects, but it does in return allow for regional development patterns. We let $DRT_{r(t),t}$ denote a vector of regional time dummies for country $i$ located in region $r$ at time $t$. The linear regression model with regional time dummies becomes:

$$y_{i,t} = x'_{i,t}\beta^{RTD} + DRT'_{r(i),t}\theta^{DRT,RTD} + \epsilon^{RTD}_{i,t} \tag{3}$$

where $\beta^{RTD}$ and $\theta^{DRT,RTD}$ are regression parameters, and $\epsilon^{RTD}_{i,t}$ denotes the error term.

Reverse causality from the output variable to the explanatory variable and mutual dependence on omitted variable may cause challenges in the mentioned approaches. To test reverse causality, we apply Dumitrescu and Hurlin's [10] test for detecting reverse causality in panel data, building on Granger [14]. The test considers whether an explanatory variable is explained by an outcome variable or not. In the empirical implementation, we apply the Wald test and tests building on the standard normal distribution.

As the last model specification, we apply the dynamic panel data model, as proposed by Arellano and Bond [3]. We also refer to Holtz-Eakin, Newey and Rosen 1988 [16], Arellano and Bover 1995 [4], and Blundell and Bond 1998 [6]. This model is known for handling reverse causality issues in the absence of solid external instruments. Such an estimation technique can be useful to tackle potential endogeneity problems. Here, we split the vector of explanatory variables into two subsets, $x_{i,t}\epsilon\left\{x^C_{i,t}, x^Z_{i,t}\right\}$, where $x^C_{i,t}$ constitutes a vector of strictly exogenous covariates and $x^Z_{i,t}$ constitutes a vector of possibly endogenous covariates. Furthermore, we assume that the error term consists of two independent composites, $\epsilon^{DPM}_{i,t} = v^{DPM}_{i,t}\rho i^{DPM}_{i,t}$. Here, $v^{DPM}_{i,t}$ is a white noise error term, whereas$\rho i^{DPM}_{i,t}$ is panel-level effects that may be correlated with the covariates. We assume that the past variations in the response variables are independent of the current shocks in the circular economy indicators that we employ. The model becomes as follows:

$$y_{i,t} = y_{i,t-1}\alpha^{DPM} + x'^{C}_{i,t}\beta^{DPM} + x'^{Z}_{i,t}\gamma^{DPM} + T'_t\theta^{DT,DPM} + v^{DPM}_{i,t} + \rho i^{DPM}_{i,t} \tag{4}$$

Here, $T_t$ represents a time trend, whereas $\beta^{DPM}$, $\gamma^{DPM}$, $\theta^{DT,DPM}$ and constitute vectors of the regression parameters. As the lagged dependent variables correlate with the current innovation in the dependent variable, measures need to be taken to make the standard estimators consistent. The panel-level effects are handled by applying estimators based on first differencing and instruments to exploit moment conditions. Here, the lagged levels of the dependent variables, the predetermined variables and the endogenous variables form the generalized method of moments type of instruments, exploiting the first differences of the strictly exogenous variables as standard instruments. In practice, we treat all our macroeconomic covariates as generalized method of moments type of instruments, while the year trend is treated as a standard instrument.

We have applied Stata in the practical implementation of the econometric model. We have used the standard commands '*reg*' and '*xtreg*' for the ordinary linear least squares model and the fixed effect models respectively. The command '*xtabond*2' [26] and '*xtgcause*' [19] is applied for the dynamic panel data model of Arellano and Bond.

## Regional Developments in the Circular Economy

When moving on to regional developments in the circular economy, we conduct two types of analyses. First, we consider the effect of circular economy indicators developing across European regions. Second, we consider the circular economy's status and average annual growth indicators across European countries. Both analyses are conducted with and without adjusting for macroeconomic influences.

When considering the unadjusted regional developments in the circular economic indicators, we apply simple linear regression models with the indicator for the circular economy as the dependent variable and regional time dummies as the only explanatory variables (in addition to a constant). The simple regression model with regional time dummies becomes:

$$y_{i,t} = \beta_0^{SRTD} + DRT'_{rt,t}\theta^{DRT,SRTD} + \epsilon_{i,t}^{SRTD} \tag{5}$$

where $\beta_0^{SRTD}$ and $\theta^{DRTS,RTD}$ represent regression parameters and $\epsilon_{i,t}^{SRTD}$ represent the error term. The regional development patterns will then be reflected by the estimated regression coefficients, $\hat{\theta}^{DRT,SRTD}$.

By nature, these regression coefficients may be below and above zero and do not involve any a priori assumption about bounds on the absolute magnitude. To transform the variables into scale, which is easier to interpret, we make use of the following formula for indexation $I$ of a variable $\phi$ for country $i$ at time $t$:

$$I(\phi_{i,t}) = \frac{\phi_{i,t} - min(\phi)}{max(\phi) - min(\phi)} \tag{6}$$

which ensures that the lowest outcome of $\phi$ is zero and the highest outcome of $\phi$ is one. The scale in between is determined by the scale of the variable in question. In the case of a dependent variable defined as a portion, we keep the original scales (e.g. $\phi_i = \hat{\theta}_i^{DRT,SRTD}$ in this case). In the case of a dependent variable defined in logarithmic form, we convert the variable to normal values before the indexation (e.g. $\phi_i = exp(\hat{\theta}_i^{DRT,SRTD})$ in this case).

When doing the same with adjustment for macroeconomic influences, we estimate the regression model specified in Eq. (2). The regional development patterns will in this case be reflected by the regression coefficients $\hat{\theta}^{DRT,RTD}$. We then apply Eq. (5) for indexation in the same manner as in the unadjusted investigation of regional development patterns.

When considering the status and the average annual growth for the unadjusted circular economy indicators over European countries, we apply the circular variables directly. For the circular variables in the logarithm, we transform them back to normal values. For the circular variables that represent portions, we do not perform such transformations.

When considering the adjusted circular economy indicators over European countries, we utilize the estimated residuals from Eq. (1), $\widehat{\epsilon}_{i,t}^{OLS}$. Then, we perform an indexation of a similar fashion as the one presented in connection with Eq. (5) above.

As a status for the circular indicators, we apply 2018 as the reference year (as some more observations are missing for 2019). For each country, the annual growth rates are estimated based on the first year and the last year with observations, implying that we can include some more countries in the comparison at the expense of the occurrence of some deviations in years assessed over counties.

## Data

In this section, we present the data used in the investigations, starting with data implementation, before moving on to descriptive statistics.

### Data Implementation

In this subsection, we account for what variables we apply in the empirical investigations, how we apply them, and from which sources they are collected. In Table 1, we list the variables used in the empirical investigations.

Among the variables in the table, the sixth first is circular economy indicators, which we apply as dependent variables in the investigations. The six latest are macroeconomic indicators, which we exploit as explanatory variables in the investigations.

Our study involves all European Union-28 countries from 2000 to 2019, except for the Czech Republic, due to limited data access for this country. In some of the investigations, we classify the countries into three regions with cultural and economic common characteristics: Western Europe, Southern Europe and Eastern Europe. When addressing regional developments in the circular economy, we use two-digit country codes (i.e. the United Nations' standard 'ISO 3166–1 alpha-2') to indicate each concerned country. An overview of the countries in the study and the corresponding regions and country codes is given in Table 2.

The variable coverage is not complete for all years' overall observation units. These differences are first and foremost related to different time spans associated with the dependent variable, implying that the dataset within the dataset associated with each regression is not that unbalanced. Yet, the unbalances are also, to some extent, caused by missing observations for a particular observation unit within the defined period. We have chosen to keep all observations in the dataset and leave the applied datasets in the regression weakly unbalanced, as balancing the dataset would have implied the loss of many observations.

### Descriptive Statistics

Before we present the empirical results, we provide some key descriptive statistics. In Table 3, we present the summary statistics.

In Table 4, we depict the correlations between the variables in the study, including the circular indicators, the macroeconomic key variables, regional dummies and time. It is worth noting that the variables involve different numbers of observations, conferring the discussion on the slightly unbalanced dataset in the previous subsection.

**Table 1** Overview of variables with corresponding descriptions, measurement units and data sources

| Variable | Description | Measured in | Source |
|---|---|---|---|
| Recycling of biowaste per capita (log) | The ratio between composed municipal waste and the total population is number refers to the recycling of biowaste | Kilograms per capita | Eurostat ("Indicators—Circular economy—Eurostat," n.d. [18]) |
| Processed material (log) | Processed material – direct inputs and recovery – recycling and backfilling | Thousand tones | Eurostat ("Indicators—Circular economy—Eurostat," n.d. [18]) |
| Circular material use rate | Circular material use rate is a composite indicator involving aggregate domestic material consumption and the circular use of materials summed up and divided by the overall material use. A higher circularity rate value shows better performance as more secondary materials are used instead of primary raw materials reducing the environmental impact in this way | Percentage | Eurostat ("Indicators—Circular economy—Eurostat," n.d. [18]) |
| The recycling rate of municipal waste | The share of recycled municipal waste in the total municipal waste generation | Thousand tones | Eurostat ("Indicators—Circular economy—Eurostat," n.d. [18]) |
| The recycling rate of electronic waste | Multiplication of the collection rate and the reuse and recycle rate | Percentage | Eurostat ("Indicators—Circular economy—Eurostat," n.d. [18]) |
| The recycling rate of packing waste | The share of recycled packaging waste in all generated packaging waste | Rate | Eurostat ("Indicators—Circular economy—Eurostat," n.d. [18]) |
| Gross domestic product per capita (log) | The ratio of the total final output of goods and services produced by the economy within a certain period expressed as real GDP to the average population of a specific year is referred to as real GDP per capita | USD | Penn World Table (version 10.0) ("PWT 10.0 ǀ Penn World Table ǀ Groningen Growth and Development Centre ǀ University of Groningen," n.d. [24]) |
| Real private investments per capita (log) | Gross fixed capital formation in the private sector | USD | AMECO database ("AMECO database ǀ European Commission," n.d. [2]) |
| Fixed capital stock per worker (log) | The stock of physical capital | USD | Penn World Table (version 10.0) ("PWT 10.0 ǀ Penn World Table ǀ Groningen Growth and Development Centre ǀ University of Groningen," n.d. [24]) |
| Unemployment rate | The ratio between the number of unemployed and the total workforce | Percentage | IMF – Government Finance Statistics (GFS) ("IMF Data Home Page—Dataset—IMF Data," n.d. [17]) |

**Table 1** (continued)

| Variable | Description | Measured in | Source |
|---|---|---|---|
| Population growth | Annual percentage variation in population | Percentage | Penn World Table (version 10.0) ("PWT 10.0 ǀ Penn World Table ǀ Groningen Growth and Development Centre ǀ University of Groningen," n.d. [24]) |
| GINI index for inequality | Gini index measures the extent to which the distribution of income among individuals or households within an economy deviates from a perfectly equal distribution. The Gini index measures the area between the Lorenz curve for the cumulative distribution of total income and a hypothetical line of absolute equality | Index points | Gini index (World Bank estimate) ("Gini index ǀ Data," n.d. [13]). In a few cases, the observations are interpolated geometrically, when in between observation, and set equal to the closest observations, when on outskirts of the observations |

**Table 2** Countries included in the study with regional classification and country codes (ISO 3166–1 alpha-2)

| Region | Country name | Country code |
|---|---|---|
| Western Europe | Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Netherlands, Sweden and United Kingdom | AT, BE, DK, FI, FR, DE, IE, LU, NL, SE and GB |
| Southern Europe | Cyprus, Greece, Italy, Malta, Portugal and Spain | CY, GR, IT, MT, PT and ES |
| Eastern Europe | Bulgaria, Croatia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia | BG, HR, EE, HU, LV, LT, PL, RO, SK and SI |

**Table 3** Summary statistics

| Variable | Obs | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Recycling of biowaste per capita (log) | 471 | 3.572 | 1.190 | 0.693 | 5.533 |
| Processed material (log) | 270 | 12.109 | 1.330 | 8.538 | 14.504 |
| Circular material use rate | 270 | 0.088 | 0.064 | 0.012 | 0.300 |
| The recycling rate of municipal waste | 527 | 0.291 | 0.182 | 0.000 | 0.672 |
| The recycling rate of electronic waste | 263 | 0.356 | 0.149 | 0.097 | 1.052 |
| The recycling rate of packing waste | 479 | 0.574 | 0.133 | 0.059 | 0.853 |
| Gross domestic product per capita (log) | 540 | 10.402 | 0.436 | 9.167 | 11.481 |
| Real private investments per capita (log) | 540 | 8.209 | 0.734 | 5.985 | 10.32 |
| Fixed capital stock per worker (log) | 540 | 12.895 | 0.525 | 10.891 | 13.62 |
| Unemployment rate | 522 | 8.837 | 4.451 | 1.900 | 27.492 |
| Population growth | 540 | 0.002 | 0.008 | -0.016 | 0.027 |
| GINI index for inequality | 540 | 31.132 | 3.519 | 24.200 | 35.900 |

Among the circular economy indicators, we see a particularly strong piecewise correlation between recycling biowaste per capita and the recycling rate of municipal waste and between the recycling rates of municipal waste and electronic waste. Conversely, the recycling rate of electronic waste is weakly negatively correlated with the circular material use rate and barely positively correlated with processed material per capita in the log.

The strongest piecewise correlations between the circular economy indicators and the macroeconomic key variables are found between recycling of biowaste per capita in logs and recycling rate of municipal waste on the one hand and gross domestic product per and real private investments – both per capita in logs – on the other hand. In addition, the circular economy indicators tend to be larger in Western Europe than in Eastern and Southern Europe and to increase over time.

**Table 4** Piecewise correlation matrix

| Variable | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| (1) Recycling of biowaste per capita (log) | 1.000 | | | | | |
| (2) Processed material per capita (log) | 0.423 | 1.000 | | | | |
| (3) Circular material use rate | 0.530 | 0.429 | 1.000 | | | |
| (4) Recycling rate of municipal waste | 0.849 | 0.474 | 0.565 | 1.000 | | |
| (5) Recycling rate of electronic waste | 0.131 | 0.085 | -0.062 | 0.336 | 1.000 | |
| (6) Recycling rate of packing waste | 0.590 | 0.370 | 0.411 | 0.752 | 0.316 | 1.000 |
| (7) Gross domestic product per capita (log) | 0.727 | 0.201 | 0.465 | 0.732 | 0.110 | 0.482 |
| (8) Real private investments per capita (log) | 0.700 | 0.161 | 0.470 | 0.690 | 0.095 | 0.398 |
| (9) Fixed capital stock per worker (log) | 0.554 | 0.097 | 0.284 | 0.508 | -0.118 | 0.433 |
| (10) Unemployment rate | -0.326 | -0.052 | -0.328 | -0.320 | -0.175 | 0.026 |
| (11) Population growth | 0.452 | -0.034 | 0.352 | 0.319 | -0.062 | 0.092 |
| (12) GINI index for inequality | -0.032 | 0.039 | -0.021 | -0.013 | -0.087 | 0.018 |
| (13) Western Europe | 0.655 | 0.378 | 0.492 | 0.733 | 0.184 | 0.459 |
| (14) Southern Europe | -0.029 | -0.172 | -0.207 | -0.299 | -0.374 | -0.274 |
| (15) Eastern Europe | -0.665 | -0.236 | -0.322 | -0.488 | 0.127 | -0.244 |
| (16) Time | 0.188 | 0.027 | 0.052 | 0.350 | 0.462 | 0.454 |
| Variable | (7) | (8) | (9) | (10) | (11) | (12) |
| (7) Gross domestic product per capita (log) | 1.000 | | | | | |
| (8) Real private investments per capita (log) | 0.944 | 1.000 | | | | |
| (9) Fixed capital stock per worker (log) | 0.753 | 0.757 | 1.000 | | | |
| (10) Unemployment rate | -0.443 | -0.520 | -0.113 | 1.000 | | |
| (11) Population growth | 0.690 | 0.704 | 0.504 | -0.372 | 1.000 | |
| (12) GINI index for inequality | -0.023 | -0.033 | 0.003 | 0.048 | 0.010 | 1.000 |
| (13) Western Europe | 0.778 | 0.806 | 0.480 | -0.428 | 0.505 | 0.019 |
| (14) Southern Europe | -0.049 | -0.078 | 0.265 | 0.240 | 0.159 | -0.033 |
| (15) Eastern Europe | -0.749 | -0.753 | -0.717 | 0.228 | -0.650 | 0.009 |
| (16) Time | 0.229 | 0.106 | 0.164 | 0.031 | -0.061 | -0.076 |

## Empirical Results

When presenting the empirical results, we start by assessing macroeconomic influences on circular economic outcomes. We then move on to the regional developments associated with the European circular economy.

### Macroeconomic Influences on the Circular Economy

In the investigation of macroeconomic influences on the circular economy, we begin by investigating correlation patterns based on pooled linear least squares regressions**.** As some of the macroeconomic variables are collinear, it is expected that some explanatory variables will turn out insignificant, despite a strong piecewise correlation with the dependent variable (confer subsection 3.2).

**Table 5** Macroeconomic influences on circular economic key variables, estimated by pooled ordinary linear least squares regressions. Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.10$

| POLS | Recycling of biowaste per capita (log) | Processed material per capita (log) | Circular material use rate | The recycling rate of municipal waste | The recycling rate of electronic waste | The recycling rate of packing waste |
|---|---|---|---|---|---|---|
| Gross domestic product per capita (log) | 1.825*** | 2.266*** | 0.041 | 0.357*** | 0.185** | 0.293*** |
| | (0.284) | (0.712) | (0.032) | (0.036) | (0.077) | (0.038) |
| Real private investments per capita (log) | 0.434** | -0.032 | 0.012 | 0.082*** | 0.023 | -0.018 |
| | (0.187) | (0.427) | (0.019) | (0.025) | (0.048) | (0.025) |
| Fixed capital stock per worker (log) | 0.085 | -0.385 | 0.012 | -0.063*** | -0.118*** | 0.026 |
| | (0.148) | (0.295) | (0.013) | (0.017) | (0.034) | (0.018) |
| Unemployment rate | 0.006 | 0.013 | -0.003** | 0.003* | -0.001 | 0.005*** |
| | (0.012) | (0.024) | (0.001) | (0.002) | (0.003) | (0.002) |
| Population growth | -25.861*** | -66.231*** | -0.084 | -8.805*** | -6.306*** | -7.196*** |
| | (7.865) | (15.548) | (0.688) | (0.906) | (1.654) | (0.894) |
| GINI index for inequality | -0.002 | 0.028 | 0.001 | 0.001 | -0.002 | 0.001 |
| | (0.011) | (0.020) | (0.001) | (0.001) | (0.002) | (0.001) |
| Constant | -20.183*** | -7.258 | -0.601*** | -3.309*** | -0.145 | -2.743*** |
| | (2.025) | (5.003) | (0.222) | (0.241) | (0.544) | (0.263) |
| Observations | 456 | 252 | 252 | 511 | 260 | 463 |
| R-squared | 0.542 | 0.138 | 0.274 | 0.617 | 0.135 | 0.376 |

The results are provided in Table 5. We see that the national production level in terms of high gross domestic product per capita is associated with positive and significant scores on the circular economy indicators, except for the circular material use rate. Instead, the circular material use rate has a negative correlation with the unemployment rate. On the contrary, the recycling rates of municipal waste and packing waste are positively and significantly associated with the unemployment rate. Intuitively, it is easy to think of positive and negative mechanisms, from unemployment to circular outcomes. On the one hand, the unemployed generally have less to spend. On the other hand, recycling concerns a good that poorer people can afford to a lesser extent.

Except for the circular material use rate, all circular economy indicators were negatively associated with population growth. This may reflect that population growth ceteris paribus calls for higher circular capacities to maintain the same level of the circular indicators. Perhaps somewhat surprisingly, capital intensity is negatively associated with municipal and electronic waste recycling rates. A possible explanation is that manufacturing and other capital-intensive sectors are overrepresented in countries with relatively high capital intensity and that these countries perform somewhat poorer on circular economy indicators. Otherwise, the GINI index is insignificant in all regressions, indicating that egalitarianism is uncorrelated with the circular economy.

Of course, pooled ordinary least squares regressions give a rather rough picture and mainly involve conditioned correlations. Moreover, many unobservables related to both country and year may affect the results. Next, we, therefore, perform fixed effect regressions with country-fixed effects and year-fixed effects, which are suited to explore the conditioned relationship between the explanatory variables and the outcome variables.

Overall, the fixed effect regressions' results are less significance than the results from the pooled ordinary least squares regressions, as depicted in Table 6. Some features resemble the POLS approach, but there are also many differences. The impact of gross domestic product per capita is only significant at a one percent significance level for recycling biowaste per capita and processed material per capita, in addition to being significant at a ten percent significance level for the recycling rate of municipal waste. Thus, economic growth appears to be reflected by more spending on the circular economy partly. For real private investments per capita, the regression coefficients for recycling of biowaste per capita and the recycling rate of municipal waste are still significant, but the signs have flipped. As gross domestic product per capita are also included in these regressions, this may partly reflect the tradeoff between investments and consumption. Capital intensity, the unemployment rate, and population growth still involve significant regression coefficients, but the signs now vary across regressions. The regression coefficient for the GINI index is still insignificant in all regressions.

The alternative fixed effect specification is a linear regression with regional year dummies. In this specification, we neglect country heterogeneities within each region (i.e. Western, Southern and Eastern Europe), but we can control for regional development patterns. We have reported the regression results in Table 7. We see that gross domestic product per capita still involves some positive and significant results, whereas many of the regression coefficients for population growth once again are negative and significant. As before, real private investments per capita, capital intensity, and the unemployment rate involve positive and insignificant regression coefficients, while the regression coefficients for the GINI index remain insignificant.

A worry is that some of the explanatory variables may be endogenous. Accordingly, we test for panel data Granger causality in Table 8. Note that this test reveals bidirectional causality patterns, which may disappear after considering other covariates and correlation

**Table 6** Macroeconomic influences on circular economic key variables, estimated by a linear regression model with country and year fixed effects and robust standard errors. Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

| FE | Recycling of biowaste per capita (log) | Processed material per capita (log) | Circular material use rate | The recycling rate of municipal waste | The recycling rate of electronic waste | The recycling rate of packing waste |
|---|---|---|---|---|---|---|
| Gross domestic product per capita (log) | 3.806** | 1.445*** | -0.010 | 0.317* | 0.135 | 0.141 |
| | (1.488) | (0.186) | (0.074) | (0.164) | (0.226) | (0.151) |
| Real private investments per capita (log) | -1.232*** | -0.026 | -0.006 | -0.120* | -0.116 | -0.079 |
| | (0.440) | (0.076) | (0.019) | (0.061) | (0.078) | (0.048) |
| Fixed capital stock per worker (log) | 0.509 | -0.737** | -0.071 | -0.023 | 0.486* | 0.350*** |
| | (1.216) | (0.318) | (0.091) | (0.094) | (0.270) | (0.103) |
| Unemployment rate | 0.019 | 0.012*** | -0.001 | -0.001 | -0.012** | 0.001 |
| | (0.034) | (0.004) | (0.002) | (0.003) | (0.005) | (0.003) |
| Population growth | -0.181 | 7.624*** | -0.430 | -0.646 | -2.797* | -1.101 |
| | (22.232) | (1.850) | (0.459) | (1.457) | (1.513) | (1.354) |
| GINI index for inequality | 0.004 | 0.000 | 0.000 | -0.001 | 0.001 | -0.001 |
| | (0.011) | (0.001) | (0.000) | (0.002) | (0.002) | (0.002) |
| Constant | -32.855** | 6.654 | 1.157 | -1.761 | -6.344* | -4.852*** |
| | (15.871) | (4.374) | (0.769) | (1.214) | (3.092) | (1.097) |
| Year dummies | Yes | Yes | Yes | Yes | Yes | Yes |
| Country dummies | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 456 | 252 | 252 | 511 | 260 | 463 |
| R-squared | 0.453 | 0.706 | 0.091 | 0.603 | 0.489 | 0.677 |
| Adjusted R-squared | 0.422 | 0.687 | 0.033 | 0.583 | 0.455 | 0.659 |

**Table 7** Macroeconomic influences on circular economic key variables, estimated by a linear regression model with regional time dummies and robust standard errors. Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.10$

| LS with RT-dummies | Recycling of biowaste per capita (log) | Processed material per capita (log) | Circular material use rate | The recycling rate of municipal waste | The recycling rate of electronic waste | The recycling rate of packing waste |
|---|---|---|---|---|---|---|
| Gross domestic product per capita (log) | 0.158 | 1.388* | 0.037 | 0.123*** | -0.023 | 0.070** |
| | (0.296) | (0.821) | (0.043) | (0.032) | (0.054) | (0.035) |
| Real private investments per capita (log) | 0.755*** | -1.383*** | -0.014 | 0.040* | 0.029 | -0.001 |
| | (0.220) | (0.466) | (0.023) | (0.023) | (0.040) | (0.024) |
| Fixed capital stock per worker (log) | -0.288* | -0.215 | 0.027** | -0.003 | -0.089** | 0.088*** |
| | (0.157) | (0.351) | (0.012) | (0.020) | (0.036) | (0.021) |
| Unemployment rate | -0.004 | 0.000 | -0.004** | 0.001 | 0.009*** | 0.004*** |
| | (0.012) | (0.032) | (0.001) | (0.001) | (0.002) | (0.001) |
| Population growth | -22.079** | -61.251*** | 0.202 | -5.086*** | 0.280 | -3.091*** |
| | (10.621) | (16.522) | (0.755) | (0.871) | (1.406) | (0.774) |
| GINI index for inequality | -0.004 | 0.010 | 0.000 | 0.000 | 0.000 | -0.001 |
| | (0.016) | (0.028) | (0.002) | (0.002) | (0.003) | (0.002) |
| Constant | -0.724 | 10.006 | -0.556* | -1.377*** | 1.441** | -1.453*** |
| | (2.720) | (7.171) | (0.302) | (0.285) | (0.630) | (0.293) |
| Regional year dummies | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 456 | 252 | 252 | 511 | 260 | 463 |
| R-squared | 0.672 | 0.342 | 0.313 | 0.738 | 0.447 | 0.639 |

**Table 8** Test statistics for panel data Granger causality. H0: The explanatory variable does not Granger-cause the outcome variable. H1: The explanatory variable does Granger-cause the outcome variable for at least one country. The panel dataset is balanced from 2000 to 2019, omitting countries with missing observations. Statistic Ž denotes standard normal statistics normalized to scale

| Test for panel data Granger causality | Recycling of biowaste per capita (log) | Processed material per capita (log) | Circular material use rate | The recycling rate of municipal waste | The recycling rate of electronic waste | The recycling rate of packing waste |
|---|---|---|---|---|---|---|
| Gross domestic product per capita (log) | | | | | | |
| Lag structure 1 | Ž: 0.363 ($p=0.716$) | Ž: 2.639 ($p=0.008$) | Ž: 5.730 ($p=0.000$) | Ž: 2.808 ($p=0.005$) | Ž: 4.236 ($p=0.000$) | Ž: 1.153 ($p=0.249$) |
| Lag structure 2 | Ž: 0.590 (p = 0.555) | Not applicable | Not applicable | Ž: 4.269 (p = 0.000) | Not applicable | Ž: -0.261 (p = 0.794) |
| Real private investments per capita (log) | | | | | | |
| Lag structure 1 | Ž: 0.913 ($p=0.362$) | Ž: 2.681 ($p=0.007$) | Ž: 6.097 ($p=0.000$) | Ž: 3.888 ($p=0.000$) | Ž: 13.991 ($p=0.000$) | Ž: 0.863 ($p=0.388$) |
| Lag structure 2 | Ž: 2.104 ($p=0.035$) | Not applicable | Not applicable | Ž: 2.474 ($p=0.013$) | Not applicable | Ž: 1.973 ($p=0.049$) |
| Fixed capital stock per worker (log) | | | | | | |
| Lag structure 1 | Ž: 2.890 (p = 0.004) | Ž: 4.367 (p = 0.000) | Ž: 4.585 (p = 0.000) | Ž: 3.135 (p = 0.002) | Ž: 9.202 (p = 0.000) | Ž: -0.512 (p = 0.609) |
| Lag structure 2 | Ž: 1.377 ($p=0.169$) | Not applicable | Not applicable | Ž: 2.011 ($p=0.044$) | Not applicable | Ž: 2.160 ($p=0.031$) |
| Unemployment rate | | | | | | |
| Lag structure 1 | Ž: 0.320 ($p=0.749$) | Ž: 1.959 ($p=0.050$) | Ž: 8.084 ($p=0.000$) | Ž: 0.445 ($p=0.656$) | Ž: 11.197 ($p=0.000$) | Ž: 0.492 ($p=0.622$) |
| Lag structure 2 | Ž: -0.210 ($p=0.834$) | Not applicable | Not applicable | Ž: 1.381 ($p=0.167$) | Not applicable | Ž: 1.515 ($p=0.130$) |
| Population growth | | | | | | |
| Lag structure 1 | Ž: 26.367 ($p=0.000$) | Ž: 8.133 ($p=0.000$) | Ž: 4.247 ($p=0.000$) | Ž: 12.729 ($p=0.000$) | Ž: 17.981 ($p=0.000$) | Ž: 21.794 ($p=0.000$) |
| Lag structure 2 | Ž: 5.584 ($p=0.000$) | Not applicable | Not applicable | Ž: 16.526 ($p=0.000$) | Not applicable | Ž: 12.317 ($p=0.000$) |

**Table 8** (continued)

| Test for panel data Granger causality | Recycling of biowaste per capita (log) | Processed material per capita (log) | Circular material use rate | The recycling rate of municipal waste | The recycling rate of electronic waste | The recycling rate of packing waste |
|---|---|---|---|---|---|---|
| GINI index for inequality | | | | | | |
| Lag structure 1 | Ž: -1.109 ($p=0.268$) | Ž: -0.038 ($p=0.969$) | Ž: -0.482 ($p=0.630$) | Ž: -0.897 ($p=0.370$) | Not applicable | Ž: -1.285 ($p=0.199$) |
| Lag structure 2 | Ž: 1.169 ($p=0.243$) | Not applicable | Not applicable | Ž: 0.333 ($p=0.739$) | Not applicable | Ž: -1.562 ($p=0.118$) |

patterns. Note that some results are omitted due to too few observations after balancing, which is required before conducting the test (and due to the the lack of covariance in the case of the recycling rate of electronic waste and the GINI coefficient). Evidently, bidirectional reverse causality is a concern in most cases. The most striking exception is the tests involving the GINI coefficients.

Otherwise, the recycling of biowaste per capita and the recycling rate of packing waste seem to suffer somewhat less from reverse causality than the other variables. Yet, the causality tests are still highly significant for population growth and partially for capital variables. There is no clear pattern on whether the test for one or two lags is most significant.

To get closer to a causal interpretation, we now turn to Arellano and Bond's [3] dynamic panel model, where dynamic correlation patterns are accounted for. As evident in Table 9, none of the regression coefficients associated with the macroeconomic explanatory variables remain significant under this approach, except for negative and significant coefficients for the impact of capital intensity and population growth on processed material per capita. However, the regression for processed material per capita does not pass the Sargan test and Hansen J test, suggesting that the regression instruments are invalid. The Sargan test also indicates invalid instruments in the regression with circular material use rate as an outcome variable. Furthermore, the lagged dependent variable is strongly significant except for the case of recycling biowaste per capita, while the autoregressive process with one lag is significant for all regressions. Obviously, the inclusion of the lagged variable as a control is an important explanation for the lack of significant results. The autoregressive process with two lags is only significant, when processed material per capita or the circular material use rate is applied as an outcome variable, but as mentioned, the regressions involve invalid instruments.

Overall, the empirical investigation does not support the hypothesis that the macroeconomic variables impact the circular economy causally, at least not in the short run. The apparent causal patterns indicated by the panel data Granger tests disappear when adjusting for the various controls, particularly the lagged outcome variables. Yet, we find support for a complex correlation between macroeconomic variables and circular economy indicators, both in terms of levels and developments.

## Regional Developments in the European Circular Economy

In the exploration of the regional developments associated with the European circular economy, we start by considering the status and development of each circular economy indicator and European regions, as shown in Fig. 2. Western Europe performs better than Southern and Eastern Europe on all indicators across the study period, except for the recycling rate for electronic waste in recent years. Nevertheless, the growth in the circular economy indicators has been higher in Eastern Europe and Southern Europe across the study period. This holds in absolute and relative terms, except for processed material per capita. The growth tends to have been higher in the 2010s than in the 2000s. Eastern and Southern Europe are closer to the Western European levels on circular indicators concerning recycling rates for waste than on indicators concerning material and on recycling of biowaste per capita.

In Fig. 3, we also present the development patterns for circular economy indicators over European regions, but we control for the macroeconomic context this time. This is done by the linear regression model with regional time dummies, where "the residuals will reflect the adjusted development patterns. Overall, the patterns are largely coincidental with the

**Table 9** Macroeconomic influences on circular economic key variables, estimated by Arellano and Bond's dynamic panel data model with robust standard errors. All macroeconomic covariates are treated as generalized method of moments type of instruments. The year trend is treated as a standard instrument. Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.10$

| DPM (Arellano-Bond) | Recycling of biowaste per capita (log) | Processed material per capita (log) | Circular material use rate | The recycling rate of municipal waste | The recycling rate of electronic waste | The recycling rate of packing waste |
|---|---|---|---|---|---|---|
| Gross domestic product per capita (log) | -0.434 | -0.108 | -0.057 | 0.036 | -0.003 | 0.177* |
| | (1.017) | (0.253) | (0.046) | (0.070) | (0.407) | (0.086) |
| Real private investments per capita (log) | -0.014 | 0.145 | 0.034 | -0.021 | 0.042 | -0.025 |
| | (0.312) | (0.119) | (0.026) | (0.031) | (0.151) | (0.039) |
| Fixed capital stock per worker (log) | 0.020 | -0.066* | 0.009 | -0.009 | -0.097 | -0.084 |
| | (0.512) | (0.034) | (0.013) | (0.023) | (0.066) | (0.051) |
| Unemployment rate | 0.007 | 0.001 | 0.000 | -0.001 | 0.004 | 0.004* |
| | (0.017) | (0.004) | (0.001) | (0.001) | (0.003) | (0.002) |
| Population growth | -2.789 | -3.751 | -0.078 | -0.764 | 3.475* | -0.927 |
| | (15.369) | (2.838) | (0.384) | (0.815) | (1.910) | (1.348) |
| GINI index for inequality | 0.001 | 0.001 | 0.001 | -0.001 | 0.008** | 0.001 |
| | (0.015) | (0.002) | (0.001) | (0.002) | (0.003) | (0.002) |
| Lagged dependent variable | -0.004 | 0.003 | 0.001 | -0.001 | 0.012** | -0.002 |
| | (0.013) | (0.005) | (0.001) | (0.001) | (0.005) | (0.002) |
| Year (trend) | 1.084*** | 1.001*** | 0.838*** | 1.050*** | 0.788*** | 0.932*** |
| | (0.161) | (0.013) | (0.103) | (0.103) | (0.145) | (0.123) |
| Constant | 11.526 | -5.515 | -1.65 | 1.245 | -24.418** | 2.477 |
| | (24.996) | (8.477) | (1.538) | (2.180) | (9.022) | (3.237) |
| Lags as covariates | 2, 3 | 2, 3 | 2, 3 | 2, 3 | 2, 3 | 2, 3 |
| Observations | 422 | 225 | 225 | 481 | 233 | 436 |
| Instruments | 23 | 23 | 23 | 23 | 23 | 23 |
| F test, *p*-value | 0 | 0 | 0 | 0 | 0 | 0 |
| AR(1), *p*-value | 0.005 | 0.018 | 0.035 | 0.001 | 0.008 | 0.010 |
| AR(2), *p*-value | 0.388 | 0.047 | 0.075 | 0.876 | 0.184 | 0.615 |

**Table 9** (continued)

| DPM (Arellano-Bond) | Recycling of biowaste per capita (log) | Processed material per capita (log) | Circular material use rate | The recycling rate of municipal waste | The recycling rate of electronic waste | The recycling rate of packing waste |
|---|---|---|---|---|---|---|
| Sargan test, *p*-value | 0.721 | 0.000 | 0.057 | 0.782 | 0.972 | 0.759 |
| Hansen J test, *p*-value | 0.798 | 0.084 | 0.397 | 0.507 | 0.911 | 0.793 |

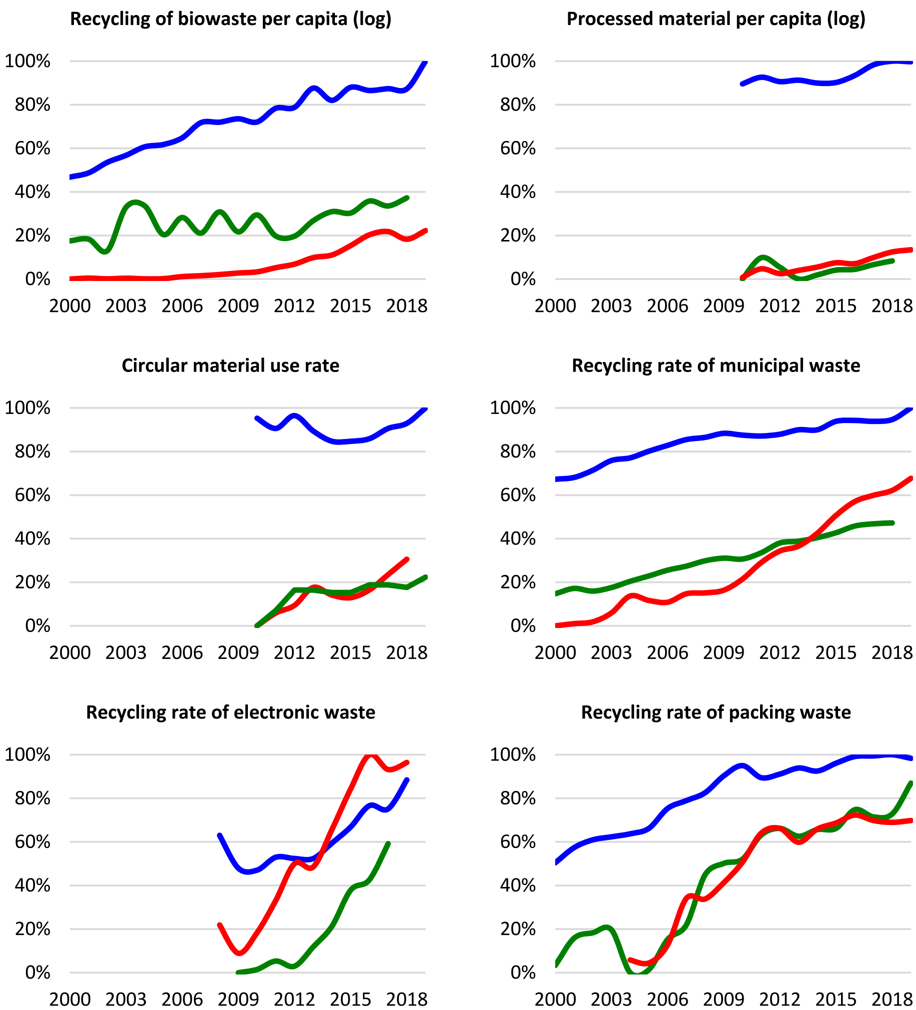



**Fig. 2** Indexed development in circular economy key figures over European regions, unadjusted. Indexation: Indexed such that the lowest and highest observations are 0 and 1, respectively. Color codes: The blue line is Western Europe, the green line is Southern Europe, and the red line is Eastern Europe

ones without controlling for macroeconomic variables in Fig. 2. Yet, Eastern and Southern Europe are considerably closer to Western Europe after the adjustment to the macroeconomic context. This suggests that macroeconomic circumstances explain parts of the differences in circular economy indicators, but not all, at least not in the short run. The unexplained differences may reflect cultural differences and the long-term impact of the historic macroeconomic environment on circular indicators.

The impressions from Fig. 2 are reinforced by Fig. 4, which depicts each country's levels and overall annual growth rates. Beyond regional patterns, the country-specific patterns regarding levels are less clear. Moreover, a country may have a high score in one circular economy indicator and a low score in another. For instance, Lithuania has high scores for recycling of biowaste per capita and the recycling rate for municipal waste, but a low

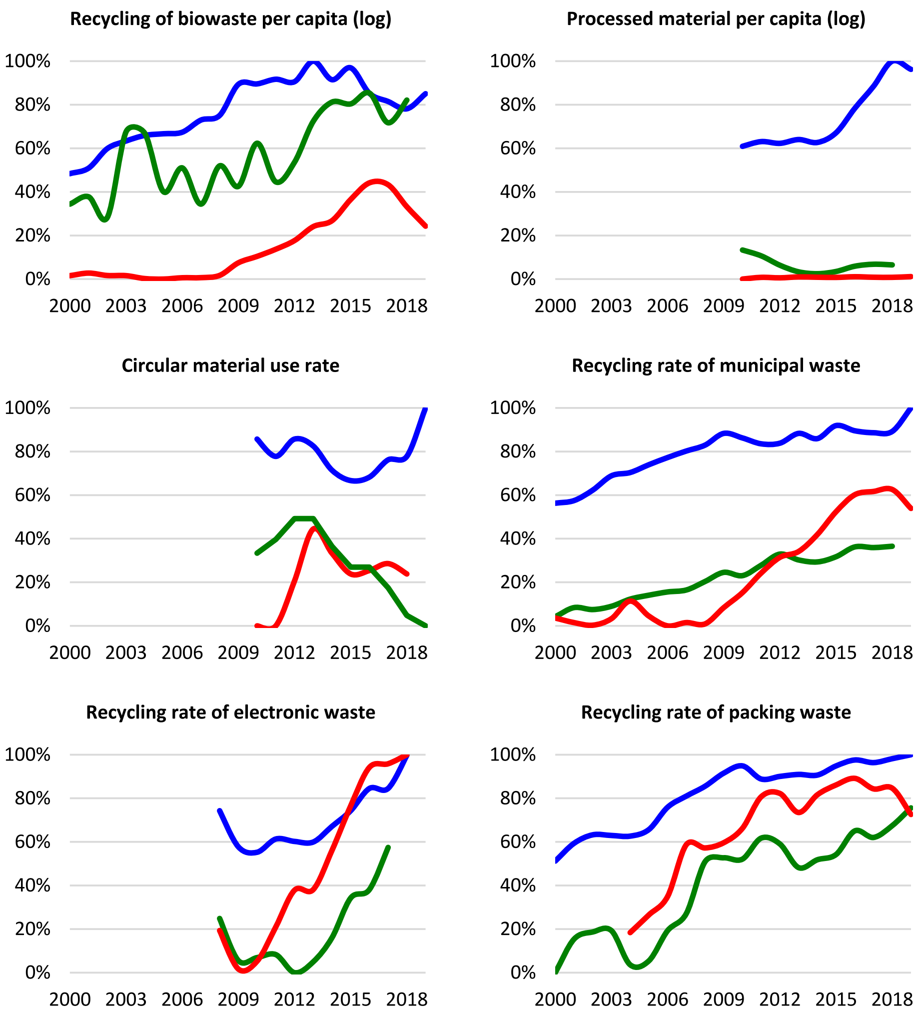



**Fig. 3** Indexed development in circular economy key figures over European regions, adjusted for macroeconomic influence, estimated as the residual in a linear regression model with regional time dummies. Indexation: Indexed such that the lowest and highest observations are 0 and 1, respectively. Color codes: The blue line is Western Europe, the green line is Southern Europe, and the red line is Eastern Europe

score for electronic waste. Another example is Germany, which holds high scores for recycling biowaste per capita, processed material per capita and the recycling rate of municipal waste, but a low score for the recycling rate for electronic waste. Some countries do, however, involve more stable scores. For instance, Malta has relatively low scores for the indicators, where the country has sufficiently many observations to be included in the figures. The growth patterns are, however, striking across regions, with the typically highest growth in Eastern European countries followed by Southern European countries and lowest growth in Western European countries.

In Fig. 5, we also depict the status and development of the circular economy indicators associated with each country, but as in Fig. 3, we have adjusted for macroeconomic circumstances. This is done based on the pooled ordinary linear least squares regressions,

**Fig. 4** Status in 2018 and annual growth over the study period for circular economy key variables, unadjusted. X-axis: Measured in logs in the upper panels and percentage points in the middle and lower panels. Y-axis: Measured in percentages in the upper panels and percentage points in the middle and lower panels. Only countries with observations in at least half of each variable's study period are included. Color codes: Blue circle is Western Europe, green rhombus is Southern Europe, and red triangle is Eastern Europe ▶

where the residuals are interpreted as the adjusted variables. Compared to Fig. 4, the patterns between regions are less clear. Eastern and Southern Europe now have almost identical scores as Western Europe overall. The growth in circular economy indicators still tends to be strongest for Eastern European countries and weakest in Southern European countries, although the patterns are somewhat weakened. Per country, the rankings are even more unsystematic over indicators after adjusting for macroeconomic circumstances.

## Conclusions

During the last two decades, the circular economy has grown considerably and received increasingly more attention within politics and research. This is particularly the case for Europe, where concerns about environmental and sustainability stand relatively strong compared to other continents. The literature on circular economy has grown substantially over the last decade, also shedding light on the connections between the circular economy and macroeconomic circumstances. Yet, how macroeconomic influences affect recycling is not fully understood. Ferrante and Germani [12] advocate for additional empirical research to determine if the correlation patterns between circular economy indicators and macroeconomic variables are causal and to understand how their development patterns interact. Other studies highlight the importance of national differences [9] and [15].

In this paper, we consider macroeconomic influences on recycling in Europe focusing on regional differences and causality. The regional division employed in the study aim to identify common characteristics that are shared within European regions in terms of recycling practices. In the empirical investigations, we examine the relation between the circular economy and macroeconomic influences in the European Union-28 countries from 2000 to 2019 (except for the Czech Republic due to limited data access for this country). As outcome variables, we employ six circular economy indicators related to waste, including recycling of biowaste and processed material (both in per capita terms and logarithms), circular material rates and the recycling rates for municipal, electronic and packing waste. As explanatory factors, we consider six sorts of macroeconomic influences, including gross domestic product and real private investments (both in per capita terms and logarithms), and fixed capital stocks (in per worker terms and logarithms), the unemployment rate, population growth and the GINI coefficient for inequality. In some of the investigations, we classify the countries into three regions with cultural and economic common characteristics: Western Europe, Southern Europe and Eastern Europe.

In the first part of the empirical investigation, the focus is on how macroeconomic conditions influence and covary with recycling. We utilize four econometric regression models, linear ordinary least squares estimator, panel data model, a standard fixed effect model with time fixed and country fixed effects, an alternative fixed effect model with regional time effects and a dynamic panel data model. Following Dumitrescu and Hurlin's [10], the test for panel data Granger causality indicates reverse causality and complex interaction patterns. This motivates the use of the dynamic panel data regression model of Arellano and Bond [3]. In the second part of the empirical investigations, we explore differences in

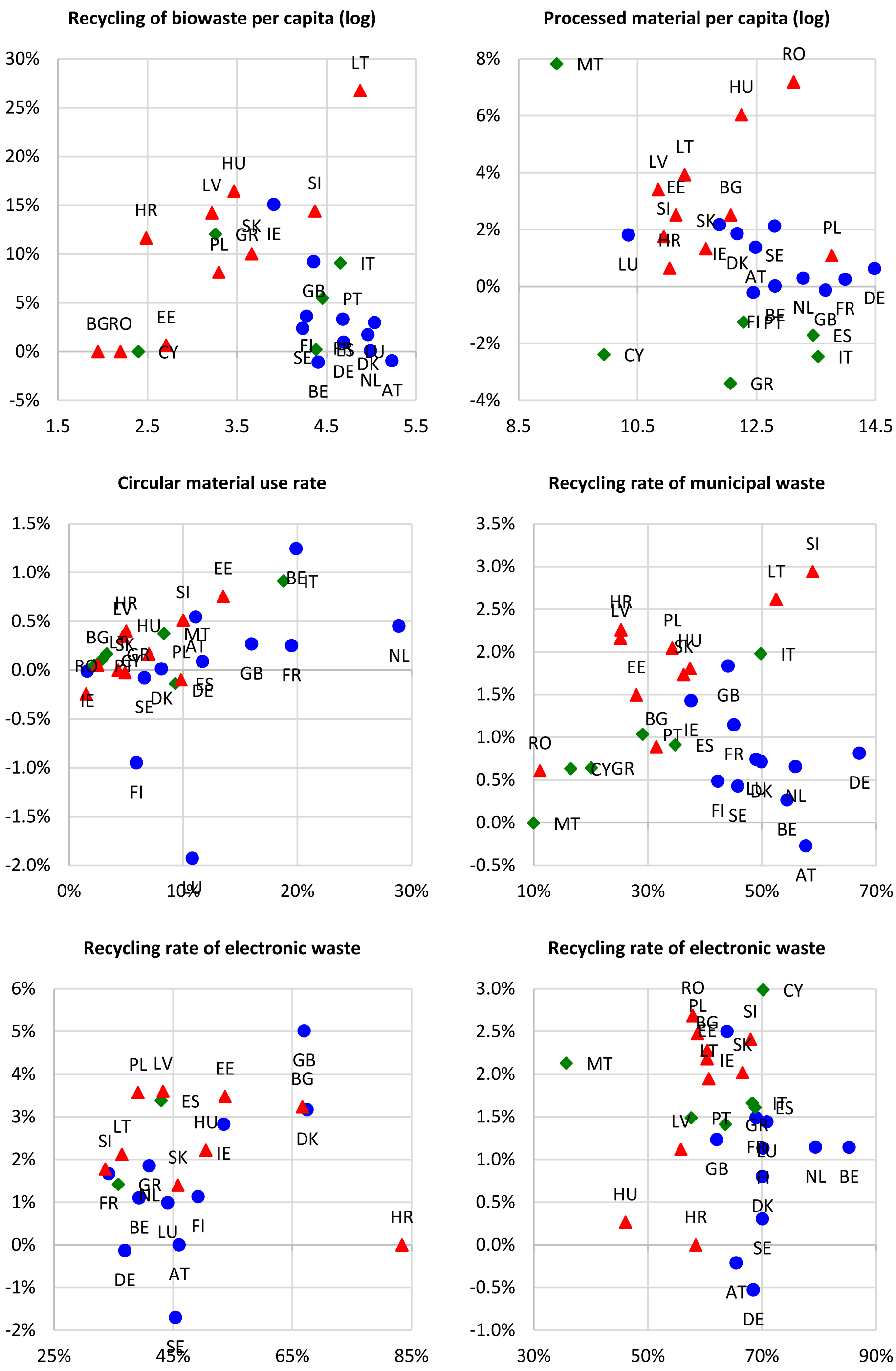

Recycling of biowaste per capita (log)
30%
25%
20%
15%
10%
5%
0%
-5%
1.5
2.5
3.5
4.5
5.5
Processed material per capita (log)
8%
6%
4%
2%
0%
-2%
-4%
8.5
10.5
12.5
14.5
Circular material use rate
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%
-1.5%
-2.0%
0%
10%
20%
30%
Recycling rate of municipal waste
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
-0.5%
10%
30%
50%
70%
Recycling rate of electronic waste
6%
5%
4%
3%
2%
1%
0%
-1%
-2%
25%
45%
65%
85%
Recycling rate of electronic waste
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%
30%
50%
70%
90%

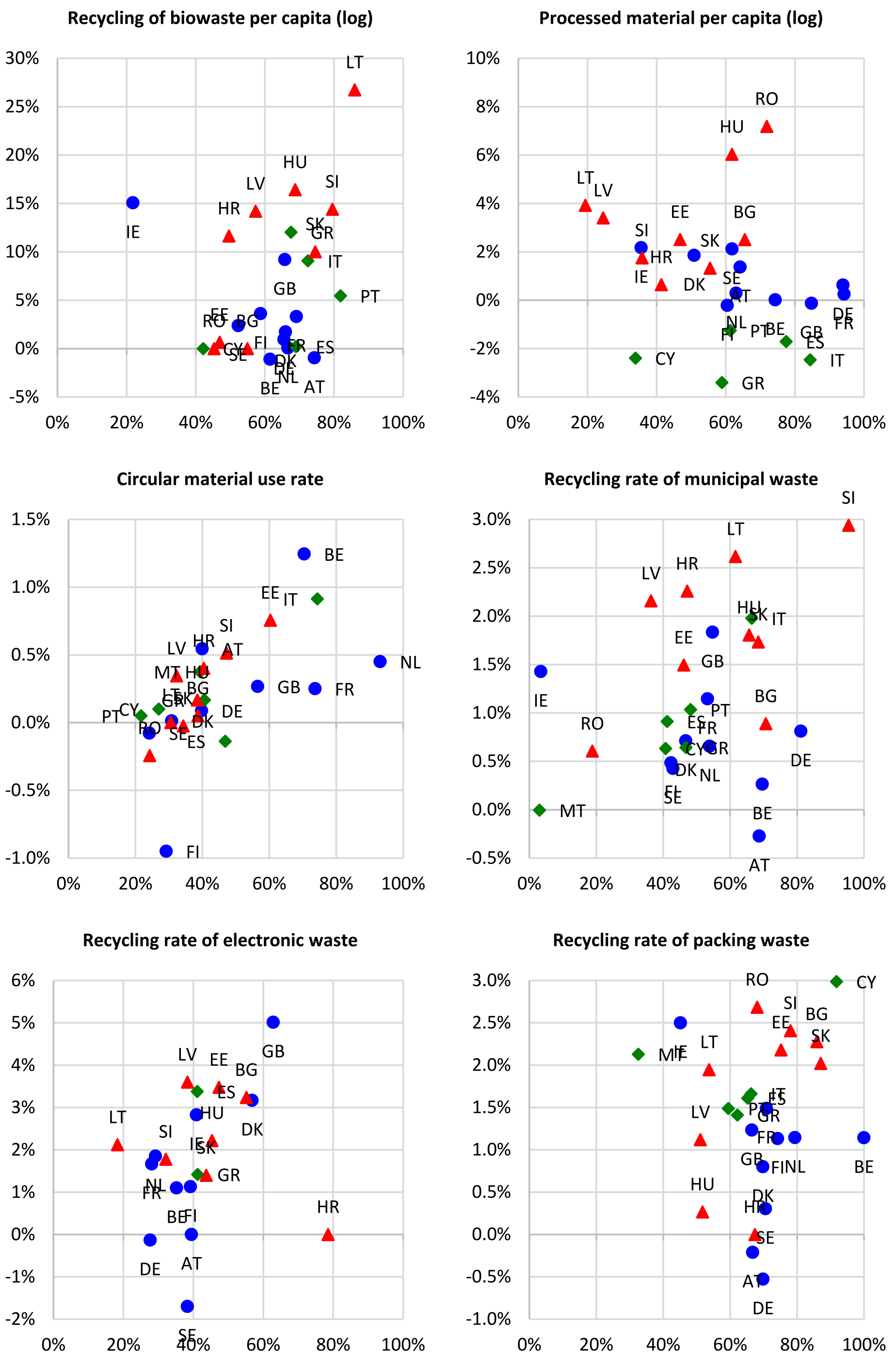
**Fig. 5** Indexed status in 2018 and annual growth over the study period for circular economy key variables, ▶ adjusted for macroeconomic influence, estimated as the residual in a linear regression model with regional time dummies. Indexation: Indexed such that the lowest and highest observations are 0 and 1, respectively. Only countries with observations in at least half of each variable's study period are included. X-axis: Measured in logs in the upper panels and percentage points in the middle and lower panels Y-axis: Measured in percentages in the upper panels and percentage points in the middle and lower panels Color codes: Blue circle is Western Europe, green rhombus is Southern Europe, and red triangle is Eastern Europe

circular economic performance between European regions and countries, before and after controlling for the macroeconomic context.

Our empirical analysis does not provide evidence to support the notion that macroeconomic key variables have a causal impact on recycling, at least in the short term. The test for panel data Granger causality indicates bidirectional causal relations, but these patterns disappear when applying the dynamic panel data approach. However, we do identify correlation patterns between macroeconomic variables and circular economy indicators, encompassing both their magnitudes and changes over time. In the pooled ordinary least squares regression, gross domestic product per capita have positive and significant impacts on all circular economy indicators except for the material rate, which instead is negative and significant for unemployment. This indicates that relatively rich countries perform better on circular economy indicators than relatively poor countries. When turning to the fixed effect models, the results become less robust and significant. Yet, there are still some signs of positive and significant impulses from GDP per capita on recycling of biowaste per capita, processed material per capita and the recycling rate for electronic waste. Unemployment yields some significant results for the fixed effect models, but these are not robust across model specifications. Neither gross domestic product per capita nor unemployment involve significant results for the dynamic panel data model. Real private investments per capita, fixed capital stock per worker and population growth involve some significant results, but these are unsystematic and not robust. Inequality – proxied by the GINI coefficient – yields no significant results and thereby seems to be less important for recycling performance.

Considerations on regional development in the European circular economy reveal some significant findings. Western Europe outperforms Southern and Eastern Europe on all circular economy indicators during the study period, except for the recycling rate of electronic waste in recent years. The patterns become similar, but weaker, when controlling for the macroeconomic context. Unexplained differences may reflect cultural differences and the long-term impact of the historic macroeconomic environment on circular indicators. Nevertheless, the growth in the circular economy indicators has mostly been higher in Eastern Europe and Southern Europe across the study period. In particular, we witness an increased performance in the circular economy in Eastern Europe and Southern Europe during the study period, especially in the 2010s. The calculations show different results for each country as well, for a country may perform better in one circular economy activity and be worse in another. Considering differences within the different European regions, circular economic performance varies much across countries. Per country, the rankings become even more unsystematic over indicators after controlling for the macroeconomic context.

Our methodological approach will also be adaptable for future studies of the circular economy and macroeconomic circumstances. We end the paper by suggesting some hopefully fruitful avenues for further research. This includes the exploration of additional variables characterizing circular economy processes and macroeconomic conditions. Moreover, the proposed econometric models allow the assessment of relationships between chosen macroeconomic indicators and selected circular economy indicators. Further research


Recycling of biowaste per capita (log)
30%
25%
20%
15%
10%
5%
0%
-5%
0%
20%
40%
60%
80%
100%
Processed material per capita (log)
10%
8%
6%
4%
2%
0%
-2%
-4%
Circular material use rate
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%
Recycling rate of municipal waste
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
-0.5%
Recycling rate of electronic waste
6%
5%
4%
3%
2%
1%
0%
-1%
-2%
Recycling rate of packing waste
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%

may include co-development patterns between the circular economic indicators, different variables characterizing circular economy processes (e.g. transition towards renewable energy sources and green patents), macroeconomic conditions (e.g. foreign direct investments, trade, research and development, interest rates and education), periods, or regional allocation.

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**Availability of Data and Materials** Data and materials will be made available on reasonable request.

## Declarations

**Ethics Approval and Consent to Participate** There were no specific ethical dilemmas related to the work with this research article. The researchers have worked in accordance with the high research standards of the journal.

**Consent for Publication** All authors have provided their consent for the publication of this article. There were no issues related to user rights concerning the input to the article have been identified.

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## References

1. Aguilar-Hernandez GA, Rodrigues JFD, Tukker A (2021) Macroeconomic, social and environmental impacts of a circular economy up to 2050: A meta-analysis of prospective studies. J Clean Prod 278:123421. https://doi.org/10.1016/j.jclepro.2020.123421
2. AMECO database | European Commission. (n.d.). Retrieved May 9, 2022, from https://ec.europa.eu/info/business-economy-euro/indicators-statistics/economic-databases/macro-economic-database-ameco/ameco-database_en
3. Arellano M, Bond S (1991) Some tests of specification for panel data:monte carlo evidence and an application to employment equations. Rev Econ Stud 58(2):277–297. https://doi.org/10.2307/2297968
4. Arellano M, Bover O (1995) Another look at the instrumental variable estimation of error-components models. Journal of Econometrics 68(1):29–51. https://doi.org/10.1016/0304-4076(94)01642-D

5. Bassi F, Dias JG (2019) The use of circular economy practices in SMEs across the EU. Resour, Conserv Recycl 146:523–533. https://doi.org/10.1016/J.RESCONREC.2019.03.019
6. Blundell R, Bond S (1998) Initial conditions and moment restrictions in dynamic panel data models. Journal of Econometrics 87(1):115–143. https://doi.org/10.1016/S0304-4076(98)00009-8
7. Bongers A, Casas P (2022) The circular economy and the optimal recycling rate: A macroeconomic approach. Ecol Econ 199:107504. https://doi.org/10.1016/j.ecolecon.2022.107504
8. D'Adamo I, Gastaldi M, Rosa P (2020) Recycling of end-of-life vehicles: Assessing trends and performances in Europe. Technological Forecasting and Social Change 152(December 2019):119887. https://doi.org/10.1016/j.techfore.2019.119887
9. Domenech T, Bahn-Walkowiak B (2019) Transition towards a resource efficient circular economy in Europe: policy lessons from the EU and the member states. Ecol Econ 155:7–19. https://doi.org/10.1016/j.ecolecon.2017.11.001
10. Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29(4):1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014
11. European Commission (2023). Circular economy action plan. Energy, Climate change, Environment. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
12. Ferrante L, Germani AR (2020) Does circular economy play a key role in economic growth? Economics Bulletin 40(3):1855–1862 (https://hdl.handle.net/11573/1430741)
13. Gini index | Data. (n.d.). Retrieved February 9, 2023, from https://data.worldbank.org/indicator/SI.POV.GINI?view=chart
14. Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. Econometrica: Journal of the Econometric Society 424–438. https://doi.org/10.2307/1912791
15. Gutberlet M, Preuss L, Thorpe AS (2023) Macro level matters: Advancing circular economy in different business systems within Europe. Ecol Econ 211:107858. https://doi.org/10.1016/j.ecolecon.2023.107858
16. Holtz-Eakin, D., Newey, W., & Rosen, H. S. (1988). Estimating vector autoregressions with panel data. Econometrica: Journal of the Econometric Society 1371–1395. https://doi.org/10.2307/1913103
17. IMF Data Home Page - Dataset - IMF Data. (n.d.). Retrieved May 9, 2022, from https://data.imf.org/?sk=388DFA60-1D26-4ADE-B505-A05A558D9A42&sId=1479329132316
18. Indicators - Circular economy - Eurostat. (n.d.). Retrieved May 25, 2022, from https://ec.europa.eu/eurostat/web/circular-economy/indicators
19. Lopez L, Weber S (2017) Testing for Granger causality in panel data. Stand Genomic Sci 17(4):972–984. https://doi.org/10.1177/1536867X180170041
20. Lu, C., Zhang, Y., Li, H., Zhang, Z., Cheng, W., Jin, S., & Liu, W. (2020). An integrated measurement of the efficiency of China's industrial circular economy and associated influencing factors. Mathematics 8(9). https://doi.org/10.3390/math8091610
21. Nikanorova M, Stankevičienė J (2020) Development of environmental pillar in the context of circular economy assessment: Baltic sea region case. Entrep Sustain Issues 8(1):1209–1223. https://doi.org/10.9770/jesi.2020.8.1(81)
22. Pham NM, Huynh TLD, Nasir MA (2020) Environmental consequences of population, affluence and technological progress for Europea-n countries: A Malthusian view. J Environ Manage 260:110143. https://doi.org/10.1016/j.jenvman.2020.110143
23. Polyakov M, Khanin I, Shevchenko G, Bilozubenko V (2021) Constructing a model of national production system for building a circular economy for international trade involvement. Entrep Sustain Issues 9(1):287–299. https://doi.org/10.9770/jesi.2021.9.1(17)
24. PWT 10.0 | Penn World Table | Groningen Growth and Development Centre | University of Groningen. (n.d.). Retrieved May 9, 2022, from https://www.rug.nl/ggdc/productivity/pwt/?lang=en
25. Razminienė K, Holmen RB, Tvaronavičienė M, Carvelli G (2024) Circular economy and economic performance: a literature review. LIFT Working paper. The Economic Integration of The Nordic-Baltic Region Through Labor, Innovation, Investments and Trade. Available at request: rasmus.bogh.holmen@vista-analyse.no
26. Roodman D (2009) How to do xtabond2: An introduction to difference and system GMM in Stata. Stand Genomic Sci 9(1):86–136. https://doi.org/10.1177/1536867X0900900106
27. Siedschlag I, Yan W (2021) Firms' green investments: What factors matter? J Clean Prod 310:127554. https://doi.org/10.1016/J.JCLEPRO.2021.127554
28. Tantau AD, Maassen MA, Fratila L (2018) Models for analyzing the dependencies between indicators for a circular economy in the European Union. Sustainability (Switzerland) 10(7):2141. https://doi.org/10.3390/su10072141

29. Van Bueren BJ, Iyer-Raniga U, Leenders MA, Argus K (2021) Comprehensiveness of circular economy assessments of regions: a systematic review at the macro-level. Environ Res Lett 16(10):103001. https://doi.org/10.1088/1748-9326/ac209c

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