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"Integrating Qualitative, Quantitative and Policy Analyses: An Empirical Study of Circular Economy and Waste Management in the EU"

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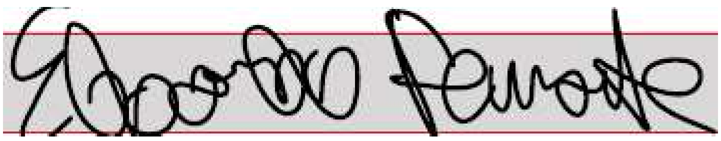

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Abstract

On March 11, 2020, the European Commission ratified the new Circular Economy Action Plan, a pivotal part of the European Green Deal. This plan is essential for establishing the EU as a global leader in the green transition and for addressing the region's economic resilience and dependency on external supply chains. Effective waste management is crucial in this context, underscoring the need for the EU to intensify its efforts. This study analyses the variables influencing waste production and recycling rates, examining their correlations and quantifying their impacts. It also delves into policy implications, using Paul Connett's Zero Waste project and the "Zero Waste Europe" initiative as case studies. The analysis spans data from 2013 to 2020, incorporating comprehensive reviews and econometric models to provide a robust understanding of waste management dynamics. The final chapter explores emerging policies in Europe, highlighting successful projects and practical improvements in waste management.

Keywords: Circular Economy Action Plan, European Green Deal, Waste management, Zero Waste Europe, Recycling Rates

JEL Codes: Q53, Q56, Q58, C58, O44

Table of Contents

1) Introduction

On December 13, 2007, the Treaty of Lisbon, also known as the "Treaty on the Functioning of the European Union" or TFEU, was officially ratified. This treaty clarified for the first time the powers of the European Union, distinguishing between three types of competences: exclusive competences, where only the Union has legislative power; shared competences, where legislative power is divided between the Union and member states; and supporting competences, where the Union acts as support for Member States (European Parliament, 2024).

Quoting the article 191 (ex Article 174 TEC): *"1. Union policy on the environment shall contribute to pursuit of the following objectives: — preserving, protecting and improving the quality of the environment, — protecting human health, — prudent and rational utilisation of natural resources, — promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combating climate change".*

Environmental legislation falls under shared competences, and a substantial part of it concerns waste management. One of the most important documents in this field is the Waste Framework Directive (2008/98/EC, and subsequently revised), which for the first time defines concepts such as waste and recycling and introduces the three pillars of waste management: the waste hierarchy, the polluter pays principle, and (more recently) extended producer responsibility, setting targets for separate collection for the first time. The "waste hierarchy" (Fig. 1) establishes a preference for waste prevention, followed by reuse, recycling, energy recovery, and finally disposal, promoting waste management that minimizes environmental impact. The "polluter pays principle" requires polluters to cover the costs of managing the pollution they generate, pushing towards a more responsible and sustainable economy. Extended producer responsibility obliges producers to manage the waste generated by their products, encouraging them to design more sustainable and easily recyclable products.

The Waste Framework Directive remained valid for 10 years, without modifications, until the 2018/851 amendment, which made significant progress with the main goal of improving waste management practices across the Union, aligning them more closely with the principles of the circular economy. The focus shifted from simple "waste management" to sustainable "materials management," aimed at protecting the environment, reducing dependence on imported resources, and promoting economic growth. This was achieved by setting more ambitious targets for municipal waste recycling (55% by 2025, 60% by 2030, and 65% by 2035), strengthening extended producer responsibility, and emphasizing the importance of the waste hierarchy.

Other important waste regulations include the Landfill Directive (1999/31/EC), amended in 2018 along with the Waste Framework Directive. This regulation aims to prevent or reduce the negative effects of landfills on the environment, defining different types of landfills and obliging Member States to limit biodegradable waste going to such facilities (particularly done by the WFD review which brought in a separate collection obligation for municipal biowaste from 01/01/24)

Figure 1

Waste Hierarchy of Waste Directive Framework

Note. https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

Also of notable importance is the Packaging and Packaging Waste Directive, the most recent version (adopted by the European Parliament on 20/06/2024) of which, from 2018 (2018/852), is an amendment of directive 94/62/EC. This directive establishes measures for the prevention, reuse, and recovery of packaging waste in member states, in addition to defining the essential requirements for packaging placed on the market.

Finally, it is essential to mention the Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19). The latest amendment, 2018/849, imposes the obligation to separately collect waste electrical and electronic equipment to allow their separation and recycling. Additionally, it promotes extended producer responsibility, encouraging the design of products that are more easily recyclable and reusable.

Figure 2

The European Green Deal

Note. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640&qid=1605784676826

The turning point, however, came with the inauguration of Ursula von der Leyen's presidency of the European Commission, whose priority became decisively addressing the issue of climate change. The new Commission sought to transform the climate crisis into an opportunity through the launch of the European Green Deal strategy on December 11, 2019 (European Commission, 2019). This reform package aims to achieve carbon neutrality by 2050, in line with the Paris Agreement of 2015. As illustrated in the image (Fig. 2), the third box from the left reads, "Mobilising industry for a clean and circular economy," thereby recognizing the strategic importance of the circular economy in tackling climate change.

In this context, the New “Circular Economy Action Plan” (CEAP) of March 2020 was introduced, establishing the necessary rules to transition from a “cradle-to-grave” to a “cradle-to-cradle” system, reducing pressure on natural resources while creating sustainable growth and new jobs. The goal is to double the circular material use rate and reduce the EU’s consumption footprint over the next ten years, while also promoting the creation of sustainable jobs. The plan includes specific measures, such as adopting a sustainable product initiative to promote circular design, empowering consumers with better information on sustainable products, and increasing transparency. It also emphasizes strengthening recycling and significantly reducing waste, with specific regulations to minimize waste in key sectors like electronics and textiles.

Additionally, the CEAP includes investments to support innovation and the adoption of circular-friendly technologies, financing research and development related to the circular economy. The Circular Economy Action Plan also commits to promoting circularity globally, integrating circular economy principles into the EU's bilateral and multilateral dialogues and agreements. This strategy not only aims to reduce environmental impact but also seeks to ensure an inclusive transition that offers tangible benefits to all sectors of society (European Commission, 2020).

1.1) Research Question

The circularity of the economy is not only a useful practice for more responsible waste management but also a crucial step for the European Union to become a global leader in the green transition. Additionally, it is vital for strengthening the EU’s economic resilience, which has been shown to be fragile and dependent on external and not always secure supply chains, especially after Russia's aggression against Ukraine (OECD, 2022).

Raw materials are essential for a successful transition (McKinsey & Company, 2022). For this reason, in May 2024, the final version of the Critical Raw Material Act was ratified, aiming to reduce the EU's dependence on imports of critical raw materials and to strengthen internal supply chains by promoting sustainability and resilience through recycling, source diversification, and technological innovation (European Commission, 2024a). Therefore, waste management is a sector where the European Union must maximize its efforts. The following chapters will attempt to answer three main questions:

1. What are the variables most closely related to waste generation, and which countries are the top performers in terms of circular economy and recycling in the EU?
2. What are the determinants of recycling and municipal waste generation in the EU?
3. How could the European Union adopt policies based on established global experiences to improve waste management?

The dissertation will address these questions in three distinct chapters. The first two questions will analyse the period from 2013 to 2020, preceding the Covid-19 pandemic and the Russo-Ukrainian war, including original and often overlooked variables. Chapter 2 will be very similar to a "Review" paper, where we will try to understand which variables are closest to the field of waste management. Chapter 3, however, will try to answer the second question through an econometric analysis using 3 distinct models.

The final chapter will examine emerging policies in Europe to answer the third question, taking as an example a project that has demonstrated significant and replicable results.

2. Qualitative Analysis

2.1) The time window

The period of interest extends from 2013 to 2020, with the collection of variables from Eurostat and the World Bank. Before analysing the trend of these variables, particularly those related to the circular economy and waste, and examining the reasons behind this trend, it is important to examine the events that marked these eight crucial years for the European Union.

2013 was the year when the sovereign debt crisis slowdown was observed, peaking in 2012 and leading then ECB Governor Mario Draghi to deliver the famous "Whatever it takes" speech in July of the same year (Kenton, 2021).

In the second quarter of 2013, the GDP of the EU and the euro area grew by 0.3%, marking the end of the recession. Economic indicators showed positive signs, but the recovery remained fragile due to the persistent difficulties of the financial and economic crisis. Domestic demand grew slowly, and financial conditions varied significantly among member states. High unemployment and uncertainty hindered investments and consumption, while exports supported growth despite the appreciation of the euro (European Economic Forecast, Autumn 2013).

Two particularly significant events in 2013 were Croatia's accession to the Union and the bank bailout of Cyprus. On July 1, 2013, Croatia became the 28th member state of the European Union, following a formal application submitted in 2003 (European Commission, 2013).

Regarding financial assistance to Cyprus, following a request for economic assistance on June 25, 2012, the European Commission, the European Central Bank (ECB), and the International Monetary Fund (IMF) agreed on an economic adjustment program with the Cypriot authorities on April 2, 2013. This program was approved by the euro area countries on April 24, 2013, and by the IMF Board on May 15, 2013, and included aid of 10 billion euros (European Commission, 2024c).

The initial context of the analysis is situated at the beginning of the time frame that will conclude with a crucial year in the history of the Union, the onset of the Covid-19 pandemic in March 2020. However, it is essential to examine the significant events that characterized the EU from 2014 to 2019.

In 2014, the European elections took place, leading to the appointment of Jean-Claude Juncker as President of the European Commission. In 2015, Juncker introduced the so-called Juncker Plan, a €315 billion package aimed at bridging the investment gap left by the financial and economic crisis in the EU (European Commission, n.d). Additionally, 2015 was a crucial year for international agreements, with significant contributions from the EU and its Member States. In September, the agreement for the 2030 Agenda was signed, identifying the 17 Sustainable Development Goals (SDGs) to be achieved by 2030 (United Nations, 2015). In December, the Paris Agreement was reached during COP21, where the signatory countries committed to keeping the temperature increase below 1.5°C (United Nations, 2015). Another key element for the analysis is the adoption of the first Circular Economy Action Plan, which included 54 actions to be implemented to promote a more circular economy (European Commission, 2015).

The year 2016 was marked in the United Kingdom by the referendum on Brexit, held on 23 June, which, with 51.9% of the votes, led to the definitive exit of the United Kingdom from the Union on 31 January 2020 (Clark, 2024). Therefore, the following analysis will concern only the current 27 EU members, excluding the United Kingdom, to ensure academic correctness, considering that this dissertation is at the community level.

In 2017, there was an almost complete recovery of the economy in the EU, with the fifth consecutive year of growth. GDP increased by 1.9%, with growth forecasts remaining steady, unemployment fell to 8%, and both the deficit and public debt decreased gradually (European Commission, 2017).

In 2018, in addition to the continuing economic recovery, the first amendments to Directive 2008/98/EC on waste were made, setting new targets and rules and further integrating the sector (EUR-Lex, 2018).

In 2019, the European Parliament elections were held, leading to the appointment of Ursula von der Leyen as President of the European Commission (European Parliament, 2019) and the promulgation of the European Green Deal at the end of the year (Chapter 1).

The year 2020 was characterized by the Covid-19 pandemic, which slowed down all economic activities, caused a contraction in GDP, and initiated another major moment of crisis for the countries of the European Union (European Council, 2024).

2.2) Trend Analysis for Variables Related to Waste Management

This section of the analysis aims to examine specific variables related to the waste and circular economy sectors, including both general variables intrinsically linked to these sectors and those specific to them. The analysis of these variables, available through Eurostat, will be conducted using two graphical representations: one chart depicting the overall data for the European Union and a panel chart representing the data for each individual Member State.

<u>1) GDP per capita</u>

The variable GDP per capita is a crucial indicator for assessing the economic health of a country or a group of countries, such as the European Union. This variable is also important due to its connection with the environment, as illustrated by the Environmental Kuznets Curve (Kuznets, 1955). Stern (2004), in the Encyclopedia of Energy, clearly explains the functioning of the Environmental Kuznets Curve (EKC), defining it as a hypothetical relationship between various indicators of environmental degradation and per capita income.

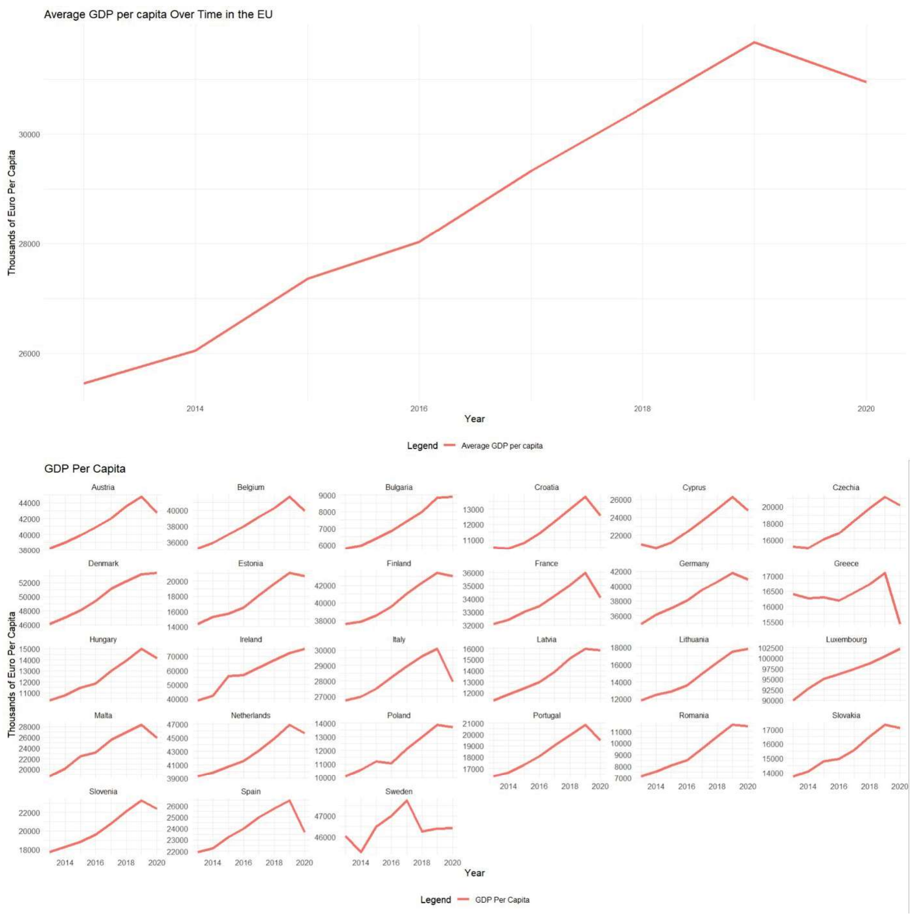
In the early stages of economic growth, pollution emissions increase, and environmental quality deteriorates; however, once a certain level of per capita income is surpassed (which varies depending on the indicators), the trend reverses, leading to environmental improvement with increasing income. This implies that environmental impacts or emissions per capita follow an inverted U-shape with respect to income per capita, which could also be related to the growth of tertiary activities and the relocation of industrial activities.

Besides per capita emissions, one of the indicators of environmental degradation that can be analysed is waste generation, giving rise to the so-called Waste Kuznets Curve. Numerous authors have investigated the relationship between waste production and per capita income levels, obtaining different results but agreeing that there is a significant relationship, although not necessarily an inverted U-shape, between per capita income and waste production (Mazzanti and Zoboli, 2005; Abrate and Ferraris, 2010; Yilmaz, 2020; Blagoeva et al., 2023). Often, an increase in consumption levels also leads to an increase in waste generation (Thogersen, 1996; Minelgaitė and Liobikienė, 2019).

Analysing the chart of GDP per capita evolution from 2013 to 2020, both at the aggregate level and for individual Member States, a growth is observed until 2019, followed by a sharp contraction in 2020 with the onset of the Covid-19 pandemic, during which GDP per capita decreased by 5.7% (World Bank). The panel chart shows how each member state, to varying degrees, experienced a decline in per capita income.

Figure 3

Evolution of GDP per capita over time (2013-2020)



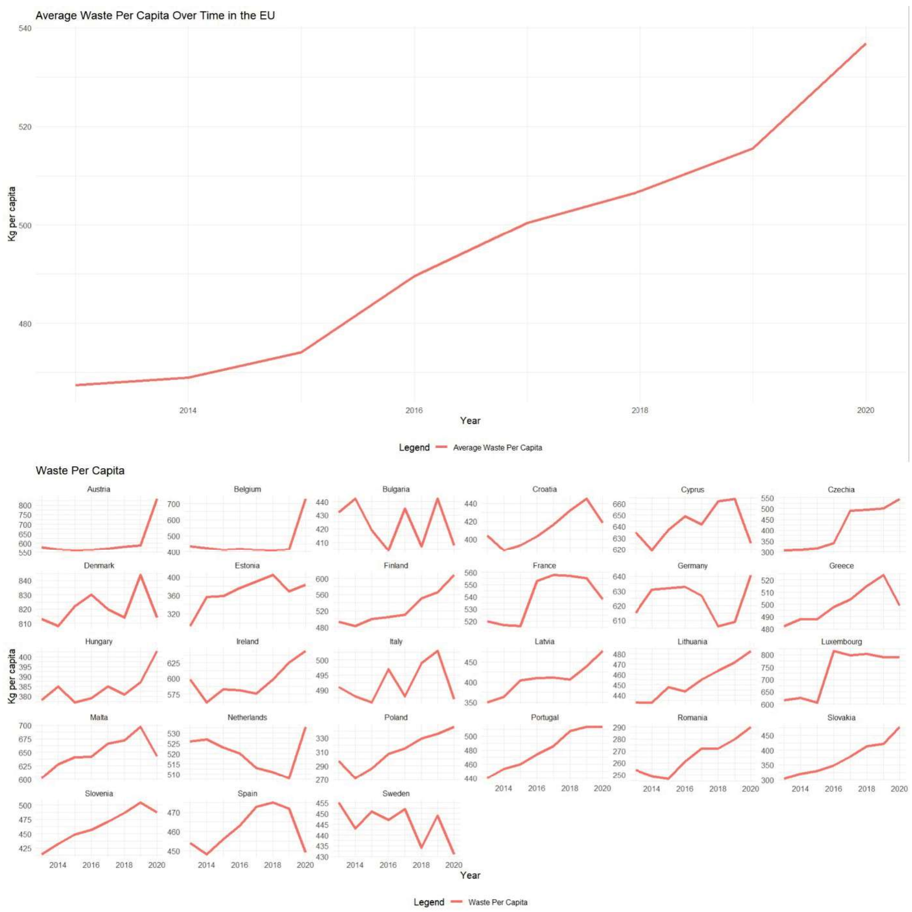
<u>2)Waste Per Capita</u>

To support the previously mentioned EKC theory, we examine two charts related to municipal waste production (env_wasmun$EUROSTAT) per capita, both at an aggregate level and at the level of individual Member States.

In the aggregate level chart, municipal waste production per capita shows a continuous increase, including in 2020 after the pandemic onset, which is counter-intuitive. Furthermore, there is a discrepancy with the data on municipal waste production and total waste generation (env_wasgen$EUROSTAT).

Figure 4

Evolution of Municipal Waste per capita over time (2013-2020)



The latter indicates growth until 2016 and a decline starting in 2018, as confirmed by a 2023 article from the European Environmental Agency. This suggests that the reduction did not result from a net decrease in municipal waste per capita, despite the panel chart showing a reduction in many countries (Bulgaria, Cyprus, Denmark, France, Italy, Greece, Malta, Spain, and Sweden), but rather from the non-municipal component of the total generated waste.

A 2021 report by Benoît Bel and Marengo, based on data from the first wave of Covid-19 in 2020, states that in countries where the pandemic led to a decrease in generated waste, it was because the increase in household waste (due to lockdown) was less than proportional to the decrease in commercial waste. Additionally, the types of waste included in municipal waste and total generated waste also vary.

3)Government Effectiveness and Corruption Perception Index

Another crucial variable in the context of the circular economy and waste management is the quality of institutions.

Numerous studies have investigated how institutions and the democratic system influence environmental quality (Congleton, 1992; Martinez, 2002; Li & Reuveny, 2006; Arwin & Lew, 2011). Additionally, the quality of institutional governance, measured through specific indicators (Kaufmann et al., 2010), has been examined for its impact on environmental quality (Chen et al., 2021).

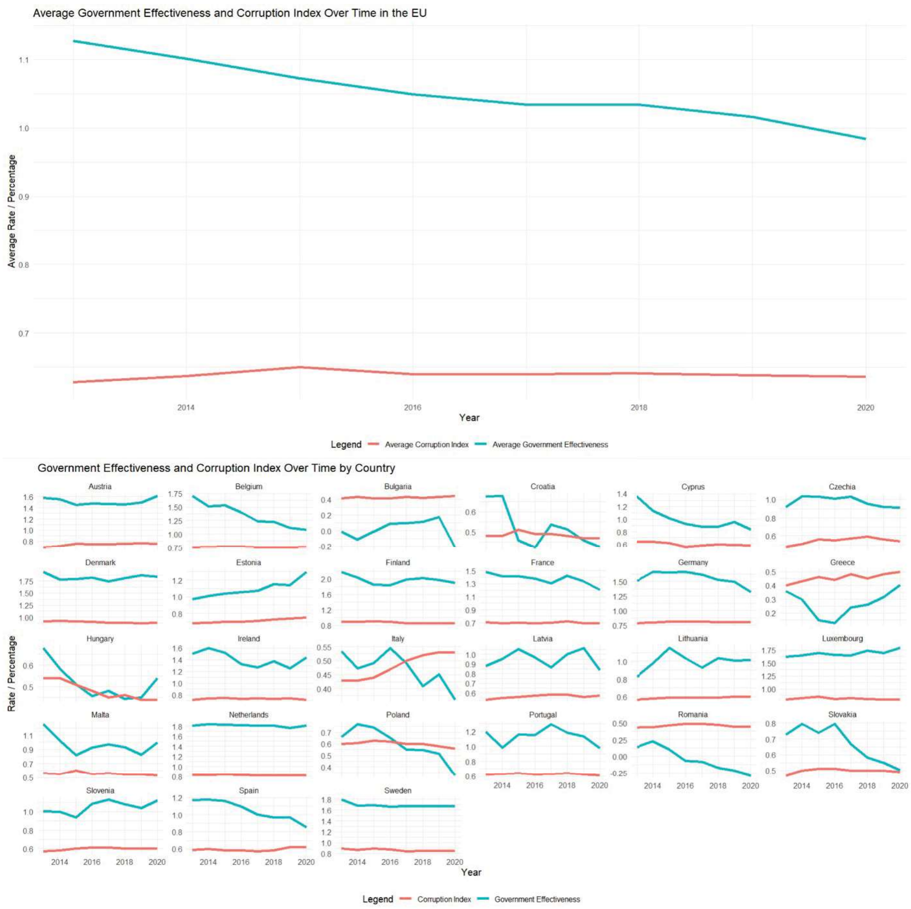
In the field of waste management, Pronti and Zoboli (2024) state that "the quality of institutions is closely related to good governance because it can reflect the ways in which authority is exercised in a country." Consequently, institutional quality can enhance waste recycling performance (Rompf et al., 2017; Argentiero et al., 2022; Pronti & Zoboli, 2024).

At the European level, two measures can be considered as proxies for institutional quality: the Corruption Perceptions Index (sdg_16_50$EUROSTAT; Transparency International) and the Government Effectiveness Estimate (World Bank; Kaufmann et al., 2010), two closely related indicators that are useful to present together.

The Corruption Perceptions Index (CPI) is a composite index based on a combination of surveys and assessments of corruption from 13 different sources. It ranks countries based on perceived corruption in the public sector, with a score of 0 representing a very high level of corruption and a score of 100 representing a very clean country. The sources used for the 2017 CPI are based on data collected in the 24 months preceding the publication of the index and include only sources that provide a score for a set of countries/territories and that measure the perception of corruption in the public sector (Eurostat).

Figure 5

Evolution of Government Effectiveness and Corruption Index over time (2013-2020)



Government Effectiveness is explained in the paper "The Worldwide Governance Indicators: Methodology and Analytical Issues" (Kaufmann et al., 2010) and captures perceptions regarding the quality of public services, the quality of the civil service and its degree of independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to these policies.

The European Union shows considerable heterogeneity in CPI levels, with Denmark maintaining a stable score of 90 and Hungary at the bottom of the ranking with just over 40. From the panel chart representing individual Member States and the summary chart of the entire Union, it is clear that the perception of corruption remains relatively stable in the Union, with a score between 60 and 65 from 2013 to 2020. An interesting study on corruption in the EU was conducted by the European Commission in 2022 (Special Eurobarometer 523, "Corruption"), highlighting, for example, that acceptance of corruption is increasing, with 28% of people considering it acceptable to give or receive a gift in exchange for a favour, and 58% believing that corruption is present in political parties and politics in general. One sector particularly affected by corruption, also due to the infiltration of organized crime (D'Amato and Zoli, 2010; D'Amato et al., 2015; Comolli, 2024), is waste management, as indicated by the Basel Institute on Governance (2021) and the UNODC study "Cash in the Trash," which examines the role of corruption, organized crime, and money laundering in waste trafficking. Erik Osmundsen, CEO of Norsk Gjenvinning, also addressed this issue in a 2019 interview with Harvard Business Review.

Government Effectiveness, during the same period, shows a decline at the aggregate level, with a particularly negative value in 2020 due to the pandemic in the more fragile countries such as Italy, Latvia, Poland, Portugal, Romania, and Slovakia. There remains a strong correlation between the two measures, with Denmark ranking highest for both perceived low corruption and governmental effectiveness.

4) Recycling Rate

One of the fundamental measures of environmental sustainability is circularity. There are various indicators that assess circularity, one of which is the recycling rate of waste and used materials. As highlighted in the article by Resourcify (Lewis, 2022), the measure of economic circularity is defined as the ratio between the "volume of recycled waste" and the "total volume of materials processed."

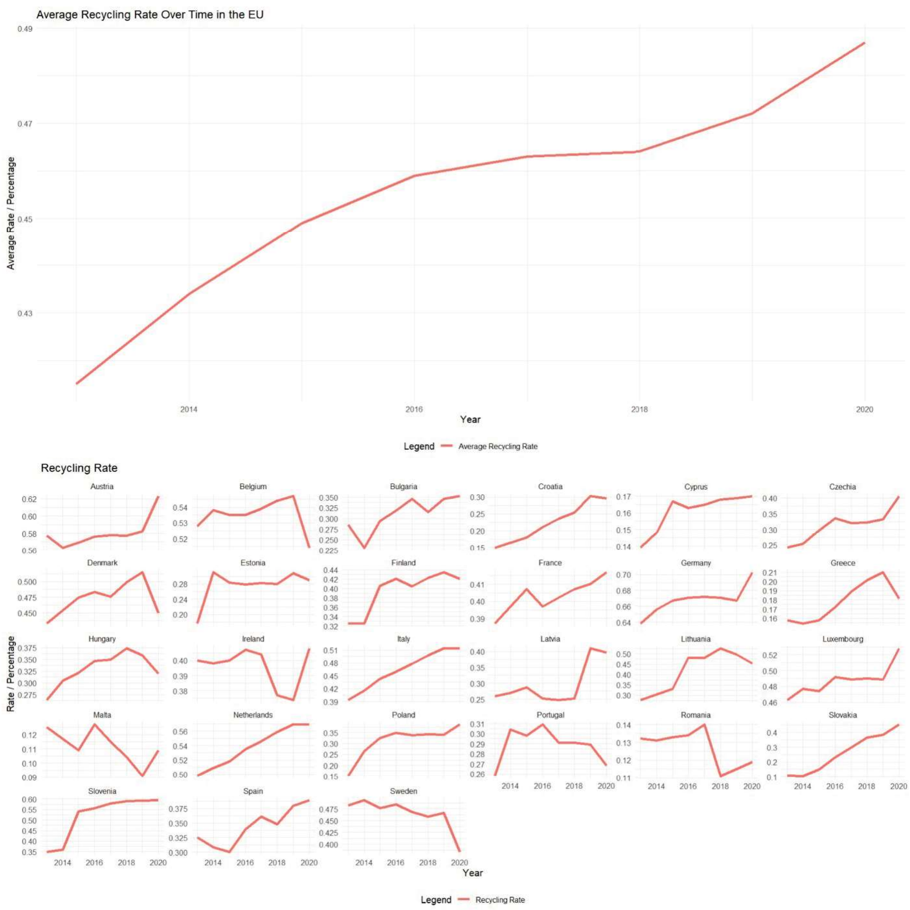
Analysing the chart of the municipal waste recycling rate in the European Union (cei_wm011$EUROSTAT), a constant growth trend is observed, reaching almost 49% in 2020. However, the panel chart reveals significant heterogeneity among the various member countries: Germany, for instance, reaches about 70% recycling, while other countries such as Cyprus, Greece, Malta, and Romania do not even surpass 20% (Alves, 2024).

These results are consistent with a 2023 report by Statista, titled "Recycling in Europe." The report also highlights the targets set by the 2018 revision of the European

Commission's Waste Framework Directive, which aims for a 60% recycling rate by 2030 and 65% by 2035.

Figure 5

Evolution of Municipal Recycling Rate over time (2013-2020)



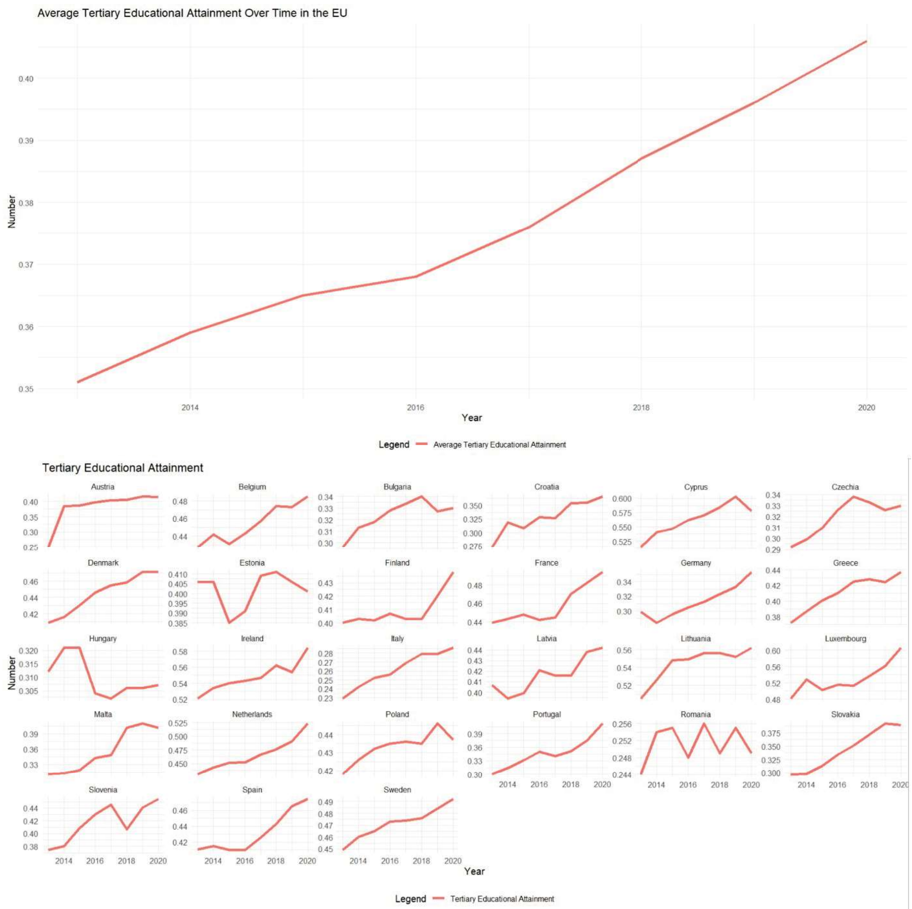
<u>5) Tertiary Education Attainment</u>

One of the variables that significantly influences the recycling rate and the total waste generation is undoubtedly the level of education. Numerous studies have included education as one of the determinants of the recycling rate. Among the first, the 1989 article by Samdahl and Robertson used a sample of data from Illinois, USA. Subsequently, the relationship between these two variables was explored by Oskamp et al. (1991), Ebreo et al. (1999), Guerin et al. (2001), Tsai (2008), and recently, using data from Italian provinces, by Argentiero et al. (2023).

A good indicator of the education level in European Union countries is Tertiary Educational Attainment (sdg_04_20$EUROSTAT), which measures the percentage of the population aged 25 to 34 that has successfully completed tertiary education (e.g., university, higher technical institute, etc.) (Eurostat).

Figure 6

Evolution of Tertiary Education Attainment over time (2013-2020)



Analysing the chart of aggregated data, it is noted that the percentage of the population with tertiary education has increased from approximately 35% in 2013 to 40.6% in 2020, with a positive trend in almost all countries except Hungary (as observable from the panel chart).

An in-depth analysis of this variable can be found in the "Eurostat Statistics Explained" of 2024. From 2013 to 2023, the percentage of the population aged 25 to 74 with tertiary education increased from 25.3% to 32.6%, while the percentage of the population with low education levels decreased from 28.7% to 22.9%.

It can therefore be affirmed that the education situation is improving. However, the target set by the "Council Resolution on a Strategic Framework for European Cooperation in Education and Training towards the European Education Area and beyond (2021-2030)" (Eur-Lex, 2021) of at least 45% of the population aged 25 to 34 with tertiary education has not been reached by many Member States, including Germany, Italy, Finland, and Austria.

6) Tourism

A significant variable in waste management is tourism. Tourist destinations face particular pressures when it comes to waste management. Numerous studies have directly linked tourism to waste production, such as the study by Mateu-Sbert et al. (2013), which shows how the increase in tourist influx leads to a proportional rise in waste generation. In this context, the effectiveness of waste sorting and recycling becomes crucial to mitigate the environmental impact of tourism, as highlighted by previous studies (Butler, 1999; Zatelli, 2014; Ezeah, 2015), which emphasize the importance of adequate preparation to manage the increased waste associated with tourist influx. Other studies consider tourism indirectly, including it in their analyses without directly examining its effects on waste or recycling (Argentiero et al., 2022; Mazzarano et al., 2022; Pronti & Zoboli, 2024).

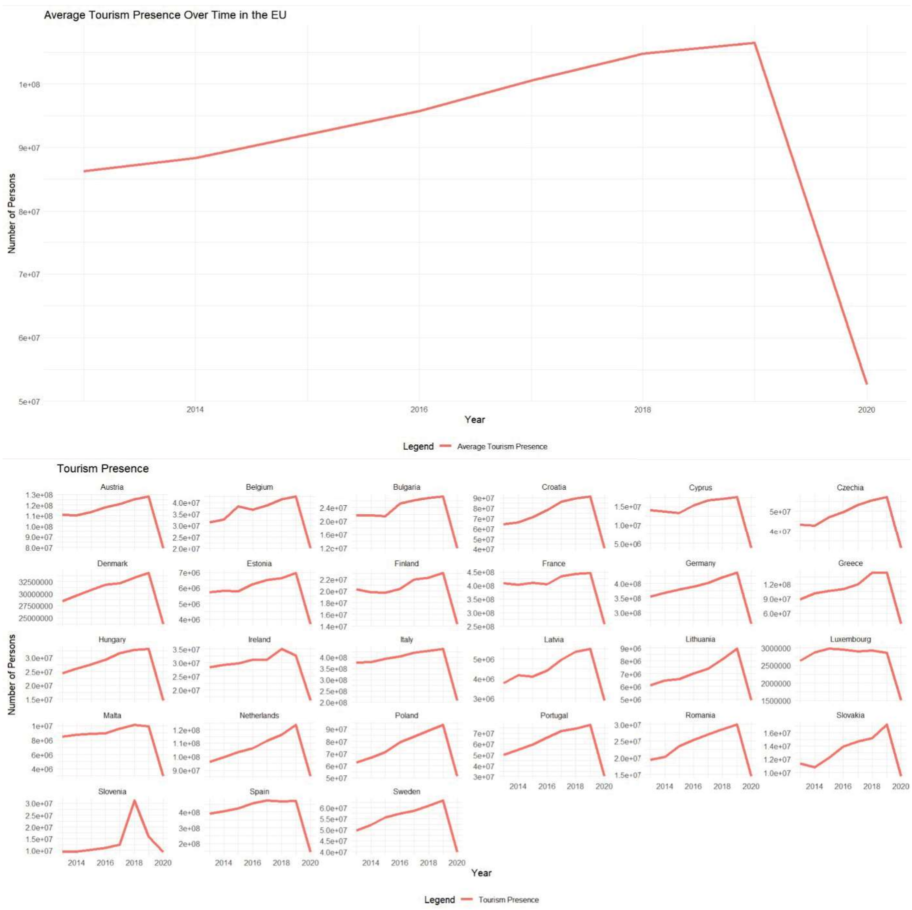
Tourism plays a fundamental role in the European Union, as the 27 Member States collectively represent the world's top destination, directly and indirectly generating approximately 10% of the EU's GDP (EUR-Lex, 2010; European Commission, n.d).

Examining the chart, one can observe the evolution of tourism within the Union (tour_occ_ninatdc$EUROSTAT), showing a consistent growth trend from 2013 onwards, with a significant drop in 2020 due to the pandemic.

This same trend is evident in all member countries in the panel chart, with a notable negative shock in 2020.

Figure 7

Evolution of Tourism Presence over time (2013-2020)



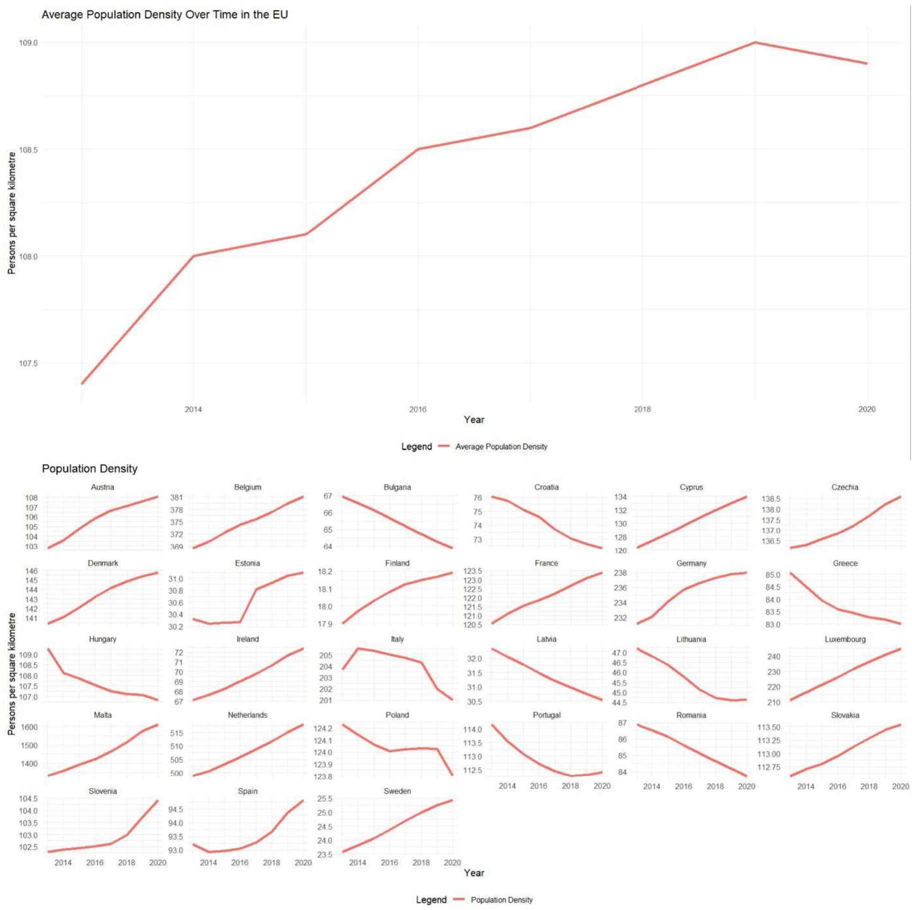
7)<u>Population Density</u>

The increasing urbanization and rising population density in metropolitan areas have a significant impact on the volume and composition of municipal waste. The densification of urban areas intensifies consumption activities and, consequently, waste production, necessitating the development of innovative and sustainable waste management strategies to mitigate environmental impacts.

Academic literature highlights the relationship between urbanization and waste management. Ying-Chu Chen (2018) emphasized how urbanization affects the quantity and composition of generated waste, while Dimpal Vij (2012) highlighted the increase in packaging, electronic waste, and other non-organic materials, which pose particular challenges for recycling and disposal.

Figure 8

Evolution of Population Density over time (2013-2020)



The analysis of the effects of urbanization on the environment (S. Uttara et al., 2012) offers a holistic view of the ecological implications of urban expansion, highlighting the urgency of integrating urban planning with environmental management strategies to address the challenges posed by urbanization and increasing population density.

Regarding the European population, from 2001 to 2022, the number of inhabitants has grown continuously each year, rising from 429 million to 447 million, a 4% increase (Eurostat, n.d). Analysing population density (tps00003$EUROSTAT), the aggregated data chart shows that in the European Union, there has been a continuous increase in density, with the exception of 2020, rising from 107.4 persons per square kilometer in 2013 to a peak of 109 in 2019.

Examining the data for individual Member States in the panel chart, a significant heterogeneity is observed. There is an increase in density in countries such as Belgium, Denmark, Germany, Luxembourg, and Malta, while a decrease is observed in the same years in countries such as Hungary, Italy, Lithuania, and Portugal. Malta is by far the most densely populated country, followed by the Netherlands, Belgium, Luxembourg, and Germany (Eurostat).

8)GHG Emissions from Waste Management

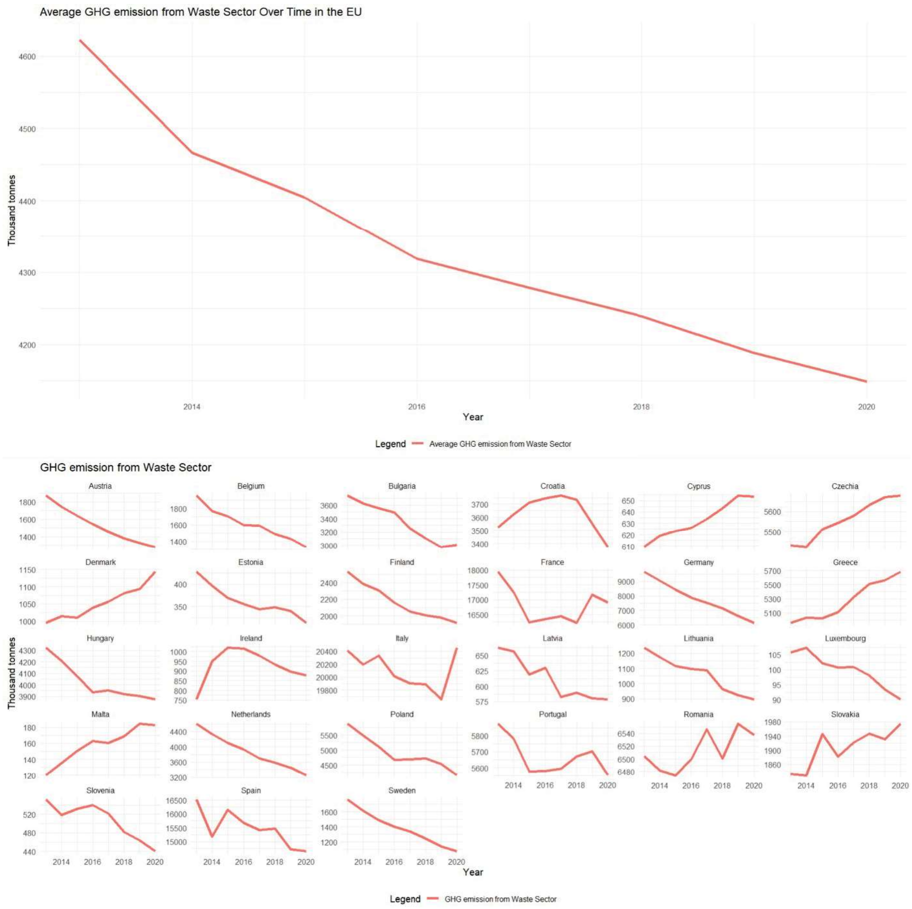
One of the variables that is not a cause but a consequence of waste production and management is greenhouse gas (GHG) emissions. In a 2021 article, Gautam and Agrawal report that waste management contributes to approximately 5% of climate-altering emissions in the atmosphere. Numerous studies have investigated the link between waste production and management and GHG emissions (Mazzanti and Montini, 2009; Mohareb et al., 2011; Castrejón-Godínez, 2015; Magazzino et al., 2021), all concluding that there is an indissoluble link between the waste sector and pollutant emissions. These emissions are generally associated with landfilling and incineration of waste (Zero Waste Europe, 2020), particularly bio-waste.

Analysing the aggregated data (env_air_gge$EUROSTAT), a significant decrease in the amount of GHG emitted by the waste sector in Europe is observed. Indeed, from 1995 to 2017, GHG emissions from waste in the European Union decreased by 42% (Eurostat, 2020), consistent with the results shown in the graph.

The panel chart shows that only Cyprus, the Czech Republic, Denmark, Greece, Italy, Malta, Romania, and Slovakia have increased their emissions from waste, while other countries have been able to almost consistently reduce them from 2013 to 2020.

Figure 9

Evolution of GHG Emission from Waste Sector over time (2013-2020)



2.3) Sustainability and Circular Economy Indicators Description and Trends

<u>9)Material Footprint</u>

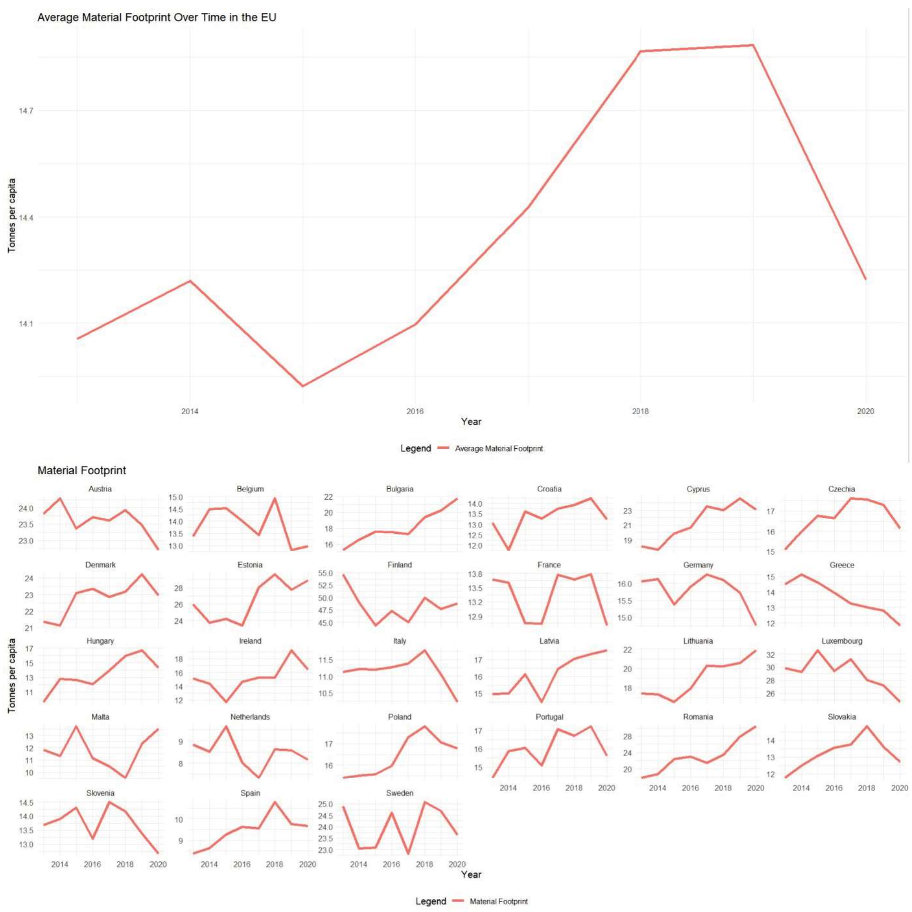
The material footprint measures the amount of raw materials extracted and consumed by human activities, including both renewable resources (such as timber and biomass) and non-renewable resources (such as minerals, metals, and fossil fuels). The relentless demand for these materials not only strains limited resources but also causes environmental degradation and biodiversity loss (UNEP, 2024). Sustainable material management and the transition to a circular economy are therefore essential to reduce the material footprint (Korra, 2022).

A 2012 study by Wiedmann et al. demonstrated that in 2008 China had the highest material footprint globally (16.3 Gt), while Australia had the highest per capita value (35 tons per capita). According to Eurostat Statistics Explained, the European Union reached its peak material footprint in 2007/2008, before the global financial crisis, with 18 tons per capita.

A 2023 report by the European Environment Agency states that between 2010 and 2022, the EU's per capita material footprint remained stable, except in 2020, when it decreased due to the economic slowdown caused by the COVID-19 pandemic.

Figure 10

Evolution of Material Footprint over time (2013-2020)



This report also references the Eighth Environment Action Programme by the European Commission, which calls for a significant reduction in the EU's material footprint to preserve natural resources and mitigate environmental impacts such as climate change and biodiversity loss.

From the aggregated community-level data (cei_pc020$EUROSTAT), a growing trend in the material footprint is observed, with a decrease in 2020 due to the pandemic, which slowed production and economic activity. Another interesting finding from the EEA report is the increase in the percentage of the material footprint represented by imports, rising from 48% in 2010 to 51% in 2020, indicating a growing dependence on imports to meet internal material demand.

The EU's total material footprint exceeds the global average (14.428 tons per capita in the EU in 2017 versus 12.2 tons globally according to the UN) and is much higher than that of low- and middle-income non-EU countries (4.7 tons per capita in 2017). Although lower than high-income countries (26.3 tons per capita), the EU's material footprint surpasses the planet's "safe operating space" for resource extraction, indicating that if the world consumed resources at the EU level, the planet's capacity to provide these resources would be exceeded.

Analysing the panel chart of individual member states, it is observed that countries such as Italy, the Netherlands, and Spain have material footprint values below the average. The Netherlands, in particular, records a per capita value between 8 and 9 tons. According to the CBS (Centraal Bureau voor de Statistiek), this is due to the high population density, which allows for more efficient use of materials for infrastructure. This also explains why only the raw material footprint for fossil energy carriers in the Netherlands was above the EU average.

10)Resource Productivity

Resource productivity is a crucial indicator of material use, closely linked to SDG 12 "Responsible Consumption and Production" (Eurostat). Resource productivity is calculated as the ratio of gross domestic product (GDP) to domestic material consumption (DMC). A rising ratio over time indicates decoupling, with greater economic growth achieved using fewer resources, which is important for the industrial competitiveness of the EU due to high material input relative to total factor inputs. In developed countries, resource productivity generally tends to rise due to efficiency improvements driven by innovation, shifts in economic structures towards services, and the relocation of extraction activities abroad (EEA, n.d).

Resource productivity (euros per kg) is closely tied to the material footprint through DMC, as DMC measures the amount of materials used directly within a national economy (DMC = Domestic Extraction + Imports – Exports). The material footprint, on the other hand, provides an additional perspective by considering the materials required along the entire global supply chain to produce a good or service, attributing them to final demand (One Planet Network, 2024).

Figure 11

Evolution of Resource Productivity over time (2013-2020)

Thus, resource productivity is an important metric to monitor as it indicates how effectively circular economy principles are being applied (EEA, n.d). A 2010 paper by Bleischwitz emphasizes the importance of this indicator, noting that measuring the efficiency of natural resource use in producing goods and services is fundamental for the transition to a low-carbon economy.

Several studies examine resource productivity (Giljum et al., 2010; Steinberger and Krausmann, 2011), but one key study, "How to Deal with Resource Productivity" by Gan et al. (2013), explores the socioeconomic factors influencing it.

The authors identify four models of influence, which can be summarized as follows:

1. Resource productivity increases with rising income levels.
2. Countries with high population density tend to exhibit higher resource productivity.
3. The economic structure has a two-phase influence on resource productivity: during industrialization, the decline in agricultural activity and the rise in industrial activity lead to higher resource productivity; post-industrialization, the decline in industrial activity and the expansion of the service sector become the main drivers of increased resource productivity.
4. The export of raw materials has a negative effect on resource productivity.

Examining the chart for the EU average, a growing trend is evident (cei_pc030$EUROSTAT), as confirmed by the Eurostat Statistics Explained report, which highlights this growth especially after the financial crisis of 2007-2008. The growth appears stable until 2020, when a sudden decrease occurs due to the pandemic, which reduced GDP more significantly than DMC, resulting in a lower ratio (Eurostat). At an aggregate level, this resource productivity amounted to more than 2 euros/kg in 2019. However, the panel chart for individual Member Statesreveals considerable heterogeneity, with ratios falling below one euro in Bulgaria, Finland, Poland, and Romania, and exceeding 3 euros/kg in France, Belgium, Ireland, Italy, Luxembourg, and the Netherlands (Eurostat). As noted in Gan et al.'s study, this heterogeneity is mainly due to differences in income levels, population density, and raw material exports.

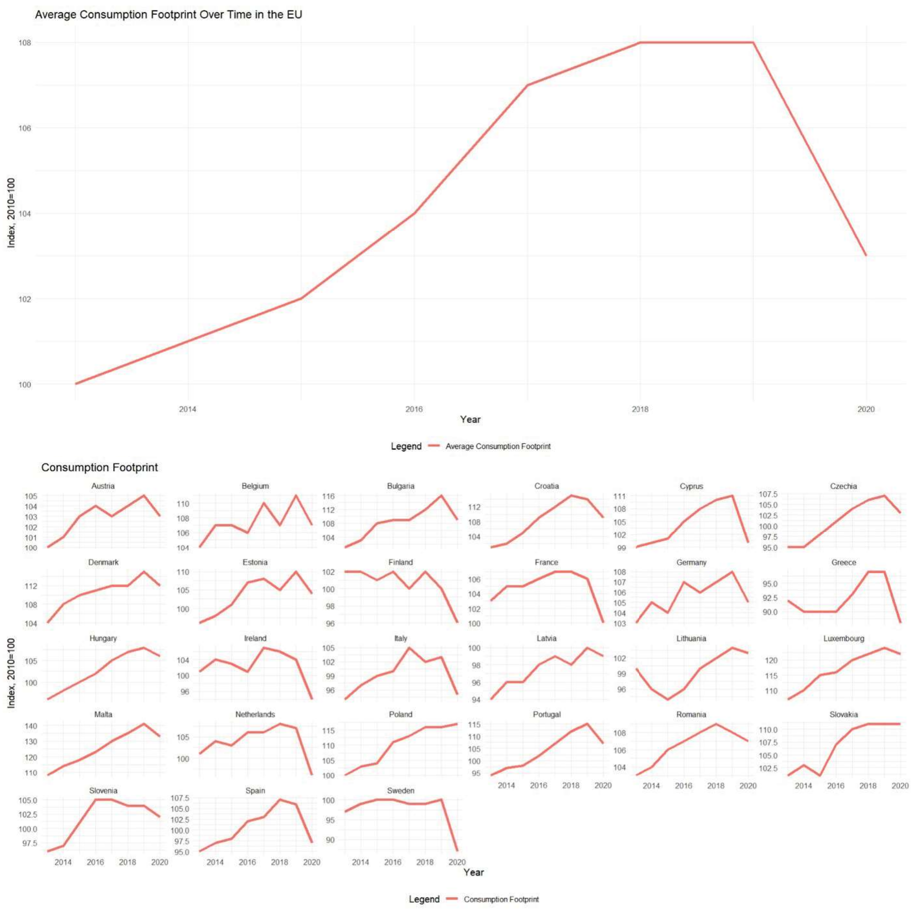
11) Consumption Footprint

The final metric that completes the picture of the impact of resource use, and the most specific one, is the Consumption Footprint. This indicator estimates the environmental impacts of consumption in the EU and its Member States by combining data on consumption intensity and the environmental impacts of representative products. The indicator covers five areas of consumption: food, mobility, housing, appliances, and household goods (Eurostat).

In the European Union, this metric is developed by the Joint Research Centre of the European Commission, as described in the 2023 JRC Science for Policy Report titled "Consumption Footprint and Domestic Footprint: Assessing the environmental impacts of EU consumption and production," edited by Sanyé Mengual and Sala.

Figure 12

Evolution of Consumption Footprint over time (2013-2020)



This report presents an LCA-based framework for assessing the environmental impacts of consumption and production on a macro scale (EU level) and a meso scale (countries, regions, and cities), combining a production-based approach (Domestic Footprint) and a consumption-based approach (Consumption Footprint).

The latter follows a completely bottom-up method (Sala & Castellani, 2019; Genta et al., 2022) based on the life cycle analysis (LCA) of representative products, which are then scaled up to obtain the overall consumption figures (Frischknecht et al., 2013).

The chart of the European Union's Consumption Footprint level (cei_gsr010$EUROSTAT), with a base of 100 in 2010, shows an 8% increase from 2013 to 2018, remaining stable for the 2018/2019 period. With the onset of the pandemic and the reduction in economic activities and consumption, the value dropped from 108 to 103, representing a drastic 5% reduction.

Examining the panel chart of the Member States, each shows a positive trend until the pandemic hit in 2020, with higher values associated with higher GDP, although most Mediterranean countries tend to have a lower per capita impact. However, the crucial measure in this case is the Consumption Footprint relative to GDP, which helps measure decoupling (either relative or absolute), meaning using fewer resources per unit of economic production and reducing environmental impacts (UNEP, 2011). The countries achieving absolute decoupling are France and Latvia; 23 countries achieve relative decoupling of consumption impact relative to GDP growth, while Croatia and Cyprus show a close correlation between these two variables, indicating no decoupling (JRC, 2023).

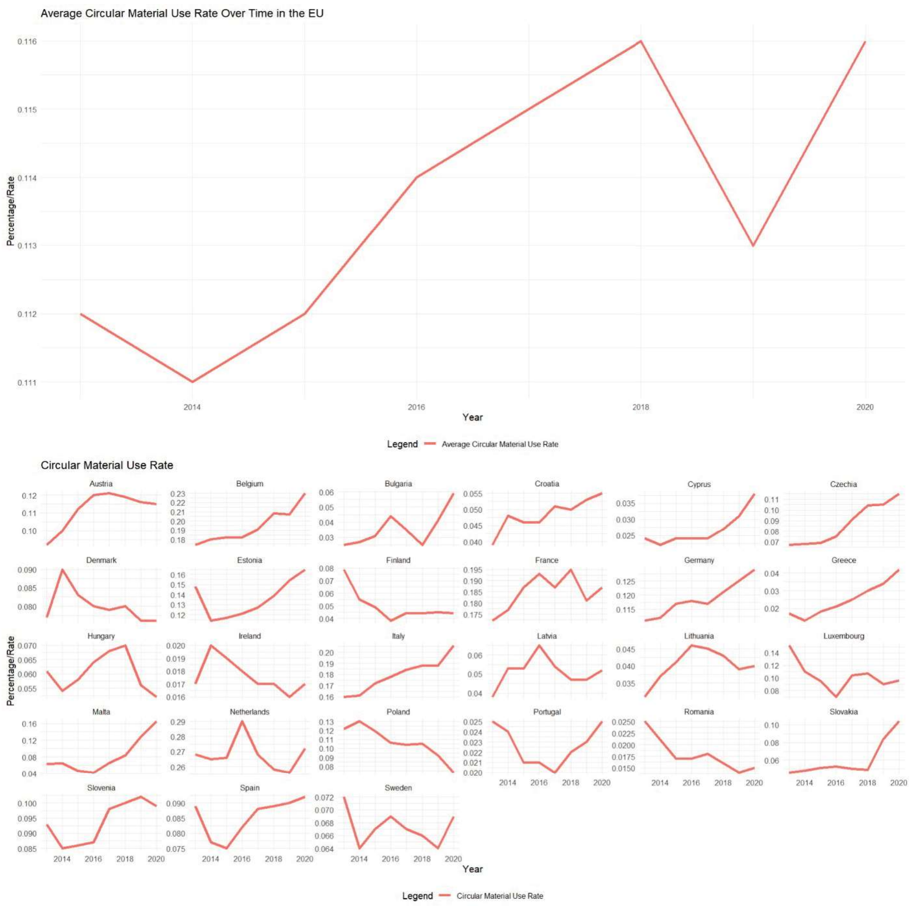
<u>12) Circular material use rate</u>

One of the tools developed by the European Union to measure the circularity of the economy is the Circular Material Use Rate. This indicator assesses the percentage of materials recycled and reintroduced into the economic cycle, thereby reducing the need to extract new raw materials. The circularity rate of materials is calculated as the ratio between the use of recycled materials and the total use of materials. The total use of materials is obtained by summing the Domestic Material Consumption (DMC) and the use of recycled materials. A high circularity rate indicates a greater replacement of raw materials with recycled materials, thereby reducing the environmental impacts of raw material extraction (Eurostat).

Eurostat Statistics Explained also explains how this indicator is linked to the Sankey diagram of material flows in the economy, illustrating the recycling cycle and the reuse of materials, and showing the proportion of recycled materials compared to the total materials used (Rowe, 2023; Eurostat).

Figure 13

Evolution of Circular Economy Use Rate over time (2013-2020)



Examining the aggregated data chart (cei_srm030$EUROSTAT), a positive trend is observed, with the circularity rate reaching 11.6% in 2020. As highlighted in a 2024 article by the European Environment Agency, the EU's Circular Economy Action Plan (CEAP) aims to double this percentage by 2030, requiring a growth rate twenty times higher than that of the last ten years.

The panel chart related to individual Member Statesshows significant variability: some countries have seen a strong increase in the indicator (Malta, Belgium, Italy, Austria, Estonia, and the Czech Republic), while others have experienced a decrease (Denmark, Finland, Luxembourg, Poland, and Romania) (EEA, 2024).

13)Persons employed in circular economy sectors

One of the key indicators to assess the impact of a green and circular economy on macroeconomic variables is the number of people employed in the circular economy sector. Several authors have examined this issue (Horbach et al., 2015; Aceleanu et al., 2017; Llorente-González and Vence, 2020; Klein et al., 2021), arriving at different conclusions about the labor intensity of the sector.

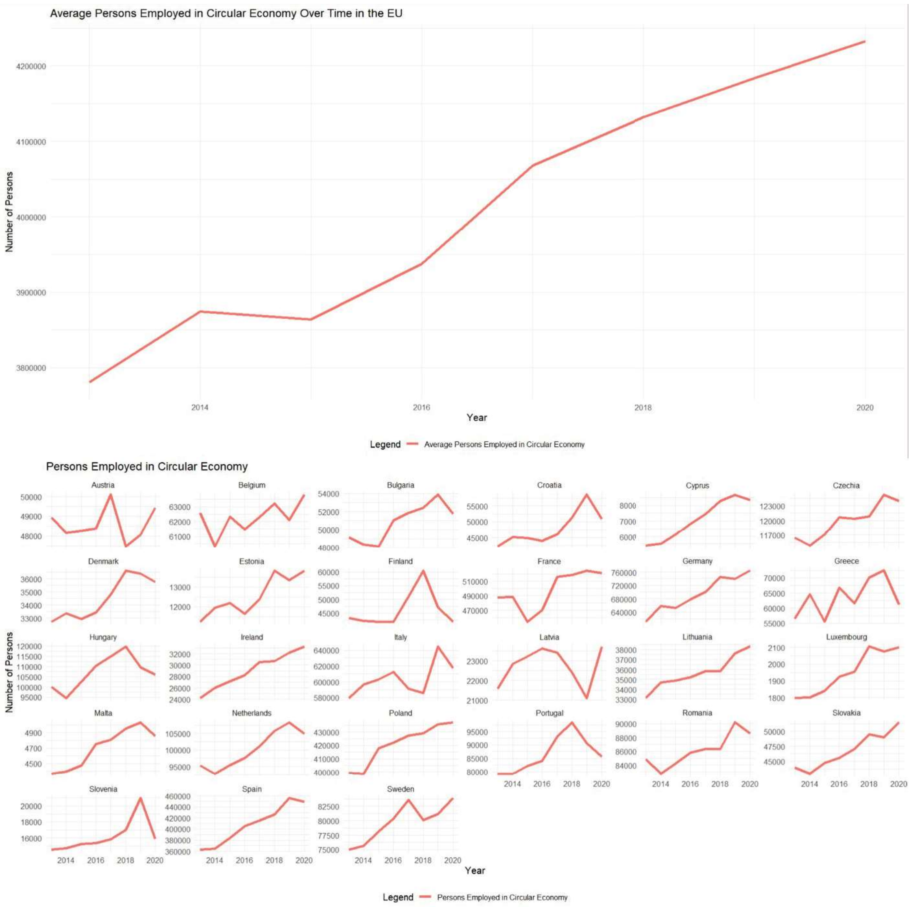
A fundamental reference is the OECD Environmental Working Paper No.162 from 2020, titled "Labour market consequences of a transition to a circular economy: A review paper" by Laubinger et al., which reviews 47 scenarios from 15 modelling studies. This paper finds that four material-intensive sectors (construction, food products, primary metals and non-metallic minerals, and power generation and distribution) account for nearly 90% of global material use but only 15% of the workforce. This suggests that job losses resulting from policies to reduce material consumption could be modest and offset by job creation in labour-intensive sectors, such as services. According to the study, job gains from circular economy policies range between 0 and 2%, indicating that a resource-efficient, circular economy could lead to a net improvement in employment rates, albeit modest. It is important to distinguish between "core", "enabling" and "mainstream" jobs in relation to the labour market impacts of the circular transition (ILO & Circle Economy, 2023). People employed in the circular economy sectors mainly only cover the "core" part, suggesting that the "enabling" and "mainstream" sectors play a supporting and integrating role of circular practices in a broader context.

The Eurostat variable "Persons employed in circular economy sectors" (cei_cie011$EUROSTAT) measures the number of people employed in three sectors: recycling, repair and reuse, and rental and leasing.

Analysing the EU-wide chart, a steady growth in the number of workers is observed, increasing from just under 3.8 million in 2013 to over 4.2 million in 2020. The panel chart for individual Member States shows a generally positive trend across all countries, interrupted only in some cases by the onset of the pandemic in 2020, but with more uniformity compared to other analysed variables.

Figure 14

Evolution of Persons Employed in Circular Economy Sector over time (2013-2020)

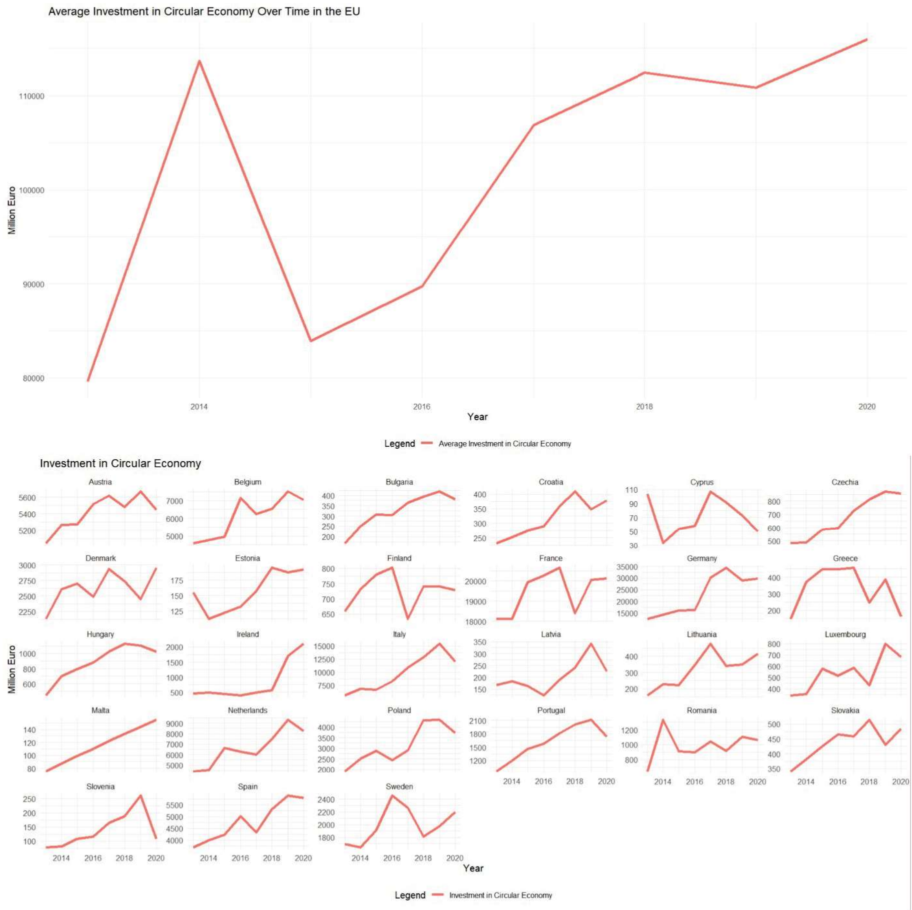


14)Private investment related to circular economy sectors

Investments play a crucial role in the green transition, and those in the circular economy are no exception. A paper by Lehmann et al. (2022) demonstrated that innovation and investments significantly reduce environmental degradation, while investments alone also promote resource efficiency. This concept is further supported by Aranda-Usón et al. (2019) and Atstaja et al. (2020), who found a strong positive correlation between higher investment levels and greater implementation of circular economy practices in businesses. Monitoring investment trends is essential for assessing the progress of the circular economy. Public investments, primarily at the European level, are standardized across Member States and detailed in the OECD's 2023 article "Financing the circular economy transition." In contrast, private investments vary significantly.

Figure 15

Evolution of Private Investment In Circular Economy over time (2013-2020)



The Eurostat variable "Private investment related to circular economy sectors" (cei_cie012$EUROSTAT) includes "Gross investment in tangible goods" in three sectors: recycling, repair and reuse, and rental and leasing. Gross investment in tangible goods refers to investments made during the reference year in all tangible assets. These include new and existing tangible capital goods purchased from third parties or produced for own use (i.e., capitalized production of tangible capital goods) with a

useful life of more than one year, including non-produced tangible goods such as land. Investments in intangible and financial assets are excluded (Eurostat).
Analysing the aggregated data chart for this variable, investments increased from 80 billion euros in 2013 to over 110 billion in 2020, with significant year-to-year variability. The panel chart reveals a positive trend across all countries, though with variations depending on the year.

15)Patents related to recycling and secondary raw materials

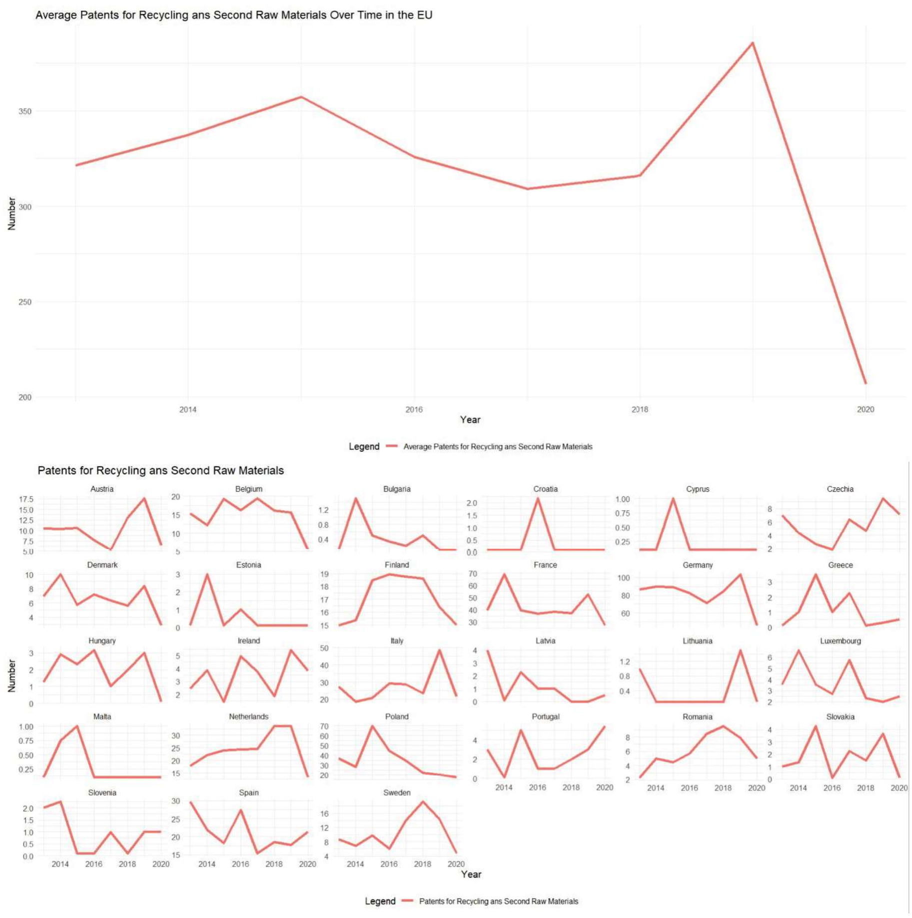
Another interesting variable to consider regarding circularity is "Patents related to recycling and secondary raw materials."
This indicator measures the number of patents related to recycling and the use of secondary raw materials. The classification of these patents was conducted using relevant codes from the Cooperative Patent Classification (CPC) (Eurostat).
Examining the aggregated data chart (cei_cie020$EUROSTAT), it is observed that the number of patents between 2013 and 2018 remained between 300 and 350, with a positive peak in 2019 with over 350 patents and a sharp decline in 2020, likely due to the pandemic, with just over 200 patents.
The panel chart shows significant heterogeneity among the various countries. Germany, France, the Netherlands, and Italy lead the ranking, while other countries, such as Croatia, Cyprus, Lithuania, and Malta, show zero patents for several consecutive years.

2.4) Correlation Analysis

Correlation analysis is a statistical method used to determine the existence and strength of a relationship between two variables or data sets. This relationship can be either positive or negative. In social sciences, Pearson correlation, also known as linear correlation, is commonly used to measure the linear relationship between two continuous variables (DataScientest, 2024).
The value of correlation analysis is well discussed in Senthilnathan's 2019 paper, which highlights the importance of the linear correlation coefficient in identifying the level of multicollinearity. It is important to remember that correlation does not imply causation.

Figure 16

Evolution of Patents For Recycling and Second Raw Materials over time (2013-2020)



Gogtay and Thatte's 2017 paper clearly explains how to interpret the results of correlation analysis, with the correlation coefficient ranging from -1 to 1: coefficients between 0.10 and 0.29 indicate a small association, coefficients between 0.30 and 0.49 indicate a medium association, and coefficients of 0.50 and above indicate a strong association.

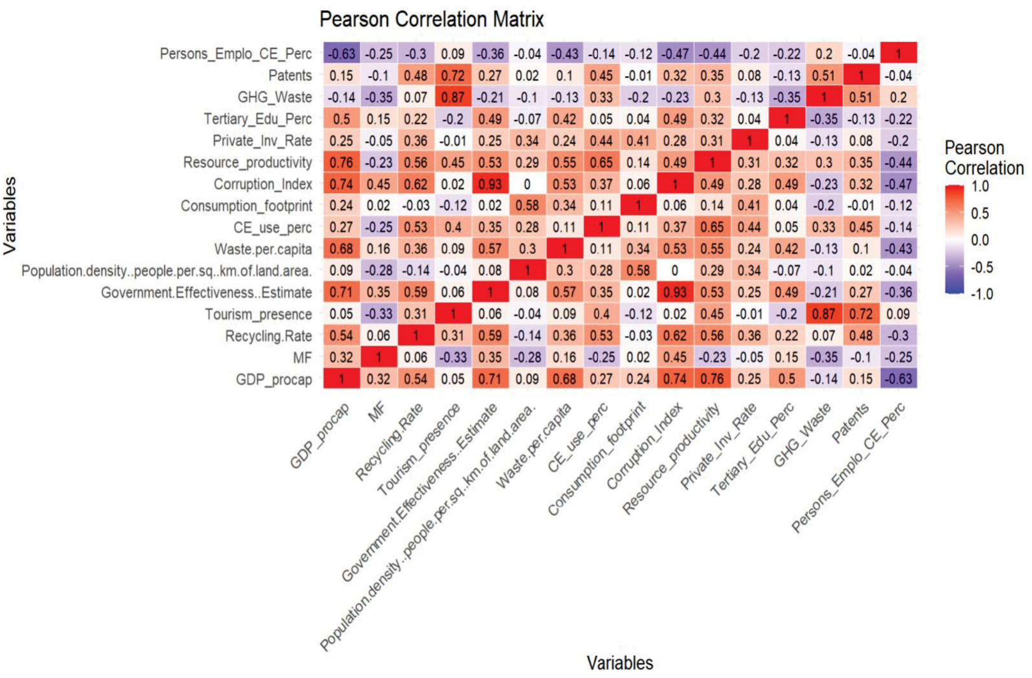
By analysing the heat-map of the Pearson Correlation Matrix, we aim to identify the strongest linear relationships between the variables (>|0.50|). The first variable, which shows very strong relationships with almost all other variables, is GDP per capita.

Two variables that have a strong relationship with GDP are the recycling rate and waste production per capita, with values of 0.54 and 0.68 respectively. This relationship has been extensively discussed in the context of the environmental Kuznets curve (previously cited literature). Interestingly, this links to the legislative approach that "punishes" Member States with low recycling rates, even though they are often those with the lowest waste generation rates, which is preferable according to the waste hierarchy. This contradiction highlights the need to consider not only recycling rates, but also overall waste generation when evaluating waste management policies.

Another frequently studied relationship is between GDP per capita, Government Effectiveness, and the Corruption Index (Lambsdorff, 1999; Garcia-Sanchez et al., 2013; Lučić et al., 2014; Nazar, 2014; Rahmadiani et al., 2023), where a strong association is always observed, though causality remains unclear. In the dataset, the relationship is positive, meaning that a high GDP level is associated with high Government Effectiveness (0.71) and a high Corruption Index score (0.74).

Figure 17

Correlation Matrix



Another significant and widely discussed relationship (0.5) is between the level of education and GDP per capita (Islam et al., 2007; Dahal, 2010; Pastor et al., 2018; Dhongde, 2021; Radcliffe, 2023). Here too, causality remains uncertain (Dahal, 2010; Korkmaz and Kalunk, 2016), although there is evidence that previous economic growth rates lead to higher education levels.

Finally, a variable strongly correlated with GDP per capita is Resource Productivity (0.76), which, as previously explained citing Gan et al.'s 2013 paper, is linked to income levels.

Other significant correlations pertain to the recycling rate. There is a strong correlation between this variable and Government Effectiveness (0.59) and the Corruption Index (0.62). The relationship is clear, and the direction of causality suggests that higher institutional quality increases the recycling rate, as previously discussed in Chapter 2.2 with references to the literature.

The strong correlation with the Circular Material Use Rate (0.53) arises from the fact that this variable is defined as "the percentage of recycled materials reintroduced into the economy." A similar explanation applies to the strong relationship with Resource Productivity (0.56), since recycled materials reintegrated into the production cycle enhance the performance of this indicator. Consequently, a strong correlation is also observed between the Circular Material Use Rate and Resource Productivity (0.65).

From the correlation matrix, it is noted that Government Effectiveness and the Corruption Index have a very high correlation (0.93). This is because the measure of government effectiveness includes the Corruption Index. Their correlations with other variables are thus always in the same direction and very similar in value. In addition to the relationships already highlighted between these two variables and the others analysed, it is important to mention the correlations with Waste Production per Capita (0.57), Resource Productivity (0.53), and Education (0.49). The first two are explained by the same literature references in Chapter 2.2, while the latter is justified by the fact that Government Effectiveness is also measured by considering public spending on education (Kaufmann et al., 2010).

Overall, observing the correlation matrix, almost all relationships are positive (with red as the predominant colour), indicating small to medium associations. The only significant negative relationship is between GDP per capita and the number of people employed in the circular economy sector (-0.63), which, however, lacks logical explanation and support in the scientific literature.

2.5) Circularity Index

Although the aim of this analysis is not to provide a new definition or calculation method for a circularity index, it is useful to integrate the study of the presented variables by synthesizing them for each Member State. Several studies have attempted to calculate a circularity index at the EU level, such as the one by Claudio Quiroga and Poza (2023), which uses Principal Component Analysis (PCA) with Promax rotation to calculate the weights of 15 circularity variables from Eurostat, and the one by Frascareli et al. (2023), which applies various methods, including PCA, to construct a Macro-Level Circular Economy Index (MaCEI). PCA has also been used in the works of Stankovic et al. (2021) and Androniceanu et al. (2021) to calculate a circularity index. Therefore, this technique has been adopted for this analysis as well.
Principal Component Analysis (PCA) is a versatile statistical method for reducing a data table to its essential characteristics, called principal components. A detailed explanation of PCA can be found in the works of Jolliffe and Cadima (2016) and Greenacre et al. (2022), while Holland (2019) explains how to adapt the model on R-Studio.
The variables included in the computation of our circularity index are:

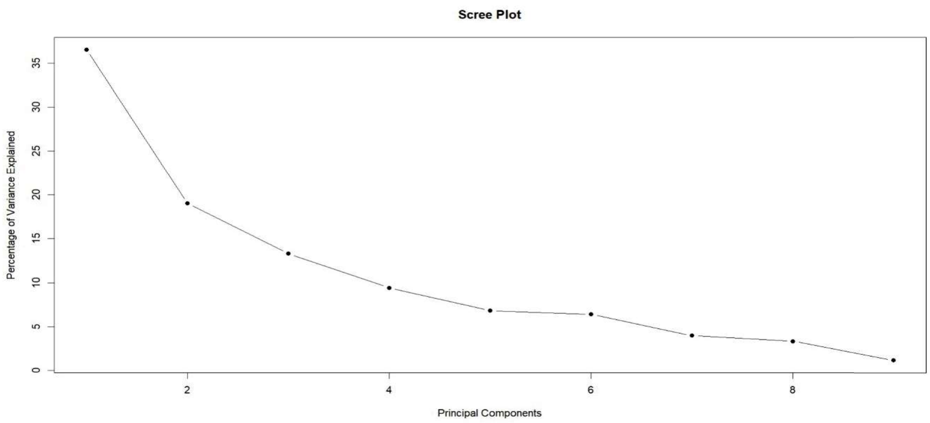
- Waste production per capita
- Recycling rate
- Material footprint
- Resource productivity
- Consumption footprint
- Circular material use rate
- Number of people employed in circular economy sectors
- Private investment related to circular economy sectors
- Patents related to recycling and secondary raw materials

In the presented analysis, PCA was applied to reduce the dataset's dimensionality and identify the most significant variables. Initially, nine relevant variables were selected, and the data were normalized to ensure uniformity of scale. PCA was then performed, and a Scree plot was used to determine the optimal number of principal components.

The Scree plot (Fig. 18) represents the variance explained by each principal component in a PCA, with each point indicating the percentage of variance captured by the corresponding component. The curve shows a sharp decline after the first component and progressively flattens out, suggesting that the first three principal components are the most significant.

Figure 18

Scree Plot of Components Variance



This helps decide how many components to retain to maximize information while reducing the dataset's dimensionality. The goal is to use only the components up to the elbow point for an efficient representation of the data. The loadings of each variable on the first three principal components were examined to assess their relative influence. Finally, the absolute weights of the loadings were calculated and normalized to quantify the importance of each variable, presenting the results in an ordered table to facilitate interpretation.

To calculate the circularity index, the weights are multiplied by the values of each variable. The variables Material Footprint, Consumption Footprint, and Waste Per Capita have a negative impact on circularity. Therefore, in the calculation, the other variables are summed, and then these three variables with a negative impact are subtracted from the total.

Table 1

Weight of the variables

Variables	Weights
Material Footprint	0.1
Resource Productivity	0.11
Consumption Footprint	0.13
Circular Economy Use Rate	0.12
Persons Employed in CE Rate	0.1
Private Investment Rate in CE	0.12
Recycling Rate	0.11
Waste Per Capita	0.09
New Patents in CE Rate	0.11

Table 2

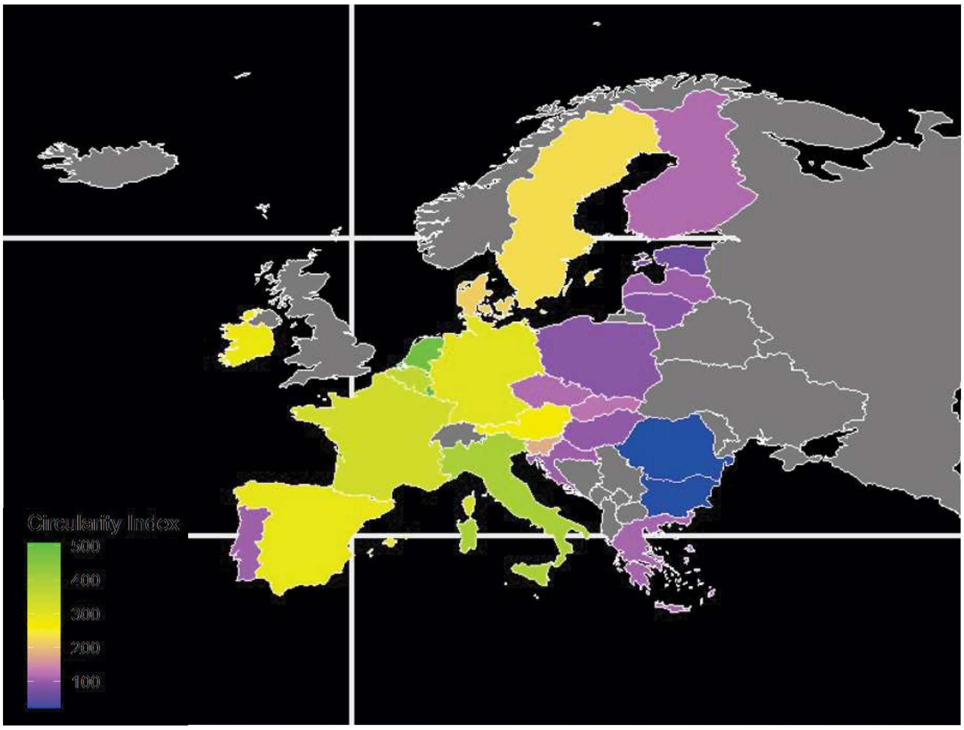
CE Index EU Member States

Countries	CE Index
Austria	269.43
Belgium	360.61
Bulgaria	22.98
Croatia	104.47
Cyprus	103.62
Czechia	117.69
Denmark	216.02
Estonia	68.89
Finland	118.33
France	332.61
Germany	301.73
Greece	111.16
Hungary	96.58
Ireland	282.11
Italy	398.19
Latvia	103.88
Lithuania	88.36
Luxembourg	508.5

Malta	166.02
Netherlands	487.25
Poland	91.33
Portugal	106.34
Romania	22.36
Slovakia	126.61
Slovenia	183.08
Spain	292.07
Sweden	230.71

Figure 19

Map of the CE Index



From the map and table, we can evaluate the highest circularity indices, which correspond to Luxembourg and the Netherlands, while the lowest indices are found in Romania and Bulgaria, results that are quite in line with expectations. Italy, France, Germany, Belgium, Spain, Ireland, and Austria, in this order, have a medium-high index value, indicating good (but not excellent) performance. The remaining 16 unnamed countries are in a situation of medium-low performance.

3) Quantitative Analysis

The next section of the analysis will be devoted to the estimation of the determinants of per capita urban waste production and the per capita recycling rate with three different econometric models. Data used were from the period 2013–2020, covering European Union countries, and were downloaded from Eurostat and World Bank databases. Table 3 presents the descriptive statistics, and most of the variables will have intuitive definitions or have already been presented in section two of the dissertation. The following are definitions of variables that were collected and which require some explanation for greater clarity:

- Organic Farm Territory: This indicator expresses the share of the total utilized agricultural area occupied by organic farming, including already hierarchically organically farmed areas and those in the process of conversion (% of the total territory).
- Perceived Health: Percentage of the Population Reporting Good Health.
- Age Dependency Ratio: The ratio of the number of persons aged 65 and above, the age when generally they are economically inactive, among people aged between 15 and 64.
- High Technology Exports: It is the share of exports of high technology products in total exports.
- EU Commission Confidence: This is an indicator of the amount of trust that people in the EU have in their Commission. It is based on the Euro-barometer, a survey conducted twice a year since 1973 to monitor the evolution of public opinion in the Member States.
- Welfare Expenditure: This includes social benefits, i.e., the transfers in cash or kind to households and individuals, aiming at relieving them of the burden of a defined set of risks or needs; administration costs, means that instead, the costs charged to the scheme for its management and administration; other expenditure, meaning miscellaneous expenditure by social protection schemes as % of GDP.
- Gender Employment Gap: The difference in employment rates between men and women aged 20-64, in percentage points.
- FIGARO contribution: Value-added supported by exports of EU Member States.

Table 3

Descriptive Statistics

Statistic	Mean	St. Dev.	Min	Max	N
Organic Farm Territory %	0.082	0.057	0.001	0.257	216
Perceived Health %	0.665	0.099	0.428	0.841	216
Tertiary Education (Tot)	148,587.200	198,789.600	1,600	848,080	216
Recycling Rate (%)	0.366	0.148	0.091	0.703	216
Tourism Presence (Tot)	90,869,340.000	132,264,951.000	1,517,245	471,199,729	216
Age Dependency Ratio (%)	0.005	0.0005	0.004	0.006	216
CO2 Emissions (Tons per capita)	6.505	2.776	2.970	18.723	216
High Technology Exports (%)	0.119	0.068	0.025	0.425	216
Industry Value Added (%)	0.224	0.061	0.100	0.383	216
Population Density (N per Km^2)	178.878	273.290	17.898	1,610.412	216
Waste Per Capita (Kg per capita)	494.944	131.109	247	844	216
EU Commission Evaluation (%)	0.463	0.110	0.190	0.760	216
Government Effectiveness (Index)	1.052	0.549	-0.287	2.181	216
Persons Employed in CE (Tot)	138,294.800	193,493.500	1,799	764,770	216
Resource Productivity (€ per Kg)	1.776	1.065	0.300	4.470	216
Consumption Footprint (Index)	104.620	7.673	87	141	216
Population (Tot)	16,474,068.000	21,760,489.000	422,509	83,166,711	216
Private Investment in CE (%)	0.007	0.003	0.001	0.017	216
Environmental Tax (%)	0.027	0.007	0.012	0.044	216
Welfare Expenditure (%)	0.234	0.062	0.137	0.380	216
Gender Employment Gap (%)	0.101	0.054	0.010	0.286	216
FIGARO contribution (%)	0.188	0.066	0.093	0.455	216

VIF is a statistical device used to check for collinearity among the independent variables in a regression model. This will also suggest that if the independent variables are strongly correlated with each other, it will affect the precision of the regression coefficients. The variance inflation factor indicates that if a VIF value comes out to be less than 10, it can be accepted. In this case, from the Table 4, it is observed that all VIF values are less than 10; hence, the analysis can proceed.

3.1) OLS Model with Robust Standard Errors

The first analysis to be conducted on the panel dataset involves the use of a simple OLS (Ordinary Least Squares) estimator with robust standard errors, also known as White

Standard Errors. This approach allows for consistent estimates and corrects for heteroscedasticity and autocorrelation, which could otherwise invalidate the estimates. In linear regression analysis, an estimator of the asymptotic covariance matrix of OLS is considered robust to heteroscedasticity if it asymptotically converges to the true value even when the variance of the regression errors is not constant. In this context, the standard errors, calculated as the square roots of the diagonal elements of the covariance matrix, are also considered robust to heteroscedasticity (Tobaga, 2021). White was the first to introduce this correction in OLS estimators in 1980, with subsequent modifications and refinements (MacKinnon and White, 1985; Arellano, 1987; Hansen, 2007).

Table 4

VIF Analysis

	VIF
log(Tourism Presence)	2.394
log(CO2 Emissions)	2.023
log(Industry Value Added)	3.526
log(Population Density)	6.254
log(EU Commission Evaluation)	2.295
log(Government Effectiveness)	7.204
log(Resource Productivity)	5.920
log(Consumption Footprint)	7.716
log(Perceived Health)	5.090
log(High Technology Exports)	2.969
log(Age Dependency)	2.678
log(Organic Farm Territory)	3.467
log(Welfare Expenditure)	8.833
log(Gender Employment Gap)	4.368
log(FIGARO contribution)	7.429
log(Persons Employed in CE)	2.938
log(Environmental Tax)	2.443
log(Private Investment in CE)	3.337
log(Tertiary Education)	2.521

In an article by Mazzarano et al. (2022), the author argues that "The use of OLS presents shortcomings in terms of robustness under the non-normality of the error structure, reducing the absence of bias and the consistency of estimates (Hansen, 2007). (...) OLS models often capture relationships with a high level of significance, which means that excluding strategies for outliers could still register statistical significance."

Equations 1

OLS with White SE

$$\log(WastePerCapita_{it}) = \beta_0 + \beta_1 \log(\text{Tourism presence}_{it}) + \beta_2 \log(\text{CO2 emissions}_{it}) + \beta_3 \log(\text{Industry value added}_{it}) + \beta_4 \log(\text{Population density}_{it}) + \beta_5 \log(\text{EU Commission Evaluation}_{it}) + \beta_6 \log(\text{Government Effectiveness}_{it}) + \beta_7 \log(\text{Resource productivity}_{it}) + \beta_8 \log(\text{Consumption footprint}_{it}) + \beta_9 \log(\text{Perceived Health good}_{it}) + \beta_{10} \log(\text{High Tech Export}_{it}) + \beta_{11} \log(\text{Age Dependency Ratio}_{it}) + \beta_{12} \log(\text{Organic Farm Territory}_{it}) + \beta_{13} \log(\text{Welfare Expenditure}_{it}) + \beta_{14} \log(\text{Gender Empl Gap}_{it}) + \beta_{15} \log(\text{FIGARO contribution}_{it}) + \beta_{16} \log(\text{Persons Empl CE}_{it}) + \beta_{17} \log(\text{Environmental Tax}_{it}) + \beta_{18} \log(\text{Private Investment in CE}_{it}) + \beta_{19} \log(\text{Tertiary Education}_{it}) + \epsilon_{it}$$

$$\log(RecyclingRate_{it}) = \beta_0 + \beta_1 \log(\text{Tourism presence}_{it}) + \beta_2 \log(\text{CO2 emissions}_{it}) + \beta_3 \log(\text{Industry value added}_{it}) + \beta_4 \log(\text{Population density}_{it}) + \beta_5 \log(\text{EU Commission Evaluation}_{it}) + \beta_6 \log(\text{Government Effectiveness}_{it}) + \beta_7 \log(\text{Resource productivity}_{it}) + \beta_8 \log(\text{Consumption footprint}_{it}) + \beta_9 \log(\text{Perceived Health good}_{it}) + \beta_{10} \log(\text{High Tech Export}_{it}) + \beta_{11} \log(\text{Age Dependency Ratio}_{it}) + \beta_{12} \log(\text{Organic Farm Territory}_{it}) + \beta_{13} \log(\text{Welfare Expenditure}_{it}) + \beta_{14} \log(\text{Gender Empl Gap}_{it}) + \beta_{15} \log(\text{FIGARO contribution}_{it}) + \beta_{16} \log(\text{Persons Empl CE}_{it}) + \beta_{17} \log(\text{Environmental Tax}_{it}) + \beta_{18} \log(\text{Private Investment in CE}_{it}) + \beta_{19} \log(\text{Tertiary Education}_{it}) + \epsilon_{it}$$

Table 5

OLS with White SE

	Dependent variable:	
	Model Waste per Capita	Model for Recycling Rate
Constant	5.209***	-1.496***
	(0.875)	(0.208)
log(Tourism Presence)	0.150***	0.008
	(0.039)	(0.011)
log(CO2 Emissions)	-0.021	0.044***
	(0.093)	(0.017)
log(Industry Value Added)	-0.131	1.129***
	(0.545)	(0.218)
log(Population Density)	0.034	0.018
	(0.036)	(0.011)
log(EU Commission Evaluation)	-0.202	-0.034

	(0.253)	(0.069)
log(Government Effectiveness)	-0.149	-0.031
	(0.132)	(0.030)
log(Resource Productivity)	0.065	0.109***
	(0.098)	(0.030)
log(Consumption Footprint)	0.050	-0.015*
	(0.033)	(0.009)
log(Perceived Health)	-0.718	0.186
	(0.640)	(0.129)
log(High Technology Exports)	-0.544	-0.447***
	(0.565)	(0.108)
log(Age Dependency)	62.391	35.856**
	(64.305)	(16.114)
log(Organic Farm Territory)	0.163	0.181
	(0.529)	(0.127)
log(Welfare Expenditure)	4.144***	0.786***
	(1.109)	(0.154)
log(Gender Employment Gap)	-0.444	-1.067***
	(0.502)	(0.152)
log(FIGARO contribution)	3.438***	1.023***
	(0.802)	(0.213)
log(Persons Employed in CE)	4.108	10.882***
	(5.809)	(2.287)
log(Environmental Tax)	-5.029	1.577**
	(3.152)	(0.713)
log(Private Investment in CE)	-1.943	8.790***
	(6.794)	(1.911)
log(Tertiary Education)	-0.013	-0.099***
	(0.087)	(0.016)
Observations	216	216
Standard Errors	White	White
R^2	0.77	0.89
Adjusted R^2	0.74	0.88
F Statistic (df = 19; 196)	33.94	81.06

Note: *p<0.1; **p<0.05; ***p<0.01

The regression results were very informative regarding the effect of various variables on "Waste per Capita" and "Recycling Rate".

For the "Waste per Capita" model, some variables emerged to be of great significance.

The constant has a 5.209 coefficient, significant at the 1% level, indicating that even in the absence of other variables, there is already a high baseline level of waste production per capita. "Waste per Capita" is undoubtedly reflective of the impact of "Tourism Presence," with a coefficient of 0.150, which is significant at the 1% level and, therefore, shows clearly that an increase in tourist presence is correlated with increased waste production. The other important variable about this is "Welfare Expenditure," where what can be seen is the coefficient 4.144, significant at the 1% level once again. This result tends to indicate that increases in welfare spending have gone hand in hand with higher waste production. Finally, the "FIGARO Contribution" is significant with a coefficient of 3.438 at the same significance level of 1%, which indicates that countries, where a higher value is created by their exports produce more waste.

The regression results for the model "Recycling Rate" outlined a host of variables significantly influencing this recycling rate.

The constant has a coefficient of -1.496, significant at 1%, indicating a low level of recycling if all other variables are held constant. The "log CO2 Emissions" variable is significant at 1% with a coefficient of 0.044, indicating that as CO2 emissions go up, so does the rate of recycling. The coefficient for "Industry Value Added" is 1.129, significant at the 1% level, indicating that an increase in industry value added goes strongly with an increased recycling rate. "Resource Productivity" has a positive and significant impact: the coefficient is 0.109, important at the 1% level. Hence higher resource productivity is associated with an increased recycling rate. The coefficient for "High Technology Exports" is -0.447, significant at 1%, implying that the higher the high technology exports, the lower the rate of recycling. The variable "Age Dependency," important at the 5% level with a coefficient of 35.856, implies that the higher the age dependency ratio, the higher the rate of recycling. The coefficient on "Welfare Expenditure" was 0.786, significant at the 1 percent level, suggesting that with the rise in welfare expenditure goes a related increase in the recycling rate. The coefficient on the "Gender Employment Gap" was -1.067, significant at the 1 percent level, indicating that as the gap between male and female employment increases, the rate of recycling falls. The coefficient for "FIGARO Contribution" is positive and significant, 1.023, important at the 1% level, thus showing that the increase in recycling of a country goes with a high impact of the EU on exports. The variable "Tertiary

Education" has a coefficient of -0.099, significant at the 1% level, indicating that an increase in tertiary education goes with a decrease in the recycling rate (very counter-intuitive). Finally, both variables, "Persons Employed in CE" and "Private Investment in CE, had a positive and significant impact on the recycling rate with coefficients of 10.882 and 8.790, respectively, all at a level of significance of 1 percent.

3.2) GLS Model

The Generalized Least Squares (GLS) method allows for the estimation of linear models under broader conditions than those required by the traditional multivariate linear regression model (Liang and Zeger, 1986).

Specifically, the GLS model, using FGLS for the panel dataset, offers highly consistent results without the need for stringent distributional requirements, simply controlling for the absence of temporal outliers (Miranda and Rocha, 2021). Moreover, the model is capable of handling both heteroscedasticity and autocorrelation, making it extremely useful for panel datasets that span multiple years (Hansen, 2006; Vogelsang, 2011; Schlicht, 2021).

Autocorrelation and heteroscedasticity were incorporated into the model through specific formulations to manage each of these issues. To address autocorrelation, the corAR1 function was used with the formulation *form = ~ Year | Countries*, which specifies a first-order autoregressive correlation structure between years within countries. For heteroscedasticity, the *varIdent* function was applied with the *formulation form = ~ 1 | Countries*, allowing for a different variance structure for each country, thus addressing the heterogeneous variance among countries.

Below are the equations describing the two models for waste production per capita (Waste per Capita) and the Recycling Rate:

Equations 2

GLS Model

$$\begin{aligned}\log(WastePerCapita_{it}) = \beta_0 + &\beta_1 \log(\text{Tourism presence}_{it}) + \beta_2 \log(\text{CO2 emissions}_{it}) + \beta_3 \log(\text{Industry value added}_{it}) + \\ &\beta_4 \log(\text{Population density}_{it}) + \beta_5 \log(\text{EU Commission Evaluation}_{it}) + \beta_6 \log(\text{Government Effectiveness}_{it}) + \\ &\beta_7 \log(\text{Resource productivity}_{it}) + \beta_8 \log(\text{Consumption footprint}_{it}) + \beta_9 \log(\text{Perceived Health good}_{it}) + \\ &\beta_{10} \log(\text{High Tech Export}_{it}) + \beta_{11} \log(\text{Age Dependency Ratio}_{it}) + \beta_{12} \log(\text{Organic Farm Territory}_{it}) + \\ &\beta_{13} \log(\text{Welfare Expenditure}_{it}) + \beta_{14} \log(\text{Gender Empl Gap}_{it}) + \beta_{15} \log(\text{FIGARO contribution}_{it}) + \\ &\beta_{16} \log(\text{Persons Empl CE}_{it}) + \beta_{17} \log(\text{Environmental Tax}_{it}) + \beta_{18} \log(\text{Private Investment in CE}_{it}) + \\ &\beta_{19} \log(\text{Tertiary Education}_{it}) + u_{it}\end{aligned}$$

$$\begin{aligned}\log(RecyclingRate_{it}) = \beta_0 + &\beta_1 \log(\text{Tourism presence}_{it}) + \beta_2 \log(\text{CO2 emissions}_{it}) + \beta_3 \log(\text{Industry value added}_{it}) + \\ &\beta_4 \log(\text{Population density}_{it}) + \beta_5 \log(\text{EU Commission Evaluation}_{it}) + \beta_6 \log(\text{Government Effectiveness}_{it}) + \\ &\beta_7 \log(\text{Resource productivity}_{it}) + \beta_8 \log(\text{Consumption footprint}_{it}) + \beta_9 \log(\text{Perceived Health good}_{it}) + \\ &\beta_{10} \log(\text{High Tech Export}_{it}) + \beta_{11} \log(\text{Age Dependency Ratio}_{it}) + \beta_{12} \log(\text{Organic Farm Territory}_{it}) + \\ &\beta_{13} \log(\text{Welfare Expenditure}_{it}) + \beta_{14} \log(\text{Gender Empl Gap}_{it}) + \beta_{15} \log(\text{FIGARO contribution}_{it}) + \\ &\beta_{16} \log(\text{Persons Empl CE}_{it}) + \beta_{17} \log(\text{Environmental Tax}_{it}) + \beta_{18} \log(\text{Private Investment in CE}_{it}) + \\ &\beta_{19} \log(\text{Tertiary Education}_{it}) + u_{it}\end{aligned}$$

Table 6

GLS Model

	Dependent variable:	
	Model Waste per Capita	Model for Recycling Rate
Constant	5.834***	-0.799***
	(0.365)	(0.176)
log(Tourism Presence)	0.037***	0.010
	(0.012)	(0.008)
log(CO2 Emissions)	0.033	0.030
	(0.038)	(0.022)
log(Industry Value Added)	-0.565*	0.037
	(0.303)	(0.144)
log(Population Density)	0.091**	0.045**
	(0.041)	(0.019)
log(EU Commission Evaluation)	-0.083	0.037
	(0.055)	(0.030)
log(Government Effectiveness)	0.043*	0.011
	(0.025)	(0.021)
log(Resource Productivity)	0.103**	0.049*
	(0.049)	(0.026)

log(Consumption Footprint)	0.081***	-0.006
	(0.020)	(0.010)
log(Perceived Health)	-0.042	0.074
	(0.148)	(0.092)
log(High Technology Exports)	0.101	-0.075
	(0.110)	(0.053)
log(Age Dependency)	128.320***	64.945***
	(29.119)	(18.967)
log(Organic Farm Territory)	0.352*	0.316*
	(0.208)	(0.173)
log(Welfare Expenditure)	0.249	0.263
	(0.294)	(0.176)
log(Gender Employment Gap)	-0.124	-0.363***
	(0.208)	(0.137)
log(FIGARO contribution)	-0.289	0.246**
	(0.188)	(0.116)
log(Persons Employed in CE)	10.852***	4.123*
	(2.634)	(2.272)
log(Environmental Tax)	-0.778	-0.520
	(1.291)	(0.822)
log(Private Investment in CE)	0.136	0.785
	(1.395)	(0.659)
log(Tertiary Education)	-0.0003	-0.038***
	(0.017)	(0.012)
Observations	216	216
Log Likelihood	355.272	503.455
R^2	0.42	0.92
Adjusted R^2	0.37	0.91
Note:		*p<0.1; **p<0.05; ***p<0.01

Indeed, it reflects significant differences between the results of OLS and GLS regression in the "Waste per Capita" and "Recycling Rate" models.

In the "Waste per Capita" model, all constants are significant in both regressions, although the baseline level is slightly higher in the GLS model. In both models, "Tourism Presence" has a substantial effect on waste production, even if this effect is more minor under GLS. Finally, "CO2 Emissions" is insignificant in both of them. In the case of "Industry Value Added", it is significant only in the GLS model, thus implying that it probably generates less waste. "Population Density" is important only in

the GLS model and shows that higher density goes with more waste. "Welfare Expenditure" is substantial in the OLS model but not in the GLS model; hence, it has an inconsistent impact. "Age Dependency" is important only in the GLS model and shows that a high age dependency goes with a high production of waste. While "FIGARO Contribution" is significant only in the OLS model, "Persons Employed in CE" is only important in the GLS model. This means that the more a country has employment in the circular economy, the more the waste production.
In the case of the "Recycling Rate" model, the constants are significant in both regressions, showing a low baseline recycling rate. For "CO2 Emissions" they are only important in the OLS model. "Industry Value Added" is significant only in the OLS model. "Population Density" only in the GLS model, where higher density correlates to a higher recycling percentage. "Resource Productivity" in both models, though weaker in the GLS model. "High Technology Exports" are significant in the OLS model. "Age Dependency" in both models, but again with a more substantial impact in GLS. It means that more significant areas of organic farms correlate with higher recycling rates only in the GLS model. "Gender Employment Gap" is significant in both models, relating negatively to the recycling rates. The contribution of "FIGARO" will be significant in both, though with a weaker relationship in the GLS model. "Persons Employed in CE" is significant in both models but has a more substantial impact in the OLS model. Tertiary education is essential in both models and shows a slight negative correlation with the recycling rate, slightly less so in the GLS model.

3.3) Fixed Effects Model

Another type of analysis that can be applied is the fixed effects or random effects analysis. Fixed effects represent variables that are constant across individuals, such as age, gender, or ethnicity, which do not change or change at a constant rate over time. In contrast, random effects are variables that vary unpredictably and non-systematically, literally representing random effects (StatisticsHowTo).

Equations 3

Fixed Effect

$$\begin{aligned}\log(WastePerCapita_{it}) = \alpha_i + &\beta_1 \log(\text{Tourism presence}_{it}) + \beta_2 \log(\text{CO2 emissions}_{it}) + \beta_3 \log(\text{Industry value added}_{it}) + \\ &\beta_4 \log(\text{Population density}_{it}) + \beta_5 \log(\text{EU Commission Evaluation}_{it}) + \beta_6 \log(\text{Government Effectiveness}_{it}) + \\ &\beta_7 \log(\text{Resource productivity}_{it}) + \beta_8 \log(\text{Consumption footprint}_{it}) + \beta_9 \log(\text{Perceived Health good}_{it}) + \\ &\beta_{10} \log(\text{High Tech Export}_{it}) + \beta_{11} \log(\text{Age Dependency Ratio}_{it}) + \beta_{12} \log(\text{Organic Farm Territory}_{it}) + \\ &\beta_{13} \log(\text{Welfare Expenditure}_{it}) + \beta_{14} \log(\text{Gender Empl Gap}_{it}) + \beta_{15} \log(\text{FIGARO contribution}_{it}) + \\ &\beta_{16} \log(\text{Persons Empl CE}_{it}) + \beta_{17} \log(\text{Environmental Tax}_{it}) + \beta_{18} \log(\text{Private Investment in CE}_{it}) + \\ &\beta_{19} \log(\text{Tertiary Education}_{it}) + u_{it}\end{aligned}$$

$$\begin{aligned}\log(RecyclingRate_{it}) = \alpha_i + &\beta_1 \log(\text{Tourism presence}_{it}) + \beta_2 \log(\text{CO2 emissions}_{it}) + \beta_3 \log(\text{Industry value added}_{it}) + \\ &\beta_4 \log(\text{Population density}_{it}) + \beta_5 \log(\text{EU Commission Evaluation}_{it}) + \beta_6 \log(\text{Government Effectiveness}_{it}) + \\ &\beta_7 \log(\text{Resource productivity}_{it}) + \beta_8 \log(\text{Consumption footprint}_{it}) + \beta_9 \log(\text{Perceived Health good}_{it}) + \\ &\beta_{10} \log(\text{High Tech Export}_{it}) + \beta_{11} \log(\text{Age Dependency Ratio}_{it}) + \beta_{12} \log(\text{Organic Farm Territory}_{it}) + \\ &\beta_{13} \log(\text{Welfare Expenditure}_{it}) + \beta_{14} \log(\text{Gender Empl Gap}_{it}) + \beta_{15} \log(\text{FIGARO contribution}_{it}) + \\ &\beta_{16} \log(\text{Persons Empl CE}_{it}) + \beta_{17} \log(\text{Environmental Tax}_{it}) + \beta_{18} \log(\text{Private Investment in CE}_{it}) + \\ &\beta_{19} \log(\text{Tertiary Education}_{it}) + u_{it}\end{aligned}$$

The fixed effects model and the random effects model have been studied by various authors over time (Bhargava et al., 1982; Borenstein et al., 2010). However, to determine which of the two models is more suitable for the type of data and regression under consideration, the Hausman test must be used (Hausman, 1978; Amini et al., 2012). The results of the Hausman test indicate that, for both the "Waste per Capita" model (p-value = 0.006166) and the "Recycling Rate" model (p-value < 2.2e-16), it is preferable to use the fixed effects model over the random effects model. This suggests that individual-specific effects are correlated with the independent variables, making the fixed effects model more appropriate for obtaining reliable and consistent estimates.

The comparison between the regression models for "Waste per Capita" and "Recycling Rate" highlights significant differences in the variables and estimated coefficients. For the "Waste per Capita" model, the constant is higher in GLS (5.834) compared to OLS (5.209), with both estimates significant at the 1% level. "Tourism Presence" shows a significant impact in both OLS (0.150) and GLS (0.037), but not in the Fixed Effects model (0.024), suggesting that tourism has a less pronounced effect when controlling for country-specific effects.

"Industry Value Added" is significant only in the GLS model (-0.565) and not in the OLS or Fixed Effects models, indicating that the GLS methodology better captures the negative impact of industrialization on waste production. "Population Density" is significant in both the GLS (0.091) and Fixed Effects (1.031) models, but not in OLS, suggesting that higher population density is associated with greater waste production when considering the peculiarities of individual countries.

For the "Recycling Rate" model, the Fixed Effects model reveals that "Industry Value Added" (0.582), "Population Density" (-0.328), "EU Commission Evaluation" (-0.119), and "Consumption Footprint" (0.136) are significant. These variables do not show the same significance in the OLS and GLS models, indicating that the Fixed Effects model is more adequate in capturing the dynamics of the recycling rate at the country level.

Both the GLS and Fixed Effects models show that "Age Dependency" is highly significant, with very high coefficients (128.320 in GLS and 234.923 in the Fixed Effects model), suggesting that a higher age dependency ratio is associated with a significant increase in the recycling rate. This result may reflect greater environmental sensitivity in populations with a high percentage of elderly people.

Table 7

Fixed Effect

	Dependent variable:	
	Model Waste per Capita	Model for Recycling Rate
log(Tourism Presence)	0.024	0.0004
	(0.043)	(0.016)
log(CO2 Emissions)	0.089	0.018
	(0.077)	(0.028)
log(Industry Value Added)	0.732	0.582**
	(0.702)	(0.260)
log(Population Density)	1.031**	-0.328**
	(0.402)	(0.149)
log(EU Commission Evaluation)	-0.148	-0.119**
	(0.162)	(0.060)
log(Government Effectiveness)	0.006	0.023
	(0.082)	(0.031)
log(Resource Productivity)	0.138	0.052
	(0.169)	(0.063)
log(Consumption Footprint)	0.398**	0.136**

	(0.185)	(0.069)
log(Perceived Health)	0.117	-0.101
	(0.551)	(0.204)
log(High Technology Exports)	0.237	-0.175
	(0.311)	(0.115)
log(Age Dependency)	234.923***	104.665***
	(55.190)	(20.463)
log(Organic Farm Territory)	-0.042	0.126
	(0.621)	(0.230)
log(Welfare Expenditure)	1.158	0.276
	(0.813)	(0.301)
log(Gender Employment Gap)	-1.451*	-0.690**
	(0.766)	(0.284)
log(FIGARO contribution)	-1.479**	0.156
	(0.669)	(0.248)
log(Persons Employed in CE)	1.518	8.875**
	(10.698)	(3.967)
log(Environmental Tax)	-5.197	-0.562
	(3.626)	(1.344)
log(Private Investment in CE)	-7.328*	4.114**
	(4.378)	(1.623)
log(Tertiary Education)	-0.054	-0.044**
	(0.050)	(0.019)
Observations	216	216
R^2	0.510	0.618
Adjusted R^2	0.380	0.517
F Statistic (df = 19; 170)	9.316***	14.462***
Note:		*p<0.1; **p<0.05; ***p<0.01

"Persons Employed in the Circular Economy" are significant in both the GLS (10.852) and Fixed Effects (8.875) models, although the impact is more pronounced in the GLS model. This indicates that an increase in employment in the circular economy sector is associated with an improvement in the recycling rate.

Finally, the "Tertiary Education" variable is significant in both models, but with different impacts: in OLS (-0.099) and GLS (-0.038) it shows a negative effect on the recycling rate, suggesting that higher levels of tertiary education might be associated with less recycling-oriented consumption behaviours.

3.4) Differences in significance of the different quantitative models

The delivery of three regression models boils down to independent, very significant differences in R^2 and adjusted R^2 values, which means different abilities of each model to explain the variability in data.

For the "Waste per Capita" model, the OLS model gives an R^2 of 0.77 and an adjusted R^2 of 0.74. Here, it means that the OLS model explains 77% of the variability in the data, with the slightly lower adjusted R^2 reflecting a correction for the number of variables included in the model. On the other hand, the GLS model gives an R^2 of 0.42 for "Waste per Capita," along with an adjusted R^2 of 0.37. The information that will be conveyed to the reader is that the GLS model accounts for only 42% of the variability in that dataset. Under the fixed-effects model, "Waste per Capita" has an R^2 equal to 0.510 and an adjusted R^2 of 0.380. This means that while it explains 51 percent of the variability in the data, the lower adjusted R^2 gives a significant penalty for the number of variables in the model, likely due to individual-specific effects.

For the "Recycling Rate" model, the above OLS model yields an R^2 of 0.89 and an adjusted R^2 of 0.88, indicating that it explains a very high proportion of data variability with a limited number of predictors that come at a small cost in terms of penalty. The GLS model improves somewhat on the "Recycling Rate" with an R^2 of 0.92 and an adjusted R^2 of 0.91, which means the GLS explains a little better than the OLS Athe underlying variability in the recycling rate. The fixed-effects model for "Recycling Rate" has an R^2 equal to 0.618, while the F-test adjusted R^2 is 0.517, indicating that the model well explains most variability in the data but that most of the model complexity gets penalized.

3.5) General Interpretation of the results

Looking at the results from these three models, what are the policy implications?

First, consider the "Tourism Presence" variable concerning waste per capita. It is significant in both GLS and OLS models but not in the fixed effects model. Therefore, it would imply that tourism presence may not be a determinant of waste production across time in a country but instead across different countries.

This, therefore, requires policies aimed at countries that are developing countries and are set to record a high amount of tourists in the reported year, as this might inadvertently increase the tonnage of waste without increasing the rate of recycling correspondingly.

The positive effect on recycling within the "Industry Value Added" variable, in both fixed effects and OLS estimates, may be due to the interpretation that more developed industries could imply larger capacities for recycling, both within individual countries and, on average, across countries. This could be because firms in countries with higher levels of industrialization can afford to invest more in effective waste management practices and technologies for recycling. Moreover, the developed industries could shift to more effective technologies that would contribute to producing less waste, just as supported by the GLS model on garbage per capita. This analysis, therefore, tends to focus on effective waste management in the most developed countries in the European Union, which is further confirmed by the high level of recycling rates observed in places like Germany, Italy, and France. It is also important to note the significance of product design in determining product lifetimes and recyclability. Well-designed products can last longer and be more easily recycled, enhancing the sustainability of waste management practices.

On the variable "Population Density," the results obtained indicate that the effect of population density on Waste per capita and recycling rates is complex and contextual. That is related to one country; it is expected that the bigger, the more waste will be produced, but the less it will be recycled, probably because logistically and infrastructurally, this would become very difficult in such situations. At the global level, however, densely populated areas can use better infrastructures or policies promoting recycling despite producing more waste. This will put a premium on the need for considering both intra-country and inter-country differences while analysing waste management and recycling dynamics.

The variable "Consumption Footprint" presents two distinct levels of analysis. Within individual countries, higher consumption is associated with both increased waste production and a higher recycling rate, suggesting that as consumption increases, so do efforts to manage and recycle waste. However, at a global level, countries with high consumption may lack adequate recycling infrastructure or policies, leading to a lower

recycling rate. This result has significant implications, especially for high-consumption countries, typically the wealthier ones.
The analysis of the coefficients for the “Age Dependency Ratio” shows a significant positive impact on both per capita waste production and the recycling rate in all considered models (Fixed Effects, GLS, and OLS). Specifically, an increase in the percentage of elderly people compared to the working-age population is associated with higher waste production, likely due to the specific consumption needs of this age group, such as increased medical needs and household consumption. At the same time, a high age dependency is correlated with an increased recycling rate, suggesting that older people might be more inclined to recycle, or that waste management policies are more effective in areas with a significant elderly population. These results highlight the importance of considering demographic dynamics in waste management and recycling policies, as the needs and behaviours of different age groups can significantly influence these aspects.
The variable "Gender Employment Gap" shows a significant negative impact on both per capita waste production and the recycling rate in all considered models (Fixed Effects, GLS, and OLS). This suggests that an increase in the gender employment gap is associated with a reduction in per capita waste production and the recycling rate. In the fixed effects model, the negative coefficient for waste production indicates that greater female participation in the labour market is linked to a reduction in waste production, perhaps due to more sustainable consumption practices or greater household efficiency. Similarly, the negative coefficient for the recycling rate suggests that a greater gender employment gap could reduce the effectiveness of recycling initiatives, reflecting lower female participation in recycling activities or a decrease in environmental initiatives. The results in the GLS and OLS models confirm these dynamics, suggesting that reducing the gender employment gap could have environmental benefits, improving both waste management and recycling practices globally.
The overall analysis of the coefficients for the "FIGARO Contribution" variable reveals contrasting effects on waste production and the recycling rate in different models. In the fixed effects and GLS models, an increase in the FIGARO contribution is associated with a decrease in per capita waste production and an increase in the recycling rate. This suggests that EU-supported exports promote more sustainable and less wasteful

production practices, also improving recycling infrastructure and policies within countries. In the OLS model, however, an increase in the FIGARO contribution is associated with both higher per capita waste production and an increased recycling rate. This result indicates that, globally, exports can stimulate consumption, leading to greater waste production, but at the same time, they incentivize recycling through improved policies and infrastructure. These findings highlight the importance of considering the specific context and internal dynamics of each country, as well as external influences, when analysing the effects of EU-supported exports on waste management and recycling practices.

The coefficients for variables such as "Persons Employed in Circular Economy Sector" and "Private Investment Rate in Circular Economy" can be examined at length to give an idea of what the implications are about per capita waste production and the rate of recycling, all that is dealt with through different models of Fixed Effects, GLS, and OLS.

Within all models, the rise in the number of people working in the circular economy positively affects per capita waste production and the recycling rate. Several incentives can explain this phenomenon. First, this is because a greater variety of people employed in the circular economy means more excellent activities in terms of collection, sorting, and processing of waste. Though this may eventually result in more waste produced as the sector boosts economic activities, this also means far more significant improvement in the capacity of recyclables, with more waste adequately managed and treated. Moreover, employment growth in this sector often goes hand in hand with investments in new infrastructure and advanced technologies for waste management, improving the effectiveness of recycling processes to reduce landfill. By developing the circular economy sector, there will be broader public awareness and education regarding recycling practices, leading to more sustainable behaviour and broader involvement in recycling.

The results on the variable "Private Investment Rate in Circular Economy" vary across models. In both fixed effects and OLS, an increase in the rate of private investment in the circular economy is found also to increase per capita waste production and, at the same time, raise the recycling rate. It implies that private investments are made in more efficient and viable production methods, reducing waste generation and enhancing recycling capabilities. In the GLS model, however, private investment in the circular economy negatively affects per capita waste production and the rate of recycling; considering variability as a whole and random effects, private investments reduce waste production pretty effectively and enhance recycling practices.

Consequently, a rise in employment within the circular economy boosts private investment. This factor is relevant to the inference that can be made regarding the use of wastes and their subsequent recycling. The greater the number of people involved in this sector, the more wastes will be produced, but on the positive side, an improved recycling rate can be expected by way of increased handling capacity and more public awareness. While having counterparts, private investments tend to reduce the creation of waste and increase the recycling rate, moving to more resource-efficient and cleaner production. These results highlight the necessity for support of jobs and private investment in the circular economy sector while seeking to maximize environmental benefits.

The final observed effect is that related to education. In all models (Fixed Effects, generalized least squares and ordinary least squares) when controlling for tertiary completed increased count is related to lower levels of waste generation per capita. This implies that education has positive externalities on consumption by bringing about more aware and sustainable behaviours that lead to fewer waste emissions. Individuals with a tertiary level education might be more environmentally aware and purchase products that have less packaging or last longer, in turn creating less waste on aggregate. By contrast, tertiary education negatively affects the recycling rate in all models. This outcome, in turn, reveals that those with higher education are more conscious of the environment, but they do not necessarily partake in recycling behaviours. A contributing factor could be that people in those states have less recycling available to them, or use other disposal methods they view as more cost-effective. It may also be many people are too apathetic or busy to take the extra steps besides merely knowing what benefits exist from recycling. Thus, the potential impact of a level of tertiary education is dual: it lowers per capita waste generation by fostering more sustainable consumption patterns, but may reduce recycling rates at the same time. In social, health and economy respectively, endowment effect plays a function in encouraging recycling behaviour that provides a strong case towards embedding environmental conservation value from proximal agencies as well as heightened tertiary micro socio issued facilities of their ecological knowledge among higher learning institutions evermore whose effects are critical to abstracting recycling results.

4) Circular Economy and Waste: The situation in European Union

"The circular economy is a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, re-manufacture, recycling, and composting. The circular economy tackles climate change and other global challenges, like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources."

Ellen MacArthur Foundation

The circular economy is a transformative approach to addressing global challenges like climate change, pollution, and biodiversity loss. Central to the United Nations' 2030 Agenda, this concept drives efforts to create a more sustainable and regenerative economic system. The European Union is actively implementing legislation to set clear targets and provide concrete solutions, guiding Member Statestoward a circular economy. The Circularity Gap Report (Circle Economy, 2013) identifies sixteen solutions across four key systems: food, construction, manufacturing, and mobility. These solutions aim to address five of the nine planetary boundaries currently being exceeded. Moreover, the adoption of circular economy strategies has the potential to significantly halt and even reverse biodiversity loss, as highlighted by Sitra (2022). The Ellen MacArthur Foundation (2019) adds that implementing circular strategies in sectors like steel, cement, plastic, and aluminium could reduce climate-altering emissions by up to 40%.

The latest European Union legislation is part of the European Green Deal package, the CEAP (Circular Economy Action Plan), which emphasizes the need for parameters such as material consumption and footprint to account for the environmental impacts related to prevalent production and consumption models (EEA, 2023d). Some key goals and ambitions outlined within the CEAP include:

- Doubling the CMUR (Circular Material Use Rate) in the next decade;
- Decoupling economic growth from resource use;
- Keeping the EU's resource consumption within planetary boundaries;
- Reducing the consumption footprint in the EU;

- Reducing total waste production;
- Halving the amount of residual municipal waste within a decade.

To monitor the achievement of targets, the European Union has two key instruments: the Circular Economy Monitoring Framework (CEMF) and the Bellagio Declaration on Circular Economy monitoring principles. The CEMF collects and evaluates statistical data on key variables, while, the Bellagio Declaration, established in 2020 and mentioned by the Council of the European Union in the conclusions on "Making the Recovery Circular and Green" (EEA, 2023a), sets out the principles for effective monitoring. The Circular Economy Monitoring Framework includes 27 variables, some of which were used in previous analyses (Chapter 2 and 3), divided into five main macro-areas (Eurostat, 2023b):

- Production and consumption
- Waste management
- Secondary raw materials
- Competitiveness and innovation
- Global sustainability and resilience

The Bellagio Declaration provides principles on how to ensure that monitoring the transition to a circular economy captures all relevant aspects and includes all relevant stakeholders (EEA; EPA; ISPRA, 2020):

- Monitor the Circular Economy Transition: Holistically monitor all relevant initiatives to capture changes in material flows, products, and economic, environmental, and social behaviours;
- Define Indicator Groups: Use indicators of material flow, environmental footprint, economic and social impact, and policies for comprehensive monitoring;
- Follow Indicator Selection Criteria (RACER): Indicators should be Relevant, Accepted, Credible, Easy to monitor, and Robust, also encouraging innovative indicators;
- Exploit a Wide Range of Data and Information Sources: Integrate official statistics, policy information, and new data sources for a comprehensive monitoring framework;
- Ensure Multilevel Monitoring: Monitor changes at all levels of the economy, involving both the public and private sectors and different scales of governance;

- Allow for Measuring Progress Towards Targets: Assess progress against relevant policy targets to inform whether policies are adequate or need adjustments;
- Ensure Visibility and Clarity: Inform policymakers, stakeholders, and citizens with appropriate indicators and user-friendly communication methods, following open data principles.

Beyond this, key actions need to be taken to establish a foundation for the transition to a circular economy. The 3R strategy (Reduce, Reuse and Recycle), which originated in the 1970s started shifting our understanding of economy from a "cradle-to-grave" towards a "cradle-to-cradle," turning linear into circular. Potting et al. (2017) took this approach further and introduced a model for the phases of material circularity: pre-use, in-use, and post-use. These actions, which have been represented by a variety of different "R" concepts to include 3Rs in the "before use," 4Rs in the during-use phase and for simplicity here, now as just simply 2R's after-use. These actions are described in detail below:

- BEFORE USE:
  - *Refuse*

    It is important for companies and individuals to prevent over-consumption unnecessary so as not to pollute the environment more. It is what underpins the European Union's Waste Hierarchy, which places waste prevention at its foundation, as a cornerstone of circularity and in order to minimize environmental impacts from treating wastes. A great example of this was carried out with Patagonia's "Don't buy this jacket" campaign, which in 2013 attempted to persuade customers to only buy what they really needed (Allchin, 2013).
  - *Rethink*

    The decisions taken in the design phase, such as selection of components and materials have a huge impact on how long a product will last for and whether it can be used again or re-manufactured into new products. Design is, therefore, vital in creating successful circular life cycles (EEA, 2017). Car sharing is an excellent example of this trend that moves from ownership to service, and one of the leading companies in the sector is Share Now, represented in more than 17 cities and with more than 10 thousand vehicles, a third of which are electric (ShareNow.com).

- *Reduce*

  During the follow-up production phase, circular economy focuses on minimizing resource use. This would involve increasing production process efficiency, the incorporation of refurbished components and using secondary recycled raw materials. A good example of Reduce is the ReEntry program (Interface.com) from Interface, a global carpet company specializing in modular carpet tiles and commercial floor coverings. Through the program, the company collects and reuses old carpet materials that would have originally been disposed of in landfills, producing new carpets with more than 60% recycled content.

- DURING USE:
  - *Retain*

    The lifespan of a product is significantly extended through proper and preventative maintenance, which is essential to keep any product running efficiently over a longer period. Apple is a great example of a company that offers maintenance and support programs to extend the life of its devices. Apple's refurbishment program ensures that products are kept in optimal condition for long-term use (Elalj, 2024).

  - *Reuse*

    Once the initial user no longer wants a product often this same item can be utilized in further applications without preparing, thereby decreasing environmental harm. If these technological advancements mean the new material is more sustainable, the best decision all comes down to life cycle assessment research. As an example, in this case, we can bring IKEA, which is active in promoting reuse through its resale program, which allows customers to bring back used furniture that can be sold to other customers (IKEA.com).

  - *Repair*

    Repair is an important aspect of the transition towards a circular economy (Lechner et al., 2021), which leads to prolonging the lifespan of products, enhancing efficiency in production and use phases, decreasing consumption related to natural material resources whilst also reducing waste generation. Fixit Clinic is an organization that teaches people how to fix their possessions. This initiative has been successful in extending the life of many products, reducing the need for new resources and the production of waste.

- *Re-manufacture*

  Sitting at the peak of waste hierarchy, re-manufacturing maintains a product's functionality, prolongs its life and minimizes loss of material. Caterpillar's Cat Reman program is a leader in re-manufacturing industrial machinery, preserving product functionality and minimizing material losses (Caterpillar.com).

- AFTER USE
  - *Recycle*

    Recycling waste materials into new products, reducing the need for virgin raw material and environmental impact of disposal. Not only recycling but this cycle is also helping us to recover valuable resources and reducing waste accumulation in landfills. There are many companies in this field, but one example is TerraCycle, a company specialized in the recycling of difficult-to-recycle materials (TerraCycle.com).
  - *Return*

    Collection and recycling efforts are meaningless, if the materials taken out of waste streams do not become secondary raw material flowing back into virgin-based value chains. Spoiler Alert is a leading platform for managing excess inventory in the consumer packaged goods (CPG) industry. It helps reintegrate recycled materials into the value chain, replacing virgin raw materials and reducing waste (SpoilerAlert.com).

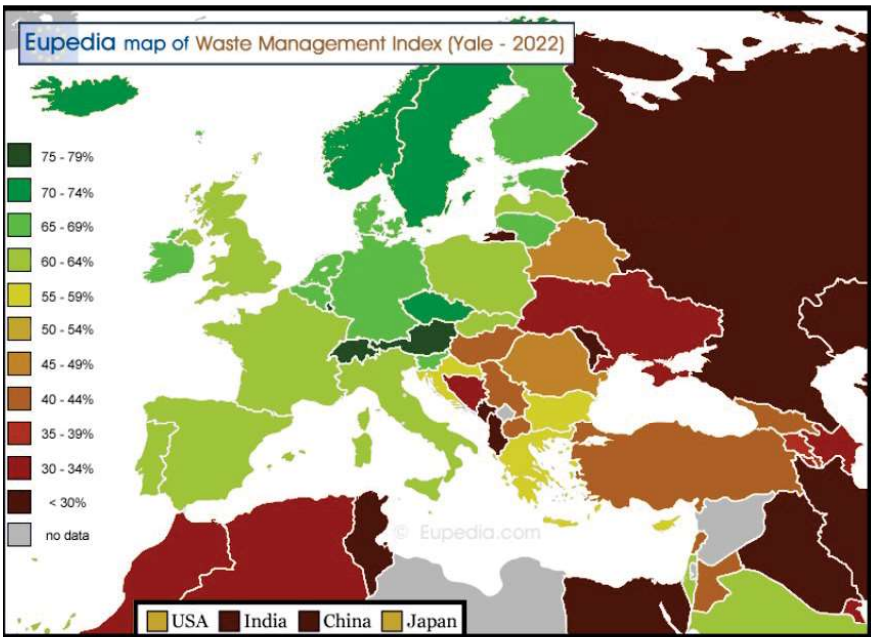
As is evident from the analysis of the different phases of the economic cycle, from initial use to post-use, the circular economy is closely linked to the production and management of waste. It is worth highlighting that an approach that considers the entire life cycle of products for the circular economy is adopted at EU policy level. In this way, product policies, such as the Eco-design Regulation in the Green Deal, have been added to the objectives and obligations on waste. These policies are closely linked, as product design defines waste generation (due to failure or difficulty in repair) and recycling rates. The European Union is one of the global leaders in waste management, as highlighted by the Eupedia map (Fig. 20) illustrating the Waste Management Efficiency Index (Yale, 2022).

However, despite progress, the EU is still far from achieving a fully sustainable management system that would classify its Member Statesas entirely circular. In 2018, waste in the EU amounted to 2.3 million tonnes (Eurostat, 2023), of which only 8% came from household waste. This data clearly shows that the idea of zero-waste in the EU is an illusion (Weghmann, 2020).

To further underline the partial sustainability of the European waste management model, it is interesting to note that waste exports to third countries increased by 66% between 2004 and 2018 (Eurostat, 2020). In 2021, the EU exported around 33 million tonnes of waste, mainly to less developed countries with lower environmental and labour standards (Abnett, 2021). This issue has recently been addressed by the European Commission, which has introduced new rules on waste shipments to increase traceability, facilitate recycling within the EU and ensure that exported waste is managed sustainably (European Commission, 2024)

Figure 20

Waste Management Index



Note. https://www.eupedia.com/europe/ecological_maps_of_europe.shtml

Analysing waste treatment trends allows for a better understanding of the situation within the European Union. As mentioned in Chapter 1, the Waste Framework Directive of 2008 introduced the concept of the waste hierarchy (Fig. 2), which underpins the European circular economy. At the top of the pyramid is waste prevention, which has received and continues to receive minimal attention, with almost no obligations for member states. Waste prevention can only be achieved by reducing packaging, production and consumption. However, this approach requires a social and cultural transformation that contradicts the EU economic growth model (Weghmann, 2020). In this context, the new legislation on Ecodesign for Sustainable Products (ESPR) plays a crucial role. Recently published, this regulation aims to improve the sustainability of products through design requirements that increase their durability, repairability and recyclability. The ESPR also introduces a Digital Product Passport to provide detailed sustainability information, facilitating informed decisions by consumers and producers. Furthermore, the regulation prohibits the destruction of unsold products such as textiles and footwear, forcing companies to disclose data on the disposal of such products (European Commission, 2024b; Ecochain, 2024).

These measures, together with the promotion of green public procurement, aim to reduce environmental impact and promote a circular economy. However, as underlined by Weghmann, real change requires a broader transformation of society and culture, challenging the current economic growth dynamics of the EU.

The second level of the waste hierarchy is recycling, which in 2016 had a rate of 48% of all waste generated. Regarding municipal waste, the recycling rate increased from 19% in 1995 to 48% in 2020 (Eurostat, 2021). It is necessary to mention the "Early Warning Report" by the European Commission (COM(2023) 304 final), which seeks to identify Member Statesat risk of not meeting the 2025 recycling targets for municipal waste and packaging waste. According to the Waste Framework Directive (2008/98) and the Packaging Directive (94/62), by 2025, Member States must take measures to achieve the following minimum targets:

- 55% preparation for reuse and recycling of municipal waste,
- 65% recycling of all packaging waste.

Regarding these objectives:

- 9 Member States are on track to achieve both targets: Austria, Belgium, Czech Republic, Denmark, Germany, Italy, Luxembourg, Netherlands, and Slovenia.
- 8 Member States are at risk of not meeting the municipal waste target but are not at risk for the packaging waste target: Estonia, Finland, France, Ireland, Latvia, Portugal, Spain, and Sweden.

- 10 Member States are at risk of not meeting both targets: Bulgaria, Croatia, Cyprus, Greece, Hungary, Lithuania, Malta, Poland, Romania, and Slovakia.

The third level of the pyramid, just before landfill disposal, is Waste to Energy (Recovery). Between 1995 and 2018, waste incineration increased by 117%, mainly contributing to the reduction of landfill disposal (Levaggi, 2020). Examining the 2019 UNDP map of incineration plants worldwide, it can be observed that Germany, France, the Netherlands, Sweden, Italy, and the UK (before Brexit) accounted for three-quarters of the entire incineration capacity in Europe (Hockenos, 2021).

However, the primary issue with incinerators is their significant pollution. Collectively, all incinerators worldwide emit as much pollution as Portugal (Hockenos, 2021), and they often burn materials that could be recycled (Zero Waste Europe, 2017). Furthermore, another relevant issue is that investments in incinerator capacity can hinder progress towards better waste treatment (higher up the hierarchy) as capital gets locked into suboptimal treatments. This is why EU funding for incinerators is limited and they are excluded from benefiting from the Sustainable Finance Taxonomy. It is also worth mentioning that incinerators have highly variable energy generation coefficients. According to Zero Waste Europe, the European Commission has decided to exclude incinerators from financial support because these plants tend to discourage waste prevention and recycling, instead promoting incineration which is less sustainable. Furthermore, the EU Taxonomy Regulation makes clear that activities leading to a significant increase in waste incineration or disposal are not compatible with the EU's circular economy objectives (Zero Waste Europe, 2021)

In this context, Paul Connett's "Zero Waste" project comes into play, which states:

"Even if we made incineration safe, we would never make it sensible. It simply does not make sense to spend so much money destroying resources we should be sharing with the future" (Puerto Rico presentation, 2010)

4.1) Zero Waste: the policies of the future

Every type of material that ends up in a landfill or incinerator represents a net loss for humanity. The concept of sustainability extends far beyond devising increasingly sophisticated methods for destroying resources; it involves halting the production of products and packaging that must be destroyed. This is the true waste prevention referenced by the European Commission. From this need to change the paradigm of waste management emerges the “Zero Waste” strategy, conceived by the American chemist and activist Paul Connett. He elaborates on this in his 2013 book, "The Zero Waste Solution: Untrashing the Planet One Community at a Time." This strategy rejects incinerators, mega-landfills, and the throwaway society in favour of a sustainable society. But what does this strategy pragmatically involve, and how could it help the EU achieve its circularity goals?

The “Zero Waste” strategy consists of ten steps for communities, whether they be municipalities, regions, or small villages. These steps are simple, practical, and politically acceptable, yielding concrete results:

5. Source separation
6. Door-to-door collection
7. Composting
8. Recycling
9. Reuse, repair, and deconstruction (not demolition) of old buildings
10. Waste reduction initiatives
11. Economic incentives
12. Residue separation
13. Industrial responsibility
14. Temporary landfill

Each step has a specific rationale. It begins with source separation, as waste is formed by mixing discarded materials, followed by door-to-door collection, which has been shown to positively affect recycling rates (Abrate et al., 2018; Laurieri et al., 2020; Abeshev and Koppenborg, 2023).

Composting organic waste, recovering methane to provide energy, and producing compost is a fundamental process, as improperly managed organic waste causes significant problems. Recycling follows, for which investment in facilities should be central to every country, as it not only provides jobs, but also reduces dependence on third countries for raw materials (Dussaux and Glachant, 2019; Rizos and Righetti, 2022). The fifth step is reuse, repair, and deconstruction, which theoretically falls under the second level of the waste hierarchy, but is often conflated with recycling, despite having distinctly different characteristics. Paul Connett cites two long-standing and operational companies in this sector that could serve as examples for policymakers and entrepreneurs: Urban Ore in Berkeley and Recycle North in Burlington. The costs of raw materials have risen and remained high compared to the pre-pandemic period due to growing demand (Baffes et al., 2024), and the carbon footprint of extraction is substantial. Focusing on reuse and repair is a cost-effective and green choice.

The sixth step concerns reduction, particularly of the residual fraction, which represents the failure of the “Zero Waste” strategy, as it cannot be repurposed. The seventh step involves economic incentives or, more precisely, economic disincentives. The "polluter pays" principle, fundamental to European environmental law (Single European Act, 1987), can also be applied to waste, with the "pay-as-you-throw" system (combined with a landfill tax and an incineration tax), which has shown concrete results in increasing recycling rates and reducing landfill waste disposal (EEA, 2023b).

Steps 8 and 10 introduce new types of infrastructure: the residue separation plant and the temporary landfill. The former serves to highlight residual waste and find any possible second use for it instead of burning it. The plant should have a conveyor belt where residual waste bags are emptied, and the people involved should extract bulky items, recyclables, and toxic substances. The rest should be compacted and placed in a temporary landfill, which has a much lower impact and cost compared to building an incineration plant. Furthermore, solutions for backfilling could be found, which are much less intrusive and cumbersome than traditional landfilling.

This innovative waste management strategy led to the foundation of “Zero Waste Europe” (zerowasteeurope.eu) by Joan Marc Simon in 2014. Zero Waste Europe is a European network of communities, local leaders, experts, and change agents working towards better resource utilization and waste elimination in Europe. It employs a bottom-up approach, starting from municipalities, businesses, and NGOs, aiming to redesign relationships with nature and resources, thereby creating unique and adaptable strategies for every context. This need for change also inspired the establishment of the “Mission Zero Academy” (MiZA) in 2021, a separate entity from Zero Waste Europe that acts as a capacity-building hub, bridging the gap between ambitious zero waste policies and their actual implementation. MiZA serves as an advisor for municipalities

and small to medium-sized enterprises seeking assistance in circular economy and zero waste strategies (Joan Marc Simon and Kaisa Karjalainen, 2024).
Through a multi-year process (Fig. 21), MiZA offers two types of certifications: Zero Waste Cities Certification and Zero Waste Business Certification. Additionally, it provides high-level networking opportunities, tools to calculate CO2 emissions from waste management, reporting capabilities for evidence-based results, and insights into EU policy, helping achieve community-level targets.

Figure 21

Zero waste certification process

Note. *Zero Waste Europe*

Currently, there are 13 certified cities and 4 certified businesses, with 50 cities and 130 businesses on the waiting list for certification. The results achieved by the certified entities are highly encouraging: the involved cities produce 20% to 50% less waste per capita than the national average and have separate collection rates of 55-90%, while the businesses achieve at least a 90% separate collection rate, with at least 30% less waste

generated. It is useful to provide two concrete examples in this context: Tilos Island (Greece) and Ribno Alpine Resort (Slovenia).
In 2021, Tilos had a legal landfill near the sea, causing water pollution and environmental issues, and a separate collection rate of only 13%. By 2023, thanks to participation in the MiZA program, the landfill was closed, and the separate collection rate reached 90% (with a 43% reduction in waste generated per capita).
Ribno Alpine Resort is the first hotel to participate in the program, achieving a 90% separate collection rate (compared to 48% in the sector), a 30% reduction in waste generated, and a 30% reduction in water and energy use.
These examples, along with others such as KrK in Croatia, Partizanske in Slovakia, Svilengrad in Bulgaria, and the famous Capannori in Italy, where it all began, demonstrate that a new waste management approach is possible.
The European Union should study these cases, understanding that in 2024 waste management still has significant room for improvement, and that the transition to a circular economy will remain distant until these improvements are implemented.
The first step should be to initiate a decommissioning plan for the 588 incineration and energy recovery plants in the EU (CEWEP, 2021) and halt the construction of new plants. Besides the previously mentioned pollution and the destruction of valuable resources that could be recycled or reused, incineration is also the most expensive method of waste management, costing between 600 and 1200 USD/tonne/year in Europe (World Bank, 2018), with initial costs ranging from 190 million to 1.2 billion USD per plant. This makes the system very capital-intensive, inevitably creating private monopolies that reduce market efficiency (GAIA, 2021). Despite this, Europe increased incineration capacity by 8 million tonnes per year between 2004 and 2020, as reported in ZWE's "Enough Is Enough: The case for a moratorium on incineration," forcing some countries to import waste to keep their plants operational. For this reason, Janek Vahk, Zero Pollution Policy Manager at ZWE, stated that it is necessary to reclassify Waste to Energy methods as disposal operations (along with Article 12 of the Waste Directive Framework), since the privileged position of this method has led to excess capacity and unsustainable and non-circular waste treatment strategies.
By decommissioning incineration plants and directing public and private investments towards initiatives like those of MiZA, using a bottom-up approach, the European

Union could make significant progress in waste management. The economic benefits would be more widely distributed, transitioning from a capital-intensive to a labour-intensive method, resulting in a net gain for the community in financial and environmental terms.

5) Conclusions

The three questions that guided the analysis have all been answered in the preceding chapters. The general objective of this dissertation, rather than presenting a one-dimensional empirical analysis, has been to demonstrate that the circular economy and waste management have various perspectives that need to be considered, and that the possible types of analysis are numerous and come with multiple implications. The European Union, despite being a leader in these overlapping fields, is still far from the utopian neutrality in terms of carbon and other pollutants derived from consumption and production. Economic growth, which is fundamental to the well-being of nations, entails the continuous use and consumption of materials, and complete recycling or reuse is still far from being a reality; the complete decoupling of production, consumption, and pollution, in a broad sense, is not yet possible.

Academia must, first and foremost, assist policymakers in making appropriate legislative choices, understanding whether, for example, it is useful to have short-term goals that imply long-term investments or to set long-term targets involving market forces to do their utmost to achieve them. Moreover, research in the field of the circular economy and waste management must adopt a bottom-up approach, aiming to "customize" policies at the local level, ensuring homogeneous and non-unequal improvement that starts from the citizen and small businesses, rather than from the high European bureaucracy, which, after setting goals (often unattainable for many realities) proceeds to punish various Member States or even regions with various transparently ineffective procedures. It is as if the European Union had the slightest idea of what happens in the small municipality of southern Italy or the village in the far east of Bulgaria. Zero Waste is just one example of how one could proceed to attempt a paradigm shift at this level, but it is certainly one of the best concerning the advancement of activities and functional procedures to follow.

The multiple limitations of the analysis mainly concern the collected variables and the non-representative historical series. However, one of the objectives during the discussion was to present many sources and citations to show how the topic has been and still is central in the academic world and policymaking, classifying the previous work not only as an empirical analysis but also as a review work of various articles (and more) that have had different levels of importance in the scientific literature on the subject. This type of work should be done once every few years, given the density of publications that manage to come out thanks to the good availability of data.

In these terms, there is a lack of research with implications both in analysis and policy, trying to understand the effectiveness of European and national policies, which is where academia should focus more. Moreover, there is an almost total lack of predictive models developed at the community level, such as CGE models, to understand the trend of waste production and the demand for circular materials in the near future.

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