The terms "circular economy" and "sustainability" are broad, with no single definition in the literature, and which attracted the interest of scientists from different disciplines (environmentalists, economists, engineers, sociologists, and others), global organisations, businesses, policymakers, whole private sector, consumers and individuals (Nobre & Tavares, 2021; Geissdoerfer et al., 2017; Aithal & Aithal, 2023). This broadness creates
room for interpretation, misinterpretation, and misuse of the term greenwashing and the risk of damage to the landscape. Organisations are moving towards a sustainable and resilient economy by implementing circular principles, generating economic value, and reducing environmental impacts. However, it is common for organisations to adapt and shape CE definitions and paradigms according to established processes within the company rather than changing their practices (Kirchher et al., 2017).

The EU governments must coordinate the transformation of the CE and processes toward resource efficiency and greater material circularity. Although average resource productivity has increased by around 40% since 2000, more is needed to compensate for the increase in material use (OECD, 2019). The CE reveals design-based principles, eliminating the negative impact of economic activities that harm the health of the population and natural systems at the design stage, reducing the waste amount and pollution level, circulating products and raw materials, and creating maximum value. EU countries envision progressing towards sustainable CE and resource efficiency. Good practices should be identified to pursue better policies for implementing the CE.

2. Complex management of circular business processes

As the world moves faster and faster into the era of the CE, governments in the EU governments are playing essential roles in driving higher resource efficiency and material circularity. The EU countries must use resources efficiently. This requires complex management, understood as various forms and practice elements needed to implement business changes associated with increasing resource use efficiency successfully.

Recycling is gaining increasing attention in almost all areas of life. There is a clear need to develop models to halt environmental degradation and propose a shift towards a more efficient economic system with less intensive resource use. In the EU, it is essential to ensure the change to a sustainable CE, which would extend for the most significant possible reduction of waste volumes while at the same time preserving the value of natural resources, raw materials, and produced products in the market longer. Recyclable wastes can reduce the need for resource extraction as reusable material is collected seeking to reuse them applying the manufacturing activities. The need to extract primary resources decreases if the lower demand is for raw materials, resulting in less waste generation, correspondingly reducing harmful effects on the natural environment and promoting the conservation of nature.

Researchers and employees emphasised the application of new business models seeking to accelerate the transition from "linear" to "circular" solutions. International corporations promoting business models that follow circularity are cyclical and want the first to break up the unidirectional linear economic system (Schaltegger et al., 2016). One fundamental question still needs to be answered in the scientific literature: how could companies move toward circularity successfully? CE research has sought answers to such questions at the firm level. Such studies focus primarily on companies' motivations for adopting the creation of circular value approaches together with propositions dedicated to motivational aspects and possibilities, e.g., increasing competitiveness through increased efficiency of cost due to lower energy demand and inputs of natural resources, creating the environment to attract sustainable segments of the customer (Gusmerotti et al., 2023) and financial, organisational, market and institutional risks and barriers to integrating CE principles into everyday business practices. Second, existing research on the CE explored the contours of new models for business by describing their constituent elements. The prevailing view is that firms' chains construct stable social systems but incorporate dynamism.

3. Resource productivity in the circular economy

The CE is an economic system that seeks to use resources efficiently, avoiding waste and accumulation with environmental protection and sustainable development (Sverko Grdíc el. al., 2020). It is often used in sustainable development (SD), seeking to reconcile economic growth while applying environmental protection (Belmonte-Ureña et al., 2021). Kirchher et al., 2017 examined 114 definitions of CE. They found that CE is generally portrayed as a combination of reduction, reuse, and recycling activities, but there is little clear linkage between CE and sustainable development. The CE goals are often associated with economic prosperity in line with the environment's quality, with little emphasis on its impact on socioeconomic justice for future
generations. According to Mavi and Mavi (2019), by combining climate changes and global warming processes and protecting natural resources, the CE seeks sustainable development through renewable energy and waste management, defining the development of the economy and minimising the non-desirable impacts on the environment. Moraga et al. (2022) observed that despite multiple and not always precise definitions, the CE does translate into concrete action plans based on specific indicators, and they proposed a classification system that categorises indicators into CE strategies and measurement scopes. The authors noted that the focus is on material conservation through recycling strategies. Cui and Zhang (2022) noted that the CE significantly impacts decarbonisation. The authors analysed the carbon impact of the CE on productivity by assessing the effect of the CE on decarbonisation through a framework of indicators along several dimensions, such as resource efficiency and economic benefits. The development of the CE has a positive impact on carbon productivity. Ding et al. (2020) described the environmental problems of China as a significant industrial-producing country consuming vast amounts of resources, emitting considerable amounts of pollutants, with correspondingly high and persistent losses on the producing country consuming vast amounts of resources, emitting considerable amounts of pollutants, with correspondingly high and persistent losses. These indicators are needed to model dynamic performance changes. Moraga et al. (2022) argued that resource efficiency indicators can measure materials’ life-cycle efficiency and are defined as benefits, not burdens. The authors found that the industrial CE maximises economic benefits by reducing negative environmental impact, reusing disposal, efficient waste management, and using renewable sources.

According to the European Commission, the CE monitoring system includes new indicators of material use estimates and resource efficiency, which measure the efficiency of using materials in the EU production and consumption system. There is also another group of indicators of waste prevention. These indicators are elements of a circular and zero economy that measure the contribution of the CE. The productivity resource of the CE is an essential indicator of how efficiently natural resources are used and how well waste is managed. Factors affecting the productivity indicator are distinguished and presented in Table 1.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient use of resources</td>
<td>The CE seeks to make the most of resources, saving them and reducing losses. These include energy efficiency, water saving, material recycling, etc.</td>
<td>Moraga et. al., 2022; Lingaitienė &amp; Burinskienė, 2021; Burinskienė et al. 2022; Yang et. Al, 2023; Figge &amp; Thorpe, 2023; Lu et al., 2024; Xijie et al., 2023; Munaro &amp; Tavares, 2023; Burke et al., 2023; Mostaghimi &amp; Behnamian, 2023</td>
</tr>
<tr>
<td>Waste minimisation</td>
<td>The CE seeks to see it as a source of resources. This means that waste is minimised, and the recovered waste is recycled and converted into innovative forms of production.</td>
<td>Kirchherr et al., 2023; Lingaitienė et al. 2022; Burinskienė et al. 2021; Yang et. al, 2023; Figge &amp; Thorpe, 2023; Lu et al., 2024; Xijie et al., 2023; Munaro &amp; Tavares, 2023; Burke et al., 2023; Mostaghimi &amp; Behnamian, 2023</td>
</tr>
<tr>
<td>Cyclicality</td>
<td>The CE promotes the cyclicality of resources; that is, resources are used to be reused without significant losses. Such could be achieved by applying repair and recycling.</td>
<td>Moraga et. al., 2022; Xijie et al., 2023; Burke et al., 2023; Kirchherr et al., 2023; Voukkali et al. 2023; Den Hollander et al., 2017</td>
</tr>
<tr>
<td>Innovation and technology</td>
<td>The CE drives innovation and technologies that allow for the use of resources more efficiently and minimise the negative impacts on nature.</td>
<td>Sehnem et al., 2022; Yang et. al, 2023; Lu et al., 2024; Xijie et al., 2023; Munaro &amp; Tavares, 2023; Burke et al., 2023; Mostaghimi &amp; Behnamian, 2023; Kirchherr et al., 2023; Voukkali et al. 2023</td>
</tr>
<tr>
<td>Cooperation and partnership</td>
<td>In the context of a CE, cooperation between businesses, public authorities, non-governmental organisations, and society is essential.</td>
<td>Munaro &amp; Tavares, 2023; Mostaghimi &amp; Behnamian, 2023; Kirchherr et al., 2023; Voukkali et al. 2023</td>
</tr>
<tr>
<td>Socioeconomic responsibility</td>
<td>Companies and organisations must take responsibility for their activities and impacts on the environment and society. This may include commitments to sustainable production, responsible supply chains, and social support projects.</td>
<td>Lingaitienė et al., 2022; Burinskienė et al. 2022; Yang et. al, 2023; Lu et al., 2024; Xijie et al., 2023; Munaro &amp; Tavares, 2023; Burke et al., 2023; Kirchherr et al., 2023; Voukkali et al. 2023</td>
</tr>
</tbody>
</table>

Resource efficiency and the CE are essential in environmental and economic protection. Resource efficiency reduces dependence on natural resources, playing a vital role in the economy and protecting the world, thus benefiting in the long term (Moraga et al., 2022; Burinskienė et al., 2022).
Resource productivity in the CE is a complex and multidimensional indicator that values economic profit and social and environmental impacts. A successful CE seeks to reconcile these aspects for long-term sustainability and prosperity.

All waste poses indirect risks. Improper disposal of waste in landfills, if not properly equipped, can contaminate drinking, surface, and groundwater (Figge & Thorpe, 2023; Petrariu et al., 2022; Lingaitiené et al., 2022).

Climate change also risks landfills built close to water (Yang et al., 2023; Xijie et al., 2023; Lu et al., 2024). Waste incineration is practised worldwide following strict public health and environmental standards, but inadequate incineration or the burning of unsuitable materials results in the release of ash residues and other harmful substances and carcinogens into the air, with a wide range of adverse health effects (Kirchherr et al., 2023; Burke et al., 2023; Mostaghimi & Behnamian, 2023).

The authors describe CE's contribution to SD and promote responsible resource use. The literature often describes indicators regarding their life-cycle impact on environmental, social, or economic aspects (Moraga et al., 2022; Kirchherr et al., 2023; Xijie et al., 2023). Examining the basic principles of the CE, Skene (2018) argued that nature operates using short cycles rather than longer lifespans and that nature's economy works as an open system rather than a closed one.

Suchek et al. (2021) state that it is estimated that the world will have 2.59 bln. tonnes of waste annually around 2030; by 2050, the amount generated globally will grow to as much as 3.40 billion tonnes. Geissdoerfer et al., 2017 argue that CE is the solution which acts as a system, focusing on reducing inputs of natural resources and wastes, slowing down CO2 and demand for energy, and closing and straightening the material's chain. Suchek et al. (2021) and Prieto-Sandoval et al. (2019) emphasise the link between CE and environmental innovations in case society reuses. According to the authors, innovative business models have strong links with product innovation for circularity, with strategies based on new business models and product development, which are slowing down, aiming to close the circulation of materials.

The SD Goals follow innovative transformations that reduce environmental impacts in different areas, emphasising the importance of cooperation in all activities in the transition towards sustainable development (Munaro & Tavares, 2023; Mostaghimi & Behnamian, 2023; Kirchherr et al., 2023).

4. Practices for reducing different types of waste

Salmenperä et al. (2021) point out that the role of management in the CE is to promote the preservation of the value of natural resources in the cycles by recycling them, reducing wastes by strengthening the dialogue and cooperation of the key actors, ensuring the sharing of waste-related data and by reinforcing the economic benefits of the CE helping to reduce greenhouse gas (GHG) emission. 3R (reduce, reuse, and recycle) initiatives help reduce GHG emissions, implement sustainable resource applications, and promote resource efficiency (Sakai et al., 2017; Ruiz et al., 2020). Patwa et al. (2021) found that the 3R practice to extend the product's life and prevent resource wastage is in line with the objectives of the CE and contributes to the ecological balance. The manufacturing energy from wastes, the application of renewed energy, and the efficient usage of resources help to reduce waste and increase economic efficiency in the CE.

Di Foggia and Beccarello (2021) carried out an empirical analysis based on an econometric approach and proposed effective waste management at the national level. The authors pointed out that waste management technologies designed to reduce waste disposal in landfills are essential in achieving the goals of the CE. The authors also assessed the impact of such a system in line with the cost of waste management. They described how much the use of landfills would reduce the mechanical-biological treatment of waste by increasing the capacity for obtaining energy from waste, which could positively impact the environment and save waste management expenses at the treatment and other disposal stages. According to Sherwood (2020), the CE is an international collaboration between all stakeholders committed to eliminating waste without value. Reducing waste and limiting the use of scarce resources is part of sustainability and ensuring circularity. It is to be seen
as a tool to promote positive action, building on the Renewable Energy Directive, the Waste Directive, and the CE Initiative, which defines waste limit values.

The practices of reducing different types of waste include various methods and strategies for reducing waste and saving the environment. Standard waste reduction practices are presented in Table 2.

<table>
<thead>
<tr>
<th>Type of waste-reducing</th>
<th>Reducing methods</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste prevention</td>
<td>Product design</td>
<td>Companies can develop products with long service lives, which are easily recycled and use less packaging.</td>
<td>Den Hollander et al., 2017; Sakai et al., 2017; Parajuly et al., 2020; Burke et al., 2023</td>
</tr>
<tr>
<td>Promotion of reuse</td>
<td>Deposit system</td>
<td>Stores can be equipped with deposit systems that allow customers to return and use the packages again.</td>
<td>Linderhof et al., 2019; Coelho et al., 2020; Cottafava et al., 2021; Balwada et al., 2021; Du Rietz, 2023</td>
</tr>
<tr>
<td>Other recovery</td>
<td>Incineration</td>
<td>Waste that cannot be recycled may be incinerated and incorporated into the production of energy, helping get electricity and heat, thereby preserving other natural resources to reduce waste.</td>
<td>Adami &amp; Schiavon, 2021; Bisinella et al., 2021; Kirchherr et al., 2023; Yang et al., 2023; Munaro &amp; Tavares, 2023; Lingaitienė et al., 2022; Istrate et al., 2023</td>
</tr>
<tr>
<td>Disposal</td>
<td>Landfill</td>
<td>Waste disposal in landfills is less desirable than waste prevention, reuse, and recycling. Still, sometimes squatters can be necessary when there are no other options or if a particular waste is hazardous and cannot be recycled.</td>
<td>Mukherjee et al., 2021; Siddiqua et al., 2022</td>
</tr>
<tr>
<td>Waste recycling</td>
<td>Waste sort and separate</td>
<td>Businesses and households can use waste sorting systems to distinguish between recycling plastic, glass, metal, and carton materials.</td>
<td>Serranti &amp; Bonifazi, 2019; Pluskal et al., 2021; Feil &amp; Pretz, 2020; Lange, 2021; da Silva &amp; Wiebeck, 2020; Lim et al., 2022</td>
</tr>
<tr>
<td>Collaborative recycling</td>
<td>with recycling plants</td>
<td>Companies can work with local recycling plants to recycle useful materials and reduce waste.</td>
<td>Serranti &amp; Bonifazi, 2019; Pluskal et al., 2021</td>
</tr>
<tr>
<td>Stimulation of biodegradation</td>
<td>Using composting systems</td>
<td>Households and communities can use composting systems to biodegrade organic waste and produce natural fertiliser.</td>
<td>Castro-Aguirre et al., 2017; Ajmal et al., 2020; Kalita et al., 2020; Soto-Paz et al., 2021</td>
</tr>
<tr>
<td>Reducing food waste</td>
<td>Using composting systems</td>
<td>Restaurants and grocery stores could apply strategies to help reduce food waste by promoting food packaging and recycling.</td>
<td>Borrello et al., 2017; Talwar et al., 2023</td>
</tr>
<tr>
<td>Waste education</td>
<td>Educational campaigns</td>
<td>Governments and non-governmental organisations can conduct educational campaigns to inform the public about waste management techniques and promote environmentally friendly behaviour.</td>
<td>Abbasi et al., 2020; Soma et al., 2020; Szakos et al., 2021; Yusuf &amp; Fajri, 2022</td>
</tr>
<tr>
<td>Training and seminars</td>
<td>Using composting systems</td>
<td>Companies can organise employee training and waste prevention, sorting, and recycling seminars.</td>
<td>Khandelwal et al., 2019; Magriotis et al., 2021</td>
</tr>
</tbody>
</table>

Preventing waste is the first and most effective way to reduce the amount of waste (Den Hollander et al., 2017). Concerning waste prevention, different authors highlight the role of product design, proposing to distinguish between eco-design and circular product design, redefining the product life cycle (Sakai et al., 2017; Parajuly et al., 2020; Burke et al., 2023). Many products, such as glass bottles, different paper, plastic packaging, shopping bags, or other waste, can be reused. Promoting reuse can reduce the need for single-use products (Balwada et al., 2021). The Circular Solution scheme, which promotes reuse, involves the involvement of circular denominators who take part in a deposit incentive scheme, paying a deposit when they buy beverages, which is then refunded to them if they recycle the beverage containers (Linderhof et al. 2019; Coelho et al., 2020; Cottafava et al., 2021; Du Rietz, 2023).

In the life cycle assessment of waste, scientists are looking for the optimal disposal or recycling solutions for each type of waste (Siddiqua et al., 2022). Waste recycling transforms old products or materials into new goods.
or raw materials. It involves processing plastic, glass, metal, and other materials to reduce the need to refine new raw materials (Kirchherr et al., 2023; Yang et al., 2023; Munaro & Tavares, 2023).

The rapidly increasing amount of waste is a global problem, of which organic waste accounts for a significant proportion (Kalita et al., 2020; Castro-Aguirre et al.). Composting is an efficient and effective way of converting organic waste into fertiliser, returning compost to agricultural land while reducing pollution (Borrello et al., 2017; Talwar et al., 2023). Stimulation of biodegradation is organic waste composting, such as food residues and vegetable waste, which can be useful as a fertiliser for natural plants or soil. This reduces the amount of organic waste in landfills and promotes the natural material cycle (Ajmal et al., 2020; Soto-Paz et al., 2021). Education and information on waste management techniques can help people understand the importance of the waste problem and raise their awareness so that they can act in a more environmentally friendly way (Soma et al., 2020; Abbasi et al., 2020; Szakos et al., 2021).

5. Recycling practices for different types of waste

Every year, the world generates an enormous amount of waste, which becomes one of the biggest environmental challenges. According to World Bank statistics, municipal waste could reach around 2.2 billion tonnes annually by 2025. Municipal, bio, and plastic waste are the three main categories of waste that are of great concern for their environmental impact (Pluskal et al., 2021). In this article, we will examine these three types of waste and the most important methods and options for recycling. Each person generates more than 1 ton of waste in a year alone. This huge part of the waste stream includes municipal waste, bio-waste, and plastic garbage. Such an intense pace of waste production poses a significant environmental challenge and requires effective recycling solutions (Kumari et al., 2019; Hasan et al., 2021). Recycling is becoming an increasingly important factor in the fight against the waste problem. The recycling of municipal, bio and plastic waste not only helps reduce landfill waste but also makes it possible to use waste as a resource for producing new products, thus contributing to developing a sustainable economy (Ajmal et al., 2020).

This article will examine the processes, principles, and options for recycling municipal, bio, and plastic waste. Understanding the importance of recycling this waste and effective recycling methods is essential to the environmental and sustainability challenge. In Table 3, we present the methods of recycling the selected types of waste.

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Recycling method</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal waste</td>
<td>Burning and obtaining energy</td>
<td>Part of the municipal waste can be used as a source of oxygen for energy production. This is a normal process, especially when recycling particular waste is impossible or inefficient.</td>
<td>Mahari et al., 2021; Kumari et al., 2019; Hasan et al., 2021</td>
</tr>
<tr>
<td>Composting</td>
<td></td>
<td>It can be recycled into compost to reduce the amount of organic waste that does not need to be incinerated or stored in landfills.</td>
<td>Ajmal et al., 2020; Oviedo-Soto-Paz et al., 2021</td>
</tr>
<tr>
<td>Processing into</td>
<td></td>
<td>Municipal waste, glass, plastic, metal, and paper can be recycled into secondary raw materials and used to produce new products.</td>
<td>Spooren et al., 2020; Pleissner &amp; Peinemann, 2020; Vincevica-Gaile et al., 2021</td>
</tr>
<tr>
<td>secondary raw materials</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bio-waste</td>
<td>Composting</td>
<td>Biofluents such as food residues, green garden and garden waste, liquid and solid food waste in industrial production, sludge, animal manure, and slurry can be processed through composting. They are considered biodegradable and can be used as a fertiliser for growing plants.</td>
<td>Soto-Paz et al., 2021; Oviedo-Chia et al., 2020; Oviedo-Ocaña et al., 2023</td>
</tr>
<tr>
<td>Anaerobic decomposition</td>
<td></td>
<td>This process breaks down biofacts containing organic matter without the presence of air. This can be beneficial for biofuel production or energy production.</td>
<td>Chavez-Rico et al., 2022; Hasan et al., 2023</td>
</tr>
<tr>
<td>Plastic</td>
<td>Mechanical processing</td>
<td>Plastic can be crushed into small pieces and used to manufacture various products. This process is often used for recycling plastic bottles or boxes.</td>
<td>Feil &amp; Pretz, 2020; Vollmer et al., 2020; Thiounn &amp; Smith, 2020; Schyns &amp; Shaver, 2021</td>
</tr>
</tbody>
</table>
Properly managing biodegradable waste makes it possible to avoid adverse environmental effects and has some benefits (Malav et al., 2020; Mahari et al., 2021). From this waste, you can get the electricity and biogas necessary for producing thermal energy and the excellent fertiliser of the earth – compost. These ways and principles may vary by region, technology, and laws. But, the general idea is to minimise the amount of waste, recycle it into new products, or use it as a resource for other areas of production or energy production. The most common practice in developing countries is the recovery of energy from municipal (solid) waste using thermal technologies such as gasification, pyrolysis, and incineration to convert the waste into energy (Kumari et al., 2019; Hasan et al., 2021) and biological technologies for composting (Ajmal et al., 2020; Soto-Paz et al., 2021). In Table 4, the authors presented the advantages and disadvantages of municipal waste, biowaste, and plastic recycling.

### Table 4. Advantages and disadvantages of waste recycling

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Waste recycling advantages</th>
<th>Description of advantages</th>
<th>Waste recycling disadvantages</th>
<th>Description of disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal waste</td>
<td>Reduced landfill load</td>
<td>Recycling reduces the amount of waste that would finally be dumped in landfills, thus reducing the load on these sites over time and preserving natural resources.</td>
<td>Processing costs</td>
<td>Recycling can be expensive, especially if particular technologies or equipment are required, leading to additional costs.</td>
</tr>
<tr>
<td>Energy production</td>
<td>Some municipal waste, such as biomass and waste fuel, can be used for energy production. Recycling processes, such as producing fuels from waste, can help reduce dependence on fossil fuels and greenhouse gas emissions.</td>
<td>Complexity</td>
<td>Sorting and recycling municipal waste can be difficult and require additional efforts and resources from the country's residents and authorities.</td>
<td></td>
</tr>
<tr>
<td>Preservation of effluents/</td>
<td>Recycling municipal waste makes it possible to obtain secondary raw materials that can be used to produce new products, thereby reducing the need to extract new natural resources.</td>
<td>Technological limitations</td>
<td>Some wastes may be difficult to recycle due to their composition or technological challenges, which can complicate the effectiveness of recycling.</td>
<td></td>
</tr>
<tr>
<td>Secondary raw materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment protection</td>
<td>By reducing waste and recycling efficiently, emissions of pollutants and environmental impacts, such as pollution of precipitation waters and soil, are reduced.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bio-waste</td>
<td>Compost production</td>
<td>Bio-waste processing can benefit compost production, which can be used as a natural fertiliser for plants, promoting sustainable agriculture.</td>
<td>Costs</td>
<td>Bio-waste recycling technologies may require significant investments and actions to develop efficient recycling facilities.</td>
</tr>
<tr>
<td>Biofuel production</td>
<td>The process of anaerobic decomposition can be used to produce biofuels, which can be helpful in energy production or as a heating source.</td>
<td>Hazardous emissions</td>
<td>Anaerobic degradation can lead to emissions of dangerous gases, such as methane, a potent greenhouse gas.</td>
<td></td>
</tr>
<tr>
<td>Plastic</td>
<td>Secondary raw materials</td>
<td>Recycling plastic waste allows you to get secondary raw materials that can be used to produce new plastic products.</td>
<td>Complexity</td>
<td>Plastic recycling can be complex and requires special equipment and technologies to obtain quality secondary products.</td>
</tr>
<tr>
<td>Environment protection</td>
<td>Reducing plastic waste and recycling reduces plastic pollution in seas, rivers, and forests.</td>
<td>Limited recycling options</td>
<td>Some types of plastics may be difficult to recycle due to their composition or technological challenges, limiting the ability to recycle them efficiently.</td>
<td></td>
</tr>
</tbody>
</table>
The advantages outlined in Table 4 show that recycling is a necessary measure from an environmental point of view regarding waste reduction and that it is, therefore, essential to find a way to ensure that the shortcomings listed can be addressed.

6. Research design and results

The authors applied the Vector Error Correction Model to analyse the relationship between two variables. The Vector Error Correction Model is a cointegrated VAR model—related to the Vector Error Correction Model (VECM). Panel VECM connection was determined between the indicator of resource productivity and domestic material consumption (measured in Euro per kilogram, chain-linked volumes) and the indicator of recycled waste biowaste:

1. Resource productivity and domestic material consumption Euro per kilogram, chain-linked volumes (RPDMCECHV)
2. REC_BIOW – Recycling of biowaste.

The Panel Vector Error Correction (VECM) model is a statistical method used to analyse the relationship between several variable time series, considering both short- and long-term equilibrium conditions. In this context, indicators of the productivity of resources and recycled waste, particularly bio-waste, are essential. The yearly data for the research was collected from the Eurostat (2024) database for 27 European countries on the indicators mentioned above.

As we see from Figure 1, in the third period, the response was positive.

Table 5 below shows the relationship between the above-mentioned indicators in different periods.

<table>
<thead>
<tr>
<th>Period</th>
<th>D(REC_BIOW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.0088</td>
</tr>
<tr>
<td>2</td>
<td>-0.0101</td>
</tr>
<tr>
<td>3</td>
<td>0.0048</td>
</tr>
<tr>
<td>4</td>
<td>0.0005</td>
</tr>
<tr>
<td>5</td>
<td>-0.0002</td>
</tr>
<tr>
<td>6</td>
<td>0.0004</td>
</tr>
<tr>
<td>7</td>
<td>0.0004</td>
</tr>
<tr>
<td>8</td>
<td>0.0003</td>
</tr>
<tr>
<td>9</td>
<td>0.0004</td>
</tr>
<tr>
<td>10</td>
<td>0.0004</td>
</tr>
</tbody>
</table>
The Resource Productivity Index, measured in euros per kilogram of material consumption in the household chain volume, shows how efficiently resources are used in the economy. A higher value means higher economic output per unit of material consumed, indicating higher resource productivity.

On the other hand, recycled waste, especially bio-waste, accounts for a high proportion of biodegradable waste that is recycled or reused rather than landfilled or incinerated. This indicator is essential when assessing environmental sustainability and waste management practices.

Conclusions

An analysis of the scientific literature has shown that there is a lack of research on the transition towards a sustainable circular economy, which aims to preserve the value of raw materials and manufactured products in the market for as long as possible by recycling waste and natural resources and by ensuring a more efficient economic system that contributes to the goals of the United Nations Sustainable Development Agenda. The paper's authors described recycling variables with the highest correlation to operational productivity that promote interaction with the circular economy to fill an identified research gap. The novelty of this paper lies in the authors showing how a selection of significant recycling variables influences the transition to a circular economy, indicating the advantages and disadvantages of these processes.

The methodology developed is suitable for studying a wider range of overfilling variables for the comparative analysis of the transition to the circular economy.

Novelty of research. A sustainable transition to a circular economy has many interlinkages with achieving economic efficiency and managing different types of waste. The interactions are significant as they allow the possibility of promoting the diversion of various kinds of waste to protect the environment and preserve natural resources. The authors of this paper have carried out a study and identified the recycling variables that have the most significant impact on the transition to a circular economy.

Recycling significantly impacts the transition to a circular economy. The authors proposed a novel model analysing the time series relationship of several variables. Considering short-run and long-run equilibrium conditions, the importance of resource and productivity indicators for recycled waste, especially bio-waste, was determined.

The researchers looked at the variables necessary for recycling, excluding less important ones. They applied a Vector Error Correction Model to analyse the relationship between the two variables. They found a panel VECM relationship between resource productivity, the internal material consumption indicator, and the recycled biodegradable waste indicator.

This methodology could be helpful for those interested in the impact of recycling indicators on the transition to a circular economy. Recycled waste can reduce the need for resource extraction, as reusable materials are collected and reused in the production process. Primary resource extraction needs decrease due to lower demand for raw materials, resulting in lower waste generation and reduced environmental impact, contributing to nature conservation. Decreasing the use of materials will positively impact the environment. In the meantime, this requires assessments relating to the use of resources, the contribution of resources to economic development, and an assessment of the macroeconomic benefits associated with increasing resource efficiency. Policy evaluation should also be strengthened to identify good practices and pursue better CE implementation policies.

The study has some limitations. The authors analysed only bio-waste since variables responded to the changes in resource productivity indicators. It is possible to prepare forecasts considering other waste types in the future.
References


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