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Article

Transition towards a circular economy to build societal resilience to energy shocks

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Abstract: This study examines how circular economy (CE) practices contribute to energy resilience by mitigating the impacts of energy shocks and supporting sustainable development. Through a systematic literature review (SLR) of recent studies, we analyze the ways in which CE strategies—such as resource recovery, renewable energy integration, and closed-loop supply chains—enhance energy security and reduce vulnerability to energy disruptions. Our research draws on academic databases, focusing on publications from 2018 to 2024, to identify key themes and practices that illustrate the transformative potential of the circular economy. Findings reveal that CE practices at macro, mezzo, and micro levels support resilience by fostering efficient resource use, reducing dependency on non-renewable energy sources, and promoting sustainable economic growth. Additionally, we highlight the roles of foreign direct investment (FDI), research and development (R&D), and supportive policies in accelerating the adoption of circular systems. The study concludes with recommendations for future research to address identified gaps, suggesting a roadmap for advancing circular economy practices as a means to enhance energy resilience and sustainability aims to reveal how wide array of factors affect transition towards more sustainable or circular economy.

Keywords: circular economy; sustainability; macroeconomic factors; regional development; economic policy; driving and hindering factors; energy shocks; resilience

1. Introduction

As global economies increasingly face challenges from resource scarcity, environmental degradation, and energy volatility, the circular economy (CE) has emerged as a vital framework for promoting sustainable development. Unlike the traditional linear model of "take-make-dispose", the circular economy prioritizes resource efficiency, waste reduction, and closed-loop systems that regenerate materials and energy which could be termed "make-use-reuse". By decoupling economic growth from resource consumption and environmental impact, circular economy practices are positioned to address pressing issues of energy resilience, environmental sustainability, and economic stability.

The use of natural resources continues to grow despite the harm of it being recognized and indisputable. The reason behind this is the growing world's population, which requires additional resources to maintain living standards and expand national economies in order to supply food, water and produce basic goods in addition to expanding transportation.

Recent studies highlight the evolving landscape of the CE and its critical role in sustainability and energy resilience. Entrepreneurship emerges as a key driver, with initiatives like circular SMEs, start-ups, and social enterprises fostering innovation and resource efficiency (Suchek et al., 2022). Mastos et al. (2021) demonstrated the potential of Industry 4.0 applications in optimizing circular supply chains, showcasing how digital tools enhance CE practices. Prieto-Sandoval et al. (2018) emphasized the importance of industrial symbiosis and environmental certifications in scaling CE adoption among SMEs. In agriculture, Barros et al. (2020) explored waste-to-energy applications, highlighting bioenergy production as a vital element of CE transitions. Similarly, Kiviranta et al. (2020) examined how surplus renewable energy can be integrated with recycling processes, providing a localized example of CE and energy industry collaboration. The importance of resource recovery in energy systems is further underscored by Abokersh et al. (2021), who proposed a framework for evaluating thermal energy storage within CE principles. To curb growing demand in energy, food and water that requires fewer natural resources, urgent new ways of consumption are needed to be introduced with the following 3Rs pattern—reduce-reuse-recycle. Ruginė and Žilienė (2024) highlighted the 3Rs as central to CE transitions, supported by innovative technologies that enable such a shift to the circular economy as they allow to build or adapt industry that has minimum impact on the environment Together, these studies demonstrate how entrepreneurship, policy, and technological innovation converge to scale CE strategies, reduce energy vulnerabilities, and promote sustainable economic systems.

Economic development may encourage transition to the circular economy due to new innovations frequently introduced while knowledge transfer are viewed as a driving force for innovations and economic development that moves within companies or entities through different channels (Burinskas et al., 2021; Šimelytė et al., 2021). Corporate enterprises are the main players in any sector of the economy and it is the role of scientists to identify the peculiarities of companies' transition towards a more circular economy. Studies imply, that companies' sizes or geographical locations within a particular region play a role in adopting circular innovations (Antonioli et al., 2022; Levický et al., 2022).

This study investigates how circular economy principles contribute to building resilience against energy shocks, defined as sudden disruptions in energy supply due to factors such as geopolitical tensions, natural disasters, or market instability. Energy resilience has become a critical concern for governments, industries, and communities worldwide, as reliable access to energy underpins economic growth and social well-being. Circular economy strategies—such as recycling, renewable energy integration, and resource recovery—offer pathways to reduce reliance on finite energy sources and enhance self-sufficiency, thereby supporting both resilience and sustainability.

The aim of this research is to synthesize existing literature on circular economy practices and their impact on energy resilience. We conduct a systematic literature review (SLR) to identify key themes, practices, and policy frameworks that have proven effective in mitigating energy shocks. Through this review, we explore the roles of foreign direct investment (FDI), research and development (R&D), and policy support in facilitating the transition to circular systems. We also examine how circular practices vary across macro, mezzo, and micro levels, from national policies and sector-wide initiatives to company-level and community-based solutions.

The review spans recent studies published between 2018 and 2024, focusing on both theoretical discussions and empirical evidence. Prior studies, such as Bassi and Dias (2019) on the adoption of CE practices in small and medium enterprises (SMEs) and Moktadir et al. (2020) on circular supply chains, provide a foundation for understanding how circular strategies can reduce energy vulnerability. Additionally, more recent work on innovative technologies, like smart grids and waste-to-energy systems, illustrates the evolving nature of the circular economy and its expanding role in energy resilience.

Through this review, we aim to identify gaps in the current literature and suggest a roadmap for future research. Given the urgency of transitioning to sustainable and resilient energy systems, this study seeks to contribute to the ongoing discourse on how circular economy practices can support energy security, particularly in the face of escalating global challenges.

This study is significant for its comprehensive exploration of how the CE practices enhance energy resilience, foster economic stability, and promote social equity. By examining CE impacts across macro, mezzo, and micro levels, it highlights how strategies like renewable energy integration and resource recovery reduce fossil fuel dependency, create green jobs, and empower marginalized communities. Governments and policymakers can use their insights to design effective CE frameworks, while businesses and SMEs can leverage findings to overcome barriers and optimize sustainability. Additionally, the study provides actionable recommendations for researchers, NGOs, and environmental organizations, contributing to a more sustainable, inclusive, and energy-secure future.

The paper is structured to begin with Methodology, outlining the systematic review process, followed by Trends and Thematic Landscape in Circular Economy Research, which highlights recent research directions. The core analysis is divided into Multilevel Perspectives on Circular Economy, examining economic and environmental impacts at macro, mezzo, and micro levels. Chapters on Circular Economy Practices at Macro, Mezzo, and Micro Levels detail specific strategies and sector applications, while The Role of Circular Practices in Energy Resilience explores how CE practices bolster energy security and mitigate energy shocks. To sum up the literature review Research Gaps in Circular Economy and Energy Resilience are identified. Roadmap to Future Research in Circular Economy and Energy Resilience outlines key areas for future research. Finally, the Conclusions synthesize key findings and provide recommendations for future research.

2. Methods

This study employs a systematic literature review (SLR) approach to explore how the principles of the circular economy contribute to building resilience to energy shocks. The study aims to synthesize existing research to identify key CE practices that enhance energy security, reduce vulnerability to energy disruptions, and support sustainable development. The review examines both theoretical discussions and empirical evidence across various regions, focusing on how circular economy strategies can mitigate the impacts of energy crises.

The SLR was chosen for this study because it offers a rigorous, transparent, and replicable approach to synthesizing diverse research on circular economy (CE) practices and energy resilience. SLRs minimize bias by systematically identifying, screening, and analyzing studies based on predefined inclusion and exclusion criteria, ensuring that only high-quality, relevant research is included. This method is particularly effective for interdisciplinary topics like CE, as it integrates insights from economics, environmental science, and policy studies. Additionally, SLRs help identify research gaps, synthesize fragmented evidence, and establish a foundation for future research (Siddaway et al., 2019; Tranfield et al., 2003). An SLR ensures that these multilevel impacts are comprehensively examined, aligning with the recommendations of Petticrew and Roberts (2006), who argue that systematic reviews are essential for evaluating multifaceted interventions and their contextual dependencies. By providing a comprehensive overview, the SLR enables this study to address the complexity of CE practices across macro, mezzo, and micro levels while capturing their role in enhancing energy resilience.

A comprehensive search was conducted across academic databases such as Scopus, Web of Science, and Google Scholar. The search focused on identifying relevant studies using keywords such as: "circular economy", "resilience", "energy shocks", "energy security", "sustainability", and "resource efficiency." This search yielded a comprehensive pool of articles, which were then subjected to a first screening based on their titles and abstracts. **Figure 1** provides the process of the systematic literature review.

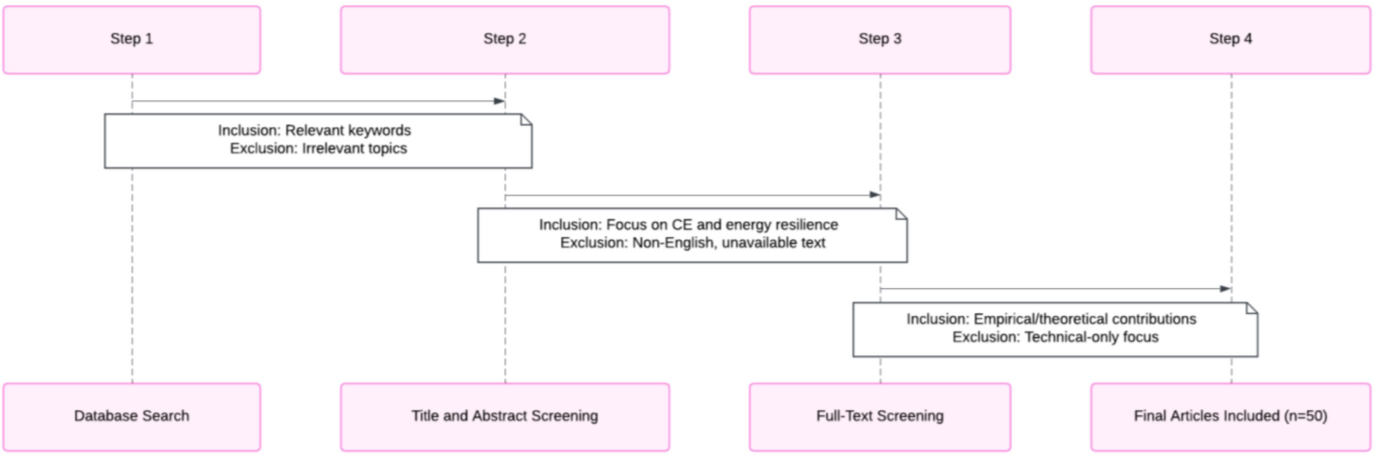

Figure 1. Systematic literature review screening process.

During this first screening, articles were evaluated for relevance to the circular economy and energy resilience. Inclusion criteria focused on studies addressing circular economy principles, energy-related resilience, resource efficiency, or sustainability, while exclusion criteria eliminated technical studies unrelated to socio-economic impacts, as well as articles unavailable in full text or written in languages other than English. The articles that passed this stage underwent a second round of screening.

In the second phase, the full texts of the shortlisted articles were reviewed to ensure alignment with the study's objectives. Articles were included if they made empirical or theoretical contributions to the adoption of circular economy strategies or discussed energy resilience within regional or sector-specific contexts. Studies were excluded if they focused solely on the technical aspects of energy production without connecting to circular economy practices, or if they were duplicates or lacked methodological rigor.

The final selection comprised articles that explicitly addressed the research themes and met the inclusion criteria while maintaining high methodological standards. These articles formed the basis for the systematic analysis, ensuring a focused and comprehensive exploration of the topic.

This search was informed by foundational research, such as Bassi and Dias (2019) on the adoption of circular economy practices in SMEs and Moktadir et al. (2020) on barriers to supply chain sustainability. Additionally, citation tracking was employed to ensure that important studies cited in key articles were also included. Journals such as Resources, Conservation and Recycling and Entrepreneurship and Sustainability Issues were heavily referenced due to their focus on sustainability and economic resilience.

Studies published between 2018 and 2024 were included to reflect recent discussions on the circular economy and its role in enhancing resilience to energy disruptions, as seen in Feyzioglu et al. (2024) and Levický et al. (2022). Papers that specifically addressed the intersection of the circular economy and energy resilience were prioritized, such as those focusing on resource management, energy efficiency, and renewable energy adoption (Bassi and Dias 2019; Feyzioglu et al., 2024). Studies focused solely on technical aspects of energy production or those unrelated to sustainability and resilience were excluded to maintain the focus on the socio-economic and environmental dimensions of the circular economy.

Our research was started by addressing scientific sources by classifying most recent studies according to the micro, mezzo or macro level of analysis. Such classification was employed to identify the research gap, the indicators used in studies by scholars, and the most often used methods.

The extracted data were analyzed using thematic synthesis to identify commonalities and key themes across the selected literature. Many studies emphasize how CE practices, such as recycling and resource recovery, reduce dependency on finite energy resources. This was particularly evident in Bassi and Dias (2019), which found that SMEs adopting circular economy principles experienced greater resilience during energy disruptions by reducing material and energy waste.

Several studies highlight how circular economy systems promote the diversification of energy sources, particularly through renewable energy integration and local energy generation. Feyzioglu et al. (2024) showed how circular economy models, such as waste-to-energy systems, contribute to energy resilience in the Mediterranean region by reducing reliance on external energy supplies.

Circular economy practices that involve closed-loop supply chains were found to enhance resilience by shortening supply chains and reducing the vulnerability to global energy price fluctuations. Moktadir et al. (2020) discussed how circular supply chains not only minimize energy consumption but also buffer against external energy shocks by promoting local production and recycling.

Studies such as Chehabeddine et al. (2022) and Levický et al. (2022) emphasize the role of policy frameworks in supporting circular economy initiatives that enhance energy security. These studies argue that government policies promoting circular energy systems—such as subsidies for renewable energy and recycling infrastructure—are critical for building societal resilience to energy shocks.

The adoption of innovative technologies within circular economy frameworks was frequently highlighted as a way to increase resilience to energy shocks. Ramadan et al. (2023) and Feyzioglu et al. (2024) both demonstrated how innovations like smart grids, energy storage, and waste-to-energy conversion allow regions to maintain energy stability even during periods of disruption.

This study is limited by its focus on English-language publications and its exclusion of purely technical papers on energy production, which may offer valuable insights into the circular economy's potential for resilience. Additionally, the circular economy is a rapidly evolving field, and ongoing developments, particularly in policy and technology, may not yet be fully represented in the available literature.

The aim of the paper is to suggest a methodological framework for the complex transition toward a more circular economy. Our approach involves first identifying the priority areas of current research and grouping them into thematic categories. Through these groupings, we aim to pinpoint gaps in knowledge and suggest a roadmap for further study.

Thus, our methodology builds on the foundational theories of economic development. Following the Kuznets curve, as economies develop, energy consumption and greenhouse gas emissions initially rise. Over time, as policies and technologies evolve, energy demand stabilizes and emissions decline. This established relationship raises questions about how circular economy strategies are linked to Gross Domestic Product (GDP) in academic literature.

Considering that new technologies are essential for a CE, we explore technology transfer mechanisms, such as research and development (R&D) and foreign direct investment (FDI), which foster knowledge and technological spillovers.

The transition toward a CE can occur at various levels, with macro-level indicators offering a broad perspective on national or regional economies. We then examine the mezzo level (industries) and the micro level (firms, communities, and societies). Initially, we review a wide range of CE issues, before narrowing the scope to focus on energy, a critical resource for essential functions like food production, water supply, and waste processing.

We hypothesize that without structured mechanisms for transitioning to a CE, coupled with the potential impact of military conflicts, vulnerable societies, nations, and industries may face significant challenges in resilience and viability. This hypothesis can be explored and potentially validated through this literature review.

SLRs have certain limitations, which were carefully addressed in this study to ensure the methodology remained robust and comprehensive. One challenge is the potential for selection bias, as the inclusion and exclusion criteria may inadvertently omit relevant studies. This limitation was mitigated by using multiple databases, including Scopus, Web of Science, and Google Scholar, along with comprehensive search terms such as "circular economy", "energy resilience", and "sustainability." Citation tracking was also employed to capture influential studies that might not have been retrieved during the initial search.

SLRs are also inherently dependent on the existing body of literature, which may not fully reflect emerging areas or newly developing concepts. To address this, the study included recent publications from 2018 to 2024, ensuring the findings reflected the latest advancements in CE and energy resilience. However, by focusing on peer-reviewed publications, the review excluded grey literature, such as policy reports and white papers, which might offer valuable insights. While this study prioritized academic rigor, it acknowledged this limitation and suggested that future research incorporate grey literature for a more holistic perspective.

Another limitation is that SLRs may lack contextual insights, particularly in interdisciplinary fields like the CE. To overcome this, the analysis adopted a multilevel approach, examining implications at the macro, mezzo, and micro levels. This allowed the study to identify broader patterns while recognizing the importance of context-specific factors.

By addressing these limitations through careful methodological design, the study ensures that the SLR provides a rigorous and comprehensive synthesis of CE practices and their role in enhancing energy resilience.

3. Trends and thematic landscape in circular economy research

Using the Web of Science platform, we retrieved 33,611 documents related to the CE. **Figure 2** illustrates the year-by-year trend in publications on the topic of the CE. Starting from 2015, the popularity of this topic surged, as indicated by the rapid growth in the number of publications. The bar chart reveals that the most significant increase in publications occurred between 2015 and 2023, with the publication count peaking in 2023. This pattern shows exponential growth in interest and research output, with the number of documents almost doubling yearly until around 2020. However, starting from 2021, the growth rate began to slow down, although the chart demonstrates that the topic continues to attract considerable attention from researchers.

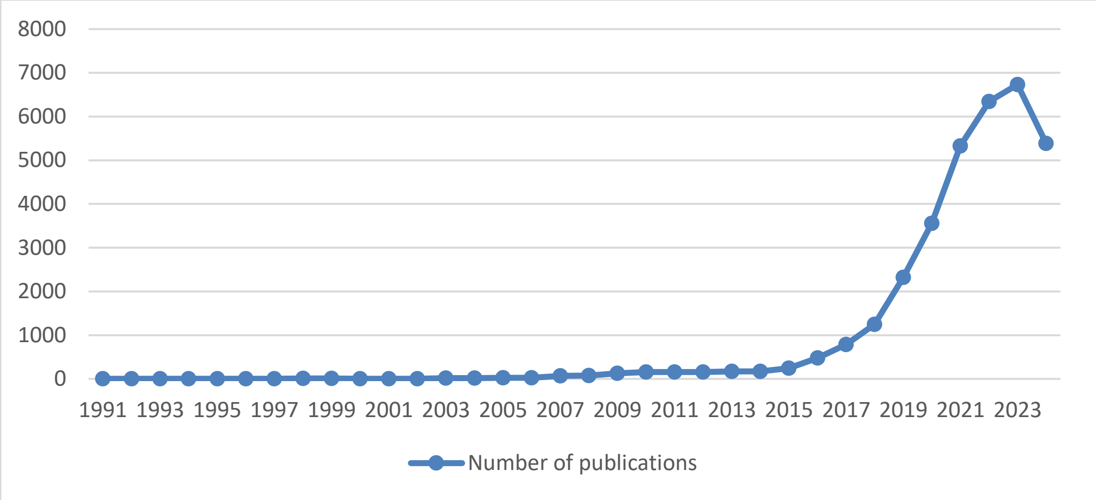

Figure 2. Publication trends on circular economy in web of science (1991–2024).

Figure 2 provides a visual confirmation of how the CE has evolved into a prominent research area in recent years. While the growth rate has decelerated, the volume of publications remains high, suggesting that interest in the CE is sustained at significant levels even in 2024.

To further analyze research trends, we conducted a co-occurrence keyword analysis on 740 highly cited papers published between 2014 and 2024. A minimum threshold of five keyword occurrences was set, yielding 315 prominent keywords from a total of 4433. Keywords such as "circular economy" (410 occurrences, total link strength 2777), "sustainability" (165 occurrences, total link strength 1214), and "waste" (55 occurrences, total link strength 375) emerged as central terms, signifying their strong influence in the dataset. The total link strength represents the degree of co-occurrence between keywords, suggesting how frequently terms are used together in the literature. For instance, "circular economy" not only appeared frequently but also had strong connections with other key terms like "waste management" (40 occurrences, total link strength 316) and "recycling" (35 occurrences, total link strength 211), reflecting the interconnectedness of sustainability topics.

This co-occurrence analysis reveals that keywords with higher occurrences and link strengths are often associated with prominent themes like sustainability, circular economy, waste management, and technological innovation, which are critical in the current discourse. Such relationships between keywords help identify clusters of related topics and suggest key areas of focus within the research landscape.

Figure 3 illustrates the keyword clusters, which reveal various interconnected themes in CE research. The central yellow cluster focuses on "circular economy", with strong connections to "waste" and "recycling." The red cluster emphasizes business models and digital transformation, particularly how Industry 4.0 technologies like big data and IoT support CE practices. Other clusters focus on material recovery (green), the bioeconomy (blue), and regional and policy influences (purple), showing the wide-ranging and interdisciplinary nature of this research field.

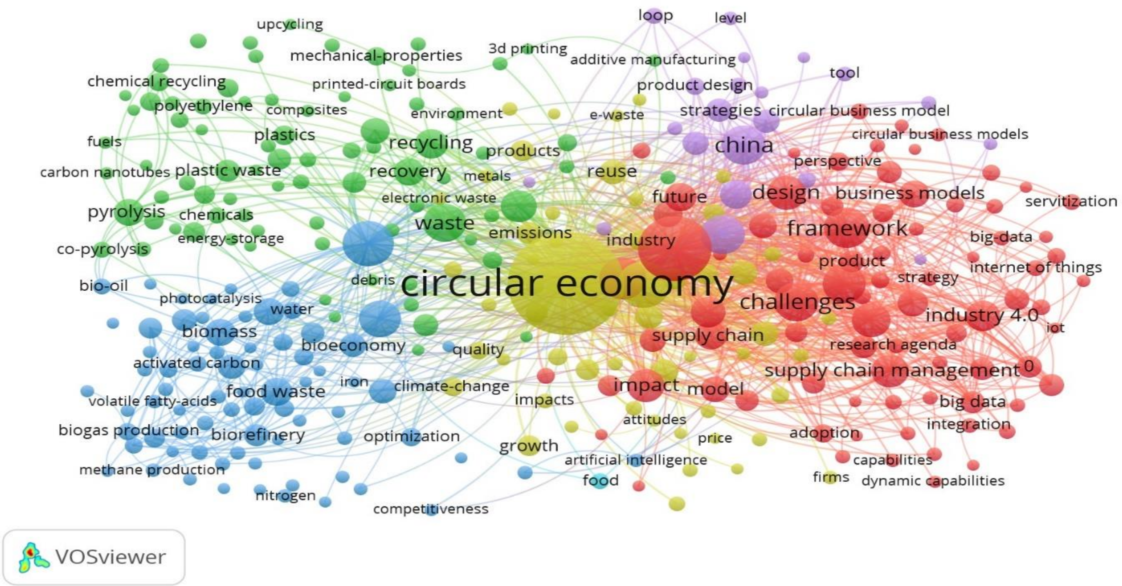

Figure 3. The Interconnected landscape of circular economy research.

The keyword map shows various interconnected research themes related to the CE, each represented by distinct clusters of keywords. These clusters are color-coded and highlight different areas of focus within CE research.

At the heart of the map is the yellow cluster, which revolves around the central concept of "circular economy". Keywords like "waste", "recycling", "reuse", and "recovery" are strongly connected to this theme. This suggests that much of the research in this area is focused on sustainable waste management and how resources can be reused and recovered rather than discarded. The prominence of this cluster reflects the widespread attention that the CE has received in academic literature, as well as its vital role in reducing waste and promoting sustainable resource use.

On the other hand, the red cluster centers around themes like "business models", "framework", and "industry 4.0". These keywords indicate a focus on how new business models, particularly those incorporating digital innovations like big data and IoT (Internet of Things), are being used to support the transition to a CE. This cluster shows that research is heavily exploring how digital technologies can improve supply chain management and support sustainable business practices. The connections between "framework", "supply chain management", and "circular business models" suggest that companies are looking for structured approaches to integrate circular principles into their operations.

In the green cluster, the focus shifts to more technical aspects of the CE, particularly around "recycling", "plastic waste", and processes like "pyrolysis" and "bio-oil" production. These keywords suggest that this cluster deals with research on material recovery technologies, especially for plastics and other challenging waste materials. There is a strong emphasis on finding innovative recycling techniques and waste-to-energy solutions. This cluster reflects the scientific and technological efforts to minimize environmental harm through effective waste recycling and resource recovery processes.

The blue cluster focuses on the bioeconomy and the use of biomass as a renewable resource. Keywords like "food waste", "biorefinery", and "biogas production" suggest that this cluster explores how organic materials can be reused in energy and material production. Research in this area is particularly concerned with transforming biological waste into useful products, contributing to the idea of a bio-based CE. This cluster highlights the growing importance of biomass in sustainable production and energy generation.

In the purple cluster, the map shows a regional and policy focus, with keywords like "China", "circular business model", and "policy." This indicates that some research is looking at how CE principles are being implemented on a national or regional scale, with China emerging as a key player. The presence of policy-related keywords suggests that successful implementation of CE practices often relies on strong policy frameworks and strategic direction from governments. This cluster underscores the importance of policy and regional factors in shaping the development of CE initiatives.

Finally, there are several smaller clusters, such as those focusing on "digital transformation", "artificial intelligence", and "machine learning." These indicate that cutting-edge technologies are increasingly being explored as tools to enhance the efficiency of CE practices, whether through predictive analytics, automation, or optimization of processes.

Overall, the keyword map illustrates that the CE is a central, interdisciplinary research area that connects various fields such as waste management, digital transformation, policy, and bioeconomy. The strong links between these clusters highlight the multifaceted nature of CE research, with technological innovation, sustainability practices, and policy frameworks all playing crucial roles in its advancement.

4. Multilevel perspectives on circular economy: Impacts on economic growth, energy consumption, and sustainable practices

The CE offers a comprehensive framework for balancing economic growth with environmental sustainability, spanning interventions at macro, mezzo, and micro levels. Across these levels, studies examine how CE practices influence economic growth, energy consumption, and greenhouse gas (GHG) emissions, providing insights into the transformative potential of sustainable practices. At the macro level, CE initiatives shape national and regional policies aimed at decoupling economic growth from environmental degradation, often framed within the Environmental Kuznets Curve (EKC) hypothesis. Mezzo-level studies explore how communities and sectors adopt circular principles to reduce resource dependency and emissions, often supported by regional infrastructures like recycling facilities and shared mobility systems. Meanwhile, at the micro level, individual firms implement circular strategies to optimize resource use, reduce waste, and lower their carbon footprint. This section synthesizes studies across these three levels, highlighting how CE practices can drive sustainable economic development by reducing energy demand and mitigating environmental impacts.

4.1. Circular economy practices on macro level

The relationship between economic growth, energy consumption, and greenhouse gas (GHG) emissions is a central theme in environmental economics. This dynamic is often understood through the Environmental Kuznets Curve (EKC) framework, which suggests that environmental degradation rises with economic growth in its early stages but eventually declines as nations adopt cleaner technologies and policies. At a certain stage of development, growth becomes less reliant on energy-intensive processes, and emissions start to decrease. In this context, the CE, which promotes the efficient use of resources through recycling, reusing, and reducing waste, plays a pivotal role in decoupling economic growth from environmental impact.

The CE presents a transformative model for national economies, emphasizing the importance of regenerating resources, minimizing waste, and reducing dependency on finite inputs. At the macro level, CE practices are instrumental in fostering sustainable growth, enhancing economic resilience, and supporting environmental goals. This section delves into CE practices through the lens of various studies, highlighting examples, analyzing complementarities, and discussing areas of divergence.

Table 1 includes a list of studies and their primary indicators, research focus, and analytical methods. It details research examining economic, environmental, and productivity indicators across various contexts, including GDP, foreign direct investment (FDI), CO_2 emissions, CE metrics, and innovation indices. The studies span diverse geographical focuses, including China, Europe, and Egypt, assessing issues like sustainability, competitiveness, and economic impact within circular and green economy frameworks.

Table 1. Key macro studies on circular economy: main indicators and methods.

Reference	Main Indicators	Methods
Barkóciová et al. (2023)	ICT service availability, cybersecurity measures, national competitiveness	Regression analysis of hybrid threats' impact on business competitiveness in the EU
Burinskas et al. (2021)	GDP, FDI, R&D, labor productivity, PPP, unit labor costs, value-added in manufacturing and ICT	Empirical analysis of FDI flows and productivity indicators to assess impact on technology transfer and competitiveness across Baltic states
Chehabeddine et al. (2022)	Water usage, renewable energy consumption, CO_2 emissions, threatened species	Data analysis using World Bank indicators, qualitative classification into ecological security model
D'Adamo et al. (2020)	GDP, population, generated and recycled ELV flows, Average Annual Growth Rate of ELV flows, percentage recycled	Linear regression model analyzing ELV flows in correlation with GDP and population; survey of managers' perspectives on CE practices
Fleacă et al. (2023)	Global Innovation Index, European Innovation Scoreboard, R&D investment	Literature review and secondary data analysis of global innovation indicators
Li et al. (2020)	Energy intensity, CO_2 emissions, GDP, trade, clean energy substitution	Fisher Ideal Index, ARDL and VAR models to evaluate impact on CO_2 emissions in China and Nigeria
Ling et al. (2020)	FDI, GDP, market openness, labor costs, rule of law, environmental and social indicators	Fuzzy Delphi Method (FDM) and Fuzzy Importance and Performance Analysis (FIPA) to assess Sustainable Foreign Direct Investment (SFDI)
Lu et al. (2020)	Energy consumption, recycling outputs, economic outputs, undesirable outputs (e.g., emissions)	DEA model, spatial autocorrelation, Tobit regression to evaluate industrial CE efficiency across China

Table 1. (*Continued*).

Reference	Main Indicators	Methods
Ntshangase et al. (2023)	Political interference, financial management, corporate governance frameworks	Thematic analysis of governance documents comparing public sector performance in South Africa
Pceļina et al. (2023)	Green Economy Index, resource efficiency, energy productivity	Statistical convergence analysis of green economy indicators across EU countries
Pham et al. (2020)	CO_2 emissions, FDI, energy intensity, renewable energy, trade openness, GDP per capita	STIRPAT model with PVAR for short-term analysis and FMOLS for long-term analysis across 28 European countries
Ramadan et al. (2023)	Green hydrogen market growth, export capacity, job creation potential	PEST analysis and scenario writing to explore green hydrogen development scenarios in Egypt
Ren et al. (2021)	CO_2 emissions, GDP per capita, FDI, energy intensity, urbanization rate	STIRPAT model and 3SLS regression to analyze interactions in the steel industry across different regions in China
Rezk et al. (2023)	Job creation, economic impact of waste reduction, government regulations	Mixed-methods with SWOT analysis on CE adoption in Egypt
Rokicki et al. (2021)	Bioenergy consumption, agricultural production, renewable energy share, Gini coefficient	Descriptive statistics, Gini concentration, correlation tests to analyze bioenergy consumption across 22 EU countries
Samašonok and Išoraitė (2023)	Material consumption, waste management policies, recycling practices	Descriptive and regression analysis of CE transition data from European datasets
Tantau et al. (2018)	Recycling rate, circular material use rate, R&D expenditure, environmental taxes	Panel regression model analyzing recycling rates and CE indicators in EU countries
Vītola (2023)	GDP, HDI, Green GDP, SDG Index, Green Economy Index	Comparative analysis of traditional and new sustainability indices across EU countries
Wang et al. (2020)	CO_2 emissions, GDP per capita, FDI, exports, imports	VAR model analyzing GDP, FDI, CO_2 emissions across Chinese provinces
Zecca et al. (2023)	Domestic Material Consumption, resource productivity, circular material use rate	Descriptive analysis of Eurostat datasets on material consumption, circular material use rates across EU

Many studies emphasize the role of FDI in promoting the CE through technology transfer. Burinskas et al. (2021) highlight how FDI from Nordic countries has been instrumental in transferring technology and knowledge to the Baltic states, with Estonia benefiting the most. The study demonstrates that FDI inflows into the high-tech and ICT sectors have enhanced productivity and supported the post-crisis recovery, promoting more sustainable practices. Likewise, Ren et al. (2021) examine FDI's impact on China's steel industry, noting that its influence on carbon emissions varies across regions. In some areas, FDI helps reduce emissions by introducing cleaner technologies, while in others, it exacerbates pollution by fueling high-emission industries. These studies underscore the potential of FDI to facilitate a CE, especially when directed toward energy-efficient technologies.

R&D is consistently highlighted as a catalyst for innovation and a core component of the CE. D'Adamo et al. (2020) emphasize the role of R&D in managing End-of-Life Vehicles (ELVs), showing that investments in recycling technologies enable sustainable waste management. Similarly, Tantau et al. (2018) find that higher R&D spending correlates with increased recycling rates and greater circular material use in the EU, underscoring the importance of sustained innovation for advancing CE. Fleacă et al. (2023) further elaborate on this point by discussing how R&D in digitalization and public-private collaborations strengthens innovation within the CE. According to their study, these innovation categories are critical for transitioning to sustainable practices, with digital solutions enhancing efficiency in resource use and reducing waste. Lu et al. (2020) also support this view, noting that better integration of existing innovations in industrial processes could improve CE outcomes, particularly in recycling and manufacturing.

Several studies link the CE to improved resource productivity. Zecca et al. (2023) and Samašonok and Išoraitė (2023) focus on how increasing domestic material consumption and resource productivity drives the CE. They argue that reducing dependency on imported materials and increasing the use of recycled materials are essential strategies for building a more sustainable and self-sufficient economy. Vītola (2023) expands on this by connecting CE principles with broader economic indicators like GDP and sustainability indices (e.g., HDI, Green GDP), offering a comprehensive view of how CE practices can promote sustainable economic growth.

Other authors highlight sector-specific applications of CE. Rokicki et al. (2021) explore bioenergy consumption in agriculture, emphasizing how CE practices can increase energy efficiency and sustainability in the agricultural sector. They point out that using agricultural residues for bioenergy can enhance resource efficiency and reduce environmental impacts. Similarly, Rezk et al. (2023) examine the potential for implementing CE principles in Egypt's agricultural sector, noting that CE strategies can drive job creation, reduce waste, and improve overall sustainability.

While most of the studies focus on resource management, many authors suggest that CE practices can indirectly enhance resilience to energy shocks. For example, Lu et al. (2020) highlight how energy-efficient production systems and recycling processes in China's industrial sectors can reduce dependence on external energy sources, making industries more resilient to disruptions. By focusing on energy intensity reduction and optimizing resource use, CE practices can help mitigate the risks associated with energy shortages.

Several studies discuss the role of clean energy in the CE and its connection to energy resilience. Li et al. (2020) investigate the link between energy intensity, trade openness, and clean energy substitution in China and Nigeria. Their findings suggest that adopting clean energy technologies is critical for reducing CO_2 emissions and enhancing resilience to energy shocks. However, they note that despite efforts to transition to renewable energy, fossil fuel dependency remains high, limiting the countries' overall resilience. Similarly, Pham et al. (2020) argue that renewable energy adoption has the potential to reduce emissions and improve energy resilience, but challenges related to energy-intensive industries continue to hinder progress.

Technological innovation plays a vital role in fostering energy resilience within the CE. Ling et al. (2020) emphasize how Sustainable FDI (SFDI) in Malaysia can help address environmental and energy challenges. Investments in clean technologies and energy innovations are viewed as essential for reducing dependence on fossil fuels and enhancing resilience. Ramadan et al. (2023) take this further by exploring the potential of green hydrogen in Egypt, arguing that hydrogen technologies could decarbonize industries, reduce fossil fuel reliance, and strengthen resilience to energy shocks.

Barkóciová et al. (2023) add an interesting dimension by examining cybersecurity's role in enabling CE practices. They argue that resilient digital infrastructure is crucial for managing CE-related data, especially in sectors reliant on resource sharing and efficient waste management. By highlighting how data security supports CE practices, Barkóciová et al. (2023) expand the conversation to include digital resilience, which is vital for securely implementing and scaling CE innovations.

Across the studies, FDI and R&D emerge as central drivers of the CE transition. FDI facilitates the transfer of clean and energy-efficient technologies, particularly in sectors like manufacturing and ICT, while R&D supports ongoing innovation to improve resource efficiency and waste reduction. The studies by Burinskas et al. (2021) and Ren et al. (2021) highlight the complementary role of FDI and local R&D investments in driving CE practices that foster sustainable growth.

Although energy resilience is not always the primary focus, many authors imply that CE practices can improve resilience to energy shocks by reducing reliance on external energy sources and fossil fuels. Lu et al. (2020) and Li et al. (2020) suggest that adopting energy-efficient technologies and transitioning to renewable energy can help industries mitigate the impact of energy disruptions, thereby enhancing overall energy resilience.

Despite the promise of the CE, several studies point to significant challenges in its implementation, particularly in reducing fossil fuel dependency in energy-intensive industries. Li et al. (2020) and Pham et al. (2020) highlight the difficulty of achieving a full transition to clean energy, as many industries continue to rely on fossil fuels. These challenges underscore the need for stronger policy frameworks and increased investments in clean energy technologies.

FDI and R&D play critical roles in supporting the transition to a CE by facilitating technology transfer and innovation. These mechanisms help improve resource efficiency, promote waste reduction, and support cleaner energy use. While the studies reviewed suggest that CE practices can enhance resilience to energy shocks, challenges remain, particularly in transitioning away from fossil fuels. Further investment in clean technologies and policy support is needed to fully realize the potential of the CE to support energy resilience and long-term sustainability.

CE practices at the macro level contribute to sustainable economic growth, environmental protection, and alignment with global sustainability goals. The reviewed studies illustrate complementary approaches to implementing CE, from FDI-driven innovation and resource efficiency to policy alignment and infrastructure development. Samašonok and Išoraitė (2023b) and Ntshangase et al. (2023) agree on the role of governance and policy, while Tantau et al. (2018) and Chehabeddine et al. (2022) underscore the contribution of recycling and waste management to regional sustainability objectives.

4.2. Circular economy practices on micro and mezzo levels

The CE offers a transformative approach to production and consumption that prioritizes resource efficiency, waste reduction, and the creation of closed-loop systems. Unlike the traditional linear economy, which relies on a take-make-dispose model, CE emphasizes sustainability by maintaining the value of products, materials, and resources for as long as possible. On both micro and mezzo levels, CE practices address the specific needs of businesses, communities, and regions, creating tailored strategies that drive sustainability, economic resilience, and environmental protection. This section explores these practices across key sectors, examining how micro-level initiatives within individual firms and mezzo-level strategies within communities work in tandem to foster a more sustainable future.

Table 2 summarizes research studies, listing key indicators, analytical methods, and research focuses. Each entry highlights specific themes in micro and mezzo level analyses such as CE practices, energy efficiency, environmental impacts, corporate governance, technological innovation, and sustainable supply chains. The studies employ diverse methods, including surveys, econometric models, regression analysis, and qualitative interviews. Geographically, the research spans multiple countries and sectors, providing insights into challenges and advancements in areas like renewable energy, waste management, and socio-economic resilience.

Table 2. Key micro and mezzo studies on circular economy: Main indicators and methods.

Reference	Main Indicators	Methods
Antonioli et al. (2022)	Company size, technological intensity, geographic location, circular innovation adoption (e.g., material reduction, energy use)	National and regional surveys, stratified sampling, CAWI method
Bassi and Dias (2019)	Firm size, R&D investment, CE activities (water use, renewable energy, waste reduction)	Flash Eurobarometer survey, multilevel ordinal probit models
Bazienė and Gargasas (2023)	Renewable technology efficiency, CO_2 emissions reduction	System dynamics modeling, energy case studies
Bezama et al. (2019)	Biomass resources, technology integration, social acceptance, sustainability assessment	Interviews, literature review, expert workshops
Fakunle and Ajani (2021)	Public perception of waste management, waste disposal methods, community infrastructure	Cross-sectional design, purposive sampling, structured and unstructured questionnaires
Feyzioglu et al. (2024)	Chemical Oxygen Demand (COD), suspended solids, oil and grease, phenol levels	Acid cracking, chemical treatment, filtration process for wastewater treatment
Fonseca et al. (2018)	Strategic CE alignment, EMS certification, CE intensity	Online survey with Likert scale, Portuguese companies
Gargasas et al. (2023)	Solar technology for energy efficiency in buildings	Laboratory experiments, solar simulation models
Gerasimova et al. (2023)	Blockchain, NFTs, smart contracts in circular supply chains	Mixed-method approach, interviews, surveys, case studies
Gonzales (2023)	Business and environmental sustainability, compliance with environmental laws	Descriptive research, Input-Process-Output (IPO) model, Likert scale survey
Gqalindaba et al. (2024)	Flood impacts, community preparedness, municipal response, infrastructure, property loss	Semi-structured interviews, purposive sampling, thematic analysis
Gupta et al. (2020)	Barriers to sustainable supply chain (technology, economic, regulatory, social)	Two-phase multi-case study, modified Delphi, Best-Worst Method
Levický et al. (2022)	CE financing willingness, SME engagement in CE	Questionnaire survey, chi-square test analysis
Moktadir et al. (2020)	Leadership, reverse logistics, ecological scarcity, competitor pressure	Best–Worst Method, DEMATEL, expert interviews
Naimoğlu and Kavaz (2023)	Energy efficiency, rebound effect in energy consumption	Econometric analysis, Fourier Engle-Granger Cointegration, FMOLS, CCR, DOLS methods
Pariso et al. (2023)	CE practices for rare materials, material recovery, remanufacturing	Min-max normalization, matrix analysis, statistical modeling on European country data
Radavičius et al. (2021)	Renewable energy integration, energy grid resilience, environmental impact	Case studies, literature review

Table 2. (*Continued*).

Reference	Main Indicators	Methods
Ramadan et al. (2024)	Waste management, economic diversification, job creation in CE	Mixed-methods, SWOT analysis, case studies, literature review
Ruschak et al. (2023)	CSR in marketing, customer perceived value (CPV)	Online survey, regression analysis, structural equation modeling
Sabauri and Kvatashidze (2023)	ESG investment indicators, sustainability reporting standards	ISSB draft standard analysis, literature review
Siedschlag and Yan (2021)	Green investments, regulatory pressures, firm characteristics	IV-probit model, sample selection, peer group analysis
Somogyi and Nagy (2022)	Climate impacts on infrastructure, energy demand, ECB climate strategies	Case study, ECB supervisory data analysis
Stavropoulos et al. (2020)	Urban circular policies, FDI, job creation	Quantitative analysis, mixed logit model
Šimelytė and Tvaronavičienė (2022)	Knowledge transfer, absorptive capacity, social innovation	Bibliometric analysis, VOSviewer software, literature review
Vochozka et al. (2023)	Household income, inflation effects, economic resilience	Statistical techniques, content analysis, econometric models
Yalçınkaya et al. (2024)	Regulatory compliance, technology integration, transparency in DSR programs	SWARA and TOPSIS methods
Zemlickienė et al. (2024)	Renewable energy, transmission capacity, domestic and international energy demand	Statistical analysis, expert consultations

Micro-level CE practices involve actions by individual businesses, organizations, and consumers to optimize resource use, reduce waste, and extend product lifecycles. These practices vary across industries but share common goals, emphasizing closed-loop systems and sustainable value retention.

Manufacturing is a resource-intensive sector where CE practices like modular design, recycling, and closed-loop systems offer substantial benefits. Gerasimova et al. (2023) examine the adoption of CE principles in high-tech manufacturing, where product modularity enables firms to manage end-of-life products effectively through repair, refurbishment, and recycling. This approach aligns with Wang et al. (2020) and Ruschak et al. (2023), who highlight modular design as a cost-effective strategy that enhances product value and meets consumer demand for sustainable options.

However, Pariso et al. (2023) note that smaller firms often lack the resources to implement modular design due to financial and technical limitations. This observation parallels Fakunle and Ajani (2021) and Šimelytė and Tvaronavičienė (2022), who underscore the importance of technology transfer and financial incentives to support SMEs in adopting CE practices. Together, these studies highlight the dual impact of modular design in manufacturing, benefiting both large and small firms when supported by targeted policy interventions and technology-sharing mechanisms.

In agriculture, CE practices center on waste reduction, regenerative methods, and resource efficiency. Ramadan et al. (2024) discuss circular approaches to agricultural waste management, such as composting, biogas production, and upcycling byproducts, which enhance soil quality and reduce reliance on synthetic fertilizers. These practices align with findings from Bezama et al. (2019) and Sabauri and Kvatashidze (2023), who highlight that waste-to-resource strategies contribute to both cost savings and environmental benefits.

Radavičius et al. (2021) extend this perspective by emphasizing the role of cooperative models in agriculture, where farmers pool resources to implement collective waste management and resource recovery systems. This collaborative approach contrasts with the individual-focused models discussed by Gqalindaba et al. (2024), who emphasize indigenous practices in agriculture. Together, these studies suggest that CE in agriculture can take various forms, from individual to cooperative models, each offering unique advantages depending on the regional context and available resources.

The textile and fashion industry has increasingly adopted CE practices such as product reuse, resale, and rental, driven by consumer demand for sustainability. Gerasimova et al. (2023) discuss the growing trend of circular fashion models that extend product life, reduce waste, and appeal to eco-conscious consumers. Their research aligns with Gonzales (2023) and Yalçınkaya et al. (2024), who also emphasize that consumers are more likely to support brands that offer sustainable options.

However, Pariso et al. (2023) warn of challenges in logistics and consumer participation in circular fashion models, particularly for small brands lacking efficient systems for managing rentals and returns. This view resonates with Vochozka et al. (2023) who also argue that operational efficiency is critical to the success of CE practices in fashion. Together, these studies illustrate the complexity of circular fashion, where both consumer engagement and logistical support are vital to the effective implementation of CE practices.

At the mezzo level, CE practices involve community and regional initiatives, often led by local governments, regional organizations, or industry associations. These initiatives create infrastructure and foster collaborations that enable widespread adoption of CE practices across various sectors, addressing both economic and environmental objectives.

Construction generates a substantial amount of waste, and CE practices at the mezzo level, such as material exchanges and recycling facilities, help mitigate this waste. Radavičius et al. (2021) discuss regional recycling hubs where construction materials like concrete, metal, and wood are reclaimed and repurposed for new projects. These hubs reduce the environmental impact of construction and create local employment opportunities in recycling and material processing, a point also noted by Bazienė and Gargasas (2023).

Somogyi and Nagy (2022) emphasize the resilience benefits of using recycled materials in construction, arguing that circular materials, such as sustainable timber and recycled concrete, enhance buildings’ resistance to extreme weather events. Their view aligns with Ruschak et al. (2023), who discuss the environmental and economic advantages of incorporating recycled materials in construction. These studies highlight the multifaceted value of CE in construction, showing how regional recycling initiatives can address environmental, social, and economic goals.

Effective waste management and recycling infrastructure are critical at the mezzo level, providing the foundation for CE practices. Gerasimova et al. (2023) discuss the role of regional partnerships in managing electronic waste (e-waste), emphasizing that joint efforts between municipalities and private recycling firms improve e-waste collection, sorting, and recycling rates. This finding is supported by

Gupta et al. (2020) and Wang et al. (2020), who both emphasize centralized recycling facilities as essential to community-wide resource recovery.

Ramadan et al. (2024) extend this perspective by focusing on public education, noting that awareness campaigns are crucial for promoting recycling participation among residents. Similarly, Samašonok and Išoraitė (2023) argue that community engagement is essential for waste sorting and recycling success. Together, these studies suggest that successful waste management at the mezzo level requires both physical infrastructure and active public engagement, illustrating the need for an integrated approach to CE within communities.

The transportation sector benefits from CE practices at the mezzo level through shared mobility systems and closed-loop supply chains. Zemlickienė et al. (2024) discuss city-led car-sharing and bike-sharing programs that reduce vehicle ownership and emissions, enhancing urban sustainability. Their findings align with those of Siedschlag and Yan (2021), who also highlight the environmental benefits of shared mobility in reducing urban congestion and pollution.

Vochozka et al. (2023) and Yalçınkaya et al. (2024) caution that these programs require well-designed infrastructure, such as dedicated lanes and easy access points, to ensure high adoption rates. This perspective is supported by Naimoğlu and Kavaz (2023), who emphasize closed-loop recycling systems for electric vehicle (EV) batteries as critical to the CE in transportation. Together, these studies show that CE in transportation requires infrastructure for shared services, resource recovery systems, and logistical efficiency, underscoring the complex, interconnected nature of circularity in this sector.

The success of CE practices often hinges on the synergy between micro- and mezzo-level initiatives. For example, manufacturers implementing modular design and recycling benefit from regional recycling facilities, which reduce logistical costs and ease material sourcing. Stavropoulos et al. (2020) and Gonzales (2023) emphasize that regional policies and incentives can lower operational barriers for firms, enhancing CE adoption.

Ramadan et al. (2024) further advocate for public-private partnerships, highlighting that collaboration between businesses, governments, and community organizations fosters a more cohesive CE ecosystem. Radavičius et al. (2021) also support this collaborative model, noting that cooperative efforts in agriculture and construction maximize resource recovery and create shared value for communities. Together, these studies underscore the importance of coordinated micro- and mezzo-level actions, demonstrating how aligned efforts can create resilient circular ecosystems that benefit both individual firms and regions.

CE practices at both micro and mezzo levels are instrumental in advancing sustainability across sectors. At the micro level, individual businesses adopt CE practices tailored to their sector, from modular design in manufacturing to waste reduction in agriculture and circular models in fashion. At the mezzo level, communities provide necessary infrastructure, policy support, and public engagement to enable CE adoption on a broader scale. Studies from Gerasimova et al. (2023); Pariso et al. (2023); Radavičius et al. (2021); Ramadan et al. (2024) and others reveal the importance of multi-level coordination, public-private partnerships, and community engagement to foster a resilient circular ecosystem. Together, these levels create a sustainable foundation for long-term economic growth, environmental stewardship, and social well-being, positioning the CE as a transformative framework for future prosperity.

5. The role of circular practices in energy resilience and preparation for energy shocks

As global economies increasingly face energy volatility due to geopolitical tensions, natural disasters, and resource depletion, the role of circular practices in energy resilience and preparation for energy shocks has become a central focus. CE practices offer a pathway to improve energy security, reduce dependency on non-renewable resources, and buffer economies against energy supply disruptions.

Energy systems worldwide are increasingly vulnerable to disruptions caused by resource scarcity, geopolitical tensions, and the transition to low-carbon energy sources. In this context, the CE has emerged as a transformative model for addressing energy shocks by promoting resource efficiency, waste minimization, and innovative energy recovery solutions. By integrating circular principles into energy systems and related sectors, CE not only enhances resilience but also fosters sustainability and economic benefits. Recent studies and real-world applications underscore the potential of CE to mitigate the impacts of energy shocks through diverse strategies.

One notable approach involves integrating renewable energy systems with circular practices to optimize resource utilization and energy efficiency. For instance, Kiviranta, Thomasson, Hirvonen and Tähtinen (2020) explored how surplus wind energy in the Åland Islands could be used for CE processes, such as material recycling and reuse, rather than being exported or wasted. Their findings demonstrated that integrating CE with renewable energy systems enhances the economic viability of renewable investments while addressing energy variability. This highlights the potential of CE to complement renewable energy technologies and create more robust energy systems.

In the construction sector, CE principles have been applied to reduce energy demand and mitigate disruptions caused by energy-intensive material production. Eberhardt et al. (2019) examined a Danish office building designed for disassembly, where the reuse of its concrete structure significantly lowered embodied CO_2 emissions and energy consumption. This case study illustrates how CE can address energy challenges in the built environment by promoting sustainable material use and minimizing waste.

Similarly, hybrid renewable energy systems designed within a CE framework can mitigate energy shocks by maximizing resource efficiency. Bist et al. (2020) investigated a geothermal-solar hybrid energy project in India, which utilized circular practices to enhance energy production while reducing waste. This approach demonstrates how combining multiple renewable energy sources within a CE context can overcome the intermittency of individual systems and provide more reliable energy solutions.

In agriculture, CE practices such as bioenergy production from waste have shown significant promise in diversifying energy sources and reducing dependence on traditional energy systems. Barros et al. (2020) mapped global research on bioenergy and highlighted its potential to transform agricultural waste into biogas, reducing greenhouse gas emissions while providing a sustainable energy source. This circular approach not only addresses energy shocks but also supports sustainable agricultural practices and environmental conservation.

Industrial sectors have also embraced CE strategies to recover energy from waste. Mastos et al. (2021) presented a waste-to-energy case study that leveraged Industry 4.0 technologies to enhance supply chain sustainability and energy recovery. By integrating digital solutions with CE principles, the study showcased how industries can create energy-efficient systems that are less vulnerable to external shocks.

Thermal energy storage (TES) technologies designed within a circular framework offer another promising solution. Abokersh et al. (2021) analyzed a high-temperature TES system using molten salts in solar power plants, demonstrating reduced material waste and improved environmental performance. By integrating recycling and reuse into the design phase, the study highlighted how TES systems can contribute to resilient and sustainable energy infrastructure. The CE framework promotes resource recirculation, minimizing waste and enhancing resource efficiency.

By decreasing reliance on raw materials, particularly fossil fuels, circular practices contribute to a more resilient energy system. Antonioli et al. (2022) demonstrate this through their study on Italian SMEs, showing that reducing raw material use and increasing renewable energy adoption can strengthen regional energy resilience. Their research emphasizes that these circular innovations reduce dependency on traditional energy sources, which helps buffer against potential disruptions.

Adding to this perspective, Mačiulis (2023) and Mindár (2024) discussed energy resilience extensively, advocating for the transition to renewable energy sources and infrastructure improvements to withstand shocks from global disruptions, such as geopolitical conflicts and fluctuating energy prices. Their insights underscore the broader importance of renewable energy adoption within circular frameworks as a means of achieving long-term energy stability.

Furthermore, Bassi and Dias (2019) explored CE practices among EU firms, finding that companies engaging in circular activities like recycling and renewable energy adoption experience reduced energy vulnerabilities. Although their focus is not solely on energy resilience, the indirect benefits of these practices highlight the potential for CE to support resilience against fluctuations in energy availability and costs.

Chehabeddine et al. (2022) address energy resilience directly by examining the increased demand for cooling systems during heatwaves, underscoring the need for energy-efficient cooling solutions and renewable energy adoption to handle climate-driven energy shocks. By improving energy efficiency and switching to renewable sources, energy systems can better cope with extreme weather-related demands.

Additionally, Gargasas et al. (2023) emphasize the role of smart energy systems and distributed energy generation, highlighting how these systems can buffer against energy demand fluctuations and increase resilience to energy shocks. Their findings underscore that integrating renewable energy sources into local grids can stabilize supply and improve resilience against disruptions.

Energy shocks, whether from sudden supply disruptions or price hikes, can have profound impacts on economies. Circular practices help mitigate these shocks by creating local, renewable energy sources and reducing energy demand. Li et al. (2020) examined the impacts of energy efficiency and renewable energy use on CO_2 emissions in China and Nigeria, highlighting that clean energy adoption not only reduces emissions but also prepares these economies for potential energy disruptions. Such practices, although focused on environmental impacts, inherently support energy resilience by reducing reliance on conventional energy sources.

Bezama et al. (2019) also emphasize the role of bio-based regional strategies, particularly in bioeconomies that leverage local, renewable resources as energy sources. These resources can provide local energy self-sufficiency, which is crucial during times of energy shock, as they reduce dependence on imported or non-renewable energy sources.

Morocco's renewable energy projects further demonstrate the importance of circular practices in energy resilience. With investments in renewable energy, Morocco has positioned itself as a potential energy supplier to Europe, potentially supporting the continent's resilience during energy crises. This example illustrates how regional renewable energy projects can contribute to broader energy security by establishing alternative supply routes.

Implementing circular energy practices requires coordinated efforts at multiple levels, from policy frameworks to organizational commitment. Studies emphasize that targeted policy initiatives and financial incentives can drive the adoption of energy-efficient, circular practices. For instance, Fonseca et al. (2018) highlighted that fiscal incentives and institutional support are crucial for expanding CE practices among companies, particularly in high-energy sectors. These incentives encourage companies to adopt sustainable practices that reduce energy demands, increasing their resilience to energy shocks.

Stavropoulos et al. (2020) add that cities with strong circular policies are more successful in attracting green investments, which in turn enhance local energy resilience. Investments in sectors such as recycling and renewable energy reduce dependency on traditional energy supplies, which is particularly valuable during energy price surges or supply disruptions.

These studies collectively underscore the role of CE in preparing for energy shocks by fostering resilience, sustainability, and economic efficiency across sectors. By embedding circular principles into energy systems, industries, and urban planning, CE offers a pathway to mitigate the impacts of energy disruptions while accelerating the transition to a low-carbon economy. The integration of innovative technologies, renewable energy systems, and waste recovery practices within a circular framework positions CE as a critical tool for enhancing energy security and sustainability in an era of growing global challenges.

Circular practices serve as a fundamental strategy for enhancing energy resilience and preparing for energy shocks. By promoting resource efficiency, renewable energy, and recycling, CE models reduce dependency on non-renewable energy sources and create more self-sufficient systems. Implementing these practices at a national and regional level through supportive policies and organizational efforts can strengthen resilience against energy fluctuations, making them vital for future energy security.

6. Identifying research gaps in circular economy and energy resilience

Current literature on the CE reveals several critical gaps that limit a comprehensive understanding of its potential impacts. While environmental benefits are well-documented, the broader socioeconomic effects of CE practices, such as job creation, economic equity, and quality of life improvements, remain underexplored. This is particularly true in regions transitioning from traditional industries to circular models, where research into the social dimensions of CE could provide valuable insights.

Another significant gap lies in the understanding of regional disparities in CE adoption. Developing countries often face challenges such as inadequate infrastructure and financial constraints, yet there is a lack of comprehensive frameworks to address these barriers. Comparative studies that explore strategies for scaling CE practices across different geographical and economic contexts are urgently needed.

The integration of emerging technologies, including artificial intelligence (AI), blockchain, and the Internet of Things (IoT), also requires more attention. While these technologies have been recognized for their potential to enhance CE practices, empirical research on their practical application, scalability, and accessibility—particularly for small and medium-sized enterprises (SMEs) and developing economies—is limited.

Moreover, standardized metrics to measure CE's impact on energy resilience are underdeveloped. While the theoretical benefits of CE in reducing fossil fuel dependency and improving renewable energy use are acknowledged, specific indicators to quantify these outcomes remain scarce. Similarly, sector-specific analyses are often limited to industries like agriculture and construction, leaving other high-impact sectors, such as transportation, electronics, and healthcare, inadequately studied despite their significant resource and waste management challenges.

Research into policy effectiveness also reveals gaps. While existing studies highlight policies such as recycling subsidies and extended producer responsibility (EPR) schemes, their long-term effectiveness and adaptability across different cultural and economic contexts have not been sufficiently evaluated. Understanding how these policies can be tailored to meet the needs of diverse regions would strengthen CE implementation globally.

Public awareness and behavioral shifts represent another critical area for exploration. Although public engagement is essential for CE adoption, there is limited understanding of how education, cultural norms, and incentives shape consumer and organizational behavior. Studies on regional differences in public attitudes and strategies for fostering sustainable practices could help bridge this gap.

Additionally, SMEs, which are key players in CE transitions, face significant financial and operational challenges. Research into innovative financing models, such as green bonds and public-private partnerships, and strategies for overcoming resource constraints is necessary to support their participation. Finally, there is a notable lack of longitudinal studies assessing the long-term environmental impacts of CE practices, such as their effects on emissions, waste reduction, and resource efficiency. Empirical evidence from such studies would reinforce the sustainability of circular systems over time.

Addressing these gaps is essential to fully realize the potential of the CE in enhancing energy resilience, fostering sustainability, and supporting inclusive economic development. Whereas, a roadmap for future research is suggested to prioritize these areas to guide global CE adoption and maximize its transformative impact.

7. Roadmap for future research in circular economy and energy resilience

The CE holds transformative potential to address global sustainability challenges, including resource scarcity, environmental degradation, and energy insecurity. However, to fully harness the benefits of CE, targeted research is essential to bridge knowledge gaps, optimize practices, and guide policy and industry actions. This roadmap outlines key areas for future research, providing a structured approach to advance understanding and support the transition toward a resilient, sustainable, and CE.

Deepening sector-specific analysis of circular economy applications. To optimize circular practices, research must delve into sector-specific applications, particularly at instantaneous high-impact industries such as manufacturing, agriculture, construction, and energy. Each of these sectors faces unique resource and waste challenges, making tailored circular strategies crucial. Future studies should focus on identifying the specific drivers, barriers, and best practices for CE implementation within each sector. For example, research could investigate the potential for circular design in manufacturing, regenerative practices in agriculture, and waste-to-energy solutions in construction. These insights would enable more effective and scalable CE solutions, maximizing economic, environmental, and social benefits within each industry.

Example: Finland’s bioeconomy strategy. Finland has developed a robust bioeconomy strategy that integrates CE principles into forestry and agriculture, focusing on biomass use for renewable energy and materials. This model emphasizes sustainable resource management, reducing dependency on fossil fuels while creating economic opportunities in rural areas (Biotalous-Bioeconomy, n.d.)

Expanding multilevel studies to include socioeconomic impact assessments. Understanding the broader socioeconomic impacts of CE adoption is essential for effective implementation, particularly at the macro, mezzo, and micro levels. While the environmental benefits of circular practices are well documented, research on the social and economic dimensions remains limited. Future studies should examine how CE strategies influence job creation, economic resilience, social equity, and quality of life, especially in regions where traditional industries are shifting to circular models. This expanded focus could provide valuable insights into the distributional impacts of CE, helping policymakers and stakeholders anticipate and address the social implications of circular transitions.

Examples: Scotland's circular economy strategy on macro level. Scotland's CE strategy prioritizes job creation in green industries, such as recycling and remanufacturing, while targeting GDP growth through resource efficiency. The strategy emphasizes inclusivity by supporting community-based initiatives and upskilling workers for the green economy (Zero Waste Scotland | Inspiring change to fight the climate crisis, n.d.).

India's renewable energy sector and circularity on mezzo level. In India, the renewable energy sector integrates CE principles through solar panel recycling and battery reuse, fostering job creation in both urban and rural areas. These efforts contribute to local economic resilience by reducing reliance on imported raw materials (IRENA—International Renewable Energy Agency, n.d.).

Kenya's waste management enterprises on micro level. Community-driven waste management enterprises in Kenya, such as those processing organic waste into compost, generate income for local residents and promote cleaner environments. These initiatives also empower women and marginalized groups by creating employment opportunities and improving community health (UNEP-UN Environment Programme, n.d.).

Examining the role of emerging technologies in enhancing circular economy practices. The integration of digital and technological advancements—such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, and smart grids—presents new opportunities to enhance CE practices. These technologies enable more precise resource tracking, efficient waste management, and improved energy use. For instance, IoT sensors can monitor product lifecycles to optimize maintenance and reuse, while blockchain can enhance supply chain transparency to support closed-loop systems. Future research should investigate how these technologies can drive innovation within CE, improve resource efficiency, and address technical challenges across sectors. Such studies would be instrumental in identifying scalable tech-driven solutions that accelerate CE transitions.

Example: Norway's blockchain for seafood traceability. Norway employs blockchain technology to enhance transparency in seafood supply chains, reducing waste and promoting sustainable practices in fisheries. This approach ensures ethical sourcing and supports circular practices in food production (Norges sjømatråd, n.d.).

Investigating policy and regulatory frameworks that support circular economy adoption. Effective policy and regulatory frameworks are essential for promoting and sustaining CE practices. While many countries have begun implementing CE policies, there is a need for further research into the effectiveness of these frameworks, especially in diverse cultural and economic contexts. Research should evaluate the impact of various policy instruments, such as tax incentives, subsidies for recycling infrastructure, and extended producer responsibility (EPR) schemes. Comparative studies across regions or nations could highlight best practices and critical gaps, providing valuable insights for policymakers seeking to create supportive environments for CE adoption. Research could also explore how policies, such as subsidies for recycling infrastructure or incentives for renewable energy adoption, influence the success of CE initiatives. By identifying effective policy mechanisms, these studies would support a more coherent and impactful regulatory landscape for circular transitions.

Example: Germany's packaging act. Encourages recyclable product designs and reduces waste (BMUV: Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, n.d.)

Developing metrics for measuring the impact of circular economy on energy resilience. Quantifying the impact of CE practices on energy resilience is essential to demonstrate the value of CE as a strategy for energy security. While many studies emphasize the theoretical benefits of CE, practical metrics are needed to measure real-world outcomes. Future research should focus on developing and refining metrics that assess how circular strategies—such as renewable energy integration, closed-loop supply chains, and resource recovery—reduce dependency on fossil fuels and mitigate energy vulnerabilities. These metrics would not only support empirical evaluations but also help policymakers and industry leaders track progress, make informed decisions, and allocate resources effectively to bolster energy resilience.

Example: Italy's industrial symbiosis program. Italy's industrial symbiosis initiatives quantify material and energy flows between companies, measuring the impact of resource sharing on energy efficiency and waste reduction. These metrics provide insights into CE's role in enhancing energy resilience (Home, n.d.).

Analyzing the financial viability and barriers of CE implementation. While CE offers economic and environmental benefits, financial and operational barriers often hinder its widespread adoption, especially among small and medium-sized enterprises (SMEs). Research should focus on understanding the financial viability of CE practices and the specific challenges businesses face, such as high initial costs, technological limitations, and resource constraints. Studies could investigate financing models, such as green loans or public-private partnerships, that reduce barriers to entry and support SMEs in implementing circular strategies. By identifying cost-effective approaches and solutions to common barriers, this research would enable more accessible and equitable CE adoption across diverse business types.

Example: Brazil's green financing for SME. Brazil offers green loans to SMEs adopting sustainable technologies, such as energy-efficient machinery and renewable energy systems. This initiative addresses financial barriers and promotes circularity in emerging markets (BNDES-O banco nacional do desenvolvimento, n.d.).

Studying the long-term environmental benefits of circular economy adoption. While CE practices are expected to yield significant environmental benefits, long-term studies are needed to confirm and quantify these impacts. Research should focus on longitudinal analyses that track reductions in greenhouse gas emissions, resource extraction, waste generation, and environmental degradation over time. These studies could compare the durability of environmental benefits across various CE models, such as recycling, reuse, and regenerative practices. Understanding the sustainability of CE practices in the long term would provide empirical evidence for their effectiveness and reinforce the case for investing in circular transitions.

Example: The Netherlands' circular agriculture initiatives offer a model for assessing long-term environmental benefits (WUR, n.d.).

Exploring public awareness and behavioral shifts supporting CE adoption. The success of CE initiatives is closely tied to public awareness and consumer behavior, which influence demand for sustainable products and practices. Future research should examine the role of public education, social norms, and behavioral incentives in promoting CE adoption. Studies could investigate the motivators and barriers that drive or hinder sustainable consumer choices, as well as the effectiveness of campaigns aimed at raising awareness. Insights from this research would help design educational and engagement strategies that foster a culture of circularity, encouraging individuals to support CE practices in their everyday lives.

Example: Sweden's national campaigns on sustainable consumption highlight the importance of public awareness in driving CE practices (Naturvårdsverket, n.d.)

Identifying critical success factors for cross-sectoral collaboration in CE. Collaboration among industries, governments, and civil society organizations is essential for implementing and sustaining CE practices. Research should investigate the factors that contribute to successful cross-sectoral partnerships, such as effective knowledge-sharing mechanisms, resource-sharing arrangements, and collaborative governance models. Future studies could focus on specific cases of multi-stakeholder initiatives, examining how partnerships facilitate the adoption of CE practices and enhance resilience. By identifying best practices for collaboration, this research would offer guidance on how to build CE ecosystems that harness the strengths of diverse sectors and stakeholders.

Example: India's plastic waste management rules. India's regulatory framework addresses plastic waste recycling through mandatory extended producer responsibility (EPR). This policy has encouraged public-private partnerships and boosted recycling rates, especially in urban regions with infrastructure constraints (Ministry of Environment, Forest and Climate Change, n.d.).

Addressing regional disparities in circular economy adoption. The adoption of CE practices varies significantly across regions due to differences in economic development, policy environments, and technological capacity. Research should investigate these disparities, focusing on barriers faced by developing economies and strategies to overcome them. For instance, studies could examine how limited infrastructure, and financial resources hinder CE implementation in low-income regions, and how international collaboration can bridge these gaps.

Example: Rwanda's e-waste recycling programs demonstrate how resource-limited regions can implement effective CE initiatives with targeted policies and partnership (UNEP-UN Environment Programme, n.d.).

8. Conclusion

During the last two decades, the circular economies has grown considerably and received increasingly more attention within politics and research. Yet, how macroeconomic influences affect the CE is not fully understood. In addition, few reviews summarize and synthesize the learning outcomes from research on the topic.

In this paper, we consider macroeconomic influences on CE with focus on Europe. As this literature is relatively new and the findings are not always well known, we start out by conducting a literature review. Scientific literature implies that transition to a more CE is a relevant process, which still needs to be observed. Scholars reveal, that companies' measures, such as size and turnover affect how they adapt CE practices. Alas, it is still unclear how macroeconomic conditions and circularity are related. Lack of knowledge is seen as a certain threat to adoption of CE practices. In this respect, regional division in this study was employed to identify common characteristics that are shared within European regions when waste management is referred in regard to macroeconomic conditions.

The review of CE practices across macro, mezzo, and micro levels reveals significant potential for supporting sustainable economic growth, enhancing energy resilience, and reducing greenhouse gas emissions. At the macro level, CE practices contribute to national and regional policies aimed at decoupling economic growth from environmental degradation, underscored by frameworks like the Environmental Kuznets Curve. By fostering sustainable practices, such as energy-efficient technologies and renewable energy adoption, macro-level initiatives demonstrate that CE strategies can align economic growth with environmental goals, even in energy-intensive industries.

Mezzo-level CE practices emphasize community and sector-wide initiatives, including waste management systems, recycling facilities, and shared mobility programs. These strategies highlight the importance of regional infrastructure and local policy support in driving resource efficiency and reducing emissions. Sector-specific applications, such as in construction and transportation, underscore the role of CE in enhancing sustainability through collaborative, localized approaches that integrate physical infrastructure and policy frameworks.

At the micro level, individual firms implement CE strategies tailored to their operational needs, often focusing on resource optimization, waste reduction, and extended product lifecycles. Studies illustrate that, while larger firms may have the resources to lead in CE adoption, small and medium-sized enterprises (SMEs) often require targeted incentives and support to overcome financial and technical barriers. The collective contribution of micro-level initiatives across sectors like manufacturing, agriculture, and fashion underscores the role of businesses in operationalizing circular principles.

The interaction between macro, mezzo, and micro levels establishes a feedback loop that enhances CE outcomes. Macro-level policies provide strategic direction, while firm-level innovation informs and refines these policies. For example, Hertwich et al. (2019) found that lightweight material designs driven by firms contributed significantly to macro-level emissions reduction goals. The mezzo level bridges macro strategies with on-the-ground implementation, providing infrastructure, fostering collaborations, and tailoring national goals to local contexts. Regional recycling hubs exemplify this translation of policy into action. Radavičius et al. (2021) describe shared facilities in agriculture and construction sectors that enabled resource recovery and waste minimization. These facilities aligned regional initiatives with national waste management objectives, cutting construction waste by over 40%.

Moreover, CE practices play an increasingly vital role in energy resilience, preparing economies for energy shocks by decreasing reliance on fossil fuels and promoting renewable energy sources. Circular approaches to energy production, waste management, and resource use contribute to building self-sufficient systems capable of withstanding disruptions in energy supply.

In conclusion, CE practices, driven by foreign direct investment, research and development, and supportive policies, provide a viable pathway for sustainable development across economic and environmental dimensions. By integrating CE principles at multiple levels, societies can work towards a resilient, resource-efficient future, contributing to long-term energy security, environmental protection, and economic stability. Implementing these practices requires coordinated efforts, robust policy frameworks, and continued investment in clean technology to fully harness the benefits of a CE model.

The suggested roadmap for future research provides a comprehensive guide to advancing CE knowledge and practices, with an emphasis on enhancing sustainability, resilience, and economic stability. By focusing on sector-specific applications, technological integration, policy frameworks, financial feasibility, and public engagement, these suggested research areas could address critical gaps and emerging challenges within the CE field. As global economies strive for sustainability, this roadmap supports the development of a resilient and circular future, where economic growth aligns with environmental stewardship and energy security. Through continued research, the potential of the CE to drive sustainable development can be realized, benefiting industries, communities, and ecosystems worldwide.

Novelty: previous research paid attention to peculiarities of economic growth and energy use interrelationships, followed by implications on environmental degradation. CE comprises social, environmental and economic pillars which are closely connected.

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