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Advancing Circular Economy through Knowledge Transfer: A Decade of Research Insights

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Abstract
Economic growth and sustainable development are central themes of the Sustainable Development Goals (SDGs) set by the United Nations and adopted by the European Commission for EU member countries. Transitioning to a circular economy (CE) aligns with the SDGs, particularly through the principles of reduce, reuse, and recycle (3Rs). This comparative analysis synthesises the contributions of multiple scholars, providing a cohesive understanding of current advancements and challenges in CE and sustainable resource management. Key themes include stakeholder collaboration, technological innovations, waste management, and policy frameworks. Effective waste management and valorisation of materials are highlighted, with significant advancements in electronic waste treatment, automotive shredder residue processing, and construction waste recycling. Moreover, the study emphasises the importance of cooperation through partnerships, as outlined in SDG17, and knowledge transfer in building trust within developed countries. The literature review reveals interactions between knowledge transfer components, such as research and development, foreign direct investment, and CE indicators, including circular material use rate and recycling rate. A bibliometric technique and VOSviewer were employed for visually representative and comprehensible literature analysis. The findings suggest that the integrated efforts of various stakeholders, technological advancements, and robust policy frameworks are essential for achieving a sustainable and circular future. By analysing these components, the research aims to evaluate the potential of EU member states to achieve sustainable development, providing valuable insights into the theoretical approaches and indicators used in CE and knowledge transfer studies.

Keywords
Circular economy, knowledge transfer, waste management, sustainability, technological innovations, stakeholder collaboration, sustainable resource management, sustainable development

Introduction

In recent decades, the consumption of natural resources has increased significantly due to the outdated linear consumption model, which follows a take-use-dispose pattern. This model is detrimental to humanity because of the environmental issues it creates, especially with the world population growing from 1 billion in 1800 to over 8.1 billion in 2024. In just the past 40 years, the population has nearly doubled, growing at a rate of about 0.91% per year, adding approximately 73 million people annually ("Worldometer - real-time world statistics," n.d.). As the population increases, so does consumption, which necessitates more production and results in the continuous extraction of natural resources, including energy resources, that need urgent alternatives.

While human prosperity has led to many benefits, it has also caused environmental damage that requires adaptation to new conditions. Therefore, it is essential to adopt new consumption patterns, specifically the 3Rs model: reduce, reuse, and recycle. Various models implement this approach and align with circular economy principles (Fontana et al., 2021; Hanuláková, Daňo, & Kukura, 2021; Lewandowski, Lewandowski, & Mateusz, 2016; Polyakov, Khanin, Shevchenko, & Bilozubenko, 2021; Rezk et al., 2023; Gerasimova, Prause & Hoffmann, 2023; Aly Hussien Aly Abdou, 2023*;* Ruginė & Žilienė, 2024).

The circular economy includes innovative business models focusing on sustainable supply and consumption chains, efficient waste management, and technologies saving resources and energy. It also emphasises reducing the use of primary natural resources, extending the life of products through closed-loop production and consumption, and recycling materials (Polyakov et al., 2021).

Technological innovations support this shift by enabling the creation or adaptation of industries with minimal environmental impact (Radavičius et al., 2021; Pariso, Picariello & Marino, 2023; Feyzioglu et al., 2024). Economic development can promote the transition to a circular economy by fostering continuous innovation (Hrab & Minculete, 2023; Fleacă, Maiduc & Croitoru, 2023; Yalçınkaya et al., 2024; Rezk et al., 2024).

In this framework, knowledge transfer is crucial for both innovation and economic development, occurring within companies and organisations through various channels (Bezama, Ingrao, O'Keeffe, & Thrän, 2019; Burinskas, Holmen, Tvaronavičienė, Šimelytė, & Razminienė, 2021; Šimelytė, Tvaronavičienė, Bøgh Holmen, Burinskas, & Razminienė, 2021; Pceļina, Lavrinenko, & Danileviča, 2023; Wang, Zhang, & Wong, 2024; Haurovi, & Chilunjika, 2024).

Measuring economic development often includes indicators emphasising the need to monitor their interconnections and transition towards a circular economy (Rybalkin et al., 2023).

The circular economy (CE) has emerged as a vital framework for promoting sustainable resource use by emphasising the continuous loop of materials through reducing, reusing, and recycling. Knowledge transfer plays a crucial role in implementing CE principles across various sectors by enabling the dissemination of innovative practices and technologies. This paper explores the interplay between CE and knowledge transfer, drawing on recent studies to illustrate the diverse applications and challenges of this approach.

In conclusion, transitioning to a circular economy requires effective knowledge transfer across sectors and stakeholders. The studies reviewed in this paper provide valuable insights into the diverse applications of CE principles, from waste management to agricultural sustainability, highlighting the importance of collaboration, technological innovation, and comprehensive regulatory frameworks.

This paper is structured to comprehensively analyse the transition to a circular economy (CE) and sustainable resource management. It begins with an introduction outlining the significance and objectives of the study. The literature review section examines existing CE and knowledge transfer research, highlighting key indicators and themes. The methodology section describes the research design and analytical tools used. Findings and discussions are then presented, focusing on stakeholder collaboration, technological innovations, waste management practices, and policy frameworks. This is followed by a bibliometric and co-occurrence analysis, a comparative analysis of CE indicators, strategic recommendations, and a concluding summary of the key insights.

Research methodology

The bibliographic literature analysis was performed on the Web of Science platform, which is known for its effectiveness in facilitating literature reviews by offering access to resources focusing on particular subject areas. Initially, the search was initiated using the keyword "circular economy," yielding 26,550 results from the Web of Science Core Collection. Subsequently, the search was further refined by incorporating the keyword "knowledge transfer," resulting in a comprehensive search outcome comprising 121 relevant documents which were used for this research.

The search covers the period from 1990 to 2024. Knowledge transfer in the circular economy started gaining interest in 2014 and peaked in 2021, after which the number of articles slightly decreased. Figure 1 illustrates the growth of the publications regarding circular economy and knowledge transfer.

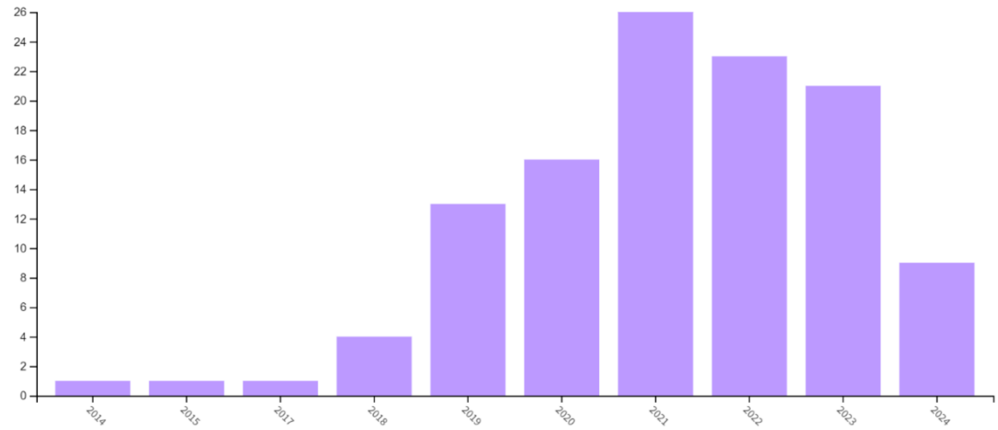

Fig. 1. Trends in publications on circular economy and knowledge transfer (2014-2024)

The primary aim of the co-occurrence analysis was to understand the interrelationships between the identified keywords. The analysis was conducted using VOSviewer, a software tool for constructing and visualising bibliometric networks. VOSviewer was utilised to generate the visualisation of the network graph. In this visualisation, the size of each node corresponded to the frequency of occurrences of the keyword, while the thickness of the edges was determined by the co-occurrence strength (total link strength). This visualisation provided an intuitive overview of the central keywords and their interconnections, highlighting key clusters and the relative importance of each term within the dataset.

The dataset used for a co-occurrence analysis comprised 978 unique keywords extracted from a corpus of documents. To ensure the analysis focused on the most relevant terms, we set a threshold requiring each document to have a minimum of 10 citations. This filter resulted in a refined list of 27 keywords that met the criteria of having a minimum occurrence of 4 within the dataset. These keywords included terms such as "absorptive capacity," "barriers," "business models," "circular economy," and others.

The co-occurrence analysis, facilitated by VOSviewer, provided a robust methodological approach to uncovering the underlying structure and connections within the dataset. By visualising the network of keywords, we gained valuable insights into the thematic landscape of the research domain, facilitating a deeper understanding of the key concepts and their interdependencies.

To explore the interrelatedness of scholarly documents within our field, a bibliographic coupling analysis was conducted using VOSviewer software. Bibliographic coupling determines the relatedness of documents based on the number of references they share, providing insights into the research landscape and identifying clusters of closely related works.

A total of 121 documents were initially considered for the analysis. To ensure the robustness of the analysis, a minimum citation threshold was set; only documents with at least 10 citations were included. Consequently, 42 documents met this criterion and were analysed further. VOSviewer was utilised to visualise the network of bibliographic couplings. The software generated a map where each document is represented by a node, and the links between nodes represent the shared references. The size of each node correlates with its citation count, and the thickness of the links corresponds to the total link strength.

The selected studies provided the foundation for our comprehensive literature analysis. A co-occurrence analysis, focusing on 978 unique keywords, was conducted using VOSviewer to identify and visualise key terms and their interrelationships. Furthermore, a bibliographic coupling analysis was performed to explore the connections between documents based on shared references, resulting in a detailed network of 42 highly cited works. Through these methodologies, we uncovered significant insights into the thematic landscape and the interdependencies of key concepts within the research domain.

Literature review

The transition to a circular economy (CE) and sustainable resource management has attracted significant attention across various industries and regions. This comparative analysis synthesises the contributions of multiple scholars, thereby providing a cohesive understanding of current advancements and challenges in these fields.

To begin with, Mishra, Chiwenga, & Ali (2019) emphasise the pivotal role of collaboration among stakeholders in driving circular business models in North African manufacturing. This study aligns with the findings of Chari et al. (2022), who explore dynamic capabilities theory to support circular and resilient supply chains in Industry 4.0, thus highlighting the importance of integrating various stakeholders in the supply chain.

Similarly, Scipioni, Russ, & Niccolini (2021) discuss organisational learning processes in SMEs to facilitate the transition to CE, underscoring the need for knowledge creation and transfer among stakeholders.

Moreover, the effective management and recycling of waste materials are central themes in multiple studies. For instance, Horodytska, Cabanes, & Fullana (2020) focus on high-quality recycled polymers in Europe, addressing contamination issues to improve recycling processes. This is echoed by Nithya, Sivasankari, & Thirunavukkarasu (2021), who highlight the potential of electronic waste (e-waste) as a resource in the CE. Additionally, Stelmaszczyk, Pierścieniak, & Krzysztofek (2021) examine the impact of managerial efforts on CE models.

In the context of automotive industry waste, Khodier, Williams, & Dallison (2018) explore pathways to improve the recovery rate of end-of-life vehicles (ELVs) by enhancing the processing of automotive shredder residue (ASR). Their work is complemented by that of Williams & Khodier (2020), who evaluate pyrolysis technologies for treating ASR and aim to support CE by producing non-hazardous products.

Furthermore, agricultural systems and food production are prominently featured in the CE discourse. For example, (Aznar-Sánchez, Velasco-Muñoz, García-Arca, & López-Felices, 2020) and Castro et al. (2019) focus on sustainable solutions for intensive agriculture in Almería, Spain, emphasising resource optimisation and waste management. Similarly, Barcaccia, D'Agostino, Zotti, & Cozzi (2020) explore the impact of COVID-19 on the Italian agri-food sector, suggesting the crisis could enhance sustainability in line with the European Green Deal.

In the realm of food packaging, Muncke et al. (2020) address the migration of hazardous chemicals from packaging into food, advocating for improved safety assessments. This theme resonates with the work of Meyer, Meijer, van den Hil, & van der Fels-Klerx (2021), who reviewed chemical food safety hazards associated with insects reared for food and feed, highlighting contamination concerns.

Additionally, technological advancements play a critical role in advancing CE practices. For instance, Lin et al. (2023) developed a method for sorting construction and demolition waste using deep learning, thus enhancing classification efficiency. This approach is mirrored by Münch, Benz, & Hartmann (2022) integration of CE principles into supply chain management in the automotive industry, using a fuzzy decision-making approach.

Moreover, the potential of waste plastic fuel (WPF) derived from HDPE through pyrolysis as an alternative fuel source is investigated by Padmanabhan et al. (2022), aligning with CE principles of energy recovery. Meanwhile, Bröring, Laibach, & Wustmans (2020) discuss the bioeconomy's reliance on biomass and bio-based processes, proposing a typology for bioeconomy innovations to enhance technology and innovation management.

Environmental impacts and LCA are crucial components of CE research. For example, Ruiz-Salmón et al. (2021) provide a comprehensive review of LCA applications in the seafood sector, while Oksana Horodytska, Kiritsis, & Fullana (2020) evaluate the environmental impacts of upcycling printed plastic scrap. Additionally, Dąbrowski, Varjú, & Amenta (2019) examine knowledge transfer in the CE between Amsterdam and Naples, focusing on eco-innovative solutions for material waste in peri-urban areas.

Collaboration among various stakeholders is fundamental to advancing CE practices. Mishra et al. (2019) highlight the role of stakeholder collaboration in enabling CE practices within a North African manufacturing company. They emphasise the necessity of cooperation among suppliers, government entities, and local businesses to transition towards a circular business model. Similarly, Razminienė (2019) underscores the importance of clusters, particularly for small and medium enterprises (SMEs), in achieving competitive advantages within the CE framework through collaborative efforts.

Effective waste management is a cornerstone of the circular economy. Several studies highlight different aspects of waste recycling and management. For instance, Nithya et al. (2021) focus on the potential of electronic waste (e-waste) as a resource, discussing the policies, recycling methods, and technological advancements necessary for effective management. Horodytska et al. (2020) address the demand for high-quality recycled polymers in the European plastic industry, emphasising the need for contaminant removal to improve recycling processes. Zanelli, Conte, Molinari, Soldati, & Dondi (2021) explore waste recycling in the ceramic industry, investigating the impact of recycled materials on the manufacturing of ceramic tiles.

Integrating CE principles into food safety and agricultural practices is crucial for sustainability. Muncke et al. (2020) discuss the importance of chemical safety in food packaging within CE initiatives, highlighting the need for better safety assessments to prevent hazardous chemical migration. In the agricultural sector, Barcaccia et al. (2020) examine the impact of the COVID-19 pandemic on the Italian agri-food sector, proposing that the crisis could enhance the sustainability of food systems in line with the European Green Deal.

Innovations in the bioeconomy and effective resource management are essential for the circular economy. Bröring et al. (2020) propose a typology for bioeconomy innovations to facilitate effective technology and innovation management. Jucker, Lupi, Moore, Leonardi, & Savoldelli (2020) explore using organic waste from insect farming, providing a sustainable waste management solution within a circular food economy framework. Additionally, Tzanakakis, Angelakis, Paranychianakis, Dialynas, & Tchobanoglous (2020) investigate water management challenges in Crete, emphasising the need for improved governance frameworks to enhance water use efficiency and adapt to climate variability.

Adopting CE principles in the automotive and construction industries is critical for reducing environmental impacts. Khodier et al. (2018) explore the challenges of adopting CE practices in the automotive industry, focusing on improving materials recovery from end-of-life vehicles (ELVs).

Life Cycle Assessment (LCA) is a valuable tool for evaluating the environmental impact of various processes within the CE framework. Ruiz-Salmón et al. (2021) provide a comprehensive review of LCA applications in the seafood sector, highlighting its importance in addressing the environmental implications of seafood production. Horodytska et al. (2020) evaluate the environmental impacts of an innovative upcycling process for printed plastic scrap, demonstrating the benefits of deinking plastic before extrusion to produce high-quality pellets.

In conclusion, the diverse studies reviewed here underscore the multifaceted nature of the circular economy and sustainability research. From stakeholder collaboration and waste management to technological innovations and environmental assessments, these studies collectively contribute to a deeper understanding of how different sectors can transition towards more sustainable and circular practices. Comparative analysis shows that while the challenges are complex, the integrated efforts of various stakeholders, technological advancements, and robust policy frameworks hold promise for a more sustainable future.

Results of the co-occurrence analysis

The co-occurrence analysis of the 27 keywords revealed significant insights into the interrelationships among the key terms in our dataset. The visualisation of the co-occurrence network allowed us to identify central keywords and understand how frequently they appeared together (Figure 2). Below are the key findings:

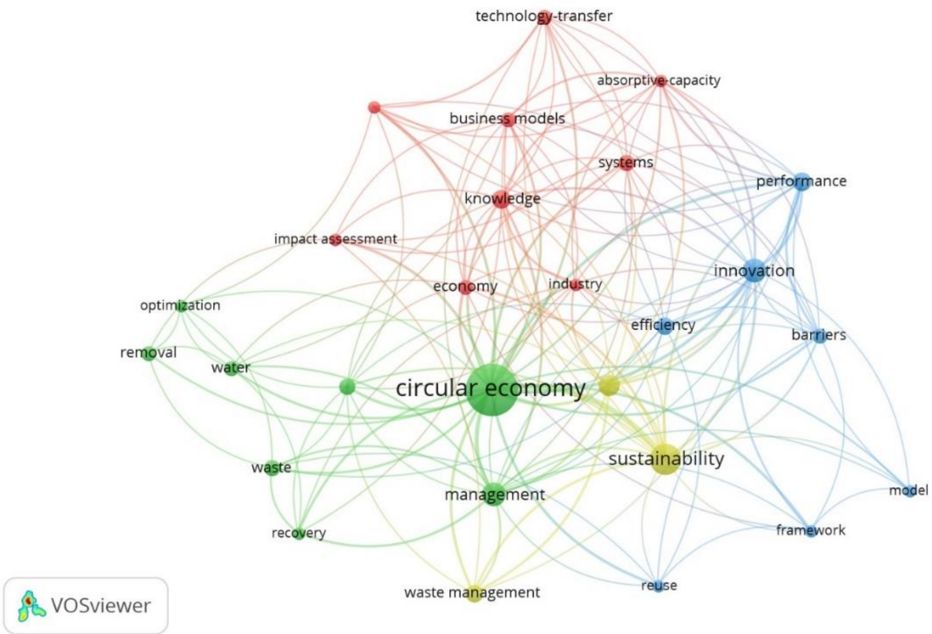

Fig. 2. Co-occurrence Analysis of Key Terms in Circular Economy and Knowledge Transfer Research (Threshold: 10 Citations, Minimum Occurrence: 4)

Central Keywords

1. **Circular Economy**: The keyword "circular economy" emerged as the most central term in the network. It had the highest occurrence, appearing 60 times, and the highest total link strength of 102. This indicates that "circular economy" is a pivotal concept within the dataset and is frequently associated with various other keywords. Its central position in the network highlights its importance in the research domain.
2. **Sustainability**: "Sustainability" was another prominent keyword, with 22 occurrences and a total link strength of 47. This shows that sustainability is a core theme that often co-occurs with other key concepts, reinforcing its significance in the context of the analysed documents.
3. **Innovation** and **Management**: Both "innovation" and "management" appeared 13 times, with total link strengths of 38 and 35, respectively. These keywords are crucial as they are linked to various other terms, indicating their broad relevance and the interconnected nature of innovation and management with other themes in the dataset.

Keyword Clusters and Relationships

1. **Knowledge and Knowledge Transfer**: The keywords "knowledge" and "knowledge transfer" were also notable, with occurrences of 8 and 10 and total link strengths of 24 and 29, respectively. These terms are interconnected and often co-occur, suggesting a strong relationship between the creation, transfer, and utilisation of knowledge within the analysed documents.
2. **Waste and Waste Management**: Both "waste" and "waste management" appeared frequently, with occurrences of 6 and 7 and total link strengths of 12 and 15, respectively. Their co-occurrence underscores the importance of waste-related issues and management practices in the context of the research.
3. **Performance**: The keyword "performance" had 8 occurrences and a total link strength of 29, indicating its relevance in discussions around various aspects of performance in relation to other key terms like innovation, management, and sustainability.

Lesser-Connected Keywords

While meeting the threshold for inclusion, some keywords had lower occurrences and total link strengths, indicating they are less central but still relevant. For example:

1. **Absorptive Capacity**: Occurred 4 times with a total link strength of 20.
2. **Barriers**: Occurred 5 times with a total link strength of 17.
3. **Business Models**: Occurred 5 times with a total link strength of 18.

Although less frequent, these keywords highlight specific areas of interest that complement the central themes of the research.

The network visualisation provided a clear depiction of the keyword relationships. Nodes representing frequently occurring keywords were larger and centrally positioned, indicating their prominence. Thicker edges between nodes illustrated stronger co-occurrence relationships, helping to identify clusters of related keywords. For instance, the strong connections between "circular economy," "sustainability," and "innovation" reflect their interrelated nature in the context of the dataset.

The co-occurrence analysis elucidated the thematic structure of the dataset, emphasising the prominence of key concepts like "circular economy," "sustainability," "innovation," and "management." It also revealed how these central themes are interlinked with other relevant keywords, providing a comprehensive overview of the research landscape. This understanding is crucial for identifying focal points in the research domain and guiding future investigations.

Results of the Bibliographic Coupling Analysis

The bibliographic coupling analysis revealed significant insights into the structure and interrelationships of the documents within the dataset. Below are the detailed findings (see Figure 3):

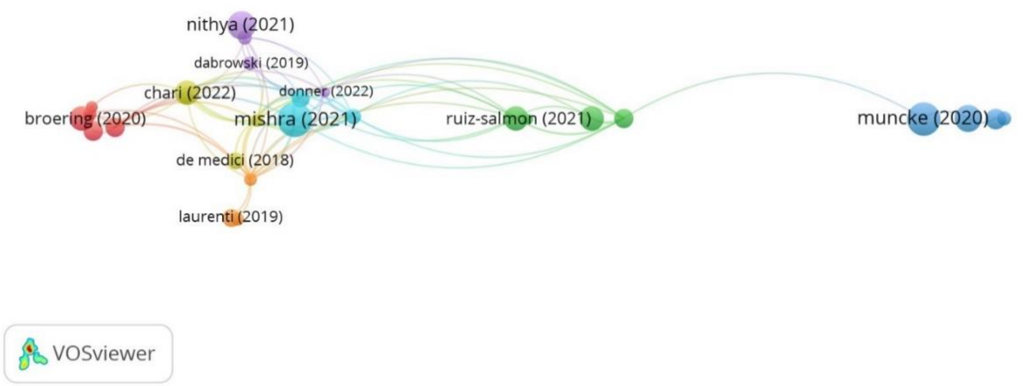

Fig. 3. Bibliographic Coupling Network of Highly Cited Documents on Circular Economy and Knowledge Transfer (Threshold: 10 Citations)

High-Impact Documents

Several documents stood out due to their high citation counts and notable total link strengths, indicating their central role and influence in the research network:

1. **Mishra et al. (2019):** With 101 citations and a total link strength of 24, this document is a pivotal piece in the network. Its high citation count signifies its broad recognition and influence within the research community, while its substantial link strength indicates that it shares numerous references with other key documents.
2. **Muncke et al. (2020)**: This document has 94 citations and a total link strength of 3. Despite its lower link strength, its high citation count highlights its significant impact on the field.
3. **Nithya et al. (2021)**: With 68 citations and a link strength of 3, this document is another influential work, though it shares fewer references with other documents compared to Mishra (2021).

Notable Documents with High Link Strength

Some documents, while not having the highest citation counts, exhibited high total link strengths, suggesting they are highly interconnected with other documents in the dataset:

1. **Salas, Criollo & Ramirez (2021)**: This document, with 16 citations, has the highest link strength of 35. This indicates it shares a substantial number of references with many other documents, making it a central node in the bibliographic coupling network.
2. **Nastase et al. (2021)**: With 14 citations and a total link strength of 31, this document also plays a significant role in connecting various research works through shared references.
3. **Münch et al. (2022)**: This document has 28 citations and a total link strength of 29, underscoring its strong interconnections within the research community.

Additional Influential Documents

Several other documents also demonstrated significant influence and connectivity within the network:

1. **Ruiz-Salmón et al. (2021):** With 55 citations and a link strength of 10, this document is well-recognised and interconnected.
2. **Chari et al. (2022)**: This document has 53 citations and a total link strength of 16, indicating both high impact and good connectivity.
3. **Scipioni et al. (2021):** With 21 citations and a link strength of 23, this document is notable for its high connectivity relative to its citation count.
4. **Donner, Radić, Erraach, & El Hadad-Gauthier (2022)**: Although it has only 11 citations, its link strength of 18 suggests it shares many references with other influential documents.

The analysis highlighted key documents that are highly cited and well-connected through shared references. Documents like Mishra et al. (2021), Muncke et al. (2020), and Nithya et al. (2021) are highly influential in terms of citation count. Meanwhile, documents such as Münch et al. (2022), Nastase et al. (2021), and Salas et al. (2021) are central in the bibliographic coupling network due to their high link strengths, indicating they share many references with other documents.

These findings suggest that while citation count is an important influence metric, the total link strength is crucial for understanding the interconnectedness and the collaborative nature of research within the field. The combination of these metrics provides a comprehensive view of the scholarly landscape, identifying both influential and highly connected documents.

Methodological Approaches in CE Research

This section provides an overview of the various methodological approaches (Table 1) employed by researchers to investigate circular economy (CE) principles and their applications across different contexts and sectors. The methods include case studies, literature reviews, interviews, bibliometric analyses, qualitative analyses, data collection and analysis, systematic reviews, statistical analyses, surveys, and workshops.

Tab. 1. Overview of Methodological Approaches in Circular Economy Research

Methodology	Authors
Case Study	(Andersen, 2022; Khodier et al., 2018; J. L. Mishra et al., 2021; Muncke et al., 2020; Nastase et al., 2021)
Literature Review	(Bansal, Singh, & Nangia, 2022; Bröring et al., 2020; Chari et al., 2022; Czarna-Juszkiewicz, Kunecki, Cader, & Wdowin, 2023; Fořt & Černý, 2022; Krohn et al., 2022; Laurenti, Singh, Cotrim, Toni, & Sinha, 2019; Möllnitz et al., 2021; Mort, Vorst, Curtzwiler, & Jiang, 2021; Nithya et al., 2021; Ruiz-Salmón et al., 2021; Salas et al., 2021; Wilke & Pyka, 2024)
Interviews	(Aznar-Sánchez et al., 2020; Iqbal et al., 2023; Krohn et al., 2022; Muncke et al., 2020; Napathorn, 2022; Stander & Broadhurst, 2021; Teerikangas & Colman, 2020)
Bibliometric Analysis	(Bansal et al., 2022; Fořt & Černý, 2022; Krohn et al., 2022; Laurenti et al., 2019; Münch et al., 2022; Razminienė, 2019b; Ruiz-Salmón et al., 2021)
Qualitative Analysis	(Aznar-Sánchez et al., 2020; Chari et al., 2022; Iqbal et al., 2023; Klemeš, Varbanov, Walmsley, & Foley, 2019; Möllnitz et al., 2021; Razminienė, 2019b; Šimelytė, Tvaronavičienė, Peyravi, & Beretta, 2023; Stander & Broadhurst, 2021)
Data Collection and Analysis	(Oksana Horodytska et al., 2020; Jucker et al., 2020; Khodier et al., 2018; Krohn et al., 2022; R. Kumar et al., 2023; Padmanabhan et al., 2022; Stelmaszczyk et al., 2021; Tzanakakis et al., 2020)
Systematic Review	(Fořt & Černý, 2022; Krohn et al., 2022; R. Kumar et al., 2023; Laurenti et al., 2019; Möllnitz et al., 2021; Salas et al., 2021; Teerikangas & Colman, 2020)
Statistical Analysis	(O. Horodytska et al., 2020; Jucker et al., 2020; Nithya et al., 2021; Padmanabhan et al., 2022; Šimelytė et al., 2023; Stelmaszczyk et al., 2021)
Surveys	(DeLorenzo, Parizeau, & von Massow, 2019; Iqbal et al., 2023; Petereit, Hoerterer, & Krause, 2022; Remøy, Wandl, Ceric, & van Timmeren, 2019; Scipioni et al., 2021; Šimelytė et al., 2023)
Workshops	(Aznar-Sánchez et al., 2020; Castro et al., 2019; Dąbrowski et al., 2019; DeLorenzo et al., 2019; Remøy et al., 2019)

Case Study Approach: The case study methodology is widely utilised to provide in-depth insights into specific contexts and phenomena. Mishra et al. (2021) employed a single case study approach to examine a manufacturing company in the fast-moving consumer goods sector, focusing on applying CE principles in an emerging economy. Similarly, Muncke et al. (2020) used a case study to explore implementing CE principles and food contact material safety in a North African manufacturing company. Khodier et al. (2018) investigated a shredder plant in the Northwest of the UK through case studies, monitoring operations and evaluating thermal processing plants for automotive shredder residue treatment. Andersen (2022) conducted case studies on an e-manufacturer with European subsidiaries to understand the impacts of the Waste Electrical and Electronic Equipment (WEEE) directive.

Literature Review: Literature reviews provide comprehensive overviews of existing research and are foundational to understanding current knowledge and identifying research gaps. Nithya et al. (2021) reviewed global e-waste generation, policies, and recycling techniques, focusing on major producers and different recycling methods. Chari et al. (2022) combined literature reviews with expert interviews in their qualitative research on sustainability in the industry. Ruiz-Salmón et al. (2021) conducted a bibliometric analysis of over 60 life cycle assessment (LCA) studies on seafood, focusing on methodological trends. Laurenti et al. (2019) systematically mapped publications on the sharing economy, analysing 589 journal articles to understand the field's diversity.

Interviews: Interviews are critical for collecting qualitative data directly from stakeholders. Muncke et al. (2020) conducted interviews with stakeholders to explore CE principles in manufacturing. Aznar-Sánchez et al. (2020) used interviews and workshops with stakeholders to characterise Almería's agricultural model and propose CE-based solutions. Iqbal et al. (2023) assessed Lahore's waste management sector through data collection and interviews with various organisations and stakeholders. DeLorenzo et al. (2019) conducted 45 interviews across Ontario's food and waste systems to understand the impacts of legislative changes on food waste management.

Bibliometric Analysis: Bibliometric analysis helps to assess research trends and influence quantitatively. Ruiz-Salmón et al. (2021) used this method to analyse LCA studies on seafood. Razminienė (2019b) combined bibliometric analysis with the Analytical Hierarchy Process (AHP) to evaluate CE literature and propose SME engagement schemes. Laurenti et al. (2019) conducted a detailed bibliometric analysis to classify and understand the sharing economy research field. Bansal et al. (2022) performed a bibliometric analysis of publications to develop a conceptual framework for sustainability research.

Qualitative Analysis: Qualitative analysis provides an in-depth understanding of complex phenomena through thematic exploration. Chari et al. (2022) employed qualitative analysis in their study on sustainability in industry, involving a literature review and expert interviews. Stander & Broadhurst (2021) used thematic analysis of interview transcripts to identify key themes in sustainable practices. Aznar-Sánchez et al. (2020) utilised qualitative methods to explore agricultural models and propose CE-based solutions.

Data Collection and Analysis: Comprehensive data collection and analysis are essential for empirical research. Khodier et al. (2018) monitored shredder plant operations and characterised automotive shredder residue. Horodytska et al. (2020) employed a life cycle assessment (LCA) methodology to analyse recycling scenarios for printed plastic waste.

Systematic Review: Systematic reviews are rigorous approaches to synthesise existing research. Laurenti et al. (2019) systematically reviewed sharing economy publications. Fořt & Černý (2022) used systematic review methods to analyse sustainable development and energy efficiency measures. Möllnitz et al. (2021) systematically reviewed building retrofits and barriers to sustainability.

Statistical Analysis: Statistical analysis is crucial for validating research findings. Jucker et al. (2020) used statistical methods to compare larval growth and nutritional composition. Šimelytė et al. (2023) applied principal component analysis (PCA) to analyse data from companies in Estonia and Lithuania. Stelmaszczyk et al. (2021) employed regression analysis and structural equation modelling (SEM) to test hypotheses in textile recycling research.

Surveys: Surveys are effective tools for gathering data from a broad audience. Remøy et al. (2019) used surveys and interviews to explore CE in urban planning. Šimelytė et al. (2023) conducted computer-assisted telephone interviews (CATI) with companies to gather data on business practices. Scipioni et al. (2021) combined focus groups with surveys to study learning processes in construction SMEs.

Workshops: Workshops facilitate interactive discussions and knowledge exchange. Castro et al. (2019) organised workshops to address sustainability challenges in greenhouse agriculture. Aznar-Sánchez et al. (2020) conducted workshops with stakeholders to develop CE-based solutions for agriculture. Remøy et al. (2019) used workshops in their study on CE in urban planning.

These varied methodologies, employed by multiple researchers, contribute significantly to advancing the understanding and implementation of circular economy principles, sustainability, and resource management across different sectors and regions.

Comparative Analysis of Studies on Circular Economy and Knowledge Transfer Indicators

This section provides a comparative analysis of various studies focusing on circular economy (CE) and knowledge transfer indicators (Table 2). The analysis identifies common themes and indicators across multiple research efforts, highlighting key areas such as reduction, reuse, and recycling of materials, environmental and resource efficiency, waste management and valorisation, and collaboration and compliance. By examining these indicators, the section aims to elucidate the critical components contributing to the successful implementation of CE principles and the effective transfer of knowledge within different sectors. This comparative approach not only underscores the recurring themes in the literature but also provides insights into the practical applications and impacts of these indicators on sustainable development.

Tab. 2. Key Circular Economy Indicators in Research

Indicator	Description	Authors
Reduction, Reuse, Recycling (3Rs)	Emphasis on reducing waste through effective recycling and reuse of materials.	(Barcaccia et al., 2020; Oksana Horodytska et al., 2020; R. Mishra, Singh, & Gunasekaran, 2023; Muncke et al., 2020; Nithya et al., 2021; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)
Zero Waste to Landfill	Achieving minimal to zero waste directed to landfills.	(Horodytska et al., 2020; R. Mishra et al., 2023; Muncke et al., 2020; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)
Resource and Environmental Efficiency	Adoption of clean technology and measures for optimising resource use and minimising environmental impact.	(Horodytska et al., 2020; R. Mishra et al., 2023; Muncke et al., 2020; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)

Indicator	Description	Authors
Collaboration and Compliance	Collaborative efforts with suppliers and stakeholders to ensure compliance with circular economy principles.	(Bröring et al., 2020; Horodytska et al., 2020; Münch et al., 2022; Muncke et al., 2020; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)
Use of Renewable Energy	Incorporation of renewable energy sources in processes.	(Mishra et al., 2023; Muncke et al., 2020; Ruiz-Salmón et al., 2021)
Waste Valorization	Efficient management and valorisation of waste materials, including recovery of valuable metals.	(Horodytska et al., 2020; Khodier et al., 2018; Nithya et al., 2021; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)
Sustainable Practices and Innovation	Implementation of sustainable practices and development of innovative recycling and production methods.	(Horodytska et al., 2020; Muncke et al., 2020; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)
Energy Efficiency	Optimisation of energy use in processes, including distribution routing.	(Horodytska et al., 2020; J. L. Mishra et al., 2021; Muncke et al., 2020; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)
Circular Economy Compliance	Adherence to regulations and standards promoting circular economy.	(Bröring et al., 2020; Horodytska et al., 2020; Münch et al., 2022; Muncke et al., 2020; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)
Material Flow Management	Effective management of material flows to optimise resource use.	(Horodytska et al., 2020; Muncke et al., 2020; Ruiz-Salmón et al., 2021; Zanelli et al., 2021)

Circular Economy Indicators:

1. **Reduction, Reuse, and Recycling of Materials:**
- Multiple studies emphasise the importance of reducing waste through effective recycling and reuse of materials (e.g., Horodytska et al., 2020; R. Mishra et al., 2023; Muncke et al., 2020; Nithya et al., 2021).
- Specific indicators such as achieving "zero waste to landfill" and efficient recycling techniques are frequently mentioned.

2. **Environmental and Resource Efficiency:**
- Adoption of clean technology practices and resource efficiency measures are highlighted (e.g., Mishra et al., 2023; Muncke et al., 2020).
- Indicators include optimisation of distribution routing to save energy, reduction in carbon footprint, and the use of renewable energy sources.

3. **Waste Management and Valorization:**
- Efficient management of e-waste and other waste materials, including recovery of valuable metals and minimising landfill disposal, are key indicators (e.g., Khodier et al., 2018; Nithya et al., 2021; Zanelli et al., 2021).
- Implementation of sustainable recycling techniques and regulatory measures to promote e-waste management are also emphasised.

4. **Collaboration and Compliance:**
- Collaborative efforts with suppliers and stakeholders to ensure compliance with circular economy principles are critical (e.g., Muncke et al., 2020; Ruiz-Salmón et al., 2021).
- Indicators include collaborative efforts for compliance, engagement with local suppliers, and adherence to environmental regulations.

Circular Economy Indicators in Contemporary Research

Circular economy (CE) indicators are pivotal for assessing and promoting sustainable practices within various sectors. A comprehensive review of the literature reveals several key indicators that are frequently cited by multiple authors, underscoring their critical role in the transition to a more sustainable economy.

Reduction, Reuse, and Recycling (3Rs). The principle of reduction, reuse, and recycling is fundamental to the circular economy. This indicator is extensively discussed by Barcaccia et al., 2020; Horodytska et al., 2020;

Mishra, Singh, & Gunasekaran, 2023; Muncke et al., 2020; Nithya et al., 2021; Ruiz-Salmón et al., 2021; Zanelli et al., 2021. These authors emphasise the need to minimise waste generation and maximise the lifecycle of materials through effective recycling and reuse practices. For instance, Muncke et al. (2020) highlight the importance of achieving "zero waste to landfill" goals, a sentiment echoed by Khodier et al. (2018), who also stress the need for comprehensive waste management strategies.

Resource and Environmental Efficiency. Efficient use of resources and minimising environmental impact are crucial components of the circular economy. Mishra et al. (2023) and Muncke et al. (2020) focus on the adoption of clean technology practices to enhance resource efficiency. Ruiz-Salmón et al. (2021) and Zanelli et al. (2021) further elaborate on optimising distribution routing to save energy and reduce carbon footprints, emphasising the broader environmental benefits of these practices.

Collaboration and Compliance Collaboration with suppliers and ensuring compliance with circular economy principles are essential for effective implementation. Muncke et al. (2020) and Ruiz-Salmón et al. (2021) underscore the importance of multi-stakeholder collaboration to achieve compliance with CE standards. Horodytska et al. (2020) and Zanelli et al. (2021) also highlight this collaborative approach and discuss the necessity of engaging local suppliers and adhering to environmental regulations to foster a more sustainable supply chain.

Use of Renewable Energy Incorporating renewable energy sources into industrial processes is another key indicator of a circular economy. Mishra et al. (2023), Muncke et al. (2020), and Ruiz-Salmón et al. (2021) advocate for the use of renewable energy to reduce dependency on fossil fuels and mitigate environmental impacts. This transition to renewable energy is seen as a critical step in achieving long-term sustainability goals.

Waste Valorization Efficient management and valorisation of waste materials are critical for reducing environmental impact and recovering valuable resources. Khodier et al. (2018), Nithya et al. (2021), and Zanelli et al. (2021) focus on the recovery of valuable metals and other materials from waste, emphasising the need for advanced recycling techniques. Horodytska et al. (2020) discuss the reduction of contaminants in recycled plastics, further highlighting the importance of waste valorisation in maintaining material quality and safety.

Sustainable Practices and Innovation The adoption of sustainable practices and the development of innovative recycling and production methods are crucial for advancing the circular economy. Muncke et al. (2020) and Zanelli et al. (2021) highlight the importance of continuous innovation in recycling technologies to enhance material recovery and reduce waste. Horodytska et al. (2020) and Ruiz-Salmón et al. (2021) also emphasise the need for sustainable practices in production processes to minimise environmental impact.

Energy Efficiency Optimising energy use in various processes, including distribution routing and production, is essential for enhancing overall efficiency. Mishra et al. (2021), Muncke et al. (2020), and Ruiz-Salmón et al. (2021) discuss the importance of energy efficiency measures in reducing carbon footprints and conserving resources. Horodytska et al. (2020) and Zanelli et al. (2021) further elaborate on specific strategies to improve energy efficiency, highlighting their role in achieving sustainable development goals.

Circular Economy Compliance Adherence to regulations and standards that promote circular economy principles is vital for ensuring sustainable practices. Bröring et al. (2020), Horodytska et al. (2020), Münch et al. (2022), Muncke et al. (2020), Ruiz-Salmón et al. (2021), and Zanelli et al. (2021) all emphasise the importance of regulatory compliance in fostering a circular economy. These authors advocate for stringent environmental standards and certifications to ensure that industries adhere to sustainable practices.

Material Flow Management Effective management of material flows is crucial for optimising resource use and reducing waste. Horodytska et al. (2020), Muncke et al. (2020), Ruiz-Salmón et al. (2021), and Zanelli et al. (2021) discuss strategies for managing material flows, such as tracking material usage and improving recycling processes, to enhance resource efficiency and minimise environmental impact.

In summary, the consistent emphasis on these circular economy indicators across various studies highlights their critical role in advancing sustainable practices. By focusing on reduction, reuse, recycling, resource efficiency, collaboration, renewable energy, waste valorisation, sustainable practices, energy efficiency, compliance, and material flow management, researchers and practitioners can effectively contribute to developing a circular economy.

Knowledge Transfer Indicators in Circular Economy Research

Knowledge transfer is crucial in advancing the principles of the circular economy (CE). Effective dissemination and application of knowledge facilitate the adoption of sustainable practices across various sectors. A review of contemporary research reveals several repetitive indicators that highlight the essential elements of knowledge transfer in the circular economy context (Table 3).

Tab. 3. Key Knowledge Transfer Indicators for Facilitating Circular Economy Transition

Indicator	Description	Authors
Training and Certifying Suppliers	Providing training and certification programs for suppliers and local businesses.	(Castro et al., 2019; J. L. Mishra et al., 2021; Muncke et al., 2020; Nithya et al., 2021)
Sharing Technical and Organisational Knowledge	Disseminating technical knowledge and organisational practices to enhance efficiency and compliance.	(Horodytska et al., 2020; J. L. Mishra et al., 2021; Muncke et al., 2020; Zanelli et al., 2021)
Stakeholder Involvement	Involving various stakeholders in redesigning products, processes, and knowledge-sharing activities.	(Horodytska et al., 2020; J. L. Mishra et al., 2021; Muncke et al., 2020; Ruiz-Salmón et al., 2021)
Collaboration and Partnerships	Encouraging collaboration between academia, industry, and policymakers to facilitate knowledge transfer.	(Bröring et al., 2020; Meyer et al., 2021; Münch et al., 2022; Muncke et al., 2020; Zanelli et al., 2021)
Innovation and Research	Promoting innovation and research to develop new technologies and sustainable practices.	(Barcaccia et al., 2020; Casanueva, Castro, & Galán, 2013; Krohn et al., 2022; Münch et al., 2022; Wilke & Pyka, 2024)
Public Awareness and Education	Raising public awareness and providing education on sustainable practices and circular economy principles.	(Barcaccia et al., 2020; Casanueva et al., 2013; DeLorenzo et al., 2019)
Technology Adoption	Encouraging the adoption of new technologies and best practices within industries.	(Bühler et al., 2023; Horodytska et al., 2020; Šimelytė et al., 2023; Zanelli et al., 2021)
Policy Support and Development	Supporting the development of policies and regulatory frameworks that promote knowledge transfer.	(Dąbrowski et al., 2019; Napathorn, 2022; Nithya et al., 2021; Obafemi, Stephen, Ajayi, & Nkosinathi, 2019)
Knowledge Networks and Clusters	Establishing knowledge networks and clusters to facilitate the exchange of information and best practices.	(Laurenti et al., 2019; Šimelytė et al., 2023; Stelmaszczyk et al., 2021; Wilke & Pyka, 2024)
Skill Development Programs	Implementing programs to develop the skills necessary for adopting circular economy practices.	(Bühler et al., 2023; Chari et al., 2022; Muncke et al., 2020; Padmanabhan et al., 2022)
Interdisciplinary Approaches	Integrating knowledge from various scientific disciplines and stakeholders to address sustainability challenges.	(Klemeš et al., 2019; Krohn et al., 2022; Wilke & Pyka, 2024)

Training and Certifying Suppliers. Providing training and certification programs for suppliers and local businesses is a fundamental knowledge transfer indicator. Castro et al. (2019), Mishra et al. (2021), Muncke et al. (2020), and Nithya et al. (2021) emphasise the importance of educating suppliers on CE principles to ensure they are well-equipped to comply with sustainable practices. Such training programs help build a competent and informed supply chain that can effectively implement CE strategies.

Sharing Technical and Organisational Knowledge. The dissemination of technical knowledge and organisational practices is vital for enhancing efficiency and compliance with CE standards. Mishra et al. (2021) and Muncke et al. (2020) highlight the need to share best practices and technical insights with stakeholders to optimise material efficiency. Similarly, Horodytska et al., 2020; Zanelli et al., 2021 stress the importance of transferring organisational knowledge to improve recycling processes and reduce contaminants in recycled materials.

Stakeholder Involvement. Involving various stakeholders in redesigning products, processes, and knowledge-sharing activities is critical for the successful implementation of CE practices. Horodytska et al. (2020), J. L. Mishra et al. (2021), and Muncke et al. (2020) underscore the importance of engaging multiple stakeholders, including SMEs and local suppliers, in collaborative efforts to align with CE goals. Ruiz-Salmón et al. (2021) also advocate for stakeholder involvement to ensure a comprehensive approach to sustainability.

Collaboration and Partnerships. Encouraging collaboration between academia, industry, and policymakers is essential for effective knowledge transfer. Muncke et al. (2020) and Zanelli et al. (2021) highlight the benefits of such collaborations in fostering innovation and developing new technologies. Bröring et al. (2020), Meyer et al. (2021), and Münch et al. (2022) further emphasise the role of partnerships in integrating CE principles into industrial applications and policy frameworks.

Innovation and Research. Promoting innovation and research is fundamental for developing new technologies and sustainable practices. Barcaccia et al. (2020), Castro et al. (2019), and Münch et al. (2022) discuss the significance of investment in research and development to drive technological advancements. Krohn et al. (2022) and Wilke & Pyka (2024) also highlight the need for continuous innovation to address sustainability challenges and improve resource efficiency.

Public Awareness and Education. Raising public awareness and providing education on sustainable practices and CE principles are crucial for fostering a culture of sustainability. Barcaccia et al. (2020) and Castro et al. (2019) emphasise the importance of public education initiatives to increase awareness of CE benefits. DeLorenzo et al. advocate for educational programs that inform the public about waste management and recycling practices.

Technology Adoption. Encouraging the adoption of new technologies and best practices within industries is a key knowledge transfer indicator. Horodytska et al. (2020), Meyer et al.(2021), and Zanelli et al. (2021) discuss the need for industries to embrace innovative technologies to enhance material recovery and reduce waste. Šimelytė et al. (2023) further highlight the role of technology adoption in achieving sustainability goals.

Policy Support and Development. Supporting the development of policies and regulatory frameworks that promote knowledge transfer is essential for the widespread implementation of CE practices. Dąbrowski et al. (2019), Napathorn (2022), and Nithya et al. (2021) stress the importance of policy support in facilitating knowledge transfer and ensuring compliance with CE principles. Obafemi et al. (2019) discuss how regulatory frameworks can drive the adoption of sustainable practices.

Knowledge Networks and Clusters. Establishing knowledge networks and clusters to facilitate the exchange of information and best practices is crucial for CE implementation. Šimelytė et al. (2023), Stelmaszczyk et al. (2021), and Wilke & Pyka (2024) highlight the benefits of creating collaborative networks that bring together diverse stakeholders. Laurenti et al. discuss how such clusters can enhance innovation and knowledge dissemination.

Skill Development Programs. Implementing programs to develop the skills necessary for adopting CE practices is a critical knowledge transfer indicator. Chari et al. (2022) and Muncke et al. (2020) emphasise the need for workforce skill development to support the transition to a circular economy. Meyer et al. and Padmanabhan et al. also discuss the importance of training programs that equip employees with the skills needed to implement sustainable practices.

Interdisciplinary Approaches. Integrating knowledge from various scientific disciplines and stakeholders to address sustainability challenges is essential for effective CE implementation. Klemeš et al. (2019) and Wilke & Pyka (2024) highlight the need for interdisciplinary collaboration to develop comprehensive solutions. Krohn et al. (2022) also emphasise the importance of integrating diverse perspectives to enhance resource efficiency and sustainability.

In summary, these knowledge transfer indicators—training and certifying suppliers, sharing technical and organisational knowledge, stakeholder involvement, collaboration and partnerships, innovation and research, public awareness and education, technology adoption, policy support and development, knowledge networks and clusters, skill development programs, and interdisciplinary approaches—are pivotal in advancing the circular economy. By focusing on these indicators, researchers and practitioners can effectively promote the dissemination and application of sustainable practices.

Advancing Circular Economy and Knowledge Transfer: Key Indicators and Strategic Recommendations

Recent interdisciplinary research has identified critical indicators and strategic recommendations essential for promoting circular economy (CE) practices and effective knowledge transfer across various sectors. These findings underscore the importance of integrating economic, environmental, and social dimensions to foster sustainable development.

Circular Economy Indicators

1. **Resource Efficiency and Waste Reduction:**

- **Recycling and Reuse Rates:** These metrics are crucial for assessing the efficiency of material recovery processes and the overall sustainability of waste management systems (Czarna-Juszkiewicz et al., 2023; Lin et al., 2023).
- **Reduction of Greenhouse Gas Emissions:** Monitoring emissions reductions provides insight into the environmental benefits of implementing CE practices, particularly in construction and manufacturing (Fořt & Černý, 2022; Krohn et al., 2022).

2. **Sustainable Material Use:**

- **Use of Sustainable Building Materials:** Adopting eco-friendly materials is essential for minimising environmental impact and enhancing the sustainability of construction projects (Fořt & Černý, 2022; Krohn et al., 2022).
- **Material Recovery from Waste Tires:** Efficient recovery and reuse of materials from waste tires highlight the potential for integrating waste products into valuable resources (Czarna-Juszkiewicz et al., 2023).

3. **Technological Integration:**

- **Energy Efficiency Improvements:** Energy efficiency measures are critical for reducing resource consumption and promoting sustainable building practices (Fořt & Černý, 2022; Krohn et al., 2022).
- **Innovative Recycling Technologies:** The development and application of advanced technologies, such as machine learning for waste classification, can significantly enhance CE processes (Lin et al., 2023).

Knowledge Transfer Indicators

1. **Interdisciplinary Cooperation**

- **Collaboration Among Stakeholders.** Effective knowledge transfer requires strong collaboration between scientists, policymakers, industry stakeholders, and the public to address complex sustainability challenges (Šimelytė et al., 2023; Stander & Broadhurst, 2021).
- **Interdisciplinary Research and Communication.** Promoting interdisciplinary research and improving communication channels are essential for sharing advanced methods and theoretical concepts (Fořt & Černý, 2022; Krohn et al., 2022).

2. **Public Awareness and Education**

- **Public Acceptance and Engagement.** Increasing public awareness and engagement in CE practices is crucial for achieving widespread adoption of sustainable measures (Czarna-Juszkiewicz et al., 2023; Petereit et al., 2022).
- **Educational Programs and Campaigns.** Targeted educational initiatives can address knowledge gaps and promote sustainable behaviors among different demographic groups (Petereit et al., 2022).

3. **Policy Support and Alignment**

- **Supportive Regulatory Frameworks.** Aligning policies and regulations to support CE practices and knowledge transfer initiatives is vital for facilitating sustainable development (Šimelytė et al., 2023; Stander & Broadhurst, 2021).
- **Incentives for Sustainable Practices.** Providing financial incentives and regulatory support can encourage the adoption of innovative technologies and sustainable practices (Kumar et al., 2024)

Recommendations for Advancing Circular Economy and Knowledge Transfer

1. **Enhance Interdisciplinary Cooperation:**

Foster collaboration among scientists, policymakers, industry stakeholders, and the public to address sustainability challenges comprehensively. Improved communication and knowledge transfer are essential to ensure cohesive efforts toward CE goals (Fořt & Černý, 2022; Krohn et al., 2022).

2. **Strengthen Policy and Regulatory Support:**

Align policy and regulatory frameworks to support long-term sustainability goals. Develop flexible and supportive regulations that facilitate the adoption of new technologies and sustainable practices (Šimelytė et al., 2023; Stander & Broadhurst, 2021).

3. **Promote Public Awareness and Education:**

Enhance public awareness of the benefits of sustainable practices and CE principles. Implement targeted campaigns and educational programs to address knowledge gaps and promote behavior change (Czarna-Juszkiewicz et al., 2023; Petereit et al., 2022).

4. **Invest in Research and Innovation:**

Increase funding for research and development to advance innovative technologies and processes. Focus on optimising materials like biochar for water treatment and developing advanced recycling technologies (Kumar et al., 2024; Lin et al., 2023).

5. **Improve Technical and Infrastructural Capabilities:**

Invest in technical infrastructure to support efficient waste management and resource recovery. Enhancing waste treatment facilities and integrating advanced technologies can significantly improve environmental outcomes (Iqbal et al., 2023).

6. **Facilitate Effective Knowledge Transfer:**

Promote the transfer of scientific and technical knowledge through partnerships and collaborative research. Applied research organisations can bridge the gap between academic findings and industry implementation (Stander & Broadhurst, 2021).

7. **Develop Comprehensive Assessment Tools:**

Create multidisciplinary assessment tools that cover social, economic, environmental, and technical aspects. These tools can aid in making informed decisions and justifying investments in sustainable projects (Fořt & Černý, 2022; Krohn et al., 2022).

Conclusion

In conclusion, this comprehensive analysis underscores the multifaceted nature of research on circular economy (CE) and sustainable resource management. The reviewed studies highlight the critical roles of stakeholder collaboration, technological innovations, waste management practices, and policy frameworks in advancing CE principles across various sectors.

Key themes such as integrating dynamic capabilities in supply chains, the importance of knowledge transfer and organisational learning, and developing advanced recycling technologies are recurrently emphasised. These elements are essential for facilitating the transition to sustainable and resilient business models, particularly in the manufacturing, agriculture, automotive, and food industries.

Effective waste management and the valorisation of waste materials remain central to CE practices. The studies demonstrate significant advancements in recycling processes, including the treatment of electronic waste, automotive shredder residue, and construction and demolition waste, all of which contribute to reducing environmental impacts and enhancing resource efficiency.

Technological advancements play a crucial role in CE, with innovations in deep learning for waste classification, pyrolysis technologies, and the production of alternative fuels from waste plastics showcasing the potential for technological solutions to drive sustainable practices. Additionally, the integration of CE principles into supply chain management through decision-making frameworks further exemplifies the intersection of technology and sustainability.

The importance of policy support and regulatory frameworks is also evident, as these provide the necessary structure for implementing and maintaining CE practices. Collaborative efforts among academia, industry, and policymakers are highlighted as vital for successfully transferring knowledge and promoting sustainable innovations.

Furthermore, public awareness and educational initiatives are crucial for fostering a culture of sustainability. Increasing public engagement and understanding of CE principles can significantly enhance the adoption of sustainable practices at both individual and community levels.

The bibliographic coupling and co-occurrence analyses reveal the interconnectedness of various research themes, emphasising the central role of terms such as "circular economy," "sustainability," "innovation," and "management." These analyses also identify key documents and influential studies that shape the research landscape, highlighting the collaborative and cumulative nature of knowledge development in this field.

Ultimately, the transition to a circular economy requires a holistic approach that combines technological innovation, effective waste management, stakeholder collaboration, and robust policy support. By addressing these interconnected areas, the research collectively contributes to a deeper understanding of how different sectors can achieve more sustainable and circular practices, paving the way for a more sustainable future.

By integrating these circular economy and knowledge transfer indicators and recommendations, stakeholders can create a robust framework for sustainable development. Fostering interdisciplinary cooperation, aligning policies, enhancing public awareness, investing in innovation, and facilitating knowledge transfer are pivotal steps toward achieving a more sustainable and resilient future.

References

Aly Hussien Aly Abdou, S. (2023). From cleaner production to green competitive advantage: evidence from Egypt. *Entrepreneurship and Sustainability Issues*, 11(1), 81–97. https://doi.org/10.9770/jesi.2023.11.1(5)

Andersen, T. (2022). A comparative study of national variations of the European WEEE directive: manufacturer's view. *Environmental Science and Pollution Research*, 29(14), 19920–19939. https://doi.org/10.1007/S11356-021-13206-Z/TABLES/5

Aznar-Sánchez, J. A., Velasco-Muñoz, J. F., García-Arca, D., & López-Felices, B. (2020). Identification of Opportunities for Applying the Circular Economy to Intensive Agriculture in Almería (South-East Spain). *Agronomy*, 10(10), 1499. https://doi.org/10.3390/AGRONOMY10101499

Bansal, S., Singh, S., & Nangia, P. (2022). Assessing the role of natural resource utilisation in attaining select sustainable development goals in the era of digitalisation. *Resources Policy*, 79, 103040. https://doi.org/10.1016/J.RESOURPOL.2022.103040

Barcaccia, G., D'Agostino, V., Zotti, A., & Cozzi, B. (2020). Impact of the SARS-CoV-2 on the Italian Agri-Food Sector: An Analysis of the Quarter of Pandemic Lockdown and Clues for a Socio-Economic and Territorial Restart. *Sustainability*, 12(14), 5651. https://doi.org/10.3390/SU12145651

Bezama, A., Ingrao, C., O'Keeffe, S., & Thrän, D. (2019). Resources, collaborators, and neighbors: The three-pronged challenge in the implementation of bioeconomy regions. *Sustainability*, 11(24), 1–18. https://doi.org/10.3390/su11247235

Bröring, S., Laibach, N., & Wustmans, M. (2020). Innovation types in the bioeconomy. *Journal of Cleaner Production*, 266, 121939. https://doi.org/10.1016/J.JCLEPRO.2020.121939

Bühler, M. M., Hollenbach, P., Michalski, A., Meyer, S., Birle, E., Off, R., … Kortmann, G. (2023). The Industrialisation of Sustainable Construction: A Transdisciplinary Approach to the Large-Scale Introduction of Compacted Mineral Mixtures (CMMs) into Building Construction. *Sustainability*, 15(13), 10677. https://doi.org/10.3390/SU151310677

Burinskas, A., Holmen, R. B., Tvaronavičienė, M., Šimelytė, A., & Razminienė, K. (2021). FDI, technology & knowledge transfer from Nordic to Baltic countries. *Insights into Regional Development*, 3(3), 31–55. https://doi.org/10.9770/IRD.2021.3.3(2)

Casanueva, C., Castro, I., & Galán, J. L. (2013). Informational networks and innovation in mature industrial clusters. *Journal of Business Research*, 66(5), 603–613. https://doi.org/10.1016/j.jbusres.2012.02.043

Castro, A. J., López-Rodríguez, M. D., Giagnocavo, C., Gimenez, M., Céspedes, L., La Calle, A., … Valera, D. L. (2019). Six Collective Challenges for Sustainability of Almería Greenhouse Horticulture. International *Journal of Environmental Research and Public Health*, 16(21), 4097. https://doi.org/10.3390/IJERPH16214097

Chari, A., Niedenzu, D., Despeisse, M., Machado, C. G., Azevedo, J. D., Boavida-Dias, R., & Johansson, B. (2022). Dynamic capabilities for circular manufacturing supply chains—Exploring the role of Industry 4.0 and resilience. *Business Strategy and the Environment*, 31(5), 2500–2517. https://doi.org/10.1002/BSE.3040

Czarna-Juszkiewicz, D., Kunecki, P., Cader, J., & Wdowin, M. (2023). Review in Waste Tire Management—Potential Applications in Mitigating Environmental Pollution. *Materials*, 16(17), 5771. https://doi.org/10.3390/MA16175771/S1

Dąbrowski, M., Varjú, V., & Amenta, L. (2019). Transferring Circular Economy Solutions across Differentiated Territories: Understanding and Overcoming the Barriers for Knowledge Transfer. *Urban Planning*, 4(3), 52–62. https://doi.org/10.17645/UP.V4I3.2162

DeLorenzo, A., Parizeau, K., & von Massow, M. (2019). Regulating Ontario's circular economy through food waste legislation. *Society and Business Review*, 14(2), 200–216. https://doi.org/10.1108/SBR-12-2017-0115/FULL/PDF

Donner, M., Radić, I., Erraach, Y., & El Hadad-Gauthier, F. (2022). Implementation of Circular Business Models for Olive Oil Waste and By-Product Valorization. *Resources*, 11(7), 68. https://doi.org/10.3390/RESOURCES11070068

Fleacă, B., Fleacă, E., Maiduc, S., & Croitoru, I. M. (2023). Research and innovation for sustainability transformation – modern outlooks and actual challenges. *Entrepreneurship and Sustainability Issues*, 10(4), 263-278. https://doi.org/10.9770/jesi.2023.10.4(16)

Feyzioglu, A., Ersoy, S., Omoruyi, T. U., Santoro, D., & Piccinetti, L. (2024). Purification of olive mill waste: a circular economy model for the Mediterranean region. *Insights into Regional Development*, 6(2), 92–102. https://doi.org/10.9770/IRD.2024.6.2(6)

Fontana, A., Barni, A., Leone, D., Spirito, M., Tringale, A., Ferraris, M., … Goncalves, G. (2021, January 21). Circular economy strategies for equipment lifetime extension: A systematic review. *Sustainability*, 13, 1–27. https://doi.org/10.3390/su13031117

Gerasimova, V., Prause, G., & Hoffmann, T. (2023). NFT-enriched smart contracts for smart circular economy models. *Entrepreneurship and Sustainability Issues*, 11(2), 93–110. https://doi.org/10.9770/jesi.2023.11.2(7)

Fořt, J., & Černý, R. (2022). Limited interdisciplinary knowledge transfer as a missing link for sustainable building retrofits in the residential sector. *Journal of Cleaner Production*, 343, 131079. https://doi.org/10.1016/J.JCLEPRO.2022.131079

Hanuláková, E., Daňo, F., & Kukura, M. (2021). Transition of business companies to circular economy in Slovakia. *Entrepreneurship and Sustainability Issues*, 9(1), 204–220. https://doi.org/10.9770/JESI.2021.9.1(12)

Haurovi, M., & Chilunjika, A. (2024). Fourth industrial revolution and social innovation dynamics in South Africa: a review. *Insights into Regional Development*, 6(2), 103–116. https://doi.org/10.9770/IRD.2024.6.2(7)

Horodytska, O., Cabanes, A., & Fullana, A. (2020). Non-intentionally added substances (NIAS) in recycled plastics. *Chemosphere*, 251, 126373. https://doi.org/10.1016/J.CHEMOSPHERE.2020.126373

Horodytska, Oksana, Kiritsis, D., & Fullana, A. (2020). Upcycling of printed plastic films: LCA analysis and effects on the circular economy. *Journal of Cleaner Production*, 268, 122138. https://doi.org/10.1016/J.JCLEPRO.2020.122138

Hrab, D.-E., & Minculete, G. (2023). Building tomorrow: additive manufacturing unleashing sustainable progress in the US military. *Insights into Regional Development*, 5(4), 115–134. https://doi.org/10.9770/ird.2023.5.4(8)

Iqbal, A., Yasar, A., Nizami, A. S., Sharif, F., Tabinda, A. B., Sultan, I. A., … Ahmad, M. (2023). Evolution of Solid Waste Management System in Lahore: A Step towards Sustainability of the Sector in Pakistan. *Applied Sciences*, 13(2), 983. https://doi.org/10.3390/APP13020983/S1

Khodier, A., Williams, K., & Dallison, N. (2018). Challenges around automotive shredder residue production and disposal. *Waste Management*, 73, 566–573. https://doi.org/10.1016/J.WASMAN.2017.05.008

Klemeš, J. J., Varbanov, P. S., Walmsley, T. G., & Foley, A. (2019). Process Integration and Circular Economy for Renewable and Sustainable Energy Systems. *Renewable and Sustainable Energy Reviews*, 116, 109435. https://doi.org/10.1016/J.RSER.2019.109435

Krohn, C., Khudur, L., Dias, D. A., van den Akker, B., Rees, C. A., Crosbie, N. D., … Ball, A. S. (2022). The role of microbial ecology in improving the performance of anaerobic digestion of sewage sludge. *Frontiers in Microbiology*, 13, 1079136. https://doi.org/10.3389/FMICB.2022.1079136/BIBTEX

Kumar, G., Perera, D., Sudheer, K. P., Zhang, P., Dhital, S., Galanakis, M., … Dhital, S. (2024). Leaching of Phytochemicals from Beans during Hydration, Kinetics, and Modeling. *Foods*, 13(2), 354. https://doi.org/10.3390/FOODS13020354

Kumar, R., Sharma, P., Sharma, P. K., Rose, P. K., Singh, R. K., Kumar, N., … Pandey, A. (2023). Rice husk biochar - A novel engineered bio-based material for transforming groundwater-mediated fluoride cycling in natural environments. *Journal of Environmental Management,* 343, 118222. https://doi.org/10.1016/J.JENVMAN.2023.118222

Laurenti, R., Singh, J., Cotrim, J. M., Toni, M., & Sinha, R. (2019). Characterising the Sharing Economy State of the Research: A Systematic Map. *Sustainability*, 11(20), 5729. https://doi.org/10.3390/SU11205729

Lewandowski, M., Lewandowski, & Mateusz. (2016). Designing the Business Models for Circular Economy—Towards the Conceptual Framework. *Sustainability*, 8(1), 43. https://doi.org/10.3390/su8010043

Lin, K., Zhao, Y., Zhou, T., Gao, X., Zhang, C., Huang, B., & Shi, Q. (2023). Applying machine learning to fine classify construction and demolition waste based on deep residual network and knowledge transfer. *Environment, Development and Sustainability*, 25(8), 8819–8836. https://doi.org/10.1007/S10668-022-02740-6/FIGURES/5

Meyer, A. M., Meijer, N., van den Hil, E. F. H., & van der Fels-Klerx, H. J. (2021). Chemical food safety hazards of insects reared for food and feed. *Journal of Insects as Food and Feed*, 7(5), 823–832. https://doi.org/10.3920/JIFF2020.0085

Mishra, J. L., Chiwenga, K. D., & Ali, K. (2021). Collaboration as an enabler for circular economy: a case study of a developing country. *Management Decision*, 59(8), 1784–1800. https://doi.org/10.1108/MD-10-2018-1111/FULL/PDF

Mishra, R., Singh, R. K., & Gunasekaran, A. (2023). Adoption of industry 4.0 technologies for decarbonisation in the steel industry: self-assessment framework with case illustration. *Annals of Operations Research*, 1–40. https://doi.org/10.1007/S10479-023-05440-0/TABLES/19

Möllnitz, S., Feuchter, M., Duretek, I., Schmidt, G., Pomberger, R., & Sarc, R. (2021). Processability of Different Polymer Fractions Recovered from Mixed Wastes and Determination of Material Properties for Recycling. *Polymers*, 13(3), 457. https://doi.org/10.3390/POLYM13030457

Mort, R., Vorst, K., Curtzwiler, G., & Jiang, S. (2021). Biobased foams for thermal insulation: material selection, processing, modelling, and performance. *RSC Advances*, 11(8), 4375–4394. https://doi.org/10.1039/D0RA09287H

Münch, C., Benz, L. A., & Hartmann, E. (2022). Exploring the circular economy paradigm: A natural resource-based view on supplier selection criteria. *Journal of Purchasing and Supply Management*, 28(4), 100793. https://doi.org/10.1016/J.PURSUP.2022.100793

Muncke, J., Andersson, A. M., Backhaus, T., Boucher, J. M., Carney Almroth, B., Castillo Castillo, A., … Scheringer, M. (2020). Impacts of food contact chemicals on human health: a consensus statement. *Environmental Health*, 19(1), 1–12. https://doi.org/10.1186/S12940-020-0572-5

Napathorn, C. (2022). The development of green skills across firms in the institutional context of Thailand. *Asia-Pacific Journal of Business Administration*, 14(4), 539–572. https://doi.org/10.1108/APJBA-10-2020-0370/FULL/XML

Nastase, I. A., Negrutiu, C., Felea, M., Acatrinei, C., Cepoi, A., & Istrate, A. (2021). Toward a Circular Economy in the Toy Industry: The Business Model of a Romanian Company. *Sustainability*, 14(1), 22. https://doi.org/10.3390/SU14010022

Nithya, R., Sivasankari, C., & Thirunavukkarasu, A. (2021). Electronic waste generation, regulation and metal recovery: a review. *Environmental Chemistry Letters*, 19(2), 1347–1368. https://doi.org/10.1007/S10311-020-01111-9/FIGURES/6

Obafemi, O., Stephen, A., Ajayi, O., & Nkosinathi, M. (2019). A survey of Artificial Neural Network-based Prediction Models for Thermal Properties of Biomass. Procedia Manufacturing, 33, 184–191. https://doi.org/10.1016/J.PROMFG.2019.04.103

Padmanabhan, S., Giridharan, K., Stalin, B., Kumaran, S., Kavimani, V., Nagaprasad, N., … Krishnaraj, R. (2022). Energy recovery of waste plastics into diesel fuel with ethanol and ethoxy ethyl acetate additives on circular economy strategy. *Scientific Reports*, 12(1), 1–13. https://doi.org/10.1038/s41598-022-09148-2

Pariso, P., Picariello, M., & Marino, A. (2023). Circular economy and rare materials: a challenge for the European countries. *Entrepreneurship and Sustainability Issues*, 11(2), 79-92. https://doi.org/10.9770/jesi.2023.11.2(6)

Pceļina, V., Lavrinenko, O., & Danileviča, A. (2023). Disproportions of the green economy in the selected countries. *Entrepreneurship and Sustainability Issues,* 11(1), 293–305. https://doi.org/10.9770/jesi.2023.11.1(18)

Petereit, J., Hoerterer, C., & Krause, G. (2022). Country-specific food culture and scientific knowledge transfer events – Do they influence the purchasing behaviour of seafood products? *Aquaculture*, 560, 738590. https://doi.org/10.1016/J.AQUACULTURE.2022.738590

Polyakov, M., Khanin, I., Shevchenko, G., & Bilozubenko, V. (2021). Constructing a model of national production system for building a circular economy for international trade involvement. *Entrepreneurship and Sustainability Issues*, 9(1), 287–299. https://doi.org/10.9770/jesi.2021.9.1(17)

Radavičius, T., Heide, A. van der, Palitzsch, W., Rommens, T., Denafas, J., & Tvaronavičienė, M. (2021). Circular solar industry supply chain through product technological design changes. *Insights into Regional Development*, 3(3), 10–30. https://doi.org/10.9770/IRD.2021.3.3(1)

Razminienė, K. (2019). Circular economy in clusters' performance evaluation. Equilibrium. *Quarterly Journal of Economics and Economic Policy*, 14(3), 537–559. https://doi.org/10.24136/eq.2019.026

Remøy, H., Wandl, A., Ceric, D., & van Timmeren, A. (2019). Facilitating Circular Economy in Urban Planning. *Urban Planning*, 4(3), 1–4. https://doi.org/10.17645/UP.V4I3.2484

Rezk, M. R. A., Kapiel, T. Y. S., Piccinetti, L., Salem, N., Khasawneh, A., Santoro, D., … Sakr, M. M. (2023). Circular economy in Egypt: an overview of the current landscape and potential for growth. *Insights into Regional Development*, 5(3), 45–57. https://doi.org/10.9770/ird.2023.5.3(3)

Rezk, M. R., Piccinetti, L., Salem, N., Omoruyi, T. U., & Santoro, D. (2024). Nigeria's transition to a circular economy: challenges, opportunities and future perspectives. *Insights into Regional Development*, 6(2), 11–23. https://doi.org/10.9770/IRD.2024.6.2(1)

Ruiz-Salmón, I., Laso, J., Margallo, M., Villanueva-Rey, P., Rodríguez, E., Quinteiro, P., … Aldaco, R. (2021). Life cycle assessment of fish and seafood processed products – A review of methodologies and new challenges. *Science of The Total Environment*, 761, 144094. https://doi.org/10.1016/J.SCITOTENV.2020.144094

Ruginė, H., & Žilienė, R. (2024). Towards a new framework of circular economy. *Entrepreneurship and Sustainability Issues*, 11(3), 278–289. https://doi.org/10.9770/jesi.2024.11.3(19)

Rybalkin, O., Lavrinenko, O., Danileviča, A., & Lizińska, W. (2023). Sustainable Development Green Index: measuring progress towards sustainable development goals in the European Union. *Entrepreneurship and Sustainability Issues*, 10(4), 279¬–292. https://doi.org/10.9770/jesi.2023.10.4(17)

Salas, D. A., Criollo, P., & Ramirez, A. D. (2021). The Role of Higher Education Institutions in the Implementation of Circular Economy in Latin America. *Sustainability*, 13(17), 9805. https://doi.org/10.3390/SU13179805

Scipioni, S., Russ, M., & Niccolini, F. (2021). From Barriers to Enablers: The Role of Organisational Learning in Transitioning SMEs into the Circular Economy. *Sustainability*, 13(3), 1021. https://doi.org/10.3390/SU13031021

Šimelytė, A., Tvaronavičienė, M., Bøgh Holmen, R., Burinskas, A., & Razminienė, K. (2021). Knowledge and technology transfer as driving force for social innovations. *Polish Journal of Management Studies*, 23(2), 512–536. https://doi.org/10.17512/PJMS.2021.23.2.31

Šimelytė, A., Tvaronavičienė, M., Peyravi, B., & Beretta, E. (2023). The impact of the external environment on transferring from linear to circular economy with the mediating role of knowledge assimilation. Journal of Infrastructure, Policy and Development, 8(2), 2699. https://doi.org/10.24294/JIPD.V8I2.2699

Stander, H. M., & Broadhurst, J. L. (2021). Understanding the Opportunities, Barriers, and Enablers for the Commercialization and Transfer of Technologies for Mine Waste Valorization: A Case Study of Coal Processing Wastes in South Africa. *Resources*, 10(4), 35. https://doi.org/10.3390/RESOURCES10040035

Stelmaszczyk, M., Pierścieniak, A., & Krzysztofek, A. (2021). Managerial Energy in Sustainable Enterprises: Organisational Wisdom Approach. *Energies*, 14(9), 2367. https://doi.org/10.3390/EN14092367

Teerikangas, S., & Colman, H. L. (2020). Theorising in the qualitative study of mergers & acquisitions. *Scandinavian Journal of Management*, 36(1), 101090. https://doi.org/10.1016/J.SCAMAN.2019.101090

Tzanakakis, V. A., Angelakis, A. N., Paranychianakis, N. V., Dialynas, Y. G., & Tchobanoglous, G. (2020). Challenges and Opportunities for Sustainable Management of Water Resources in the Island of Crete, Greece. *Water*, 12(6), 1538. https://doi.org/10.3390/W12061538

Wang, S., Zhang, S., Xi, G., & Wong, M. C. (2024). Analysis of innovation efficiency and influencing factors of listed companies in Beijing-Tianjin-Hebei economic zone based on improved DEA. *Insights into Regional Development*, 6(2), 24-47. https://doi.org/10.9770/IRD.2024.6.2(2)

Wilke, U., & Pyka, A. (2024). Assessing the relevance of different proximity dimensions for knowledge exchange and (co-)creation in sustainability-oriented innovation networks. *Sustainability Science*, 1–17. https://doi.org/10.1007/S11625-024-01463-Z/METRICS

Williams, K. S., & Khodier, A. (2020). Meeting EU ELV targets: Pilot-scale pyrolysis automotive shredder residue investigation of PAHs, PCBs and environmental contaminants in the solid residue products. *Waste Management*, 105, 233–239. https://doi.org/10.1016/J.WASMAN.2020.02.005

Worldometer - real time world statistics. (n.d.). Retrieved May 14, 2024, from https://www.worldometers.info/

Yalçınkaya, A., Feyzioglu, A., Boyraz, C., Haliloglu, H., Santoro, D., & Piccinetti, L. (2024). Demand side response program for more sustainable electricity market: a case study of Türkiye. *Insights into Regional Development*, 6(1), 11–22. https://doi.org/10.9770/ird.2024.6.1(1)

Zanelli, C., Conte, S., Molinari, C., Soldati, R., & Dondi, M. (2021). Waste recycling in ceramic tiles: a technological outlook. *Resources, Conservation and Recycling*, 168, 105289. https://doi.org/10.1016/J.RESCONREC.2020.105289