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REVIEW PAPER

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INNOVATIVE APPROACHES IN SUSTAINABLE ENGINEERING FOCUS ON THE IMPLEMENTATION OF CIRCULAR ECONOMY PRINCIPLES AND THE INTEGRATION OF RENEWABLE ENERGY APPLICATIONS – A REVIEW

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ABSTRACT

This review presents an integrated examination of recent advances in sustainable engineering, linking circular economy strategies, renewable energy applications, and water reuse technologies within a unified framework of resource efficiency. Unlike existing literature that discusses these areas separately, this study synthesises their interrelationships and identifies how combined implementation can accelerate sustainability outcomes. The review assesses current practices in sustainable construction, life cycle assessment, renewable energy deployment, and industrial and municipal water reuse, drawing on case studies from Qatar, the United Arab Emirates and China. Trends, challenges, and research gaps are critically assessed, highlighting the need for large-scale validation, standardised assessment metrics, and supportive regulatory mechanisms. The paper presents a conceptual framework that connects materials, energy, and water efficiency and outlines actionable directions for engineers and researchers to scale sustainable engineering solutions.

Keywords: sustainable engineering, circular economy, renewable energy, life cycle assessment, water reuse

INTRODUCTION

Over the last 20 years, the global market has consistently prioritised energy conservation and the recycling or reuse of water, even before the establishment of criteria such as BREEAM and LEED. An essential aspect of these endeavours has been the implementation of water and energy metering, which involves transferring the accountability and financial burden of consumption to the individual user. Implemented through the use of devices such as hot- and cold-water meters, heat meters, and electricity meters, this strategy has demonstrated its efficacy as an economic method for reducing energy consumption and media usage by decreasing utility bills. Furthermore, there has been a growing acceptance of the principles of the circular economy, which advocate for the reuse of resources. This encompasses the process of reusing treated air in mechanical ventilation and air conditioning systems, collecting rainwater, utilising condensate from cooling systems, and repurposing treated wastewater for activities such as toilet flushing and irrigation of green spaces,

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particularly in hot equatorial areas. This review examines novel methods in sustainable engineering, with a specific emphasis on incorporating circular economy ideas and integrating renewable energy technologies. The text discusses existing techniques, accomplishments, and challenges, offering valuable insights and recommendations for future studies and the development of policies to promote global sustainability. A study by Papadakis, Savvides, Aimilios and Michopoulos (2024) examines the difficulties faced by cities as they develop due to population increase, even in the presence of insufficient mobility infrastructure. They emphasise the need for cities to create sustainable urban mobility plans (SUMPs) in order to tackle this problem. The study provides optimal methods for encouraging a shift in transportation modes by aligning them with public transit policies, promoting active mobility, and discouraging the use of private vehicles.

Maqbool, Arul and Ashfaq (2023) evaluated the level of knowledge among UK practitioners on sustainable construction methods and identified obstacles preventing their implementation. A hybrid methodology was employed, incorporating questionnaire surveys and interviews to gather data from professionals across various fields, as illustrated in Figure 1. The results indicated that professionals in the field possess a higher level of knowledge regarding sustainable practices, with the most prevalent ones being reduce, reuse, and recycle. The primary obstacle was the desire to uphold existing methods rather than the issue of cost. Overcoming these obstacles could enhance the implementation of environmentally friendly building practices in the United Kingdom.

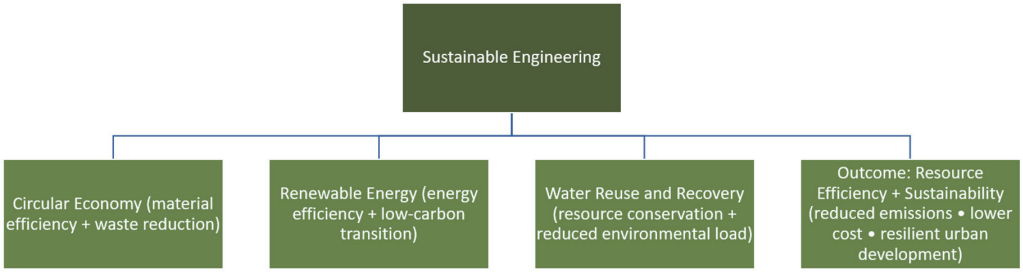

Fig. 1. Integrated framework linking circular economy, renewable energy, and water reuse for sustainable engineering

Source: own work.

Mariyam, Cochrane, Al-Ansari and McKay (2024) developed a techno-policy framework that prioritises sustainable solid waste management in Qatar. The text highlights the significance of private sector training, plastic recycling, and tackling mega-events. The framework also emphasises the necessity of interdisciplinary collaboration, awareness campaigns, and efficient waste management measures. Nevertheless, the absence of complete open data gives rise to difficulties that require focused endeavours in various situations. Hafdhi and Euchi (2023) introduced a novel approach called the multi-attribute superiority, inferiority, and non-inferiority selection approach (MASINISA) to assist consumers in making well-informed choices regarding the selection of renewable energy options in Tunisia. The technique employs comparative measures of superiority, inferiority, and non-inferiority to assess the quality of evidence for the goodness or poverty of a treatment. The suggested MASINISA version was tested at the STEG Company in Tunisia, and all the renewable energy technologies it produced were deemed acceptable by STEG specialists. Duckett, Troldborg, Hendry and Cousin (2024) emphasise the necessity of incorporating climate change and the circular economy into water reuse initiatives in regions like Scotland, where water scarcity is not a significant concern. They propose implementing innovative strategies to overcome obstacles to reuse, such as intricate regulatory

frameworks and trust dependencies. The notion of a 'yum factor' or 'yuck factor' can be employed to facilitate the swift growth of municipal-scale reuse. Despite the rapid growth of studies on sustainable engineering, the existing literature remains fragmented across the circular economy, renewable energy, and water reuse, making it difficult to identify their combined contribution to resource-efficient development. Therefore, this review aims to consolidate recent advancements and critically examine how these three domains complement each other in supporting sustainable engineering practices. The literature used in this review was identified through the Scopus and Web of Science databases, utilising keywords such as 'circular economy', 'renewable energy', 'sustainable construction', 'water reuse' and 'resource efficiency'. Only peer-reviewed articles that were recently published were included to ensure the inclusion of recent insights.

CIRCULAR ECONOMY IN ENGINEERING

The engineering industry prioritises the circular economy, which seeks to reduce waste and enhance resource efficiency by reusing and recycling commodities. This section examines the application of circular economy ideas in several engineering disciplines, with a focus on innovative approaches and successful case studies. The research conducted by Dsilva, Zarmukhambetova and Locke (2023) emphasise the significance of life cycle assessment (LCA) in the building industry for reducing carbon dioxide emissions associated with the production and use of materials. The study, which focused on a G+2 structure in Dubai, found that meticulous material selection and early engagement with LCA resulted in a significant 26% decrease in the building's embodied carbon. The report emphasises the importance of political support in establishing sustainable practices and promoting circularity in the building industry. Pujadas-Gispert et al. (2020) highlight the potential to enhance energy efficiency and reduce the environmental impact of the construction industry. The building envelope plays a crucial role in reducing energy consumption throughout a building's lifespan, as most energy is used during its operation and maintenance. The study assesses the design, construction, and thermal efficiency of a ventilated façade that can be easily installed, disassembled, and packed into containers. The outside structure is constructed using bio-based materials, aligning with the principles of a circular economy. The cladding's outer layer consists of hygiene paper, grass, reeds, recovered textiles, waste from drinking water treatment, bio-based polyester resin, and other miscellaneous components. Temperature and air velocity measurements conducted in Dubai revealed that the façade significantly contributed to preserving cool temperatures within the flat, particularly during the hottest hours of the day. The façade is an attractive option for areas with hot summers and mild winters, as it can reduce energy consumption and lessen the environmental impact of building materials. The study emphasises the importance of the building envelope in implementing sustainable construction practices.

Al Martini et al. (2023) investigated the mechanical properties of concrete mixtures that included recycled concrete aggregate obtained from demolished buildings in Abu Dhabi. The researchers found that concrete with a 20% content of recycled concrete aggregate is appropriate for use in structural applications. Moreover, most ternary blend mixes successfully attained the intended design strength. The research advocates for the broader adoption of root cause analysis in the construction sector. Abu-Hijleh and Jaheen (2019) revealed that the Dubai administration has shown a strong inclination towards integrating sustainable principles across the different phases of construction. This is evident from the introduction of the green building regulations and specification in 2011. This study examines the effectiveness of these limitations and evaluates the benefits of improving the prerequisites to achieve PassivHaus standards, as illustrated in Figure 2. The villa case study at Jumeirah Park was evaluated using the IESVE energy modelling program. The implementation of the updated Dubai green building regulations and specification resulted in reductions in cooling load of 5.9%, 8.7%, 1.6%, 11.0%, and 20.0%, as indicated by the findings. The adoption of PassivHaus standards resulted in a 48% reduction in the cooling load.

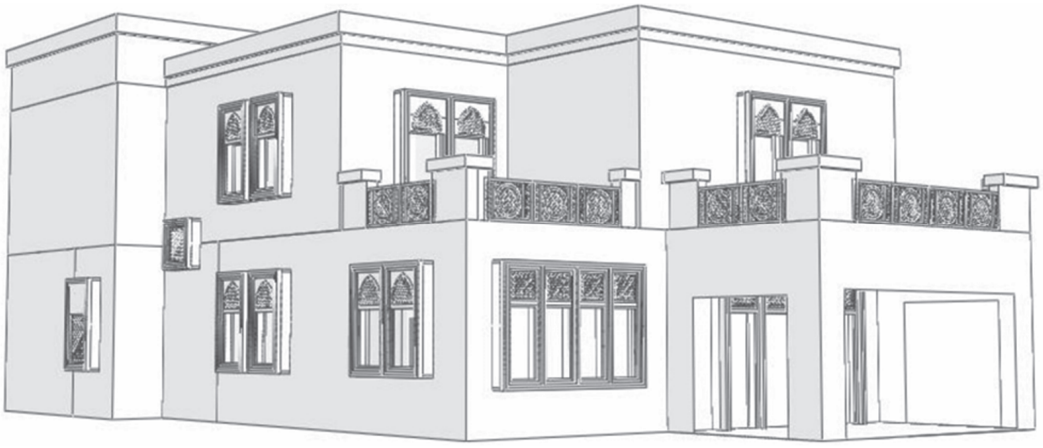

Fig. 2. IESVE villa energy model

Source: Abu-Hijleh and Jaheen (2019).

Obaideen et al. (2021) examine how the growth of the global economy affects the supply of and demand for energy, which in turn influences the creation of sustainable development goals (SDGs). Solar energy has the potential to mitigate energy footprints. The study examines the role of the Mohammed bin Rashid Al Maktoum Solar Park in the United Arab Emirates in advancing the SDGs, with a specific focus on its environmental impact through the implementation of clean and cost-effective energy sources. The park has successfully negated the output of 6.5 million tonnes of carbon dioxide equivalent and accomplished multiple SDGs. Overall, the reviewed studies demonstrate a strong consensus that circular economy strategies significantly reduce embodied carbon and enhance material efficiency in the construction sector. However, while some works highlight bio-based materials and façade systems as major contributors to energy efficiency, others emphasise the recycling of aggregates and the implementation of performance-based regulations. A common research gap is the lack of long-term performance assessments of circular materials under real environmental conditions, along with limited policy frameworks that support large-scale adoption. While circular economy strategies reduce material waste and embodied carbon, their full benefits can only be achieved when supported by clean energy systems. Therefore, the following section examines renewable energy technologies, which play a complementary role in enhancing resource efficiency and reducing the environmental footprint of sustainable engineering projects.

SCOPE AND METHODOLOGY OF THE REVIEW

The objective of this review is to consolidate and critically evaluate recent advancements in sustainable engineering with an emphasis on circular economy strategies, renewable energy applications, and water reuse technologies. The scope of the review encompasses peer-reviewed research articles, case studies, and technical reports that focus on the implementation of sustainable engineering approaches in urban and industrial contexts.

The literature for this review was collected from the Scopus and Web of Science databases using keywords such as ‘circular economy’, ‘sustainable construction’, ‘renewable energy technologies’, ‘water reuse’ and ‘resource efficiency’. Only articles published between 2019 and 2024 were considered to ensure recent developments. The selected studies were analysed based on their objectives, methodologies, outcomes, limitations, and contributions to sustainability, enabling a thematic comparison across the three major domains.

RENEWABLE ENERGY TECHNOLOGIES AND THEIR APPLICATIONS

Renewable energy technologies are crucial in reducing carbon emissions and promoting sustainable development. This section examines the latest advancements and applications of renewable energy, including solar, wind, and bioenergy, as well as their impact on various industries and urban development. Vignisdottir, Barrera-Cardenas and Pascual-Muñoz (2023) examine the growing proportion of electric vehicles and plug-in hybrids in the automotive industry, which necessitates the development of energy centres and charging infrastructure. The use of renewable energy technologies has the potential to make a significant contribution towards achieving low-carbon transportation. Hassan and El-Rayes (2024) devised an innovative multi-objective optimisation framework to enhance the efficiency of building schematic design for the purpose of generating renewable energy on-site. The model prioritises the optimisation of renewable energy generation, the reduction of construction and operational expenses for renewable energy, and the maximisation of the savings-to-investment ratio for integrated renewable energy systems. The model was utilised to enhance the schematic design of a 6,500 m^2 building, emphasising its unique contributions and innovative possibilities.

Chen (2024) investigates the influence of renewable energy technology innovation (RETI) on the urbanisation process in China's prefecture-level cities between 2010 and 2021. The results indicate that RETI plays a key role in promoting urbanisation by enhancing industrial structure, productivity, and rural income. The report presents a conceptual framework and practical suggestions for achieving effective and sustainable urban growth. Although renewable energy reduces the dependence on fossil fuels, urban sustainability also depends on efficient water management. The transition towards circular resource use requires not only low-carbon energy systems but also innovative approaches for water reuse and wastewater recovery, which are examined in the next section.

WATER REUSE AND RESOURCE EFFICIENCY

Water reuse and resource efficiency are essential for addressing water scarcity and enhancing sustainability. This section examines cutting-edge technologies and strategies for reusing water, including desalination and wastewater treatment, to optimise resource efficiency and minimise environmental impact. Lanter et al. (2024) examined the highest possible desalination recovery ratio (RR_{max}) for safely disposing of desalination brine in water-scarce areas such as Kenya. Water samples were collected from the Mara Triangle and analysed to assess contaminant concentrations in relation to established safety thresholds for salinity and hazardous components. The findings indicated that the Mara Triangle had impressive water recoveries, with a maximum ratio of over 94% for agricultural irrigation and 98% for livestock watering. The primary constraint for brine reuse was predominantly salinity, with the boron concentration being the secondary factor. All areas were able to cultivate the most salt-tolerant crops. Amaral, Martins and Dias (2023) emphasise the significance of finding service providers that demonstrate exceptional performance in crucial operational metrics for the long--term viability of the wastewater treatment sector. The study finds Portuguese service providers that excel in wastewater reuse efficiency and examines the key factors that drive their operations. The report suggests promoting the development of smaller service providers to achieve economies of scale and establishing effective infrastructure maintenance methods to support the increasing use of wastewater reuse.

The food industry can achieve sustainable water use by transitioning to circular practices and actively exploring possibilities for water recycling (Harasztiné, Sebestyén & Somogyi, 2024). An illustrative case study was conducted using a chicken processing factory to demonstrate that enhancing wastewater treatment technology can result in a nearly 30% reduction in metal depletion and a 90% decrease in chemical use. Additional mitigation could be accomplished by selecting technical or agricultural reuse alternatives. The study showed an 11.0–17.1% reduction in freshwater consumption and a corresponding decline in metal depletion units –7.6% in 2018 and 2.6% in 2019 – when reusing technology was implemented. Although there are legal

obligations and societal concerns, the study indicates that water reuse is a viable and ecologically responsible option for the food business.

Rodríguez-Castillo et al. (2024) investigate the utilisation of recycled wastewater as a viable solution to mitigate the depletion of freshwater resources. The researchers assess the sustainability of the Anaerobic--Algal Membrane Bioreactor (A2MBR) in Central Chile. The study revealed that the implementation of the A2MBR system resulted in enhanced water supply and nutrient recovery, as well as lowered indicators of global warming, eutrophication, and acidification potential. Furthermore, the treatment costs associated with this system were shown to be competitive when compared to other available solutions. Nevertheless, it is necessary to conduct pilot demonstrations and a comprehensive long-term social assessment in order to verify the validity of these sustainability benefits.

Thomassen et al. (2024) conducted a prospective extended life cycle assessment to compare the environmental impact of a new design of reusable packaging for 2 kg of rice with that of a standard single-use packaging. The study revealed that the reusable rice packaging has the potential to be utilised up to five times. However, it was observed that its influence on global warming and depletion of fossil resources is two to three times greater. The sensitivity analysis identified the reusability and return rate as the most influential parameters. If these parameters could be improved to achieve a value of 99.8%, with a total of 16 uses, the environmental impact of the reusable packaging would be lower than that of its conventional single-use counterpart in terms of climate change. The significant food-to-packaging ratios highlight the need to minimise food waste. Assuming that the packaging design could decrease food losses by 0.2%, the reusable packaging for rice would have a minor impact on water use, mineral resources, and metal resources compared to the single-use packaging for rice. This is true even though the reusable packaging unit itself has a higher environmental impact.

Guleria et al. (2024) investigated the effectiveness of one-pass capacitive electrodialysis on a pilot scale to improve water use and minimise environmental impacts. The study found that one-pass capacitive electrodialysis produced high-quality greenhouse irrigation water, which had decreased Na^+ retention compared to other compounds. The nutrient concentration factors reached their highest values of 2.3 $mg \cdot L^{-1}$, 2.7 $mg \cdot L^{-1}$ and 1.9 $mg \cdot L^{-1}$, respectively. However, there was no significant improvement in ion removal for any of the input compositions at voltages above 12 V and water recovery rates above 80%. The specific energy consumption of one-pass capacitive electrodialysis was one-fourth that of the modelled reverse osmosis system and previous electrodialysis tests. The highest specific energy consumption ever reported for one-pass capacitive electrodialysis was 0.24 $kWh \cdot m^{-3}$.

CASE STUDIES OF SUSTAINABLE ENGINEERING PRACTICES

Case studies offer concrete and practical insights into the implementation of sustainable engineering methods across various geographic regions and industries. This section provides a summary of real-life examples, highlighting the successful application of sustainable practices and showcasing the benefits and challenges encountered in these efforts (Al-Hamrani et al., 2021). The construction sector makes a significant contribution to environmental footprints and the depletion of natural resources. The goals of sustainable construction include minimising waste and having a positive impact on climate change. Qatar's commitment to achieving a sustainable FIFA World Cup in 2022 led to the implementation of an LCA for the Education City Stadium. The study employed the cyclopean concrete method, which involves mixing concrete with stones excavated from the site to construct the stadium's foundation. The cyclopean concrete approach resulted in a 32% decrease in greenhouse gas emissions in comparison to conventional concrete. This indicates that the cyclopean concrete technique can deliver satisfactory structural performance using site-excavated stones as a cost-efficient substitute for conventional aggregates, resulting in a lower environmental footprint. Figure 3 illustrates the application of both bottom-up and top-down techniques in building ecologically friendly structures.

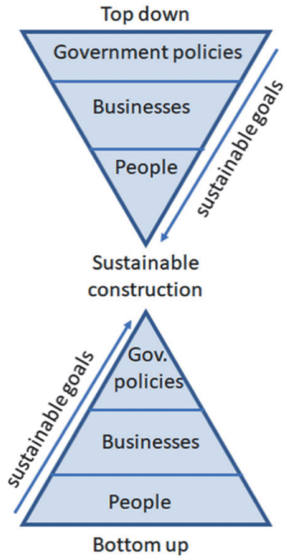

Fig. 3. Utilisation of both top-down and bottom-up methodologies in environmentally friendly construction

Source: Maqbool et al. (2023).

Ahn et al. (2022) performed a comprehensive analysis of the existing literature to find a total of 23 guiding principles that are based on the concept of circular economy in the construction business. The study examined mass timber construction, an environmentally friendly alternative to conventional building materials, and its potential to facilitate the transition towards a low-carbon society. The analysis revealed that although the environmental advantages of mass timber manufacture and building are extensively documented, their potential and circular economy potential are frequently disregarded. There is a lack of evidence and practical examples of prefabricated mass timber panels reaching the end-of-life stage and incorporating circular economy concepts compared to traditional building types. The evaluation identified significant knowledge gaps and urgent research needs for advancing comprehensive strategies in preparing mass timber construction for the circular economy. The results highlight the need to address these deficiencies in the building sector to achieve a more environmentally friendly and circular economy.

Tushar, Mainul Bari and Khan (2022) present a comprehensive multiple-criteria decision-making framework for selecting suppliers in the construction industry with a focus on circular practices. The framework utilises the fuzzy analytical hierarchy process and the preference ranking organisation technique for enriching evaluations (PROMETHEE II) to establish a supplier ranking, with the best-ranked suppliers at the top and the worst-ranked at the bottom. The primary factors for supplier selection include punctual delivery, adherence to specifications, rejection rate, pollution control efforts, utilisation of eco-friendly packaging, and compliance with environmental legislation. This technique is anticipated to strengthen the circular supply chain model and enhance business sustainability.

Wuni and Shen (2022) study circular economy principles in modular construction projects in Hong Kong. Their study employed a range of research approaches, including literature review, consultation, questionnaire survey, mean score ranking, factor analysis, and fuzzy synthetic evaluation, to identify a total of 21 relevant factors. The five primary variables include timely completion of design, strong commitment from the client, effective leadership from the contractor, a team with adequate experience, and a collaborative work environment.

The study also identified three clusters of success factors: streamlined supply chain management, specialised knowledge and early commitment, and collaboration and information management. Torgautov et al. (2022) examined the significant global influence of the building industry on waste generation. The circular economy offers a feasible approach to minimising waste associated with construction and demolition. This study aims to create a framework for strategically developing actions and initiatives that promote environmental consciousness in the construction industry. The technique used by developing economies, such as Kazakhstan, is a balanced scorecard. Key activities include minimising transportation expenses, executing continuous improvement initiatives, overseeing contractor management, accurately forecasting material needs, and facilitating information sharing within the organisation.

Li, Sun, Song, Li and Hao (2021) analyse the sustainability of Rizhao City, a coastal circular economy eco-city, throughout the period from 2005 to 2017. The study found that socioeconomic development's dependence on regional non-renewable resources leads to a larger environmental loading ratio. The circular economy's performance was enhanced with a self-support ratio exceeding 94%. To enhance the sustainability of Rizhao City, further policy recommendations are necessary due to the inadequate coordination within the existing system (Yu et al., 2024).

FUTURE TRENDS AND CHALLENGES IN SUSTAINABLE ENGINEERING

This section examines the emerging patterns and challenges encountered in the field of sustainable engineering. In the pursuit of a more environmentally friendly future, numerous innovative methods and technologies are being examined and implemented. Nevertheless, the journey towards sustainability is filled with challenges that must be addressed to ensure enduring prosperity and global acceptance:

1. The use of circular economy ideas is anticipated to increase, with a specific emphasis on waste reduction and improving resource efficiency. The implementation of recycling technologies and the development of sustainable material design will be essential in effectively reducing resource consumption.
2. The transition to renewable energy sources, such as solar, wind, and biofuels, will continue to gain momentum. To fully harness the potential of renewable energy, it is essential to address the challenges associated with storage, grid integration, and cost reduction.
3. The advancement of intelligent cities that employ data and technology to enhance urban infrastructure will be crucial. The challenges encompass guaranteeing data security, overseeing urban development, and promoting public acceptance and engagement.
4. Advanced water reuse and desalination technologies will play a crucial role in tackling water scarcity. Effectively managing water resources and successfully addressing regulatory and public perception obstacles will be crucial for achieving sustainable water utilisation.
5. Implementing efficient policies and regulations will be crucial in promoting the acceptance and implementation of sustainable practices. Establishing uniform international standards, offering incentives, and ensuring adherence will present notable challenges.

Although technological progress in sustainable engineering is rapid, deployment remains limited by several barriers, including high upfront investment, insufficient policy enforcement, fragmented regulations across regions, and limited public awareness. Moreover, industries are often hesitant to adopt circular and renewable solutions due to uncertainties in long-term performance and a lack of standardised evaluation metrics. To accelerate progress, more substantial government incentives, mandatory reporting of embodied carbon, investment in pilot-scale demonstration projects, and the development of international certifications for circular materials and water-energy recovery systems are urgently needed.

CONCLUSION

This section provides a concise overview of the key discoveries and insights gained from our examination of innovative methods in sustainable engineering, with a particular focus on the importance of circular economy concepts and the integration of renewable energy sources. The evaluated papers provide a comprehensive understanding of current practices and future trends, highlighting both achievements and areas that require further improvement.

1. Our review highlights the need to use circular economy principles in many sectors. Implementing strategies that prioritise resource efficiency and reduce environmental impact is crucial for achieving sustainable development across various sectors, including construction and waste management.
2. The incorporation of sustainable energy technologies, such as solar and wind power, is crucial in decreasing carbon emissions and improving energy sustainability. The studies analysed have demonstrated practical implementations and highlighted the need for ongoing innovation to address current obstacles in this field.
3. Employing LCA approaches in construction and other industries aids in the identification and reduction of environmental impacts. Our review highlights the effectiveness of LCA in reducing carbon emissions associated with products and promoting the use of sustainable materials.
4. Effective water reuse strategies and advanced technology are crucial for tackling water scarcity and enhancing resource efficiency. The evaluated research yields encouraging outcomes in desalination and wastewater treatment, contributing to the implementation of sustainable water management strategies.
5. The results underscore the need for additional investigation and supportive measures to promote the implementation of sustainable practices. To achieve the shift towards sustainable engineering, it is crucial to foster collaboration across multiple disciplines, raise public awareness, and establish robust regulatory frameworks.

To summarise, this research demonstrates substantial advancements in sustainable engineering, while also highlighting the persistent challenges and opportunities for growth. To attain global sustainability goals, it is imperative to continue making efforts in innovation, receiving policy backing, and fostering collaboration. Despite significant progress, current research still lacks large-scale pilot demonstrations and long-term performance assessments of circular materials and integrated energy–water systems. Policymakers should prioritise mandatory embodied-carbon reporting, incentives for integrating renewable energy, and regulatory support for industrial water reuse. Engineers and researchers should focus on developing scalable models that combine material, energy, and water efficiency rather than treating them independently. Coordinated policies, industrial adoption, and interdisciplinary research will be essential for realising the full potential of sustainable engineering.

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Authors' contributions

Conceptualisation: T.B.; methodology: A.S. and T.B.; validation: A.S. and T.B.; formal analysis: A.S., T.B. and W.S.; investigation: A.S. and T.B.; resources: A.S. and T.B.; data curation: A.S. and T.B.; writing – original draft preparation: A.S. and W.S.; writing – review and editing: A.S. and W.S.; visualisation: T.B.; supervision: T.B.

All authors have read and agreed to the published version of the manuscript.

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INNOWACYJNE KIERUNKI W INŻYNIERII ZRÓWNOWAŻONEJ Z UWZGLĘDNIENIEM GOSPODARKI O OBIEGU ZAMKNIĘTYM I TECHNOLOGII ODNAWIALNYCH ŹRÓDEŁ ENERGII – PRZEGLĄD

STRESZCZENIE

W niniejszym przeglądzie przeanalizowano nowatorskie strategie w zakresie inżynierii zrównoważonej ze szczególnym uwzględnieniem implementacji koncepcji gospodarki o obiegu zamkniętym i integracji technologii energii odnawialnej. Główne tematy obejmują tworzenie planu zrównoważonej mobilności miejskiej (SUMP), ocenę zrównoważonych metod budownictwa oraz wkład technologii energii odnawialnej w rozwój urbanizacji i zrównoważenia środowiskowego. W artykule omówiono również znaczenie oceny cyklu życia (LCA) w ograniczaniu emisji dwutlenku węgla w budownictwie, wpływ globalnej ekspansji gospodarczej na podaż i popyt na energię oraz potencjał energii słonecznej w osiąganiu celów zrównoważonego rozwoju (SDGs). Ponadto przeanalizowano metody ponownego wykorzystania wody i poprawy efektywności wykorzystania zasobów w przemyśle i gospodarce komunalnej. Studia przypadków przeprowadzonych w Katarze, Zjednoczonych Emiratach Arabskich i Chiny dostarczyły praktycznych spostrzeżeń dotyczących wdrażania tych zrównoważonych metod. W artykule zaprezentowano ramy koncepcyjne łączące efektywne wykorzystanie materiałów, energii i wody oraz określono praktyczne wskazówki dla inżynierów i badaczy dotyczące skalowania zrównoważonych rozwiązań inżynieryjnych.

Słowa kluczowe: inżynieria zrównoważona, gospodarka w obiegu zamkniętym, energia odnawialna, ocena cyklu życia, ponowne wykorzystanie wody