Circular Economy 4 (2025) 100140

Contents lists available at ScienceDirect

Circular Economy

journal homepage: www.journals.elsevier.com/circular-economy

Review

The SDG accelerator: Circular economy solutions through efficient sustainable consumption

Anupam Khajuria [a,*], Prabhat Verma [b], Atienza Vella [c], Daniela Zanini-Freitag [d], Hao Xin [e], Indu K. Murthy [f], Jatinder K. Arora [g], Kamani Sylva [h], Lakshmi Menon [f], Sushma Pardeshi [i], Ulrich Kral [d], Xiao Liu [j]

[a] Institute for the Advanced Study of Sustainability, United Nations University, Tokyo 1508925, Japan
[b] Department of Applied Physics, Osaka University, Osaka 5650871, Japan
[c] Institute for Governance and Rural Development (IGRD), College of Public Affairs and Development, University of the Philippines at Los Baños (UPLB) College, Laguna 4031, Philippines
[d] Environment Agency Austria, Vienna 1090, Austria
[e] Regional Centres of Expertise on Education for Sustainable Development (RCE)-Hangzhou, Hangzhou 310012, China
[f] Center for Study of Science, Technology and Policy, Bangalore 560094, India
[g] Punjab State Council for Science and Technology, Chandigarh 160019, India
[h] Department of Engineering Management, Faculty of Engineering, University of Peradeniya, Peradeniya 20400, Sri Lanka
[i] CSIR-National Environmental Engineering Research Institute (NEERI), Nagpur 440020, India
[j] The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), Beijing 100600, China

ARTICLE INFO

Article history:
Received 8 October 2024
Received in revised form
18 February 2025
Accepted 30 March 2025
Available online 14 April 2025

Keywords:
Waste management
Recycling
Sustainable consumption and production (SCP)
Circular economy
Quality education
Education for sustainable development (ESD)
Social governance
Nature-based solutions (NbSs)
United Nations sustainable development goals (UN SDGs)

ABSTRACT

The integration of sustainable consumption, education, and circular economy principles is essential for effective waste management and achieving the United Nations sustainable development goals (UN SDGs). This research approach, including applied project conclusions, examines the role of education in promoting sustainable consumption and circular economy practices, highlights key aspects of circular economy solutions and addresses the challenges of waste management in India, China, and the Philippines. This paper draws on sessions from the 18th and 19th International Conference on Waste Management and Technology, which focused on expanding waste management services and integrating quality education for sustainable practices. The findings underscore the importance of robust waste management policies, public awareness, and innovative recycling technologies to achieve sustainable consumption and production (SCP). Furthermore, the paper emphasizes the need for collaboration among policymakers, educational institutions, and industry stakeholders to foster a culture of sustainability and circularity. By leveraging education to drive systemic changes in consumption patterns and waste management, this study contributes to a deeper understanding of how these elements collectively support the achievement of the UN SDGs, particularly SDG 12 (responsible consumption and production) and SDG 4 (quality education).

1. Introduction

The United Nations sustainable development goals (SDGs) rely on promoting sustainable and responsible consumption while also providing education on the circular economy. Sustainable consumption entails using resources efficiently and selecting products with minimal environmental impact, ensuring that present needs are met without compromising the ability of future generations to meet their needs (Khajuria et al., 2022). This approach is crucial for several SDGs, especially Goal 12, responsible consumption and production (UNEP, 2018a); Goal 13, climate action (UNEP, 2018c); and Goal 15, life on land (UNEP, 2018b). The promotion of sustainable consumption practices can significantly reduce waste, decrease greenhouse gas emissions, and conserve natural resources, thereby contributing to a resource-saving and environmentally friendly society for all humans.

The pursuit of sustainable development has never been more crucial than in the current era, where environmental degradation

* Corresponding author.
E-mail address: khajuria@unu.edu (A. Khajuria).

https://doi.org/10.1016/j.cec.2025.100140

and resource depletion pose significant challenges to global well-being (Huo & Peng, 2023; Khajuria and Verma, 2025). At the heart of this effort lies the promotion of sustainable and responsible consumption, quality education, and the circular economy. These interconnected concepts are crucial for achieving effective waste management, which is vital for meeting the UN SDGs. In particular, SDG 12 seeks responsible consumption and production, whereas SDG 4, which is related to quality education (UNEP, 2019), underscores the importance of sound education in fostering informed and responsible global citizens. Integrating these goals through the principles of the circular economy can significantly contribute to the broader objective of sustainable development.

Sustainable consumption means using resources more efficiently and mindfully to meet current needs without compromising the ability of future generations to meet their own needs. It involves promoting long-lasting, reusable, and recyclable products to reduce strain on natural resources and decrease waste. Consumers can drive market demand toward sustainability by making informed choices that favor environmentally friendly products and green services based on sharing and longer use of products (UNEP, 2017). This shift not only helps the environment but also strengthens the economy and promotes social equity.

Education plays a transformative role in advancing sustainable consumption and the circular economy. Education is crucial for embedding sustainable consumption practices within society. Learning and training raise awareness of key concepts of the circular economy, share knowledge, and build capacities among civil societies that are asked to make use of circular economy practices. The circular economy model emphasizes the continuous use of resources through recycling, reusing, and remanufacturing, in contrast to the traditional linear economy, which is based on "take-make-dispose" principles. Integrating circular economy principles into educational curricula at all levels can equip individuals with the knowledge and skills needed to innovate and implement sustainable practices. It equips individuals with the knowledge, skills, and values necessary to adopt sustainable practices in their daily lives and professional activities. This type of education fosters a mindset geared towards resource efficiency and environmental stewardship, aligning with SDG 4. By understanding the benefits and practices of the circular economy, students and professionals can drive systemic changes that support sustainability. Moreover, education can empower communities to advocate for policies and practices that promote sustainability, thereby driving systemic changes at the local, national, and global levels.

Effective waste management is a critical component of sustainable development, directly contributing to several SDGs, including those focused on health, clean water, and cities. The implementation of circular economy principles in waste management can significantly increase its effectiveness, transforming waste from a problem into a resource (Kopecká et al., 2024). Policies and practices that promote recycling, composting, and safe disposal of hazardous waste are essential for protecting human health and the environment. Furthermore, international cooperation and knowledge sharing are vital for scaling successful waste management practices globally. By fostering sustainable consumption, quality education, and circular economy strategies, we can make significant strides towards achieving the UN SDGs, ensuring a sustainable and prosperous future for all.

The achievement of UN SDGs requires the commitment and participation of not only national leaders, decision-makers, and administrators but also every member of the community. Therefore, there is a need to educate and empower individuals with the knowledge and skills to make informed and responsible choices, particularly in their consumption practices. This will enable them to engage in various activities and programs that impact themselves and the environment. One of the urgent issues in recent years has been the increasing problem of waste management in many countries. While numerous policies and regulations have been developed, the main challenge lies in their effective implementation (Ren & Zuo, 2024). Research indicates that there is a need for additional support, such as providing necessary physical and social infrastructure, to effectively promote waste management and implement a circular economy.

The integration of sustainable and responsible consumption, quality education, and the circular economy represents a powerful strategy for achieving effective waste management and advancing the UN SDGs. By fostering informed consumer choices, equipping individuals with essential knowledge and skills, and transforming waste management practices, we can address some of the most pressing environmental challenges of our time. This holistic approach not only enhances environmental sustainability but also promotes economic resilience and social equity, contributing to a more sustainable and just world. As we move forward, it is imperative to continue advocating for and implementing these principles to ensure the well-being of current and future generations.

Against this background, the aim of this paper is to explore a landscape in which a number of key elements for the transition towards a circular economy are presented, including country initiatives, awareness and capacity building programmes, and industrial applications related to sustainable consumption. The key elements reflect the interactions between policy, legislation, education and business and therefore provide a common understanding of the enablers that contribute to the SDGs.

2. Research methodology

The findings from specialized sessions at the 18th and 19th International Conferences on Waste Management and Technology were reviewed and compiled in this article. The 18th conference session, held in Sanya, China, on May 23, 2023, focused on "International Partnerships for Expanding Waste Management Services of Local Authorities (IPLA) - an SDG Partnership towards the 2030 Agenda for Sustainable Development Goals". The findings are based on presentations, discussions and interactions among the participants, which included policymakers, researchers and experts from various countries, including China, Fiji, India, Japan, the Philippines, Thailand and the United Kingdom. The data were analyzed qualitatively, with a focus on the exchange of ideas related to sustainable development goals, innovative circular economy solutions, and practices surrounding the 3Rs (reduce, reuse and recycle), and their experiences and insights into plastic waste management, climate change, and nature-based solutions were shared.

The 19th conference session, held in Hangzhou, China, on May 19, 2024, addressed the topic of "Integrating Quality Education in Sustainable and Responsible Practices for Achieving the United Nations SDGs". This session focused on promoting knowledge exchange and showcasing exemplary practices in terms of resource efficiency and a circular economy across various waste streams. The importance of education for sustainability was underscored, with an emphasis on collaboration among policymakers, universities, research institutes, and the business sector. The participants from Austria, China, India, Japan, the Philippines, and Sri Lanka included policymakers, engineers, researchers, educators, and experts with diverse backgrounds and expertise in waste management and sustainability. These discussions highlighted exemplary practices in waste management and sustainability, with qualitative analysis aimed at understanding the role of education in promoting sustainable practices across different waste streams.

3. Results and discussion

3.1. Key aspects of circular economy solutions

Circular economy solutions revolve around the principle of designing out waste and pollution, ensuring that resources are continuously cycled back into the economy rather than being disposed of. While in a linear economy, the resource goes through product design, manufacturing, and consumption to the waste, in a circular economy, it goes back into the production loop through recovery via various channels, including a complete recycling process or remanufacturing of the product or even through its reuse or other side products. This keeps the resource in the production loop as long as it still has some economic value before being sent to the residual waste. This reduces resource extraction and makes the economy stronger (Fig. 1). A key aspect of this is product design, which prioritizes durability, repairability, and recyclability. By designing products to last longer and be easily disassembled, repaired, or upgraded, manufacturers can significantly reduce waste and make it easier to recover valuable materials at the end of a product's life cycle. Additionally, adopting modular design principles allows components to be replaced or updated without discarding the entire product, further extending its useful life and reducing resource consumption. There are various applications of modular design principles that can effectively extend the product life cycle and enhance the user experience, such as modular furniture that can be easily assembled and disassembled. Similarly, home appliance manufacturers now design products such as washing machines and dishwashers with modular components. For example, parts such as motor or heating elements can be replaced without needing to discard the entire unit, leading to less waste and more sustainable practices.

Another crucial aspect of circular economy solutions is the implementation of closed-loop supply chains. In a closed-loop system, materials are perpetually cycled through the production process, minimizing the need for virgin resources and reducing the environmental impact. This involves creating robust systems for collecting, sorting, and processing used materials so that they can be reintroduced into manufacturing processes. Companies can establish take-back schemes and collaborate with recycling firms to ensure that materials are efficiently recovered and reused. Advanced technologies, such as blockchain and the Internet of Things (IoT), can enhance transparency and traceability in supply chains, ensuring that materials are accurately tracked and efficiently managed throughout their lifecycle. Blockchain technology provides a decentralized ledger that ensures that all transactions involving materials are recorded securely and transparently. The Internet of Things devices allow real-time monitoring of materials throughout the supply chain. Both technologies facilitate greater collaboration among various stakeholders in the supply chain.

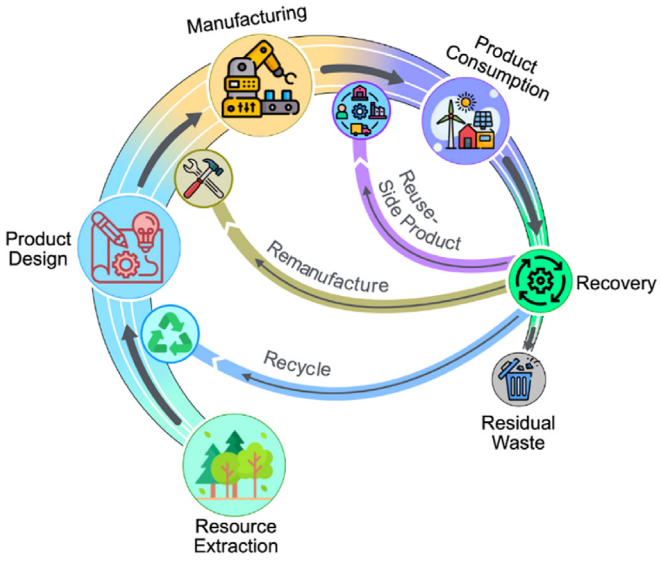

Fig. 1. Conceptual diagram of the circular economy.

Finally, business models that support circular economy principles are essential for their successful implementation. Models such as product-as-a-service, where companies retain ownership of products and lease them to consumers, encourage manufacturers to design for longevity and facilitate maintenance and upgrades. Sharing and collaborative consumption models, which promote the shared use of products such as vehicles, tools, and appliances, also reduce the need for individual ownership and decrease overall resource demand. Moreover, incentivizing consumers to return products for recycling or refurbishment through deposit schemes or discounts can foster a culture of responsibility and engagement with circular practices. By integrating these business models, companies can create value while contributing to environmental sustainability and resource efficiency.

3.2. Understanding the principles of sustainable consumption and production and education

Sustainable consumption involves the use of services and products that meet basic needs and improve quality of life while minimizing the use of natural resources, toxic materials, and emissions of waste and pollutants over the life cycle so as not to jeopardize the needs of future generations. At its core, sustainable consumption requires a shift in consumer behavior, encouraging individuals and communities to make more environmentally conscious decisions. This includes reducing the consumption of goods, opting for products with a lower environmental impact, and embracing practices such as recycling and reusing. This principle underscores the need for consumers to consider the environmental footprint of their choices and adopt lifestyles that contribute to environmental preservation. Sustainable consumption is not solely about individual choices but also about creating systemic changes in production processes and supply chains to ensure that sustainability is embedded in the fabric of consumer products and services.

The education of circular economy principles is integral to promoting sustainable consumption and production (SCP). Educating individuals about the circular economy is meant to raise awareness and promote a shared understanding of the value of resources and the importance of extending the lifecycle of products. It emphasizes a closed-loop system where waste is minimized and resources are continuously reused. This education can occur at various levels, from primary schools to universities and within communities and workplaces in continuous professional development. By integrating circular economy concepts into education systems, we can equip future generations with the knowledge and skills needed to innovate and drive the transition towards more sustainable economic models.

The principles of the SCP and circular economy education must be integrated into a cohesive framework to maximize their impact. This framework can be embedded within formal education curricula, professional training programs, and public awareness campaigns. For example, schools and universities can incorporate courses on sustainability, environmental science, and resource management to instill these values from an early age. Vocational training and corporate workshops can focus on sustainable

practices and circular economy strategies relevant to specific industries. Public awareness campaigns can highlight the importance of sustainable consumption and demonstrate practical ways individuals can contribute. Additionally, partnerships between governments, businesses, and non-profitable organizations are crucial to creating supportive policies and incentives that encourage sustainable practices. By fostering a culture that values sustainability and circularity, we can drive collective action towards a more resilient and environmentally responsible society.

3.3. Case studies

3.3.1. 3R policies on plastic waste management—case of India

The amount of plastic waste generated in India was approximately 4.1 million tonnes per annum from 2020 to 2021, as reported by the Central Pollution Control Board (CPCB), India (CPCB, 2021). Over the past five years, per capita plastic waste generation has nearly doubled due to rapid urbanization and various contributing factors (MOHUA, 2019). The increase in plastic waste production and subsequent microplastic pollution poses a significant threat to humans, wildlife, and ecosystems. The implementation of environmental education, promotion of plastic pollution prevention, and adoption of a circular economy offer a practical pathway for achieving the SDGs (Liu et al., 2023).

India stands as one of the prominent consumers of plastic products globally and has implemented various measures to regulate the manufacturing, consumption, and waste management of plastics. The government has established plastic waste management rules and regulations, which are regularly updated. One such measure is the implementation of extended producer responsibility (EPR), making manufacturers and producers accountable for the proper collection and processing of plastic throughout its lifecycle. Additionally, several states and union territories have enforced strict bans on single-use plastics. The Swachh Bharat Abhiyan (Clean India Mission) is a nationwide cleanliness campaign aimed at achieving proper waste management in both urban and rural areas (MOHUA, 2025). This campaign encompasses awareness programs, cleanliness drives, and infrastructure development for waste management, including plastic waste. Furthermore, initiatives such as Clean India Mission-2, Swachhta Hi Seva, Swachhta Pakhwada, and Swachhta Grahi are focused on generating awareness in the community and fostering behavioral change. The formal education system integrates environmental education and plastic waste management into school and college curricula. Moreover, non-governmental organizations organize cleanliness and awareness campaigns to support informal education efforts (Dhodapkar et al., 2023).

Challenges in providing effective education to every sector of society stem from the large population, vast geographical and cultural diversity, and limited access to formal education and awareness programs, especially for rural and marginalized communities. Other challenges, such as illiteracy, language barriers, behavioral change, and limited infrastructure, also require attention. However, opportunities exist for implementing feasible and effective environmental education. These opportunities include fostering a culture of innovation by creating sustainable alternatives to plastics and innovative plastic recycling technologies. Various stakeholders in the plastic value chain can collaborate to share resources and expertise. Education can empower citizens to advocate for policy reforms and regulations that promote plastic pollution prevention and sustainable waste management, such as the effective implementation of EPR. Awareness initiatives can stimulate consumer demand for environmentally friendly products and packaging, such as recycled plastic products, biodegradable alternatives to plastic, and packaging-free options. Compared with other nations, India has a higher rate of plastic waste recycling (nearly 61%) (Shanker et al., 2023). The following section discusses the 3R policies on plastic waste management in India.

Plastic waste recycling involves the collection and processing (remanufacturing/value recovery) of plastic via mechanical or chemical methods. Mechanical recycling involves collection, sorting, grinding, washing, drying, agglomeration, extrusion/compounding, and ultimately pelletizing of the plastic. Conversely, chemical recycling is employed for value recovery of plastic waste through techniques such as depolymerization, thermal and catalytic pyrolysis, and gasification, which can yield fuel, syngas, and monomers (Zhuo & Levendis, 2014). The recycling of plastic waste plays a crucial role in realizing the circular economy of plastic (van Eygen et al., 2018). Notably, India boasts a high plastic waste recycling rate of nearly 60%, with a predominant focus on mechanical recycling within the sector (Shanker et al., 2023).

Research into the intricacies of plastic waste recycling and its associated environmental impacts is paramount for comprehending the existing gaps and challenges in striving toward a true circular economy (Pardeshi et al., 2023; Sharma et al., 2024). Evaluating various parameters influencing plastic waste recycling is indispensable for assessing its long-term sustainability. The major challenges identified in the plastic waste recycling sector are subsequently discussed.

a) Plastic waste sorting and segregation

Presently, there is a dominance of manual sorting and segregation methods. Magnetic and air-based separation is generally used for separating metals and other contaminants (paper, dust particles, etc.) from plastic, respectively. Density-based (sink-float) separation is widely used for the separation of different types of plastics from mixed plastic waste. Properly sorting, homogenizing, and cleaning plastic waste streams are important for obtaining good-quality recycling (Hahladakis & Iacovidou, 2019). The use of advanced sorting and segregation methods, including FT-NIR and AI-based separation, is important for increasing the level of resource efficiency; however, it is not widely practiced in the current scenario.

b) Resource consumption during recycling of post-consumer plastic waste

The post-consumer plastic waste from domestic, municipal, and curbside streams is highly heterogeneous and contaminated with soil and other impurities. A large quantity of water is required for cleaning procedures involving hot and cold washes with detergents and caustic reagents. Additionally, a significant amount of water is used in density separation. The cleaning and separation process also consumes a noteworthy quantity of energy. This not only increases resource consumption but also drives up the overall cost of recycling. Optimal resource consumption is essential to achieve sustainability and “Responsible Production and Consumption”.

c) Use of additives and fillers during the manufacturing of virgin plastic

The intentional addition of additives such as stabilizers, fillers, antioxidants, plasticizers, pigments, and metals during the manufacturing of virgin plastic materials serves to enhance the specific properties of plastic products. However, these chemicals become embedded in the matrix of the targeted plastic, leading to contamination of recycled material and potential leaching during its usage. This renders recycled plastic unsuitable for high-quality applications, such as food-contact packaging, and hinders closed-

loop recycling. The establishment of standards is necessary to regulate the use of additives during the manufacturing of virgin plastics. The lack of information regarding the chemical composition of additives used and their behavior during reprocessing may limit the use of recycled plastic (Hahladakis & Iacovidou, 2019).

d) Degradation of the polymer during thermomechanical extrusion

Repeated thermal extrusion of plastics can significantly impact the properties of polymers, leading to alterations in their molecular structure. This process can reduce the molecular weight of polymers via thermo-mechanical and thermo-oxidative chain scission. Consequently, it can increase the degree of crystallinity and reduce elongation at break, ultimately influencing the quality of the plastic (Schyns & Shaver, 2021).

e) Recyclability of plastic

Thermoplastics are known for their versatility and stability, making them capable of being recycled numerous times. However, the presence of heterogeneity, contamination from additives and other external sources, and thermo-mechanical degradation all contribute to a decrease in plastic recyclability.

f) Lack of efficient chemical recycling and upcycling technologies

The current share of chemical recycling of plastic waste is approximately 1%. Thermal or catalytic pyrolysis is predominantly used by chemical recycling industries to generate industrial-grade pyrolysis oil as a primary end product. However, many of these industries lack suitable reactor designs, and kinetic studies are needed to produce high-quality end products such as aliphatic solvents or pure chemicals. Most existing chemical recycling technologies are unable to effectively process PET and PVC waste as well as multi-layered plastics. Upcycling technologies, such as the production of value-added products such as graphene from plastic waste, are still at the pilot scale. In India, the depolymerization industry is the sole industry that converts PET waste into monomers, but the gasification of plastic waste is not widely practiced.

3.3.2. 3R policies on plastic waste management—case of the Philippines

The Philippines is experiencing an increase in waste generation due to factors such as population growth, urbanization, and changes in lifestyles. According to a report by the World Bank Group (2021), the country is the third largest contributor of mismanaged plastic waste that enters the ocean annually. The Department of Environment and Natural Resources (DENR) reported that 28% of the waste generated in the country is recyclable, with 10.55% being plastic waste (DENR, 2018). Additionally, 74% of plastic leakage in the country originates from waste that has already been collected (McKinsey & Company and Ocean Conservancy, 2018). The lack or limited recycling and recovery facilities, as well as improper waste disposal, are contributing factors to the occurrence of plastic leakage (Mogol et al., 2022). To address waste management issues, the country has implemented various policies and programs (Table 1). One of these is the Ecological Solid Waste Management Act of 2000, also known as RA 9003, which became effective in 2001. This act mandates waste minimization through recycling, resource recovery, reuse, and composting. It also requires segregation at the source and the establishment of material recovery facilities (MRFs) in every barangay or cluster of barangays for recyclable waste. Additionally, sanitary landfills (SLFs) are designated as the final disposal sites for residuals (Republic of the Philippines, 2000).

The Extended Producers Responsibility Act of 2022 (RA 11898) came into force on July 23, 2022. The act requires obliged enterprises to establish or phase in extended producer responsibility (EPR) programs for plastic packaging within six months from the effective date. Its goal is to effectively manage plastic packaging waste; reduce production, import, supply, or use of plastic packaging with low reusability, recyclability, or retrievability; and achieve plastic neutrality through recovery and diversion schemes (Republic of the Philippines, 2022). Various government agencies have implemented strategies and initiatives to address waste management issues in the country. Some examples include the National Plan of Action for the Prevention, Reduction, and Management of Marine Litter (NPOA-ML) by the Department of Environment and Natural Resources (DENR) and the Philippine Action Plan for Sustainable Consumption and Production (PAP4SCP) by the National Economic and Development Authority (NEDA). In support of the vision of a “Philippines free of marine litter through shared responsibility, accountability, and participatory governance,” NPOA-ML aims to achieve “zero waste to Philippine waters by 2040” (DENR, 2021). The PAP4SCP encourages waste reduction and refuses single-use plastics and other unsustainable products and packaging materials. It aims to achieve zero waste by developing and adopting innovative technologies aligned with circular economy principles (NEDA, 2020).

However, despite the implementation of these policies and initiatives, the compliance rate is still very low, and plastic littering continues to pollute the environment. The average national collection rate is 54.89% as reported in the 2021 Database of the Environment Management Bureau, DENR (Mogol et al., 2022). One of the possible reasons for this low compliance is the lack of the infrastructure required for waste management, as shown in Table 2. As presented by Mogol et al. (2022), the 2022 database of the National Solid Waste Management Commission (NSWMC) shows that approximately 60% of barangays (or 27,229 barangays/LGUs) have no access to MRFs and that approximately 68% of LGUs (or 1110 LGUs) in the country have no access to sanitary landfills (SLFs). Mogol et al. (2022) also highlighted the need for the government to provide the required infrastructure to address waste management problems in the country fully. According to the assumptions of their study, the required collection vehicles for unbaled rigid and flexible

Table 1
Some of the waste management policies in the Philippines.

Year	Title of policy
1975	PD 825: Providing Penalty for Improper Disposal of Garbage and Other Forms of Uncleanliness and For Other Purposes
1999	RA 8749: An Act Providing for a Comprehensive Air Pollution Control Policy and for Other Purposes
2001	RA 9003: An Act for an Ecological Solid Waste Management Program, Creating the Necessary Institutional Mechanisms and Incentives, Declaring Certain Acts and Prohibited and Providing Penalties, Appropriating Funds Therefor, and for Other Purposes
2004	RA 9275: An Act Providing for a Comprehensive Water Quality Management and for Other Purposes
2008	RA 9512: An Act to Promote Environmental Awareness Through Environmental Education and For Other Purposes
2022	RA 11898: An Act Institutionalizing the Extended Producer Responsibility on Plastic Packaging Waste, amending for This Purpose Republic Act No. 9003, otherwise known as the “Ecological Solid Waste Management Act of 2000”

Table 2
Infrastructure requirements—case of the Philippines.

Number of barangays without access to MRFs[a]	27,229
	60%
Number of LGUs without access to SLFs[a]	1110
	68%
Required number of collection vehicles at the current collection rate of 54.89% for unbaled rigid and flexible plastic waste[b]	864
Required Number of collection vehicles at 100% collection rate for unbaled rigid and flexible plastic waste[b]	2222
Required units of MRFs at the current collection rate of 54.89% for rigid and flexible plastic waste[b]	37,823
Required units of MRFs at 100% collection rate for rigid and flexible plastic waste[b]	97,315
Required additional SLFs within 10 years[b]	105

[a] Data source from NSWMC (https://nswmc.emb.gov.ph/NSWMC).
[b] Data source from Mogol et al. (2022).

plastic waste from the current collection rate of 54.89%–100% collection rate require 864 and 2222 collection vehicles, respectively. In addition, the 10-year total requirements of MRF at 54.89% and 100% collection rates are approximately 37,823 units and 97,315, respectively, for rigid and flexible plastic waste. Considering the estimated waste generation of 10,760.31 tons per day in 2021 to 13,500 tons per day in 2032, there is a need to establish approximately 105 more SLFs within 10 years (Mogol et al., 2022). This shows that, indeed, there is a lack of waste management infrastructure in the country and that there is a need for the government to allocate resources to improve compliance with waste management policies.

As illustrated in the above discussion, the principle of the circular economy is integrated into many of the country's waste management policies, but the challenge is more related to its implementation. Moreover, although the policies are in place, there is a need to provide supporting mechanisms, such as the provision of the required infrastructures to fully promote 3R and circular economy in waste management. The local government units (LGUs) and the private sector do not need to carry the burden alone, but the participation and collaboration of the various stakeholders are necessary. Recognizing the limitations of the local government in terms of capacity and resources and the advantages of collaborative approaches, the government should promote local collaboration on waste management in the country (Atienza, 2020).

In addition to providing the physical infrastructures discussed above, there is also a need to strengthen the social infrastructures required for more effective waste management. This section focuses on the relevant role of education and increased awareness in promoting and strengthening waste management implementation. Section 56 of the Philippines' RA 9003 mandates the integration of waste management in school curricula at all levels, whereas Strategy 8 of the DENR's NPOA-ML mandates the development and implementation of social marketing and communication campaigns. To provide some examples of the best waste management practices and initiatives by local governments, the cases of Barangay San Jose, Tagaytay City, and the Municipality of Nagcarlan, Laguna, are discussed. Barangay San Jose, Tagaytay City is one of the model barangays for its effective implementation of waste management. Barangay officials conducted eco-pulong (consultations), eco-surveys, eco-meetings, and eco-patalastas (notices/announcements) to ensure that members of the community understood solid waste management (SWM) policies and regulations. Other initiatives include the establishment of an eco-garden and the implementation of the "Palit-basura" (waste-for-goods-exchange) program, in which each household is given an "Eco Book" to record the volume of their recyclable waste, which they can exchange with some basic necessities such as rice, soap, vitamins, etc. Through these initiatives, the positive change in behavior in the community has been very evident and contributes to sustainable waste management in barangays. On the other hand, the Municipality of Nagcarlan is a second-class municipality in the province of Laguna and is approximately 102 km from Manila. Recognizing the relevant role of local government officials in effectively implementing waste management, they conduct lectures and training for newly elected barangay officials, especially those in charge of SWM. The Municipal Environment and Natural Resource Office (MENRO) staff also conducts awareness campaigns during barangay assemblies and conducts house-to-house campaigns to ensure that members of the community are informed of SWM policies and guidelines. Currently, 43 out of 52 barangays have already constructed material recovery facilities (MRFs), as mandated by law. Based on the experiences of these cases, waste management may not need high-cost and complex technologies; rather, local and simple solutions may be more practical and sustainable. This, however, requires that members of the community be empowered with knowledge and skills to fully participate in waste management activities and programs.

3.3.3. 3R policies on solid waste management—case of China

The National Development and Reform Commission of China regarded the circular economy as the principal guide of the 11th Five Years Plan (2006–2010). The Chinese government subsequently issued the Circular Economy Promotion Law in 2008. To explore the development path and model of the circular economy, the National Development and Reform Commission, together with the Ministry of Finance and other departments, has carried out a series of pilot demonstrations. During the 11th Five Year Plan period (2006–2010), 178 units were selected for extensive pilot projects in key industries, industrial parks, key fields, and at the provincial and municipal levels, and 60 typical cases of circular economy models were explored and formed. During the 12th Five Year Plan period (2011–2015), special pilot demonstration work was carried out on weak links in the development of the circular economy, including 100 demonstration projects for the circular transformation of industrial parks, 100 pilot projects for resource utilization and harmless treatment of kitchen waste, 49 national "urban mining" demonstration bases, 42 remanufacturing pilot projects, 28 demonstration bases for circular economy education, and 101 construction areas for circular economy demonstration cities and counties (Zhao et al., 2017).

As the main carrier of modern social development and the main producer of solid waste, cities have become the main battlefield for solving environmental problems related to waste by promoting the recycling of solid waste in the urban dimension. The State Council of China released the "Zero-waste City" Construction Pilot Program in 2018, selecting "11 + 5" cities to construct a system of indicators, coordinating the comprehensive management of solid waste at the urban level, exploring the establishment of a comprehensive management system and technical system, and forming a batch of replicable and promotable demonstration models from 2019 to 2021. The pilot program has six key tasks: the first is to strengthen the guidance of top-level design and give full play to the macro guidance role of the government; the second to fifth tasks include

management, recycling, and disposal of industrial solid waste, agricultural waste, household waste and hazardous waste; and the sixth task is to stimulate the vitality of market entities and cultivate new models of industrial development. Since 2022, the central government has pushed forward another "113 + 8" city to make an effort toward "zero-waste city" construction. After working on another two Five-Year Plans from 2026 to 2035, all the cities in China will reach the basic requirements for a "zero-waste society." Li and Li (2024) developed a five-dimensional evaluation index system, which serves as the foundation for differentiating the evaluation of various cities and found that through the construction of a "zero-waste city," Shenzhen has improved its management measures and support capacities, establishing a model with distinct Shenzhen characteristics. However, the full effectiveness of certain measures for source reduction and reutilization has not been fully transmitted to the disposal process; in particular, the substantial amounts of domestic waste landfill and construction waste disposal pose significant obstacles for Shenzhen to achieve zero waste.

In addition to the work of "zero-waste city," the National Development and Reform Commission of China issued the "14th Five Year Plan for the Development of Circular Economy" in 2021 (Liu & Liu, 2023). The plan focuses on the key issues that urgently need to be solved in the field of the circular economy, proposes targeted measures, and deploys five key projects: the construction of an urban waste material recycling system, the development of park recycling, the demonstration of comprehensive utilization of bulk solid waste, the demonstration of resource utilization of construction waste, and the innovation of key technologies and equipment for the circular economy. It also includes six key actions: high-quality development of the remanufacturing industry, recycling of waste electrical and electronic products, full life cycle management of automobile use, full chain governance of plastic pollution, green transformation of express packaging, and recycling of waste power batteries.

Driven by the aforementioned policies, the recycling industry has achieved many outcomes, with many facilities and enterprises merging. During the 13th Five Year Plan period (from 2006 to 2020), China's circular economy achieved significant results in development. Compared with 2015, China's main resource output rate increased by approximately 26% in 2020, energy consumption per unit of GDP has continued to decline significantly, and water consumption per unit of GDP has decreased by 28% (Ji et al., 2023). In 2020, the comprehensive utilization rate of crop straw reached over 86%, and the comprehensive utilization rate of bulk solid waste reached 56%, significantly enhancing the utilization capacity of renewable resources.

By 2024, relevant policies had been intensively introduced in China, indicating the direction and path for the development of the circular economy in various regions and departments. In February 2024, the General Office of the State Council issued the "Opinions on Accelerating the Construction of the Waste Recycling System," which proposed accelerating the construction of a comprehensive, efficient, standardized, and orderly waste recycling system. In March 2024, the State Council issued the "Action Plan for Promoting Large Scale Equipment Renewal and Consumer Goods Trade", proposing the implementation of recycling and reuse actions.

Through these pilot demonstrations, several beneficial typical experiences have been formed, and rich experience has been accumulated for the innovation of the circular economy system.

3.3.4. Role of multiple stakeholders in contributing to the "zero-waste city"—case of Hangzhou City, China

Achieving a zero-waste city requires a comprehensive and integrated approach, with collaboration among multiple stakeholders playing a crucial role in promoting sustainable practices. Hangzhou's experience demonstrates how interdisciplinary and cross-sectoral partnerships can significantly drive progress toward this goal. These initiatives by Green Zhejiang, a local non-profit environmental organization, highlight the power of collaboration in fostering a zero-waste culture. Programs such as the "zero-waste school" and "zero-waste city" exemplify how social organizations, educational institutions, and urban policymakers can work together to cultivate environmental awareness and develop sustainable urban strategies. These initiatives involve organizing construction promotion meetings and steering committee sessions to incorporate zero-waste concepts into school curricula and city planning, highlighting the essential role of education in fostering a sustainability mindset.

The "Garment Rebirth Project" further emphasized the impact of collaborative efforts in waste management. Through partnerships with organizations such as the Tibet Luobu Love Group, Green Zhejiang has facilitated the recycling and reuse of old clothes, supported disaster-stricken areas, and created employment opportunities for disabled individuals. This project demonstrates how public participation and cross-sectoral collaboration can synergistically achieve social responsibility and environmental sustainability. Platforms such as the Qiantang Forum roundtable meeting facilitate dialog among experts, scholars, and professionals from diverse fields, addressing challenges in solid waste management through innovative solutions. Such meetings are crucial for exchanging knowledge and collaborative problem solving, highlighting the importance of interdisciplinary approaches in addressing environmental issues.

On significant environmental days, Green Zhejiang's partnerships with science museums and community organizations to hold zero-waste exhibitions illustrate how public engagement can be leveraged to promote sustainable practices. Activities such as making soap from waste oil and recycling kitchen waste not only raise awareness but also encourage active citizen involvement in environmental protection. In summary, Hangzhou's case demonstrates that collaboration among multiple stakeholders is essential for driving the behavior changes needed to achieve a zero-waste city. By fostering partnerships across different sectors and disciplines, cities can develop innovative, sustainable solutions that promote resource efficiency and environmental stewardship. This collaborative approach is vital for advancing toward a sustainable and resilient urban future.

3.3.5. Public collaboration in sustainable consumption and production—case of Shenzhen City, China

In Shenzhen City, China, social organizations and public education play crucial roles in actively promoting waste sorting and management. More than 100,000 individuals participated in voluntary supervision for waste sorting in 2022, with over 92,000 successfully completing their roles, contributing a total of 185,350 service hours. The "Dandelion Trainers Team" has been established to educate the public, particularly students, about waste management. This team includes 50 Dandelion volunteer lecturers and 48 Dandelion teachers working in all primary and secondary schools in Yantian. They aim to integrate waste management values and social responsibility into the local culture.

Furthermore, public education activities such as the "Milk Cartons Collecting Action" have also been promoted in Yantian (UN-Habitat, 2023). This initiative involves students investigating the milk carton collection and resource utilization process, encouraging them to participate in pre-processing, cleaning, and recycling of the cartons. These efforts highlight the importance of public involvement and education in the transition to social governance and demonstrate the importance of collaborative social governance in China's current state of social civilization.

3.4. Integrating sustainable consumption and production and education for sustainable development

The integration of sustainable consumption and production (SCP) with education for sustainable development (ESD) represents a critical pathway towards fostering a more sustainable and equitable society. SCP focuses on reducing resource use and environmental degradation while promoting economic and social well-being, aligning closely with the transformative goals of ESD, which aims to equip individuals with the knowledge, skills, and values necessary to drive sustainable change.

3.4.1. Embedding SCP principles in the educational framework: opportunities and challenges

The significance of the SCP and ESD in educational programs has been well established for several decades. As stated by Pandey and Vedak (2010), "Education is the key intervention for bringing change in knowledge, values, behaviors, and lifestyles and is required to achieve sustainability and stability" (p.3). Educational institutes play a crucial role in defining and achieving sustainable development and sustainable consumption and production, with various stakeholders expected to contribute to these efforts. However, there have been criticisms of ESD for its inherent anthropocentrism, with calls for educational institutions to reconstruct their programs to pursue ecological justice (Kopnina, 2014).

In contrast, the circular economy presents an integrated approach that combines development and ecological sustainability. By aiming to reduce the consumption of virgin resources and optimize the circulation of already extracted resources, the circular economy strives to minimize ecosystem damage and avoid anthropocentric consumption and production. Given the significance of the circular economy, educational institutions play a crucial role in integrating circular economy concepts into their curriculum to ensure that future generations are equipped with the knowledge and understanding necessary for ecological sustainability. This may involve tailoring circular economy education to different disciplines, as exemplified by the work of Kirchherr and Piscicelli (2019) in the field of engineering, which specifically focuses on identifying circulation indicators for production. Collaboration across different disciplines in the supply chain is also key to effectively addressing resource circulation. To facilitate the internalization of circular economy concepts in students, various approaches have been examined, including case studies designed to encourage lifelong learning. Educational institutions play a vital role in identifying and implementing effective approaches for quality education on SCPs and the circular economy, with the overarching goal of promoting ecological sustainability and social well-being.

3.4.2. Industrial applications and educational programs through a circular economy—case of Punjab, India

In India, the agrarian sector, especially in Punjab, is facing significant environmental challenges due to the large amounts of agro-waste generated from crops such as wheat and rice. Despite efforts by both the state and central governments to manage this waste through various methods, the burning of paddy straw in fields remains a major challenge (Parihar et al., 2023). Approximately 3–4 million tons of paddy straw are still being burned in open fields each year. This practice leads to air pollution and related health issues (India State-Level Disease Burden Initiative Air Pollution Collaborators, 2021). In response, the Punjab State Council for Science & Technology (PSCST) has initiated research and development studies to investigate the use of paddy straw pellets as a substitute for fossil fuel in the brick sector, which is a major contributor to air pollution. These efforts resulted in the state mandating that brick kilns replace at least 20% of their coal with paddy straw pellets. This initiative has attracted interest from other states and countries, with PSCST collaborating with the International Centre for Integrated Mountain Development (ICIMOD) to spread this technology throughout the South Asian region. Furthermore, the Green Schools Programme (GSP) in Punjab highlights the state's dedication to sustainability and environmental education.

During 2023–2024, approximately 7246 schools participated in a program that involved environmental audits focusing on six critical areas: air quality, energy consumption, food sustainability, land use, water conservation, and waste management (CSE, 2017). Students, guided by their teachers, collected data and assessed their schools' environmental practices, providing hands-on learning experiences that went beyond theoretical knowledge. The program aimed at enhancing environmental awareness, promoting sustainable behavioral changes and integrating eco-friendly practices into school operations (Thokchom Paonam Robinson, 2023). Punjab's outstanding performance resulted in 70 schools being recognized as green schools, earning the state the Best Green State and Best Green District awards. These achievements highlight the program's success in promoting sustainability within the educational sector and demonstrate the positive impact of involving students directly in environmental management.

To build on the successes of these initiatives and further promote sustainable development, several recommendations are proposed: Integrating ESD principles more deeply into the curriculum is essential. This involves emphasizing interdisciplinary learning, critical thinking, and participatory teaching methods. Establishing robust local and global partnerships will provide strong support networks for ESD initiatives. Continuous professional development for educators and administrators, along with fostering research and innovation in ESD, will ensure the program's ongoing improvement. Encouraging community and student engagement through practical, real-world projects and leveraging technology for ESD learning will further enhance the program's reach and effectiveness. These steps not only address environmental challenges but also prepare students to become proactive leaders in sustainability, embedding environmental education as a core component of their learning experience. The dissemination of Punjab's success story in South Asia has the potential to reduce air pollution and greenhouse gas emissions significantly, promote local employment, and decrease reliance on imported coal, contributing to broader environmental and economic benefits.

3.5. Utilizing nature-based solutions to promote circular economy

Nature is a laboratory for many interesting phenomena, including the circular economy. It has been said that *"Everything is reused or repurposed in nonhuman ecosystems. The natural world is the perfect circular* economy, *where everything, even after its lifetime, becomes a source for something else*" (Sala, 2020). The Nature-based solution (NbS) is an umbrella term for approaches that leverage ecosystem services to protect, manage, and restore natural or modified ecosystems while addressing societal challenges, benefiting biodiversity, and improving human well-being, as stated in the IUCN Global Standard for Nature-based Solutions (IUCN, 2020). These approaches are designed to address issues rooted in a site-specific context with a broader understanding of natural and socio-cultural systems and their interlinkages. NbS thus represents a "low impact development" solution that can catalyze the transition to a circular economy. This demands a rethinking of our physical environment from its current linear model to one that emulates the tenets of circularity. Nested within this broader scope,

NbS to promote circular economy integrates the principles of nature conservation, sustainable resource management, and regenerative practices to minimize waste, optimize resource use, and promote resilience (Atanasova et al., 2021). Both NbS and circular economy aim to emulate inherent circularity in nature via a system's thinking approach (Ramos et al., 2019).

Nature-based solutions offer a powerful approach to waste management and circular economy education by demonstrating how natural systems can inspire sustainable practices. By learning from ecosystems' efficient use of resources and their natural cycles of decomposition and regeneration, students can develop a deeper understanding of waste as a resource and recognize the potential for closing loops. This knowledge can empower individuals to adopt sustainable behaviors, support innovative solutions, and contribute to building a more circular economy.

It is important to understand that meeting the challenges of growth and urbanization is pivotal and has a role in the transition of society to a circular economy. These challenges derive from a wide variety of environmental impacts associated with the production of materials, the operation of systems in a built environment, and the outdoor processes that support the built environment. As decentralized hubs of economic growth, urban and peri-urban areas are nerve centers of production and consumption. They become the sources and sinks of resources where NbS can play an appropriate role in addressing the circularity gap (Atanasova et al., 2021). Multiple systems (but not limited to), namely, biodiversity, energy, food, materials, waste, and water, coexist in spatial proximity in urban and peri-urban systems, and there is continuous feedback among them, creating interconnections (Sukhwani et al., 2020). Here, the deployment of NbS warrants a system-specific and infrastructure-focused approach, considering the key systemic problem to be addressed and identifying leverage points to create nexus and interlinkages with other systems (Fig. 2).

The case of the East Kolkata Wetlands (EKW) highlights a successful NbS that upholds waste-water food circularity in urban Kolkata. Covering approximately 12,500 ha, this Ramsar site manages more than 80% of Kolkata's wastewater, filtering it over three to four weeks before uncontaminated water is discharged into the Bay of Bengal (Gosh, 2018). Wastewater offers essential organic nutrients that enable fishing, paddy, and vegetable cultivation in the region while terrestrially locking in 60% of the carbon from the effluents (Pal et al., 2018). (It additionally offers livelihoods for 1.1 million people and supplies approximately one-third of the city's fish requirements. As a major land resource that is constantly facing encroachment pressures, EKW continues to make an economic case for NbS by providing savings of approximately INR 4680 million (approximately US$ 56 million) per annum in sewage treatment costs (Dey & Banerjee, 2018). Beyond the circularity lens, wetlands offer a habitat for migratory birds and native fauna, flood management, and heat mitigation, especially during extreme climate events.

Fig. 2. Conceptual diagram of a systemic nature-based solution (NbS) approach to circularity.

This geographical advantage of EKW may not apply to new NbS projects elsewhere, where land is often a limited resource. In such cases, a scalar approach may be more amenable (Odongo et al., 2022). The choice of scale determines the mobilization of resources to mediate upstream (regulatory and policy) and downstream (implementation and stakeholder engagement) impacts across systems. One such example is the Chennai Urban Horticulture Initiative. This initiative strategically utilizes rooftops (beginning with school rooftops) to create community gardens across the city's low-rise, high-density built fabric. It integrates multiple strategies, such as providing organic produce for users; segregating and composting organic waste; managing rainwater runoff; mitigating urban heat islands; promoting biodiversity; and engendering community kinship—encompassing biodiversity, climate and governance issues. Over the next decade, the project aims to scale up the NbS across six lakh households to reduce the vulnerability of 2.5 million inhabitants to extreme climate events (Resilient Chennai and Okapi Research & Advisory, 2019). Such projects have the capacity to influence upstream policies to mandate site-scale interventions that can snowball into urban resilience strategies. They demonstrate the potential to deploy NbS to address the trade-offs between actions for immediate economic benefits and long-term impacts on ecosystems holistically.

3.6. Global education policies for circular economy

Throughout the world, global, national, and regional strategies for the circular economy have been developed (EESC, 2019). These strategies, programs, and plans support the implementation of a circular economy in the coming years. According to the Organization for Economic Cooperation and Development (OECD), an international organization that provides a form for governments to share experiences and identify good practices, the OCED initiative on circular economy in cities and regions, especially "promotors, facilitators and enablers" is crucial in the governance of circular economy. Capacity building in addition to data assessment, innovation, financing, and regulation are key elements for enabling the transition towards greener societies (OECD, 2020). Among other issues, capacity building is a key accelerator of the pathway to circular economy (Fig. 3).

In the following, two showcases are used to demonstrate the underlying educational approach and perception of knowledge production to move towards inclusive circular economies.

3.6.1. International trade and economic cooperation

This showcase particularly addresses small and medium enterprises and women-owned businesses to create an environment that makes use of their local knowledge and practical expertise. This furthermore enables and empowers them to participate in an inclusive transition. Support measures in international trade include investment in workplace education, the provision of education, technical assistance and capacity building, the facilitation of access to digital platforms, and finally, the transfer of technologies (state-of-the-art and technical standards), know-how, and machinery (UNECE, 2022).

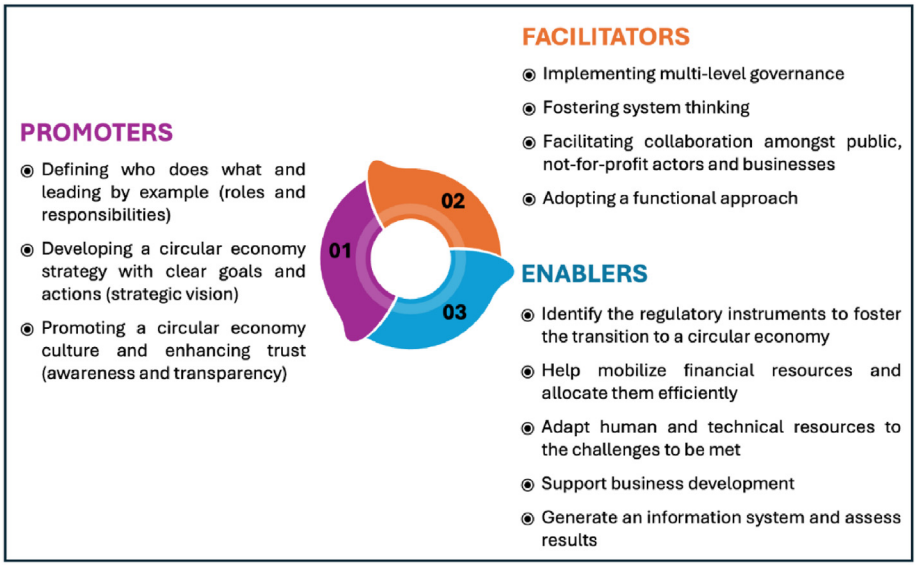

Fig. 3. Role of different stakeholders in promoting the circular economy (OECD, 2020).

3.6.2. Inter-governmental work and consolidated action

In this showcase of inter-governmental work and collaboration among various stakeholder groups (economy/industry, education, research, civil society organizations, etc.), it is relevant that the government institutions in place inform future research and education programs about their strategies and activities on the way to a circular economy. Governments and authorities are asked to apply self-checks and assessments when preparing and applying circular economy action plans. In the field of education, they ask themselves if and how representatives of research and education are involved in the creation and design process. Later, in implementation, it is crucial to reassess whether there is a structured mechanism for the government to engage businesses, research, and civil society in circular economy policymaking (UNECE, 2023). It is relevant to offer education and training activities and materials that, on the one hand, support national and local authorities and decision-makers in preparing and implementing circular economy strategies. On the other hand, the participants in the training and learning settings benefit from the multiple stakeholders invited to the training. These settings facilitate peer learning and interdisciplinary exchange on certain thematic issues, harmonization processes, the application of directives, and other international policies/guidance documents within the current pathway of the circular economy.

The UNEP Circularity Platform (https://buildingcircularity.org/), the UNEP Life Cycle Initiative (https://www.lifecycleinitiative.org/) and the Basel, Rotterdam and Stockholm Conventions (https://www.brsmeas.org/) are prominent global examples that include capacity-building activities. The global dimension of such training is important. The European Union Council Recommendation of June 2022 (The Council of the European Union, 2022) highlights relevant considerations on learning for green transition and sustainable development. Green skills and competencies for citizens prepared for green infrastructure (separate collection and waste management, public procurement, green infrastructure such as urban wastewater plants, renewable energy plants, etc.) are needed in green transformation to build circular societies. To conclude, two aspects should be considered for green education: the link between educational degrees and the future workplace of citizens. First, education and training must address the skill gap so that students and workers obtain the relevant skills that they particularly need and apply to the future job market. Companies, small and medium enterprises, and other organizations need confidence in the training and education that their (future) employees receive. Second, the learners must receive tailor-made training and education that they can apply in the region where they live and work. This avoids a brain drain when higher-educated students and workers leave the country and use their expertise elsewhere in the world. This conclusion has been drawn based on an work in green education on the Western Balkan Region within the project of EU4Green (EU4Green, 2024). The European Union Council recommendation points out that sustainability competencies can help learners become systemic and critical thinkers, as these competencies develop agencies and form a knowledge base for everyone. These green competencies are to be achieved in any informal or formal learning setting.

To conclude, global education initiatives such as those mentioned above are usually designed to support specific transition goals or policy implications of circular economy action plans and strategies. These programmes are designed to align with specific policies that facilitate the transition to sustainable systems. By engaging businesses, research institutions, and civil society organizations in the design, implementation, and recognition of training, collaboration can be fostered. Additionally, the structured mechanism ensures that these initiatives address regional needs through practical, experimental, collaborative learning. This approach supports professional development and promotes interdisciplinary cooperation, driving the adoption of the circular economy approach across sectors.

4. Conclusions and future perspective

The study highlights various country initiatives, awareness and capacity-building programmes and industrial applications related to sustainable consumption. The implications of this study underscore the critical role of collaborative efforts between governments, civil society, and multistakeholder initiatives such as public–private partnerships. Furthermore, the study emphasizes the importance of the regional context of programmes or initiatives to address multiple challenges, including waste management, plastic reduction and the potential of circular economy solutions.

Since 2008, China has developed a model based on laws and policies, with several special projects implemented, such as path industrial parks, 100 pilot projects for kitchen waste recycling, and national "urban mining" demonstration bases, etc. to promote the circular economy. It has achieved remarkable results, with continuous improvement of the institutional system and orderly promotion of industrial development. Moreover, "zero-waste city" construction has offered another city-level channel for waste recycling and disposal, involving policymaking, industrial waste, agricultural waste, household waste, hazardous waste, construction waste, and recyclable materials, to promote the development of the circular economy in another era.

In India, the Swachh Bharat Abhiyan (Clean India Mission) further promoted waste management through awareness and infrastructure development. While challenges such as population size and diverse demographics persist, India has opportunities to innovate in terms of plastic alternatives and recycling technologies. The integration of environmental education into formal and informal settings is crucial for fostering behavioral change and citizen advocacy for sustainable practices. Likewise, the Philippines is grappling with increasing waste generation and plastic leakage into the ocean. The country has enacted laws such as the Ecological Solid Waste Management Act and the Extended Producer Responsibility Act to promote waste reduction, recycling, and proper disposal. While the Philippines has a framework for a circular economy in its policies, the focus should be on strengthening implementation through infrastructure development, social awareness, and multi-stakeholder collaboration.

Public education can contribute greatly to the transition to a circular economy. Reaching a consensus on sustainable development is the key to achieving the ultimate goal of a circular economy—responsible use of resources and zero waste. The concept of circular economy has gained attention because of its potential to promote sustainability by meeting human needs while contributing to ecological balance. Educational institutes play a crucial role in integrating the circular economy into their curriculum. This concept involves multiple disciplines and collaboration with various stakeholders to promote sustainable consumption and production by implementing a circular supply chain. The goal is to optimize resource usage while preserving the natural environment. Educational institutes must identify effective approaches to incorporate circular economy strategies into their teaching practices, aiming to bring about positive changes in society by promoting ecological sustainability and social well-being.

The incorporation of quality education and the fostering of multi-stakeholder collaboration are essential for advancing sustainable consumption and achieving the SDGs through circular economy practices. By leveraging interdisciplinary education and engaging diverse stakeholders, we can promote innovative solutions, enhance resource efficiency, and drive systemic change. The success of initiatives such as Green Zhejiang's zero-waste projects exemplifies the potential of collective efforts in building a sustainable future. As we move forward, continued collaboration and education will be pivotal in creating resilient and sustainable communities, building on a trained workforce and engaged individuals worldwide.

Leveraging the power of nature toward a circular economy requires us to unlearn our linear, 'action for impact' model that offers immediate results. NbS requires us to work with nature's complexities with an iterative monitoring and evaluation framework over time to build resilience. When planning infrastructure-based NbSs, we must map systemic boundaries and feedback loops to understand their wider impacts on the landscape. They require a global standard to increase the scale and impact of the NbS approach. Such standards will bring in the much-needed finance for NbS, as it demonstrates its alignment with international best practices, thereby assuring potential funders, investors and decision-makers.

CRediT authorship contribution statement

Anupam Khajuria: Conceptualization, Methodology, Writing – original draft, Writing- review & editing, Visualization. **Prabhat Verma**: Writing - original draft. Writing – review & editing. **Atienza Vella**: Writing - original draft. **Daniela Zanini-Freitag**: Writing - original draft. Writing – review & editing. **Hao Xin**: Writing - original draft. **Indu K. Murthy**: Writing - original draft. **Jatinder K. Arora**: Writing - original draft. **Kamani Sylva**: Writing - original draft. **Lakshmi Menon**: Writing - original draft. **Sushma Pardeshi**: Writing - original draft. **Ulrich Kral**: Writing - original draft. Writing – review & editing. **Xiao Liu**: Writing - original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank all organizers and sponsors for holding the 18th and 19th ICWMT, enabling this work.

References

Atanasova, N., Castellar, J. A. C., Pineda-Martos, R., Nika, C. E., Katsou, E., Istenič, D., Pucher, B., Andreucci, M. B., & Langergraber, G. (2021). Nature-based solutions and circularity in cities. *Circular Economy and Sustainability, 1*, 319–332.

Atienza, V. (2020). Promoting local collaboration on waste management: Lessons from selected cases in the Philippines. In M. Kojima (Ed.), *Regional waste management – inter-municipal cooperation and public and private partnership* (pp. 122–134). Jakarta: ERIA. ERIA Research Project Report FY2020 no. 12.

CPCB. (2021). *Annual report 2020–21 on implementation of plastic waste management rules*. Delhi: Central Pollution Control Board (CPCB). Available at: https://cpcb.nic.in/status-of-implementation-of-plastic-waste/.

CSE. (2017). *How green is your school? An environmental audit for schools*. India: Centre for Science and Environment (CSE). Available at: https://www.cseindia.org/how-green-is-your-school-an-environmental-audit-for-schools-7748.

DENR. (2018). *National solid waste management report 2018*. Quezon City, Philippines: Department of Environment and Natural Resources (DENR). Available at: https://media.neliti.com/media/publications/411212-a-long-standing-problem-a-review-on-the-eae285a3.pdf.

DENR. (2021). *National plan of action for the prevention, reduction and management of marine litter (NPOA-ML)*. Quezon City, Philippines: Department of Environment and Natural Resources (DENR). https://www.seaknowledgebank.net/sites/default/files/2024-04/Jan%202022%20Final%20Philippines%20NPOA-ML%20%281%29.pdf.

Dey, D., & Banerjee, S. (2018). How expensive is the decay of East Kolkata Wetlands? An estimation of opportunity cost for Kolkata. In Mukherjee J. (Ed.), *Sustainable urbanization in India. Exploring urban change in South Asia*. Singapore: Springer.

Dhodapkar, R., Bhattacharjya, S., Niazi, Z., Porter, N., Retamal, M., Sahajwalla, V., & Schandl, H. (2023). *National circular economy roadmap for reducing plastic waste in India*. Australia: Commonwealth Scientific and Industrial Research Organisation. Available at: https://research.csiro.au/circulareconomy/circular-economy-roadmap-for-reducing-plastic-waste-in-india/.

EESC. (2019). *Circular economy strategies and roadmaps in Europe: Identifying synergies and the potential for cooperation and alliance building. Executive summary*. Brussel: European Economic and Social Committee (EESC). Available at: https://www.eesc.europa.eu/sites/default/files/files/qe-01-19-465-en-n.pdf.

EU4Green. (2024). *Building green skills for the future: A look at EU4Green's micro-credentials portfolio*. Available at: https://eu4green.eu/building-green-skills-for-the-future-a-look-at-eu4greens-micro-credentials-portfolio/.

Gosh, S. (2018). *A new study on East Kolkata Wetlands' carbon-absorption abilities is a wake-up call for conservation*. Available at: https://scroll.in/article/874651/a-new-study-on-east-kolkata-wetlands-carbon-absorption-abilities-is-a-wake-up-call-for-conservation.

Hahladakis, J. N., & Iacovidou, E. (2019). An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): Focus on recycling. *Journal of Hazardous Materials, 380*, Article 120887.

Huo, J., & Peng, C. (2023). Depletion of natural resources and environmental quality: Prospects of energy use, energy imports, and economic growth hindrances. *Resources Policy, 86*, Article 104049.
India State-Level Disease Burden Initiative Air Pollution Collaborators. (2021). Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019. *The Lancet Planetary Health, 5*, e25–e38.
IUCN. (2020). *IUCN global standard for nature-based solutions. A user-friendly framework for the verification, design and scaling up of NbS* (1st ed.). International Union for Conservation of Nature (IUCN). Available at: https://portals.iucn.org/library/sites/library/files/documents/2020-020-En.pdf.
Ji, L., Sun, Y., Liu, J., & Chiu, Y. H. (2023). Analysis of the circular economy efficiency of China's industrial wastewater and solid waste - based on a comparison before and after the 13th Five-Year Plan. *The Science of the Total Environment, 881*, Article 163435.
Khajuria, A., Atienza, V. A., Chavanich, S., Henning, W., Islam, I., Kral, U., Liu, M., Liu, X., Murthy, I. K., Oyedotun, T. D. T., Verma, P., Xu, G., Zeng, X., & Li, J. (2022). Accelerating circular economy solutions to achieve the 2030 agenda for sustainable development goals. *Circular Economy, 1*, 100001.
Khajuria, A., & Verma, P. (2025). Circular economy for "blue skies" in building resilient cities—towards the UN 2030 Agenda for Sustainable Development Goals. *Frontiers in Sustainability, 6*, Article 1479452.
Kirchherr, J., & Piscicelli, L. (2019). Towards an education for the circular economy (ECE): Five teaching principles and a case study. *Resources, Conservation and Recycling, 150*, Article 104406.
Kopecká, R., Hrad, M., & Huber-Humer, M. (2024). The role of the waste sector in the sustainable development goals and the IPCC assessment reports. *Österreichische Wasser- und Abfallwirtschaft, 76*, 300–307.
Kopnina, H. (2014). Future scenarios and environmental education. *The Journal of Environmental Education, 45*, 217–231.
Li, Y., & Li, J. (2024). Method development and empirical research in examining the construction of China's "Zero-waste Cities". *The Science of the Total Environment, 906*, Article 167345.
Liu, J., Hu, Z., Du, F., Tang, W., Zheng, S., Lu, S., An, L., & Ding, J. (2023). Environment education: A first step in solving plastic pollution. *Frontiers in Environmental Science, 11*, Article 1130463.
Liu, C., & Liu, C. (2023). Exploring plastic-management policy in China: Status, challenges and policy insights. *Sustainability, 15*, 9087.
McKinsey & Company and Ocean Conservancy. (2018). *Stemming the tide: Land-based strategies for a plastic free ocean*. Available at: https://oceanconservancy.org/wp-content/uploads/2022/07/full-report-stemming-the.pdf.
Mogol, G., Atienza, V., Lavtizar, V., & Hayashi, S. (2022). *Waste management infrastructure gap. Rapid assessment of plastic waste management infrastructure gap in the Philippines*. Available at: https://unhabitat.org.ph/wp-content/uploads/2022/11/HOCCI-Waste-Management-Infrastructure-Gap.pdf.
MOHUA. (2019). *Plastic waste management. Issues, solutions, and case studies*. New Dheli: Ministry of Housing and Urban Affairs (MOHUA). Available at: https://sbmurban.org/storage/app/media/pdf/SBM%20Plastic%20Waste%20Book.pdf.
MOHUA. (2025). *Swachh Bharat Mission–urban*. New Dheli: Ministry of Housing and Urban Affairs (MOHUA). Available at: https://sbmurban.org/.
NEDA. (2020). *Philippine action plan for sustainable consumption and production (PAP4SCP)*. Pasig City, Philippine: National Economic and Development Authority (NEDA). Available at: https://faolex.fao.org/docs/pdf/phi228020.pdf.
Odongo, V., Barquet, K., & Green, J. (2022). *Addressing scale in nature-based solutions. SEI discussion brief*. Stockholm Environment Institute. Available at: https://doi.org/10.51414/sei2022.043
OECD. (2020). *The circular economy in cities and regions. Synthesis Report, OECD Urban Studies*. Paris: OECD Publishing. Available at: https://doi.org/10.1787/10ac6ae4-en
Pal, S., Chakraborty, S., Datta, S., & Mukhopadhyay, S. K. (2018). Spatio-temporal variations in total carbon content in contaminated surface waters at East Kolkata Wetland Ecosystem, a Ramsar Site. *Ecological Engineering, 110*, 146–157.
Pandey, N., & Vedak, V. (2010). Structural transformation of education for sustainable development. *International Journal of Environment and Sustainable Development, 9*, 3.
Pardeshi, S., Sharma, R., Shanker, R., Joseph, J., Khan, D., Vaidya, A., & Dhodapkar, R. (2023). Mechanical recycling scenarios in India through the lens of plastic circular economy. *Journal of Material Cycles and Waste Management, 25*, 3425–3439.
Parihar, D. S., Narang, M. K., Dogra, B., Prakash, A., & Mahadik, A. (2023). Rice residue burning in northern India: An assessment of environmental concerns and potential solutions—a review. *Environmental Research Communications, 5*, Article 062001.
Ramos, G., Hynes, W., Müller, J. M., & Lees, M. (2019). *Systemic thinking for policy making. The potential of systems analysis for addressing global policy challenges in the 21st century*. Available at: https://one.oecd.org/document/SG/NAEC(2019)4/en/pdf.
Ren, Z., & Zuo, G. (2024). Challenges of implementing municipal solid waste separation policy in China. *Sustainability, 16*, 8081.
Republic of the Philippines. (2000). *Ecological solid waste management act of 2000 (RA 9003)*. Available at: https://pepp.emb.gov.ph/wp-content/uploads/2016/06/RA-9003-Ecological-Solid-Waste-Management-Act-of-2000.pdf.
Republic of the Philippines. (2022). *The extended producer responsibility act of 2022 (Republic act No. 11898)*. Available at: https://legacy.senate.gov.ph/republic_acts/ra%2011898.pdf.
Resilient Chennai and Okapi Research & Advisory. (2019). *Chennai urban horticulture initiative. Chennai resilience Centre*. Available at: https://resilientchennai.com/urban-horticulture/.
Sala, E. (2020). *The nature of nature. Why we need the wild*. Washington, D.C.: National Geographic. Available at: https://rewilding.org/the-nature-of-nature-why-we-need-the-wild/.
Schyns, Z. O. G., & Shaver, M. P. (2021). Mechanical recycling of packaging plastics: A review. *Macromolecular Rapid Communications, 42*, Article e2000415.
Shanker, R., Khan, D., Hossain, R., Islam, M. T., Locock, K., Ghose, A., Sahajwalla, V., Schandl, H., & Dhodapkar, R. (2023). Plastic waste recycling: Existing Indian scenario and future opportunities. *International journal of Environmental Science and Technology, 20*, 5895–5912.
Sharma, R., Pardeshi, S., Joseph, J., Khan, D., Chelani, A., & Dhodapkar, R. (2024). Integrated analytical hierarchy process-grey relational analysis approach for mechanical recycling scenarios of plastics waste in India. *Environmental Science and Pollution Research, 31*, 23106–23119.
Sukhwani, V., Shaw, R., Deshkar, S., Mitra, B. K., & Yan, W. (2020). Role of smart cities in optimizing water-energy-food nexus: Opportunities in Nagpur, India. *Smart Cities, 3*, 1266–1292.
The Council of the European Union. (2022). *Council Recommendation of 16 June 2022 on learning for the green transition and sustainable development* (2022/C 243/01). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022H0627(01.
Thokchom Paonam Robinson, A. (2023). Environmental auditing in colleges: Practices and principles. *International Journal of Science and Research, 12*, 1241–1248.
UN-Habitat. (2023). *China waste wise cities good practices: Series I*. United Nations Human Settlements Programme. Available at: https://unhabitat.org/china-waste-wise-cities-good-practices-series-i-0.
UNECE. (2022). *Accelerating the circular economy transition: Policy options for harnessing the power of trade and economic cooperation*. Geneva: United Nations Economic Commission for Europe (UNECE). Available at: https://unece.org/trade/publications/policy-brief-accelerating-circular-economy-transition-policy-options-harnessing.
UNECE. (2023). *Institutional arrangements for the circular economy*. Geneva: United Nations Economic Commission for Europe (UNECE). Available at: https://unece.org/trade/publications/institutional-arrangements-circular-economy-circular-step.
UNEP. (2017). *The long view: Exploring product lifetime extension*. United Nations Environment Programme (UNEP). Available at https://wedocs.unep.org/20.500.11822/22394.
UNEP. (2018a). *SDG 12 Issue brief: Ensuring sustainable consumption and production patterns*. United Nations Environment Programme (UNEP). Available at: https://wedocs.unep.org/20.500.11822/25764.
UNEP. (2018b). *SDG 15 Issue brief: Promoting the sustainability of terrestrial ecosystems and halting desertification, land degradation and biodiversity loss*. United Nations Environment Programme (UNEP). Available at: https://wedocs.unep.org/20.500.11822/25765.
UNEP. (2018c). *SDG13 Issue brief: Taking urgent action to combat climate change and its impact*. United Nations Environment Programme (UNEP). Available at: https://wedocs.unep.org/20.500.11822/28241.
UNEP. (2019). *SDG 4 Issue brief - sustainable Development Goal 4 (SDG 4): Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all*. United Nations Environment Programme (UNEP). Available at: https://wedocs.unep.org/20.500.11822/28443.
van Eygen, E., Laner, D., & Fellner, J. (2018). Circular economy of plastic packaging: Current practice and perspectives in Austria. *Waste Management, 72*, 55–64.
World Bank Group. (2021). *Market study for the Philippines: Plastics circularity opportunities and barriers. East Asia and pacific region marine plastics series*. Washington, DC: World Bank Group. Available at: https://hdl.handle.net/10986/35295.
Zhao, K., Guo, Z., Wei, H., & Wang, Y. (2017). *Review of the development of resource recycling industry during the "12 Five-Year Plan" period*. Available at: https://www.ndrc.gov.cn/xwdt/gdzt/xyqqd/201708/t20170802_1197808.html.
Zhuo, C., & Levendis, Y. A. (2014). Upcycling waste plastics into carbon nanomaterials: A review. *Journal of Applied Polymer Science, 131*(app), Article 39931.