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Circular economy approach in solid waste management system to achieve UN-SDGs: Solutions for post-COVID recovery

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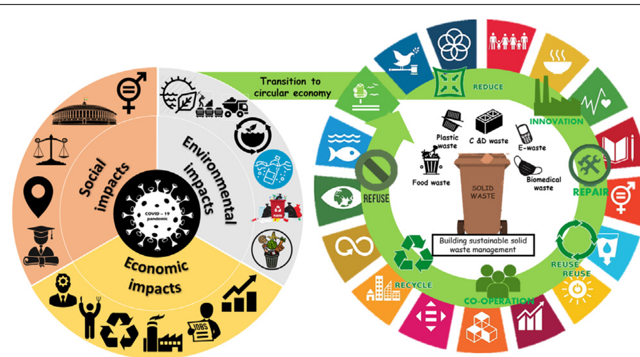
HIGHLIGHTS

- The Paper investigated the impact of COVID-19 on the progress of the UN-SDGs.
- The guiding principles of UN-SDGs are analogous to that of circular economy (CE) based solid waste management (SWM).
- The CE based SWM have potential to create green jobs apart from bringing socio-economic benefits.
- To achieve UN-SDGs, CE based SWM should be treated as a priority.
- The COVID response fund should also be used to facilitate the transition to full adoption of circular economy model.

GRAPHICAL ABSTRACT



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ABSTRACT

The COVID-19 pandemic and the ensuing socioeconomic crisis has impeded progress towards the UN Sustainable Development Goals (UN-SDGs). This paper investigates the impact of COVID 19 on the progress of the SDGs and provides insight into how green recovery stimulus, driven by circular economy (CE)-based solid waste management (SWM) could assist in attaining the intended targets of UN-SDG. It was understood in this review that the guiding principles of the UN-SDGs such as, public health, environmental concerns, resource value and economic development are similar to those that have driven the growth of waste management activities; thus, in order to achieve the goals of UN-SDG, a circular economy approach in solid waste management system should be prioritized in the post-COVID economic agenda. However, policy, technology and public involvement issues may hinder the shift to the CE model; therefore, niche growth might come from developing distinctive waste management-driven green jobs, formalizing informal waste pickers and by focusing in education and training of informal worker. The review also emphasized in creating green jobs by investing in recycling infrastructure which would enable us to address the climate change related concerns which is one of the key target of UN-SDG. The CE-based product designs and business models would emphasize multifunctional goods, extending the lifespan of products and their parts, and intelligent manufacturing to help the public and private sectors maximise product utility (thus reducing waste generation) while providing long-term economic and environmental

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benefits. The study also recommended strong policies that prioritized investments in decentralization of solid waste systems, localization of supply chains, recycling and green recovery, information sharing, and international collaboration in order to achieve the UN-SDGs.

Contents

1. Introduction

The year 2020 was marked as the start of the 'Decade of Action' by United Nations to deliver the SDGs by 2030. However, with a global death toll of over 3.4 million people (while we write) and an impending socio-economic crisis, COVID-19 has derailed the progress made so far in achieving the United Nations Sustainable Development Goals (UN SDGs) (Guan et al., 2020; Sachs et al., 2020.). Independent of the disease's real spread, every country including the high-income countries in Europe and North America have been adversely affected by the economic ramifications induced by the pandemic (Sachs et al., 2020). For instance, job hours wasted in 2020 was equal to 255 million full-time workers, resulting in $3.7 trillion in lost labour revenue (ILO, 2020). Even after investing US$ 18 trillion as an economic stimulus, global economies are projected to lose US$ 12 trillion or more by the end of the year 2021 (Gates, 2020). Moreover, the disproportionate socioeconomic implications of the COVID-19 pandemic pose a greater risk for developing nations and weaker demographics to reach their targets set by SDGs. So, in the face of a crisis, where the root causes, uneven impacts and vulnerability levels of different populations are demonstrated, the importance and the required urgency in implementation of the SDGs becomes apparent.

Solid waste management (SWM) is a crosscutting problem that influences different facets of growth in all three domains of sustainability: environment, economy, and society (Rodic and Wilson, 2017). The guiding principles of SDGs can be broadly categorized as similar to the goals that have guided the growth of SWM practices over time, namely: public health (SDG 3), environmental issues (SDG 6 & 13) and resource value (SDG 11), with more recent additions to climate change (SDG 13) (Wilson, 2007). For example, SDG 12.3 (halve the per capita global food waste at the retail and consumer levels), SDG 14 (proliferation indiscriminate use and disposal of plastic waste causing marine litter and micro plastic related concerns) cannot be met without meeting the goals of sustainable SWM. Uncollected waste and poorly disposed waste have significant health and environmental impacts (SDG 6 &13). The cost of addressing these impacts is many times higher than the actual cost of developing and operating simple, adequate waste management systems (Kaza et al., 2018). The SWM can be specifically linked to 12 out of the 17 UN-SDGs as the main utility system that more than 2 billion people currently lack (Rodic and Wilson, 2017).

Global waste is expected to grow to 3.4 billion tonnes by 2050 from the current 2.01 billion tonnes. Solid waste-related emissions are anticipated to increase to 2.38 billion tonnes of CO_2-equivalent per year by 2050 if no improvements are made in this sector (Kaza et al., 2018). Thus, a paradigm shift is necessary from the depletive 'produce-consume-dispose' model of the linear economy to the 'reduce-reuse-recovery-recycle-redesign-remake' model of the circular economy, which is more regenerative and restorative (can have a positive impact on SDGs 1, 3, 6 - 9, 11, and 13 - 15). The circular economy reflects a structural change that creates long-term stability, maximises the usage and circulation of commodities, resources, and nutrients (SDG12) while providing economic, environmental, and societal benefits (SDG 1, 2, 9, 13 - 15) that help the public and private sectors address both short- and long-term objectives of SDGs (Ellen MacArthur Foundation, 2020). Circular economy based SWM can be an integral component in promoting the three cornerstones of sustainable development (economic development, social inclusion, and environmental protection).

The immediate goal once pandemic starts to ebb out would be to revive economic activity without restoring old trends of environmental deterioration (Sachs et al., 2020). So, as a response to an economic slowdown brought upon by COVID, trillions of dollars in fiscal stimulus have been started to make available around the globe (Masterson, 2020; IMF, 2021). However, achieving resilient and low-carbon economic growth requires policymakers to think beyond safeguarding just national economies through crisis; but, to also take critical steps for a greater structural transition that is more robust against future global threats (Masterson, 2020). To reverse the significant setback and ensure a resilient and sustainable economic rebound, countries would need to brace for a different post-COVID economy by enabling money, labour, expertise and innovation to shift into new industries and sectors (World bank, 2020a). To meet the present needs and reserve the rights of development for future generations, a set of waste management strategies integrating the concept of sustainable development should be developed to achieve the goal of protecting the environment while yielding economic and social benefits (Wan et al., 2019).

In accordance with the preceding discussion, the objective of this paper was to present a case for how the integration of circular economy based sustainable solid waste management into the COVID-19 response could help in mitigating the impact caused by the COVID-19 pandemic to United Nation Sustainable Development Goals (UN SDGs). The first part of the paper highlights the impact of the COVID-19 pandemic on the progress of UN-SDGs. The second part of the paper elucidates in detail how sustainability goals UN-SDGs align with the that of solid waste management, and investigated the feasibility of integrating a circular economy model into a solid waste management system using a COVID-19 economic response to meet UN-SDG objectives. In addition, some major challenges hindering our transition to the circular economy were outlined along with few unique policy recommendations that can help in designing indigenous solutions for smooth transition guided by the principles of SDGs.

2. Implications of COVID-19 on the progress of SDGs

The objective of SDGs was to emphasize global attention and converge the efforts of society to inspect and accelerate the progress towards accomplishing the individual 169 targets spread across multiple facets of development exemplified by the 17 goals. The success of sustainable development goals could be related to two important pillars - sustainable economic growth and globalization. However, the economic slowdown due to COVID-19 has resulted in an incapacity of the industrialized countries to support the development of others. COVID-19 has also demonstrated the non-resilience of the SDGs to different global stressors. For instance, (Naidoo and Fisher, 2020) has demonstrated that almost two-thirds of the 169 targets as specified by the 17 SDGs were either under threat or not well-placed to mitigate its impacts. Moreover, around 10% are predicted to amplify the impacts of future pandemics.

The uncertainties associated with the long-term impacts of COVID-19 on economic recovery could be linked to the production factors including labour, capital stock, and productivity, along with some distributional implications (Hughes et al., 2021). The impacts hampering with the progress of SDGs could be either explicit or implicit. The explicitly affected goals are 1, 2, 3, 4, 8, 10, and 12. While some of the goals such as 5, 6, 7, 9, 11, 13, 14, 15, and 16, due to the divergence in the priorities are implicitly affected (Mukarram, 2020). The final goal of 17, would be instrumental for consolidating the global efforts and to bring back the momentum required for making up to the losses in the progress of SDGs during the post-COVID period.

2.1. Economic implications

The advent of the COVID-19 pandemic has resulted in an unprecedented socio-economic-ecological crisis, threatening the lives and livelihoods of people, while rewinding decades of progress. The economic recession consequent to the predicted contraction in global GDP (by 5.2%) and per-capita GDP (by 6.2%) (World Bank, 2021) has triggered a sharp increase in unemployment, underemployment, decline in labour income, and increased challenges in job quality (SDG 1). With a reduced flow of aid and resources from developed economies, the impact of the global recession will be very severe for the poorer countries. World Bank has predicted the decline in global remittances to low and middle-income countries (LMICs) by about 20% ($445 billion) in 2020 due to the pandemic and shutdown (World Bank, 2020b). The Organization for Economic Co-operation and Development (OECD) also projected that the external private finance in developing economies to lose USD 700 billion that could exceed the impact of the 2008 financial crisis by 60%, thereby risking and creating major setbacks in financing for sustainable development in developing economies (OECD, 2020,) (SDG 10). Impacts of COVID-19 on the United Nation Sustainable Development Goals is presented in Fig. 1.

The International Labour Organization (ILO) reported a reduction of working hours by 10.7% (≈305 million full-time jobs) in 2020 as compared to the last quarter of 2019 (ILO Monitor, 2020). In the year 2020, 114 million people lost their jobs due to the COVID-19 pandemic and the resulting lockdown. ILO predicted workforce displacement in that 38% of the global workforce (1.25 billion workers) employed in the most vulnerable sectors (Retail trade, accommodation and food services, and manufacturing). These sectors comprising micro, small and medium-sized enterprises with little to no income security and social protection will be the hardest hit due to COVID-19. For instance, the UN World trade organization (WTO) estimates a loss of 850 million to 1.1 billion international tourist arrivals accounting for $910 million to $1.1 trillion in export revenues and 100-120 million jobs in the tourism sector (World Tourism Organization (UNWTO), 2020). With approximately 54% of the jobs in tourism held by women, who are more likely to be entrepreneurs and hold low skilled jobs in this sector, has made them the most vulnerable population for job loss (UNCTAD, 2020) (SDG 8).

2.2. Environmental implications

Restrictive measures on human mobility and supply chain disruptions have led to a shortage of labour in local agriculture and food-related activities thereby causing huge material losses. Especially, the reduced demand resulting from the shutdown of restaurants, catering services, food markets and public canteens have considerably limited their sales and caused increased production of perishable food wastes (FAO, 2020). Even with the partial opening of the food outlets, the volatility in the demand could also be responsible for the increase in the production of food waste (SDG 12).

The restrictions, disruptions in supply chains and confinements have forced behavioural changes worldwide. Increased locally-sourced production and online-based services have proved to support responsible consumption. Moreover, increased dependence on single-use plastics due to the false perception of hygienic superiority might retract the progress achieved by the shift to sustainable alternatives. However, with the recovery to normal, the solidity of these transitions in consumption and production would be tested (UNEP, 2020a). Disruptions in the existing waste management systems like shortage of staff, capacity constraints of treatment facilities, disruptions in the plastic recycling facilities due to the pandemic, have reduced the recycling and recovery activity (SDG 12). The increased dependence on online food and supplies delivery has raised the proportion of plastic packaging waste in the municipal solid waste stream. For example, an additional 1,47 tons of plastic waste comprising mostly takeout packaging and food delivery by Singapore's residents during their eight-week lockdown period (Bengali, 2020). An increased abundance of single-use plastic waste such as fast-food packaging, confectionary wrappers and drink bottles in the London waterways amidst the relaxation of lockdown regulations and social distancing rules (Konyn, 2020; Ro, 2020). The temporary disruptions caused in the waste collection of cities along with the inadequate infrastructure for the change in the dynamics of the waste generation have led to increased waste mismanagement, thereby resulting in pollution. However, the reduced waste generation from the commercial and industrial sectors due to the temporary halt in economic activity should also be acknowledged (UNEP, 2020b; Sharma et al., 2020) (SDG 14).

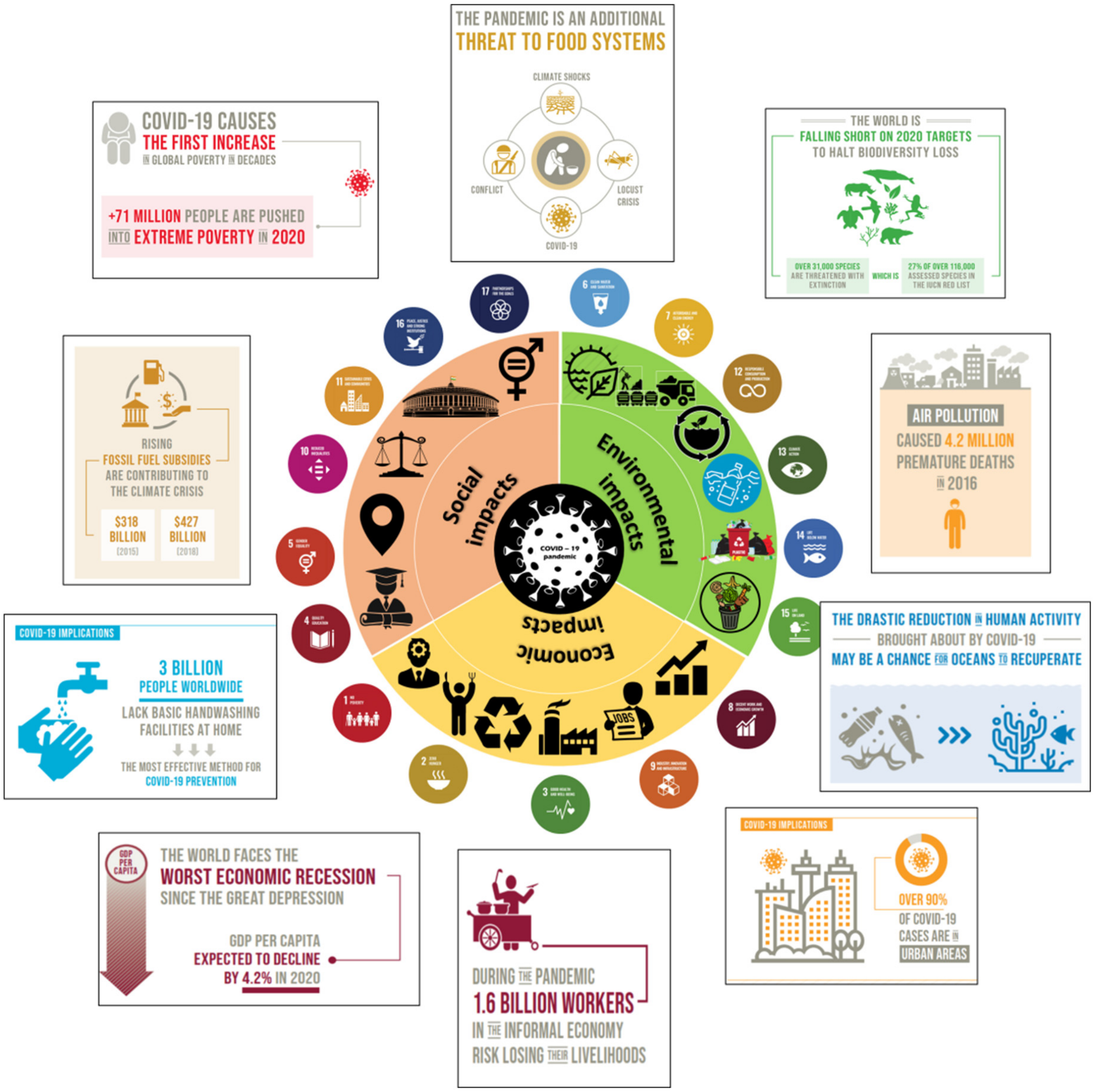

Fig. 1. Impact of COVID-19 on the United Nation Sustainable Development Goals (United Nations, 2020).

The health crisis induced by the COVID-19 pandemic has resulted in the generation of an enormous amount of biomedical waste (BMW). For instance, daily bio-medical waste generation in India increased by 25% in 2020 due to COVID-19 (Yearender, 2020). The increase in the use of facial tissues, gauze pieces, masks, oxygen masks, test tubes of nasopharyngeal swabs, cotton swabs, saline bags, disposable syringes, and needles to treat COVID-19 patients become part of the hazardous BMW. The used PPE is a source of potentially infectious BMW that requires special attention during waste management. The inadequacies of existing facilities like incineration to manage the increased generation of biomedical waste have also increased the risk of hazardous waste disposal in an open environment (BIR, 2020; Vanapalli et al., 2021c) (SDG 14). The health risks associated with the improper handling of infectious COVID-19 waste (especially in developing countries) for the sanitation staff due to the lack of access to safety equipment like PPE should also be taken into consideration (SDG 3, 8). Other people who are more prone to get infected from unregulated disposal of virus-laden waste in developing countries would be the informal waste collectors.

The restrictions associated with the pandemic have pushed the global workforce to work from home resulting in accelerated demand for electronics, especially in the form of information and telecommunication equipment (Laptops, mobiles, digital thermometer etc). For instance, in a survey conducted by Blancco and Joensuu, 97% of the companies were found to buy new laptops, and 77% of Americans also had to buy a new device to support remote work access (Cunningham, 2020). Even with the pandemic receding, many companies are forced to invest in better digital technology and home office setups, which has driven a huge spike in the consumption of electronic goods (Cunningham, 2020). This can be associated with an enormous rise in global electronic waste generation (SDG 3, 11, 12).

Although UN in its SDG report 2020 has predicted a 6% drop in greenhouse gases (GHGs) for 2020 due to COVID-19, United in Science, 2020 has reported atmospheric CO_2 concentrations of above 410 ppm during the first half of 2020, with no signs of reduction due to the pandemic. However, global fossil CO_2 emissions in 2020 were estimated to fall by 4 - 7% in 2020 due to COVID-19 confinement policies. For instance, their values dropped by 17% in April 2020 compared to 2019; but they have returned to within 5% (1–8% range) below 2019 levels in June (UNEP, 2020b; United Nations, 2020). Moreover, the long-term exposure to air pollution resulting in pre-existing respiratory diseases could increase the risk of mortality due to COVID-19 (Wu et al., 2020) (SDG 13).

Although with reduced industrial and commercial activity during lockdowns, there was a significant reduction in water pollution, this can be viewed as a temporary solution. Especially during the lockdown period, the temporary halting of some major industrial activities has helped to reduce the pollution load on surface waters (Yunus et al., 2020). For instance, among the 36 real-time monitoring stations of the river Ganga in India, water from 27 stations met the permissible limit, depicting the implications of reduced industrial pollution on the days of lockdown in India (Singhal and Matto, 2020). Moreover, disruptions in the waste collection services might have induced solid waste mismanagement and caused dumping into the waters (Patel et al., 2020; Yunus et al., 2020) (SDG 6). Despite the reduced activity in the sea might have caused temporary relief to direct marine pollution (Rume and Islam, 2020), the sudden rise in the daily use of single-use PPE which contain a significant portion of plastic to reduce the risk of infection has significantly increased along with the associated risks of marine pollution. With an estimated rise in the global sales of disposable face masks to $166 billion in 2020 compared to $800 million in 2019, (UNCTAD, 2020), almost 75% of it is estimated to be in landfills or end up as marine litter (UNCTAD, 2019). For instance, Oceans Asia has reported finding at least 70 face masks disposed of along a stretch of just 100 m, with an additional 30 washed up on shore on a beach in Lantau Island at the end of February (OCEANS ASIA, 2020). Further, the disintegration of plastic waste into microplastics in the oceans can adversely impact the health of aquatic biota and subsequently be ingested by humans through their food chain (Vanapalli et al., 2021b). The additional problems of plastic waste clogging of drains and canals could increase mosquito breeding, posing a risk of vector borne-diseases (Vanapalli et al., 2019).

2.3. Social implications

The COVID-19 poses an additional threat to the food systems, indirectly reducing purchasing power and the capacity to produce and distribute food, which affects the most vulnerable populations. According to the Food and Agriculture Organization (FAO) estimate, food systems involving the sectors of processing, services, and distribution, are estimated to lose more than 451 million jobs (35% of formal employment) (Torero, 2020) (SDG 2). Moreover, with 62% of the global workforce (2 billion) employed in the informal sector, the risk of losing their livelihoods due to the pandemic is real. Even migrant workers which represent 4.7% of the global labour force (164 million workers with approximately 50% women) (ILO, 2018) were badly affected during the ongoing crisis due to increased vulnerability due to migratory and employment status. Although the e-commerce sector which is expected to grow by USD 100.63 billion (Technavio, 2021) was absorbing some of the displaced labour, lack of income, health and social securities to the workers seems to be a depriving factor (SDG 8).

Depending on the severity of the economic contraction, the COVID-19 pandemic was forecasted to bring around 150 million into extreme poverty by 2021 (World Bank, 2020b) (SDG 1). Especially, small-scale food producers comprising 40–85% of all food producers in developing regions are hit hard by the crisis (United Nations, 2020). UN global report on the food crisis, 2021, has reported that at least 155 million people have faced food insecurity crisis in 2020 because of conflict, extreme weather events and economic shocks linked as part of the COVID-19 pandemic (IFPRI, 2020), which implies 38.2 - 80.3 million people in poor countries who rely on food imports falling into the hunger trap (Swinnen and McDermott, 2020).

2.4. Specific implications on solid waste management

The impacts of COVID-19 can be mainly classified into the change in waste composition, and quantity, infection risks, disposal frequency, timing (temporal), and spatial distribution. The variations in the waste generation rates, frequency and demands at places of collection have stifled the existing treatment facilities, thereby restricted their adaption to the sudden changes. Also, the decision associated with whether to continue or avoid the recycling considering the safety concerns of the workers against infection was difficult. The technoeconomic uncertainties related to the volume changes, ambiguous policies and guidelines, duration of the emergency, and the constraints with accommodation of safety measures have led many leading recycling programs to suspend services (Fan et al., 2021). The price drop in the secondary materials and the decrease in the demand for primary material could be the key reasons for the decline in the profit of the waste to materials industry in China by 43% during the COVID-19 pandemic (Zhou et al., 2021). However, with the advantage of achieving energy recovery and safe disposal of waste, waste to energy (WTE) industry has compensated the other options of management with non-hazardous municipal solid waste along with hazardous and non-hazardous medical waste during the pandemic and is expected to be booming post COVID-19 pandemic. In spite of the safety advantages of WTE, the environmental superiority of waste to material over of incineration in the waste management hierarchy poses a dilemma to zero waste and source separation and could not be seen in line with the concept of sustainable waste management as proposed by the SDGs.

The solid waste industry is expected to be confronted with declining revenue and rise in operational cost post pandemic in the short-term. For instance, an estimated 55.8 billion $CNY \cdot a^{-1}$ reduction in the turnover of the thirty listed companies in the solid waste industry was predicted by ARIMA-Intervention model in the year 2020 (Zhou et al., 2021). This can be attributed to the overall global economic recession which in turn restricts the monetary support from governments and waste producers who were also affected by the pandemic. Also, the change in the policies and shift in the allocation of funds to indispensable sectors and services affected during the pandemic could compromise the action plans associated with waste generation reduction, promotion of recycling, and elevating level of waste management systems as depicted in the 2030 agenda of SDGs.

3. Circular economy based sustainable solid waste management as a tool for accelerating the progress of achieving SDGs

Geissdoerfer et al. defined circular economy (CE) as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops (Geissdoerfer et al., 2016). Incorporating CE principles in waste management systems could enable the recovery of economic growth. The CE system strives to integrate the three pillars of sustainable development (economic, environmental and social) through a symbiotic approach to recover energy and material from waste, design durable products and extend the service life of systems. This regenerative model can bring a balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations (Geissdoerfer et al., 2016).

The circular economy needs a smarter approach to bend the linear flow of material (Fig. 2) to avoid disposal and this transition requires swift actions and strong policies. A framework based on 10 common circular economy strategies (i.e., recover, recycling, repurpose, remanufacture, refurbish, repair, re-use, reduce, rethink, refuse) or 10 R is often proposed to transit into a circular economy (Morseletto, 2020). Morseletto organized the idea of 10R into three groups approach: (a) useful application of materials; (b) extend the lifespan of products and their parts; (c) smarter product manufacturing and use (Morseletto, 2020) (Fig. 3).

The first approach in dealing with the linear flow is to introduce the concept of refuse, rethink, and reduce for smarter product use and manufacture. 'Refuse' refers to making a product redundant by abandoning its function or by offering the same function with a different product. 'Rethink', signifies the importance of making a product more intensive through product sharing or by promoting multi-functional products

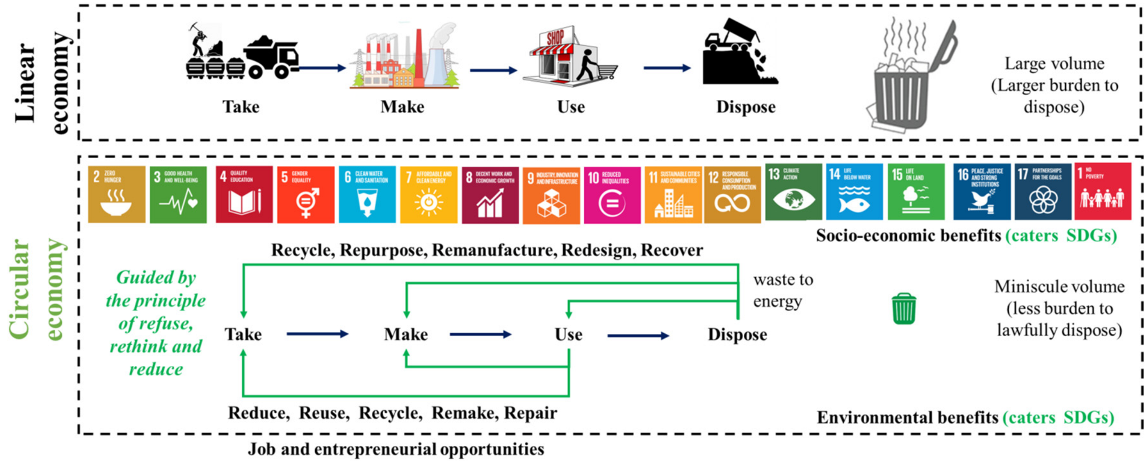

Fig. 2. The difference between linear and circular economy showing ways to achieve SDGs.

into the market. The concept of 'Reduce' infers increasing the efficacy of the products or by consuming fewer natural resources in its manufacture.

The second approach of dealing with the linear material flow is by making sure the products manufactured along with their parts have extended lifespans. This could be achieved by the principles of reuse, repair, refurbish, remanufacture, and repurpose. By reusing the same product after disposal that can still fulfill its original function by another consumer. Repairing and maintaining the defective product so it can be used with its original function. Refurbishing and restoration of an old product can bring its utility back. The used parts of the discarded product could be remanufactured into a new product with the same function. Repurposing the use of a discarded product or its parts could be converted into a new product with a different function. Manufacturing

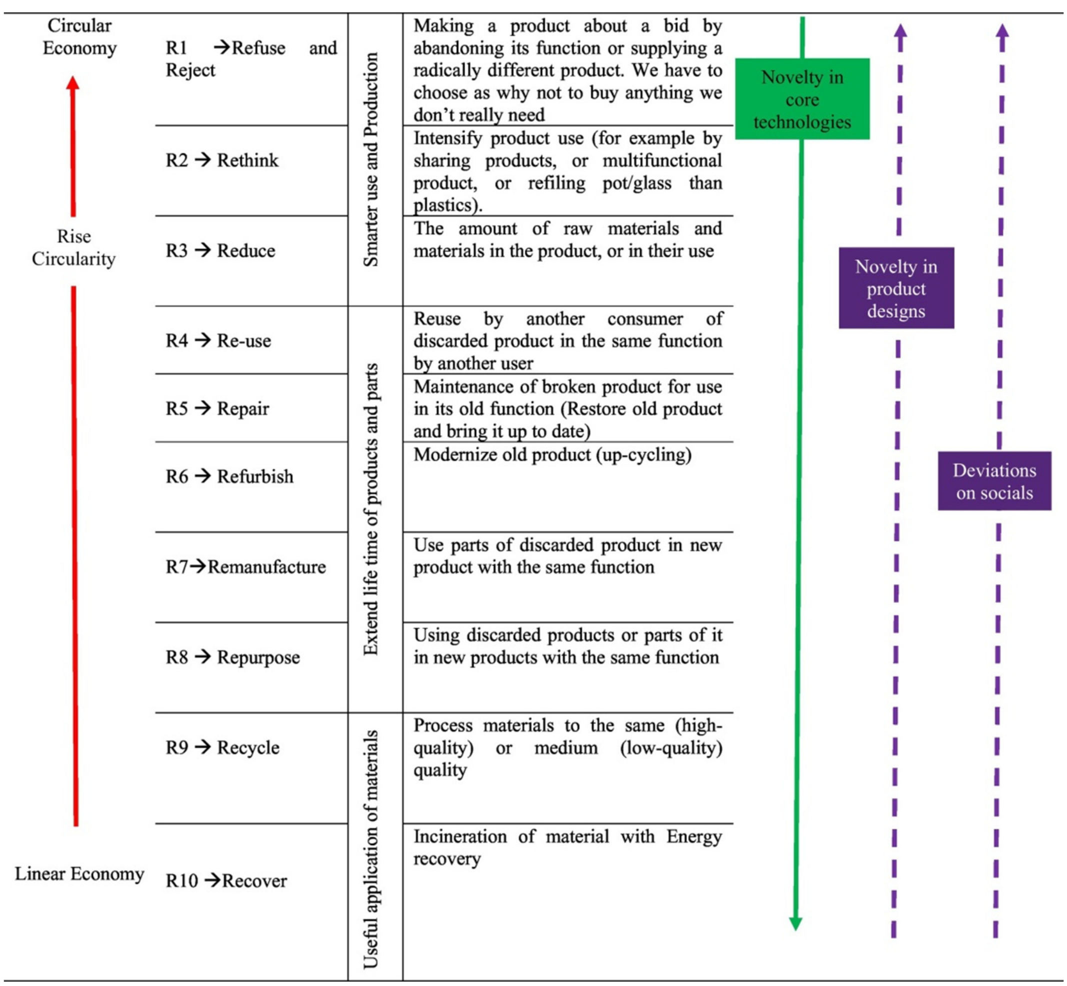

Fig. 3. Concept of 10R during the implementation of circular economy based solid waste management (Zorpas, 2020) (with permission from Elsevier Licence number 5041781434699).

products that encourage reparability, upgradability will encourage sufficiency, modest growth rates, which could further help slow resource loops and reduce waste generation (Bocken et al., 2016).

The third approach is to increase the useful application of the materials. The principle of recycling and recovery is critical in this approach and it is where most of the circular policies (and targets) are currently concentrated (Ghisellini et al., 2016). The strategies of recovery and recycle are often considered as efficient solid waste management techniques in the waste management hierarchy as compared to landfilling, or combustion without heat recovery (Morseletto, 2020).

It is self-evident that the process of green recovery post pandemic would still need to focus on job creation. Investments in recycling, reuse, remanufacturing, maintenance refurbishing and repair services prevent cities from sinking in their garbage while quickly creating jobs for vulnerable groups (Gulati et al., 2020). The global annual waste generation rate is expected to rise from 2 billion tons per year to 3.4 billion tons per year by the year 2050 (Kaza et al., 2018). For every 1000 metric tons of waste, 3 to 20 recycling, reuse and recovery jobs are needed vs. 0.1 landfill and incineration jobs (Goldstein et al., 2011). According to the International Labour Organization (ILO, 2018), by 2030, 45 million workers in the waste management sector could be added, as well as 50 million jobs in related circular economy services like repair and remanufacturing, if the world shifts to more recycle, reuse, and repair via a circular economy scenario (IISD, 2020; Gulati et al., 2020). Investments in recycling infrastructure can also offer opportunities to address climate change related issues apart from creating additional jobs.

3.1. Linking solid waste management and UN-SDGs

Poor waste management involves anything from a lack of effective recycling systems and infrastructure to unregulated disposal of waste which pollutes the air, water, and soil (SDG 12, 13, 14). Non-scientific landfills and waste dumps that are open and unsanitary lead to air pollution and contamination of ground water (SDG 11, 13). Debris dispersal pollutes habitats, and toxic chemicals from electronic waste or industrial garbage put a strain on urban dwellers' health and the climate (SDG 3, 13). Around 44% of the global waste generated is organic waste (mostly food and green water) (Kaza et al., 2018), and this percentage is even higher in most of the developing nations. The major disposal option currently followed around the world is open dumping (around 33%). Recycling accounts for just 13.5% while, composting and incineration accounts for 5.5% and 11.1%, respectively. The current global trends of waste composition, treatment and disposal options are presented in Fig. 4. It was estimated that 1.6 billion tons of carbon dioxide equivalent (CO_2-equivalent) of greenhouse gas (GHG) emissions were emitted from solid waste management and disposal in 2016, which accounted for about 5% of the global GHG emissions. Among the waste management components, waste disposal and treatment accounts for the highest amounts of carbon emissions sector as per European Union data (Eurostat, 2020). Without sectorial improvements, solid waste-related emissions are projected to rise to 2.6 billion tons of CO_2-equivalent of GHGs by 2050 (Kaza et al., 2018).

Each component of solid waste presents both challenges and opportunities. Waste management using a market-based sustainability approach would help in making the cities clean and green while also bringing direct economic benefits to the people involved in it (SDG 8). The additional socio-environmental benefits like improved living standards, breathable air, clean water and land, health and education could also be achieved which are the major goals of UN-SDGs. Municipalities in low-income countries are spending about 20% of their budgets on waste management, on average—yet over 90% of waste in low-income countries is still openly dumped or burned (Kaza et al., 2018). It has been estimated that a 10 to 15% reduction in global greenhouse gas emissions could be achieved through landfill mitigation and diversion, energy from waste, recycling, and other types of improved solid waste management. Also, including waste prevention could potentially increase this contribution to 15–20% (Wilson, 2007).

The case study (Nizami et al., 2017a, 2017b, 2017c) of Madinah City with the focus on energy, economic and environmental savings by adopting waste recycling found out that the estimated around 10,200 tons of methane (CH_4) emissions and 254,600 Mt.CO_2 eq. of global warming potential (GWP) can also be saved. In addition, carbon credit revenue of US $5.92 million, and landfill diversion worth of US $32.78 million can be achieved with net revenue of US $49.01 million every year only by recycling 24.21% of MSW in Madinah city (Nizami et al., 2017a, 2017b, 2017c). In another similar study Nizami et al. found out

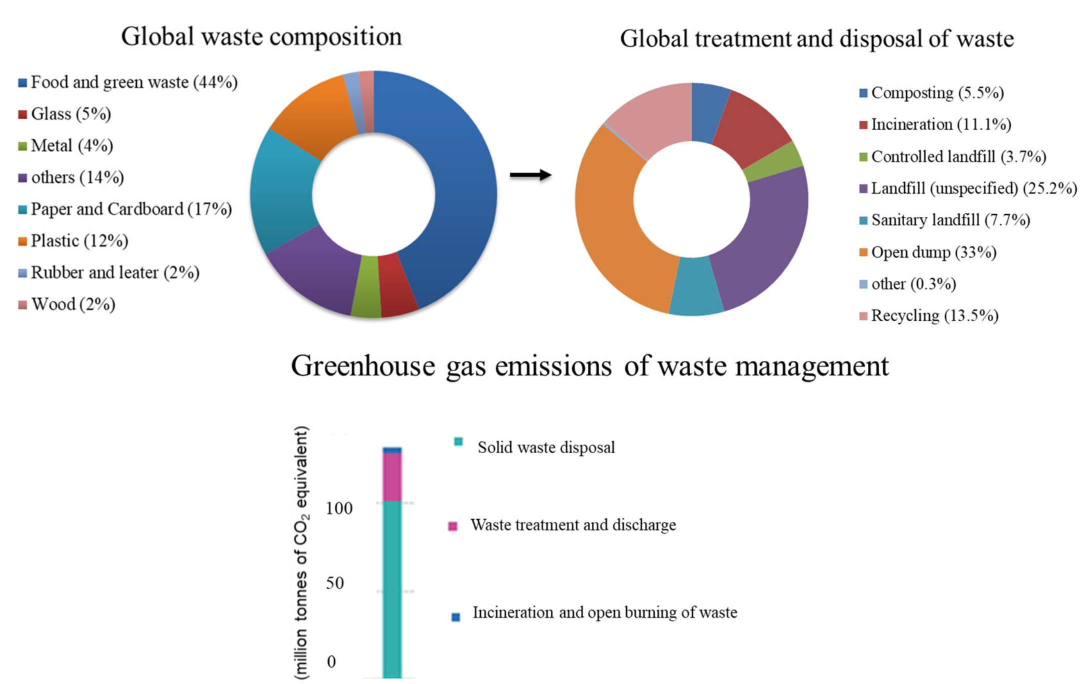

Fig. 4. Global waste composition and treatment and disposal trends (Eurostat, 2020; Kaza et al., 2018).

that by adopting waste-based biorefinery and recycling, the holy city of Makkah can reduce the global warming potential (GWP) of 1.15 million Mt.CO_2 eq while generating total revenue of 758 million SAR (Nizami et al., 2017a, 2017b, 2017c). So, understanding the prospects of each component of solid waste, from economic, social, and environmental perspectives is important to integrate the necessary responses that could help achieve SDGs. Table 1 present the link between the components of solid waste management and UN Sustainable development goals.

3.1.1. Food waste

The mismatch between substantial amounts of food produced and its limited consumption has severe environmental, social, and economic implications. Estimates suggest that 8-10% of global greenhouse gas emissions are associated with unconsumed food (Environmental protection England, 2020) (SDG 13). The UN report estimates 17% of the global food production ends up being wasted, which amounts to 931 million metric tons (1.03 billion tons) of food. Ironically, an estimated 821 million people went hungry during the year 2017 (SDG 2) (Hub ISK, 2019). The SDG 12.3 aims at halving per capita global food waste at the retail and consumer levels and reducing food losses along the production and supply chains, including post-harvest losses. During the pandemic, the broken food chains, panic buying and stock piling contributed to an increase in food loss and wastage, while lockdown mechanisms, unemployability, unprecedented health, economic and social crisis contributed to an increase in hunger (FAO, 2020; Sharma et al., 2020). World Food Programme estimated that the COVID-19 pandemic has doubled the number of people suffering from acute hunger i.e., about 130 million along with the 135 million people already suffering from hunger due to climate change, man-made conflicts and economic turndowns (Ellen Macarthur Foundation, 2019) (SDG 2). While food loss and waste contribute to about $940 billion in annual economic loss, optimisation of these systems can create substantial monetary benefits for farmers, companies, and households. So, the development of sustainable agriculture approaches including reduction in food waste will play a major role in achieving SDG13 (Climate Action).

Post COVID-19, the goal of achieving “Zero Hunger, SDG2” needs to be reinforced by understanding interconnectivity between economic, environmental dimensions of food systems to develop sustainable solutions integrating the circular economy model and food waste management. Efficient policies will promote that bring out circular economy-based applications like material and energy recovery, development of secondary products, designing green solutions, infrastructure development, industry interactions, and employment creation which can help in achieving the SDGs. Across the supply chains and production processes, the application of circularity principles can bring additional economic opportunities (SDG 8). Post COVID-19 pandemic, the EU Commission aims to develop a contingency plan from the stock of lessons to reinforce their ‘Farm to Fork’ strategy, this aims to accelerate the transition towards sustainable food systems to achieve neutral or positive environmental impact, mitigate climate change, reverse the loss of biodiversity, ensure food security, nutrition and public health, preserve affordability and promote fair trade (BINNS, 2019). The transition to these systems will equip and enable the governments to achieve a combination of SDG indicators viz., SDG 2 (end hunger, malnutrition, food security, agriculture, fair trade), SDG 6 (Water use efficiency, wastewater treatment), SDG 8 (economic growth; productivity, employability), SDG 12 (Food loss and Wastage), SDG 13 (Adapt climate change measures), SDG 15 (forest and land degradation, loss of biodiversity, natural habitats). Food waste, on the other hand, accounts for 8% of annual anthropogenic GHGs emissions; development of circular economy strategies would enable annual savings of 1.7 billion tonnes of CO_2 (Hub ISK, 2019). Development of enhanced collection, redistribution and valorisation systems will enable the development of economic opportunities from the organic material. It is estimated that an annual economic opportunity of USD 155-405 billion by 2030 can be achieved by the reduction of food waste (Ellen Macarthur Foundation, 2019). The establishment of food banks and distribution centres will equip in reducing hunger and improving food security. Processing waste to new products provides an economic opportunity; For example in 2019, Renewal mill raised USD 2.5 million by developing a flour producing venture using soya milk and tofu by-products (Hub ISK, 2019). Ananas Anam developed a leather-like material (Pinate) from pineapple leaves (Hub ISK, 2019); National university of science and technology, Russia development of bio-polymer ceramic composite from egg shells for fixing implants and bone defaults in the skull (BINNS, 2019) are few innovations in transforming food by-products for material use in the bioeconomy. Development of valorisation mechanisms like composting, anaerobic digestion and hydrothermal carbonization for inedible food and unavoidable food waste can also be other viable options of resource recovery and job creation (Sharma et al., 2021; Sharma and Dubey, 2020a, 2020b). For example, (Waqas et al., 2018) concluded that the composting of food waste not only provides sustainable management to MSW in Gulf countries but has a potential to fulfill compost demand in the region that was estimated to be about 500,000 tons per year in 2015 only in KSA with total net savings of US $70.72 million per year.

As depicted in Fig. 5, food waste prevention policies need to be devised based on the geographic and regional-specific conditions by integrating community needs, food supply variations, waste generation rate, behaviour and attitudes of stakeholders. Policy directives requires a multi-facet approach to address logical, infrastructure and social aspects associated with waste prevention. Public participation, performance indicators, political willingness, uncertainty on policy outcomes are the challenges in the implementation of food waste prevention policies. The economic component in policy should emphasizes notions like food waste as a resource and impacts on the environment along with other behavioural intervention. Logistic based policies should include economic incentives like tax benefits, subsidies to improve food packaging, labelling, mandating targets on waste prevention, designing waste collection systems, promoting redistribution and donation. The social component empowers people to understand food safety, nutrition values, food shopping, routine planning, and waste sorting and resource recovery.

3.1.2. Plastic waste

The surmounting amount of plastic pollution has already harnessed enough attention for its proliferation in the environment. (Virto, 2018) reported that 80% of marine litter is composed of waste plastics and estimated that by the year 2050, oceans will carry more plastic than fish (SDG 14). The advent of COVID-19 was estimated to result in the generation of 1.6 million tonnes/day of plastic waste since the outbreak (Benson et al., 2021). The rise in the use of single-use plastics can be associated with our fixation for hygiene, fear of contraction of virus from reused materials, and extensive demand for plastic packaged products which in turn has resulted in the generation of substantial amounts of waste plastics.

Addressing the issue of plastics from the value chain perspective not only minimizes environmental pollution, but also the consumption of fossil fuel - since 20% of total oil production is used for plastic production (Syberg et al., 2021). So, development of innovative products that facilitate harmonized standards relating to sustainable and circular design should be one of the major goals of legislations. For instance, Canadian Strategy on “Zero Plastic Waste” incorporates a directive on extended producer responsibility, which encourages producers to design and develop products that are easier to incorporate in the circular value chain. The development of products based on renewable resources like bioplastics from organic waste streams reduces plastic production from fossil fuels is an example of shift towards a circular economy (European commission, 2017). In the food and beverage sector, alternate solutions are being designed to reduce the usage of single-use plastics. For example, trials are underway to test paper bottle by Coco-cola

Table 1
Linking components of solid waste management to achieve UN Sustainable development goals.

Waste management goal[a]	Sustainable development goal	Indicator
Primary (Directly achievable goals)		
Reduction of food waste and loss.	Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round. 2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons. 2. c Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, to help limit extreme food price volatility.
Informal Sector Integration. Waste collection services Eliminate open dumping and open burning	Goal 3. Ensure healthy lives and promote well-being for all at all ages	3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
Creating technical and Nontechnical jobs Upgradations in managerial and Administrative positions Informal sector integration	Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors. 8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services. 8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value 8.8 Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular, women migrants, and those in precarious employment
Development of waste treatment technologies. Biomaterials from food waste	Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all 9.3 Increase the access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets 9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities
Waste collection services	Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management 11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels 11.c Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials
Landfill waste diversion Waste recycling, Remanufacturing and reusing approaches Creation of green jobs (technical and non-technical)	Goal 12. Ensure sustainable consumption and production patterns	12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses 12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, following agreed international frameworks, and significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment 12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse 12.a Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production
Clean and green waste treatment technologies	Goal 13. Take urgent action to combat climate change and its impacts	13.2 Integrate climate change measures into national policies, strategies and planning
Plastic waste management	Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

(continued on next page)

Table 1 (*continued*)

Waste management goal[a]	Sustainable development goal	Indicator
Eliminating unregulated open dumping and open burning	Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements
Development of waste treatment technologies	Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	17.7 Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms, including on concessional and preferential terms, as mutually agreed 17.17 Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships
Secondary (indirectly achievable goals)		
Informal Sector Integration	Goal 1. End poverty in all its forms everywhere	1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day 1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions 1.b Create sound policy frameworks at the national, regional and international levels, based on pro-poor and gender-sensitive development strategies, to support accelerated investment in poverty eradication actions
Waste education and training	Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	4.3 By 2030, ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university 4.4 By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship
Creating technical and nontechnical jobs Upgradations in managerial and administrative positions Informal sector integration	Goal 5. Achieve gender equality and empower all women and girls	5.1 End all forms of discrimination against all women and girls everywhere 5.5 Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life 5.c Adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels
Harnessing energy via biological and thermal conversion methods	Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all	7.2 By 2030, increase substantially the share of renewable energy in the global energy mix 7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology and promote investment in energy infrastructure and clean energy technology

[a] Adopted with modification from (Wilson et al., 2015).

to eliminate plastic from packaging (BBC News, 2021). The EU Single-use plastic directive aims to reduce the utilization of food containers and cups for beverage by adopting and promoting reusable alternatives by 2026 (Climate Action Tracker, 2020). UK government is encouraging a shift towards multi-use products by levying taxes on single-use plastics that come into enforcement from 2022 (Environmental Protection England, 2020).

Recycling promotes local development by re-internalizing jobs within a region. A plant that produces 50,000 metric tonnes of recycled plastic employs about 30 people on average (d'Ambrières, 2019). By developing an efficient recycling system, a local industry can emerge and recover material, energy and so economic value from recycling waste plastics. However, due to the technical constraints in plastic waste recycling systems compared to a relatively simple conventional waste disposal system, recycling is often considered a costly option. So, to encourage such environmentally sustainable ventures, this additional cost must be covered by producers and consumers of plastic goods through extended producer responsibility (EPR) (d'Ambrières, 2019). Moreover, transition to economic and environmentally sustainable technologies such as pyrolysis with a potential to deliver by-products of good commercial value can enhance material and energy recovery from plastic waste following circular economy principles (Vanapalli et al., 2021a). Plastic material flows to different processing methods, associated financial equation of different processing methods, and the EPR concept is presented in Fig. 6.

Development of waste handling capacities and infrastructure will equip handling the increased waste. Policies on material recovery and energy recovery, extended producer responsibility and integration of the informal sector improve the economic activity and equip in employment creation. An overview of the key drivers for integrating the pillars of sustainability and governance to circular economy approaches in plastic waste management to achieve sustainable development goals is presented in Fig. 6.

Extended producer responsibility, increasing investor's confidence, incentivizing responsible consumer behaviour equip in the long-term economic viability of plastics recycling. EU directive on packaging and packaging waste amended in 2018 promotes recycling and reuse of packaging waste facilitating the transition towards circular economy (Climate Action Tracker, 2020). EU directive on single-use plastic is adopting measures to develop separate collection systems for individual waste streams (ex: beverage bottles) to increase the recycling rate. Globally, in 2016 around 41% of the plastics were mismanaged and it is estimated to increase by 56% in 2040. Integration of the plastic recycling systems with circular economy approaches reduces GHG emissions by 25%, entry of plastics into the ocean by 80%, generates savings by about USD 200 billion per year and creates an additional 7 lakh employment opportunities (Ellen Macarthur Foundation, 2019).

The transition to these systems will enable the governments to directly achieve a combination of SDG indicators viz., SDG 8 (Annual growth rate of real GDP per capita; Proportion of informal employment

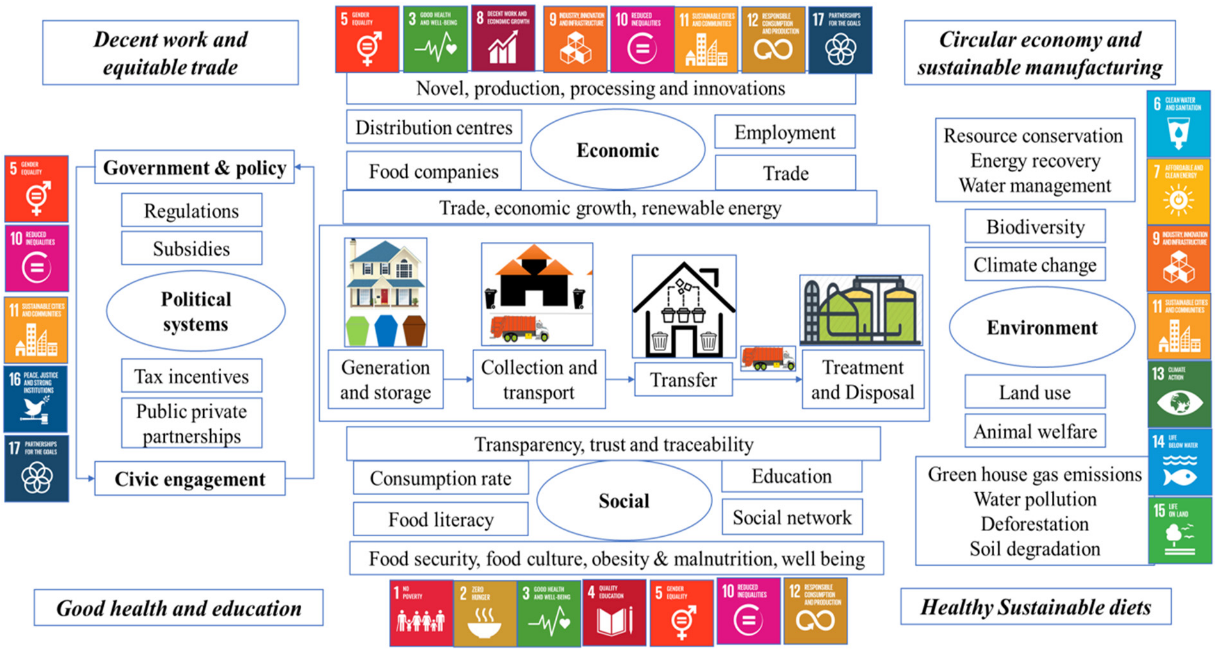

Fig. 5. Food waste prevention policies with multi-facet approach to address logical, infrastructure and social aspects associated with waste prevention.

in non-agriculture employment; Unemployment rate, by sex, age and persons with disabilities); SDG 9 (Manufacturing employment as a proportion of total employment; Proportion of small-scale industries in total industry value added), SDG 11 (Urban solid waste collection and discharge), SDG 12 (reduction of waste generation through prevention), SDG 13 (Adapt climate change measures), SDG 14 (Preventing marine pollution). On the other hand, SDG 1 (decreasing poverty level), SDG 2 (end hunger) and SDG 5 (Gender equality) are also influenced indirectly.

3.1.3. Construction and demolition waste

Building and infrastructure sector contributes to environmental impacts by utilizing natural resources and energy during its design lifetime. The building sector accounts for utilizing 32% of the total global energy, extraction of 40% of natural resources in industrialized countries, consumption of 70% of electricity, 12% of potable water, occupies 45–65% of landfills, 30% of GHG emissions in operation phase, and 18% in material utilization and transportation phases (Umar et al., 2012; Zou et al., 2019). Designing energy-efficient buildings improves indoor

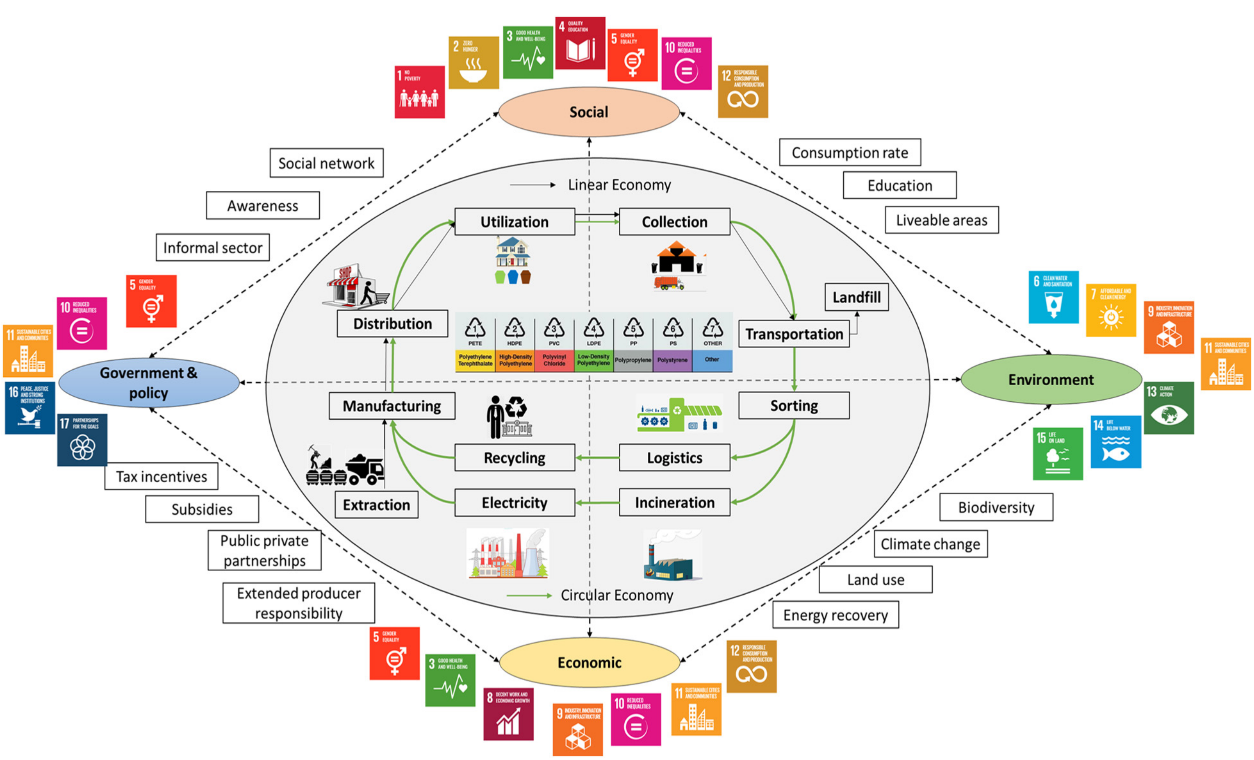

Fig. 6. An overview of the key drivers for integrating the pillars of sustainability and governance to circular economy approaches in plastic waste management.

comfort levels, minimizes reduce energy consumption and reduces overall building cost. The SDG 11 (Urban solid waste collection and discharge) and SDG 13 (Climate Change) and energy policies aiming to promote sustainable construction and global environment well-being can be achieved through the application of energy-efficient systems. Alawneh et al. (2018) reported that the application of LEED v2.2 water efficiency credits, energy and atmosphere standards in the design of green buildings contribute to the realization of seven SDGs (6, 7, 8, 9, 12, 13, and 15).

Investments of USD 1 million in the green construction sector for a low carbon-built environment would create 8 - 21 vs. 3 jobs in the fossil fuel sector. These green building sectors hold up to 58% of the emission abatement potential in cities globally (Gulati et al., 2020). Green design also aims to reduce building waste that usually ends up in landfills, which should be one of the major aims during the construction process.

Construction and building materials are the major components contributing to buildings total energy consumption and GHG emissions during their lifetime. The utilization of local building materials or recycled materials minimizes the construction cost by about 60%. The development of a low-cost housing design enables housing access to low-income people at affordable cost. This approach equips in reduction of poverty (SDG1), clean water and sanitation (SDG6), industry innovation and infrastructure (SDG9), reduce inequalities (SDG10), development of resilient local community (SDG11) and combating climate change (SDG13). Good health and promoting the well-being of communities - the goal of SDG3 can be achieved by improving the indoor environment in the buildings and workspaces. Selection and promotion of green materials in the indoor environment promotes well-being and prevents low progression and long duration diseases. Innovations in building materials and construction practices lead to sharing of knowledge, development of partnerships and strengthening of bilateral relationships. Programs are being designed and developed at regional, national, and international levels to educate, assist and train construction stakeholders. This will equip in achieving the goals and targets of SDG 17 (partnerships for goals) (Nubholz et al., 2019). In the construction industry, replacing virgin material with recycled material equips in reducing 14-18% GHG emissions by 2050 in G7 countries. The utilization of recycled aggregate reduces emissions by 40% and recycled steel by 90% providing scope for reducing the risk of future climate crisis (Masterson, 2020). Incorporation of circular economy approaches in construction and demolition waste systems promotes transition towards the recycling of C&D waste, reduces stress on natural resources, lowers greenhouse gas emissions and improves job opportunities as shown in Fig. 7.

3.1.4. Biomedical waste

The use of disposable items to reduce viral transmission is a necessary part of controlling the spread of the virus. However, with the number of people requiring access to health care and increasing during the pandemic and as the vaccination drives gather pace across all countries, there is a tremendous surge in the quantum of biomedical waste generation. With an endeavour to reduce health problems (SDG 3), it is essential to have a safe and reliable method of segregation and disposal of BMW, because of its higher potential for infections and injuries. On average 0.5 kg/bed/day of hazardous waste is generated in developed countries and in developing countries, 0.2 kg/bed/day of hazardous waste is generated (WHO, 2018). As per the World Health Organization (WHO), 85% of BMW is non-hazardous and 15% of BMW includes potentially infectious waste (WHO, 2020.). Apart from the associated health risks, improper handling and disposal practices of BMW can cause adverse environmental effects including soil and groundwater contamination, killing beneficial microbes in septic systems, physical injuries through sharps, etc.(Sharma et al., 2020). Such situations are more predominant in developing countries that lack the necessary infrastructure leading to the dumping of infected or hazardous waste along with other municipal solid waste. So, during the pandemic where the risks are higher, crucial steps will be access to the appropriate treatment facility and safe disposal of waste, which would control the related health and environmental hazards (Sangkham, 2020).

The global market for medical waste management is expected to have a strong demand for additional capacity building and advanced solutions. Success in healthcare waste management will speed progress

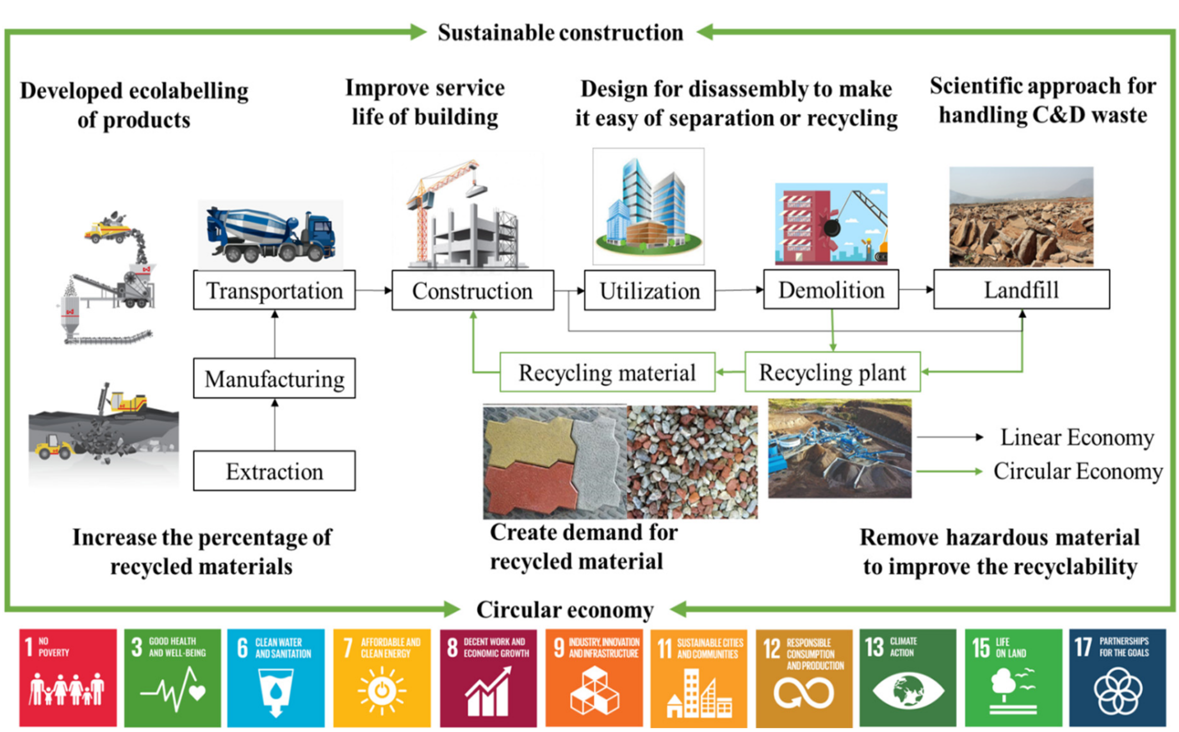

Fig. 7. Incorporation of circular economy approaches in construction and demolition waste management.

towards meeting several of the UN Sustainable Development Goals, particularly: (3) Good health and wellbeing, (6) Clean water and sanitation, (8) Decent work and economic growth (12) Responsible consumption and production and (13) Climate action. Healthcare waste management is one area that has been persistently under-recognised and under-resourced, with enormous knock-on effects for workers, patients and the community. Solving this problem would remove direct and indirect threats to the health of over half the world's population (SDG 3). The WHO, recognizing the interrelation between waste and water, has incorporated healthcare waste management into its water, sanitation and health program for healthcare. To be truly successful, this program must implement waste treatment technologies that do not create toxic residues or emissions in their own right (SDG 6). Despite carrying out a task vital to society, waste workers are too often underpaid, under-educated and under-protected. In many cases, not only do workers lack a living wage, but working conditions violate their human right to a safe working environment. There needs to be a step-change in the way healthcare waste management and its workers are viewed. It needs to be recognised as an essential public service, with professional standards, vaccinations, training, decent conditions, a living wage and respect for the men and women that carry it out (SDG 8).

Sustainable choice of products that are inclined to the principles of circular economy is also necessary. The healthcare sector needs to leverage its buying power to ensure that the materials it purchases generate minimal amounts of toxic, non-repairable, non-recyclable waste. By advocating for the replacement of these products with safer alternatives, the healthcare system can help kick-start the global circular economy. Minimizing waste, segregating at source, avoiding incineration, and recycling all conserve resources and energy. Research conducted by HCWH proved that autoclaving waste has CO_2 emissions at least fifteen times lower than waste incineration (Health Care Without Harm, 2020). Organic wastes produce methane gas as they degrade, but if this is done in a controlled manner in a biodigester, the methane can be captured for use as a biofuel. Because methane has a stronger greenhouse effect than carbon dioxide, burning it reduces the CO_2 emissions of the waste, which can help in the mitigation of climate change. Sustainable healthcare waste management technologies such as bio-digestion and autoclaving can also play a role in making healthcare systems more resilient to disasters (SDG 12). Treatment through microwave technology, as used in the Sterilwave equipment, is considered a reliable, clean and modern solution with low operating costs (Sterilwave, 2020.). Finally, a regional network can be developed to share experiences and lessons learned to accomplish the BMW management system and overcome the obstacles not only for this pandemic but also beyond.

3.1.5. Electronic waste

Fuelled by higher consumption rates of electric and electronic equipment, shorter life spans, and few options for repair, global production of E-waste is predicted to double by 2045 from an existing amount of 53.6 Mt. in 2019 (an average of 7.3 kg per capita) (Forti et al., 2020; Cunningham, 2020). Moreover, with the increased remote working resulting in higher demands for robust technical infrastructure and digital transformation across business models, E-waste is expected to see a sudden surge due to the pandemic (Cunningham, 2020). Irregular E-waste disposal can be associated with health and environmental hazard, due to the presence of toxic additives and hazardous substances, which are harmful to human health and well-being (Ranganathan, 2018). Economically, E-waste is an 'urban mine' with the potential to recover several precious, critical, and other noncritical metals (Iron, copper, and gold) that, if recycled, can be used as secondary raw materials (Fig. 8). The value of raw materials in the global e-waste generated in 2019 is equal to an approximate value of USD 57 billion (Forti et al., 2020) (SDG 8). There is also an increasing momentum in technologies that enable higher yields and quality of material recovery in these outer loops. So, capturing residual value or utility is central to reaching a circular economy for electronics. If the materials in e-waste are not recycled, they cannot substitute primary raw materials and reduce GHG emissions (SDG 13) from extraction and refinement of primary raw materials. A total of 98 Mt. of CO_2-equivalents were released into the atmosphere from discarded fridges and air-conditioners that were not managed in an environmentally sound manner (SDG 3, 11, 12, 13). This is approximately 0.3% of global energy-related emissions in 2019 (Swinnen and McDermott, 2020). E-waste contains several toxic additives or hazardous substances, such as mercury, brominated flame retardants (BFR), and chlorofluorocarbons

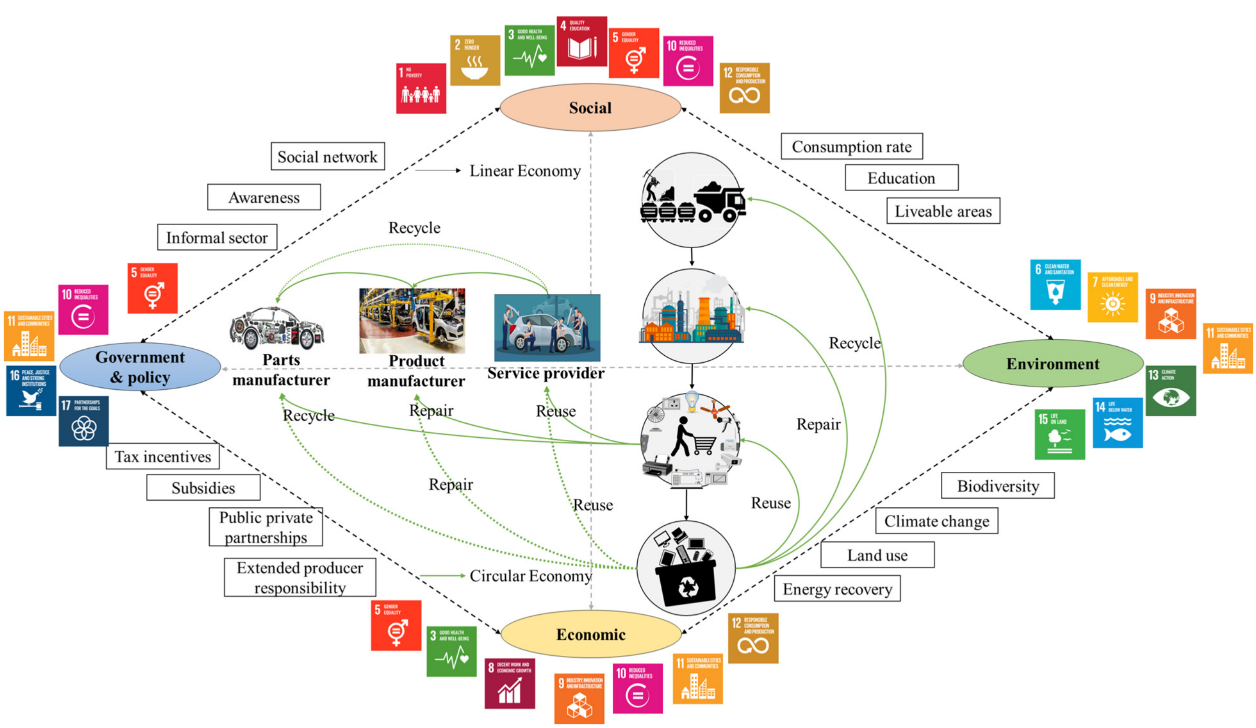

Fig. 8. Circular economy approaches in management of electronic waste.

(CFCs), or hydrochlorofluorocarbons (HCFCs). A total of 50 t of mercury and 71 kt of BFR plastics are found in globally undocumented flows of *E*-waste annually, which are largely released into the environment and impacts the health of the exposed workers (Forti et al., 2020) (SDG 3). E-waste management closely relates to many SDGs, such as SDG 8 on decent work and economic growth, SDG 3 on good health and well-being, SDG 6 on clean waste and sanitation, and SDG 14 on life below water. Given the high raw material demand for the production of electrical and electronic equipment (EEE), E-waste also closely relates to the SDG indicators on the material footprint (SDGs 8.4.1 and 12.1.1), and the SDGs on the domestic material consumption (SDGs 8.4.2 and 12.2.2). Relatively general indicators are being used to measure progress towards these SDGs.

By contrast, a more specific sub-indicator has to be recognised for monitoring growth in the E-waste stream, which is of particular concern due to both its potential hazardousness and its high residual value. Business models in which the manufacturer retains ownership and responsibility for the product, have led to high rates of recovery and reuse in products such as modems (Morseletto, 2020). Adapting such business models can help in the capture of greater value in electronic products, while developing a new type of relationship with customers, and keeping valuable resources in use for longer. Substantially greater efforts are urgently required to ensure smarter and more sustainable global production, consumption, and disposal of electrical and electronic equipment.

3.2. Focus on the informal sector

Development of policies and frameworks which will emphasize the role of the informal sector through circular economy approaches will enable us to achieve gender equality, improvement of occupational health, reduce inequalities, eradication of poverty and hunger as shown in Fig. 9. The global informal economy provides an earning livelihood to over 2 billion workers (62% of working personal) in the year 2020. Informal employment represents 18% in high-income countries, 67% in middle-income countries and 90% in low-income countries. The larger proportion of women of low and low-middle income countries in informal employment puts them in a more vulnerable situation compared to the male population (ILO, 2018). The ILO estimated that 400 million informal sector workers are at the risk of abject poverty. The women waste pickers relatively faced challenges in collecting due to movement restriction and selling waste due to reduced prices (Chakraborty, 2015). In Delhi, a single informal waste picker collects about 10-15 kg daily of waste by foot and 50–60 kg of waste on a tricycle. In 2018, it was estimated that 20% of waste in the cities is being recycled through informal waste picking. Pandemic and lockdown lead to a decrease in informal activity due to fear of transmission due to lack of protective equipment (WIEGO, 2020).

With only 30-70% of the waste collected undergoes processing and treatment in low-income and middle-income group countries, open dumps and unsanitary landfills provides eminent scope for itinerant waste pickers to recover valuable recyclables for their livelihood. This informal recycling reduces the associated environmental pollution from waste in the landfills and adds value to the recycling sector while harnessing increased informal employability opportunities (Aparcana, 2017; Fei et al., 2016). Despite these benefits, the informal sector faces severe negative socio-economic conditions. However, due to the social, economic, legal, managerial, and political constraints, the formalization process has not been successful to the full extent. So, policy makers and local authorities have been on the task of developing mechanisms to integrate the informal sector based on individual country contexts.

For instance, European Union estimates with an investment of $90 trillion (Gopalakrishnan et al., 2019) the application of CE principles in waste management will create up to three million jobs by 2030 and help in reaching the targets of the Paris Agreement. A UK study estimated that implementation of higher recycling, reuse and remanufacturing rates will result in a 0.15–0.28% decrease in unemployment by 2030 in a conservative to ambitious scenario (Masterson, 2020; WRAP, 2015). Meyer (2012) also estimated that improvement of point resource efficiency in the EU could create approximately 1.5 lakh additional jobs and an additional increase of resource efficiency up to 25% which could create up to 2.6 million jobs.

4. Challenges and barriers in transiting to circular economy and policy recommendations

The circular economy model is expected to face challenges of uncertainty, competing claims and promises and high rates of failure and pioneer burn-out (Olleros, 1986). The 'liability of newness' causes such

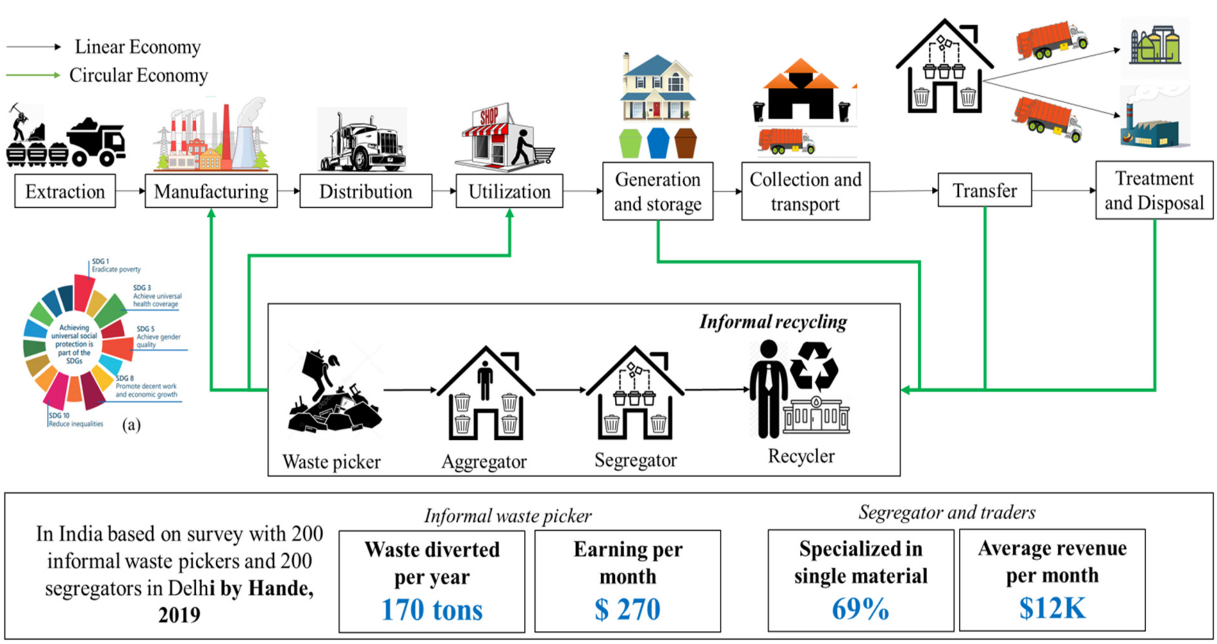

Fig. 9. The role of the informal sector in designing supply chain by incorporating circular economy approaches(Hande, 2019; ILO, 2018; Valencia, 2019).

radical ideas to be viewed as strange, unstable, or unknown, reducing their cultural credibility, social recognition, and financial capital (Michael and Mary, 2001). If we aim to overcome the current fragmentation of initiatives and their tendency to remain isolated or short-lived, more and more sustainability experiments, local projects, urban experiments, and living laboratories should be prioritized and funded for achieving their full potential for lasting and wide-ranging change (Michael and Mary, 2001; Turnheim et al., 2018). Research, innovation, trial and error, and real-world demonstration could act as catalysts for niche development (Geels, 2019). These transitions come about through the interplay between processes at niche, system, and landscape levels (Geels, 2019). Geels (Geels, 2019) has classified the socio-technical transitions that take several decades into four phases with different core activities and struggles (Fig. 10). They are: (a) Research and Development (experimentation phase) (b) Foothold establishment by innovation (stabilization phase) (c) Diffusion of innovation into mainstream markets (diffusion, disruption phase) (d) new economic model replaces the old one, and becomes institutionalized and anchored in regulatory programmes, user habits, views of normality, professional standards, and technical capabilities (institutionalisation, anchoring phase). Policy and technological limitation along with reluctant public participation could hinder transition to circular economy. However, if post COVID stimuli is directed for the development of a specific green job-driven by waste management system, formalization of informal waste pickers, investment in recycling infrastructure, research and development of new product designs and business models, intelligent manufacturing could result in initial creation of the niche which could help in realization of circular economy in few decades.

4.1. Barriers

Some of the massive barriers hindering the implementation of the circular economy to make it “business as usual” can be categorized into three groups: (1) policy; (2) technology and (3) public participation (Geng and Doberstein, 2010).

4.1.1. Policy barriers

From a policy perspective, many countries lack a centralised platform for promoting the circular economy. The existing fragmented regulatory systems in some of the developing countries have been detrimental against corporate enthusiasm to develop environmentally friendly technologies and products. For instance, in the case of China, policies such as a high corporate value-added taxing system on recycled products (Mao and Kang, 2005), low effluent discharge fees have encouraged rapid industrial development based on short-term economic benefits (Geng and Doberstein, 2010). Moreover, the tax loopholes associated with the regulation and control of consumption behaviour, discourage the development of a systematic public attitude towards green consumption (Ren, 2005). Further, the lack of detailed policies encouraging green production, technologies, and consumption and in some cases, ambiguities in their stringent implementation have created a platform for regular relapses over environmental compliances as committed by many emerging informal recycling/recovery enterprises (Dutta and Goel, 2021; Puckett and Smith, 2002). Unbalanced regional development also makes the initiation and implementation of a national policy unrealistic and impractical in all sectors and regions at the same time. Adoption of a systematic iterative approach that considers collecting relevant experiences and lessons from pilot studies planned and carefully monitored in key areas could help in setting up national regulations and standards through gradual promotion of the concept to new sectors and regions (Geng and Doberstein, 2010).

4.1.2. Technology barriers

Although it is quite evident that innovations in eco-design, cleaner production, and life cycle assessment, will help revolutionise the related fields of biotechnology, information technology and materials science

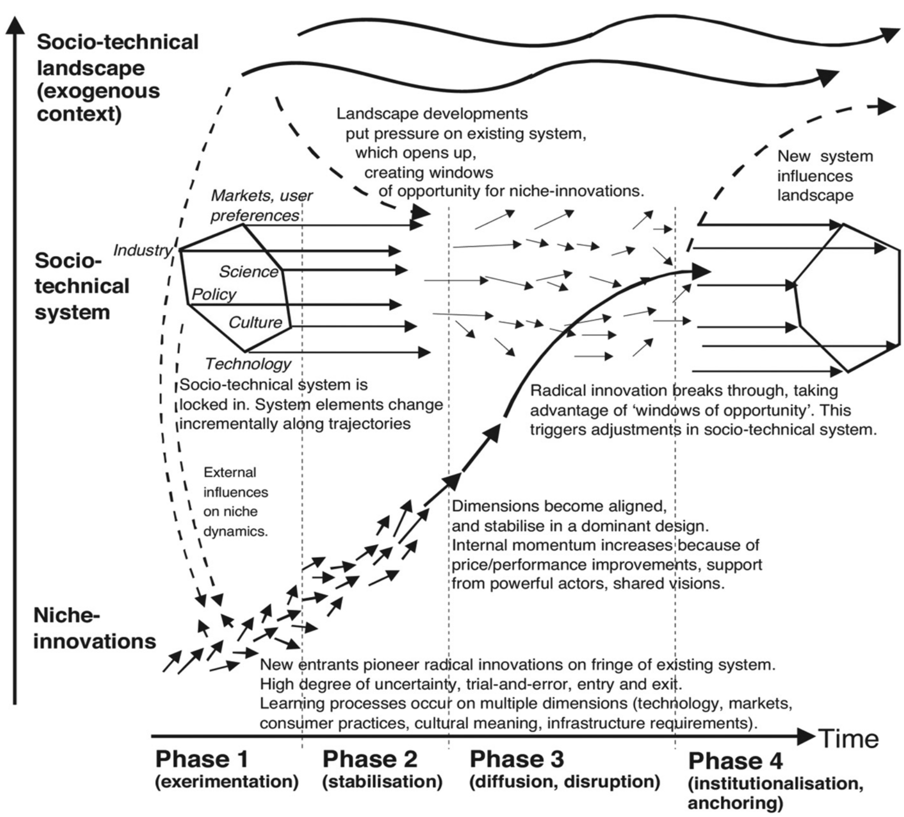

Fig. 10. Multi-level perspective on socio-technical transitions (Geels, 2019) (with permission from Elsevier Licence number 5041790223993).

(Chen and Bacareza, 1995), global demand for environmentally superior technologies is still weak, with inadequate technical capabilities and financial resources (Banks, 1994). Moreover, constraints in efficient training and financial support have limited the sustainability in technology transfers from developed to developing countries (Geng and Wu, 2000). The fragmented management frameworks often create an information barrier with zero collaboration among various stakeholders causing systemic restriction in ease of access to information needed to the corporate world for effective planning and management. This in turn discourages their interest in the creation of scenarios for optimal reduction, reuse, and recycling.

4.1.3. Public participation barriers

The array of potential contributions from every consumer in the implementation of a circular economy is mostly limited by the lack of necessary human and institutional capacities to encourage public participation in a growing economy (Geng and Doberstein, 2010). Due to the relative infancy of the circular economy concept, inadequate understanding of its principles by governments and industries alike creates a lack of appreciation for its benefits leading to inaction. Periodic implementation of awareness campaigns to build an understanding of the concept, accompanied by an objective review of the shared experiences from different parts of the world could boost public association to the circular economy. Moreover, clearly enunciated short-, medium- and long-term goals designed to directly address the needs and create the overall conditions for the circular economy, followed up with regular assessment should be specifically considered for capacity building at various levels of implementation (Geng and Doberstein, 2010). Development of functional eco-industrial networks as part of an industrial symbiosis could also be an effective way to complement traditional technical assistance (Gao et al., 2006). Building better communication between all stakeholders, and adoption of innovative public participation programmes could facilitate proficiency in the implementation of the circular economy.

4.2. Policy recommendations

Post COVID climate-mitigation stimulus should focus on adopting changes that accelerate change to a low carbon-based economy (Climate Action Tracker, 2020). Climate Action Tracker has suggested strategies that invest in green energy infrastructure - including energy efficiency and low and zero-carbon energy supply technologies - have the strongest effect on reducing emissions, irrespective of an optimistic or pessimistic economic recovery by 2030 (Climate Action Tracker, 2020). Economic equality, access to healthcare facility, access to quality education and creating equal economic and livelihood opportunities need to be immediate and long-term priorities of post COVID-19 planning. Focus on achieving sustainable development goals and the creation of a more inclusive society should be the centre of the post COVID-19 recovery model. As a science-driven design, this new economic model would prevent the extortion of climate change and all other environmental disasters. Policy instruments for waste and resource management should be steered using the idea of economic instrument, social instrument, and direct regulation and enforcement as presented in Fig. 11.

Policy recommendations intended for policymakers

1. The COVID -19 response funds should focus on support for the elimination of open dumping and burning, creation and development of infrastructure for sound management of hazardous waste, formalizing informal waste pickers into recycling business, education and training of informal workers regarding safety standards and health protection, and creation of green jobs. This would address both unemployment and environmental degradation, thereby create better livelihood opportunities, and education for children and better healthcare facility for women, especially in developing nations. The funding could be redirected through governmental and non-governmental organizations (NGOs) which are closely working in these areas.
2. In developing nations SWM services are often provided by individuals and small and medium enterprises. The COVID response fund should make provision to support them which will improve livelihoods and directly contribute to SDGs 1 and 8.
3. The COVID response should also focus on improving the wages of women involved in the informal sector of waste management, who are often not paid equally. Formalizing the informal waste picker and providing mechanisms to initiate the benefits of modern healthcare service like health insurance should also be the priority of COVID-19 response strategy. The focus should also be on imparting education to the children of informal workers, this will directly influence in achieving some of the major SDGs (SDG 3,5 and 5)
4. Food losses in the supply chain should be reduced by prioritising local production, local storage and local combustion; therefore, COVID-19 response strategy should make plans to develop this infrastructure. By doing so, the possible future pandemic could be fought well. Technology-based innovative solutions to address food loss and food waste should also be a part of post COVID recovery (SDG 12.3)
5. The COVID response fund should support behaviour change and awareness programs to motivate waste reduction, source-separation and reuse through extensive communication, outreach activities and international collaboration (SDG 17).
6. Ensure access to adequate, safe, and affordable solid waste collection services for all. Uncollected waste is often dumped in waterways or burned in the open air, thus directly causing pollution and contamination (SDG 6,11and 13).
7. Foster in strengthening the prioritization to invest in green sectors, localization of supply chains, and decentralization of waste systems with bottom-to-top approach, commitment towards recycling and green recovery, regional coordination on the environment and natural resource (SDG7, 11 and 12). Subsidies and tax exemptions to promote investments in waste infrastructure (SDG 12).
8. Post COVID response in the development of initiatives on capacity building, direct benefit transfer and welfare policies for informal sector to improve both recycling rate and well-being (SDG 1, 2, 3 and 8).
9. With the current trend of "planned obsolescence" - deliberately designing products with flaws, technical limitations, incompatibility, obstacles for repair to promote new replacement within few years of their purchase there is an increased concern of wastage of energy and resources. Challenging this corporate unsustainability strategy to make technically durable products with high recyclability should be the focus of premium business models. Legislating a complete

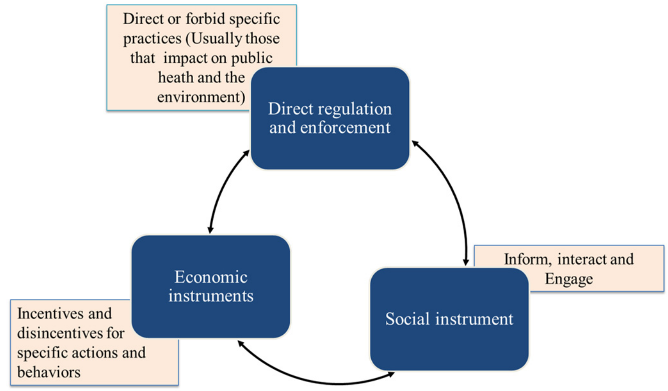

Fig. 11. Policy instruments for waste and resource management (Wilson et al., 2015).

ban on all forms of 'Planned obsolescence' (systemic, perceived, programmed, legal, etc.,) and recognizing 'sustainable consumption' as a consumer right. Further, a labelling system indicating the durability of a device can be mandated, so that the consumer has the choice between a cheap product and an expensive durable product (SDG 12).

10. Selection of waste to energy technologies depend on regional waste characterization (Nizami et al., 2017a). Post COVID response should address the challenges and innovation in adopting waste to energy (renewable energy) (SDG 7) technology in developing nations through knowledge sharing and international collaboration (SDG 17). Waste in developing countries is a promising source of energy and value-added products. Waste biorefineries can achieve a circular economy, especially in developing countries (Nizami et al., 2017a). Waste-to-energy has the potential to add new green jobs while quickly aiding the quest for a renewable energy source (Nizami et al., 2017b) (SDG 7).

5. Conclusion

This study focused on the effects of COVID-19 and the ensuing socio-economic crisis on the United Nations Sustainable Development Goals (UN-SDGs). Furthermore, this paper intended to investigate the feasibility of integrating a circular economy model into a solid waste management system using a COVID-19 economic response for meeting UN-SDG objectives. The review found that the COVID-19 has seriously impacted the progress made in achieving UN-SDGs. Inadequate waste management systems which are inextricably associated with several UN-SDGs, have been the source of health and environmental concerns, thus necessitating the serious attention of policymakers. According to the study, because the guiding principles of UN-SDGs such as managing public health and environmental concerns are analogous to that of waste management operations, thus tackling the latter would help us achieve the former. The review emphasized that the proposed fiscal stimulus for an economic rebound should incorporate a framework based on circular economy strategies such as recovery, recycling, repurpose, remanufacture, refurbish, repair, re-use, reduce, rethink, refuse into product designs and business models in order to speed up the process of achieving SDGs in a post-COVID world. The review also highlighted the importance of understanding the prospects of different component of solid waste: food waste, plastic waste, construction waste, biomedical waste, electronic waste which presents both challenges and opportunities to integrate the necessary responses that could help the public and private sectors address both short and long-term objectives of UN-SDGs. The review also found that management of solid waste using a market-based sustainable approach would help in bringing direct economic benefits to the people through job creation and help in achieving additional socio-environmental benefits like improved living standards, breathable air, clean water and land, health and education which are the major goals of UN-SDGs. Despite the hurdles to adopt circular economy-based solid waste management, the study emphasized that post-COVID economic response measures may be leveraged as an opportunity to catalyse the transition towards its full adoption worldwide. The study also highlighted that if the post-COVID-19 recovery model revolves on the central premise of easing the transition to circular economy-based solid waste management, it will enable the UN-SDGs be met on schedule.

The paper also presented the policy recommendation that would help policy makers worldwide to make transition to circular economy based solid waste management. The paper recommended in improving the living standard and formalizing the informal waste pickers in developing nations in order to realize UN-SDGs by focusing in education, training, capacity building and healthcare facilities using a COVID -19 response funds. The paper also recommended that the COVID response should also focus on facilitating behavioural changes, outreach activities and international collaboration to tackle solid waste management woes. The paper also recommended legislating a total prohibition on all kinds of planned obsolescence and recognizing sustainable consumption as a consumer right. This would not only assist to minimize waste generation, it would also assure energy and resource conservation, both of which are important UN-SDGs. Moreover, to achieve some of the major UNSDGs, the study emphasized that investments in waste biorefinery and waste to energy in developing nations should be prioritized as a COVID-19 response strategy since they have the potential to create green jobs and foster entrepreneurial opportunities.

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.

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