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HOW WASTE CAN BE INTEGRATED INTO A CIRCULAR ECONOMY

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ABSTRACT

This research presents a sequential optimisation model that investigates the process of implementing a framework for a circular economy. The basic tenet of the system is that local governments are responsible for collecting garbage, which is then partially reused by a recycling company in the production of electricity, thermal energy, and other goods.

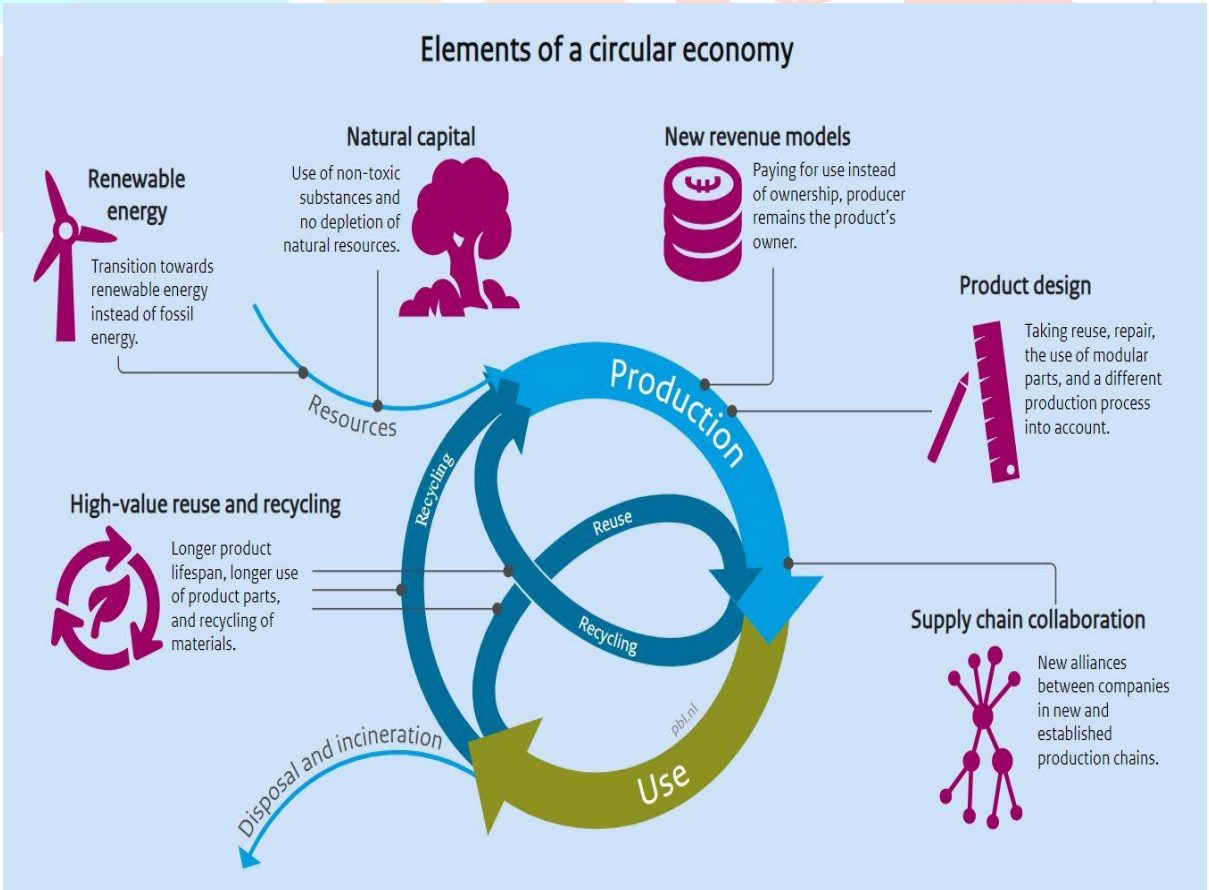
The communities that are being considered collect waste materials that can be recycled as well as waste materials that cannot be recycled. These different types of waste are separated by the residents, who then either sell them to a company that recycles them or dispose of them in a landfill, depending on the type of waste. While taking into account the costs associated with waste collection and disassembly, every municipality makes it a priority to maximise the revenue that can be generated from the sale of recyclable garbage to businesses that specialise in recycling. In contrast, the recycling company seeks to maximise its overall profitability by capitalising on the disparity between the revenues generated from the sale of newly manufactured items and the expenses incurred in procuring and processing recyclable waste materials. This disparity exists because the recycling company sells newly manufactured items at a price that is higher than the cost of procuring and processing recyclable waste materials.

Within the context of this closed-loop supply chain, the municipalities determine the pricing structure for recyclable garbage that they can provide to the recycling firm, as well as the taxation that is imposed on individuals for waste management services. On the other hand, the recycling company takes into consideration the pricing proposals made by the municipalities when deciding how much recyclable material to purchase for processing and how much of it to acquire.

We recommend utilising an iterative decomposition strategy as the means by which to bring about the equilibrium of the entire supply chain. This technique was developed for the purpose of garbage collection in the Lombardy Region of Italy and takes into account the sequential decision-making process that is followed by both the municipalities and the recycling company.

INTRODUCTION

It is a significant challenge for densely populated metropolitan regions that do not have sufficient landfill capacity and possess waste management systems that are ineffective to deal with the rising volume of municipal garbage that is being produced as a direct result of the economic development of societies. According to Soltani et al. (2015) and Genovese et al. (2017), the problem of waste management is of critical significance on a global scale because of the implications it has for economic growth as well as the effects it has on the preservation of the environment and the well-being of humans. The provision of this service is of the utmost importance to our society, particularly in those areas of our metropolitan regions that have a dense population. Throughout the course of human history, waste has been regarded as the non-essential byproduct of a linear economic model that adheres to a "take, make, and dispose" strategy to the management of supply chains. The production of raw materials for use in the manufacture of finished goods is the first step in this model. Next comes the utilisation of those raw materials, and the process concludes with the disposal of any residuals that are still present. There is a substantial body of evidence that lends credence to the idea that failing to adhere to best practises for waste management results in significant losses for society, the environment, and the economy as a whole. The adoption of policies that prioritise the concepts of reusing, reducing, and recycling has made it easier to achieve the goals of energy and raw material conservation, trash recycling, and the reduction of carbon emissions.



Within the framework of a circular economy, there is a fundamental shift that takes place in how waste is perceived. Instead of being regarded as a problem, waste transitions into the role of a novel resource within this new framework. To ensure the establishment of a society that achieves zero waste is the ultimate goal of the

circular economy, which aims to eliminate waste completely. It is possible to lessen the negative effects on the environment, the amount of energy used, and the financial repercussions by reusing and recycling waste products and discontinuing the use of landfills. This would also entail a reduction in the amount of waste that is produced as well as the alignment of the objectives of waste management with those of the circular economy. From the preceding statement, it is possible to draw the conclusion that waste management can be approached using a hierarchical framework that is comprised of many different policies that vary in terms of their levels of sustainability. These policies include the prevention and reduction of waste, as well as its reuse, recycling, and recovery of lost energy.

EUROPEAN UNION

According to the documentation provided by the European Commission (2015), Europe has taken on an important role in waste management as a result of the implementation of the EU Action Plan for Circular Economy in December 2015. This plan was revised in the year 2020. "The user's The 2015 package demonstrates the significant importance of waste treatment in the attainment of the circular economy framework. It outlines precise aims and objectives for waste treatment, with a particular emphasis on municipal trash, packaging waste, food waste, bio-waste, and vital raw materials. Specifically, it establishes standardised objectives for waste treatment."

Within the framework of the EU Action Plan for the Circular Economy, the European Commission has issued guidelines pertaining to the generation of energy from waste. This approach can be regarded as an effective means of augmenting energy production, comprising both electricity and heat, while concurrently mitigating greenhouse gas emissions originating from the waste sector and diminishing reliance on landfills (European Commission, 2017).

The percentage of municipal garbage in Europe that has been recycled or composted has exhibited a consistent upward trend, rising from 17% in 1995 to 48% in 2019. The user's text is too short to fully express their point.

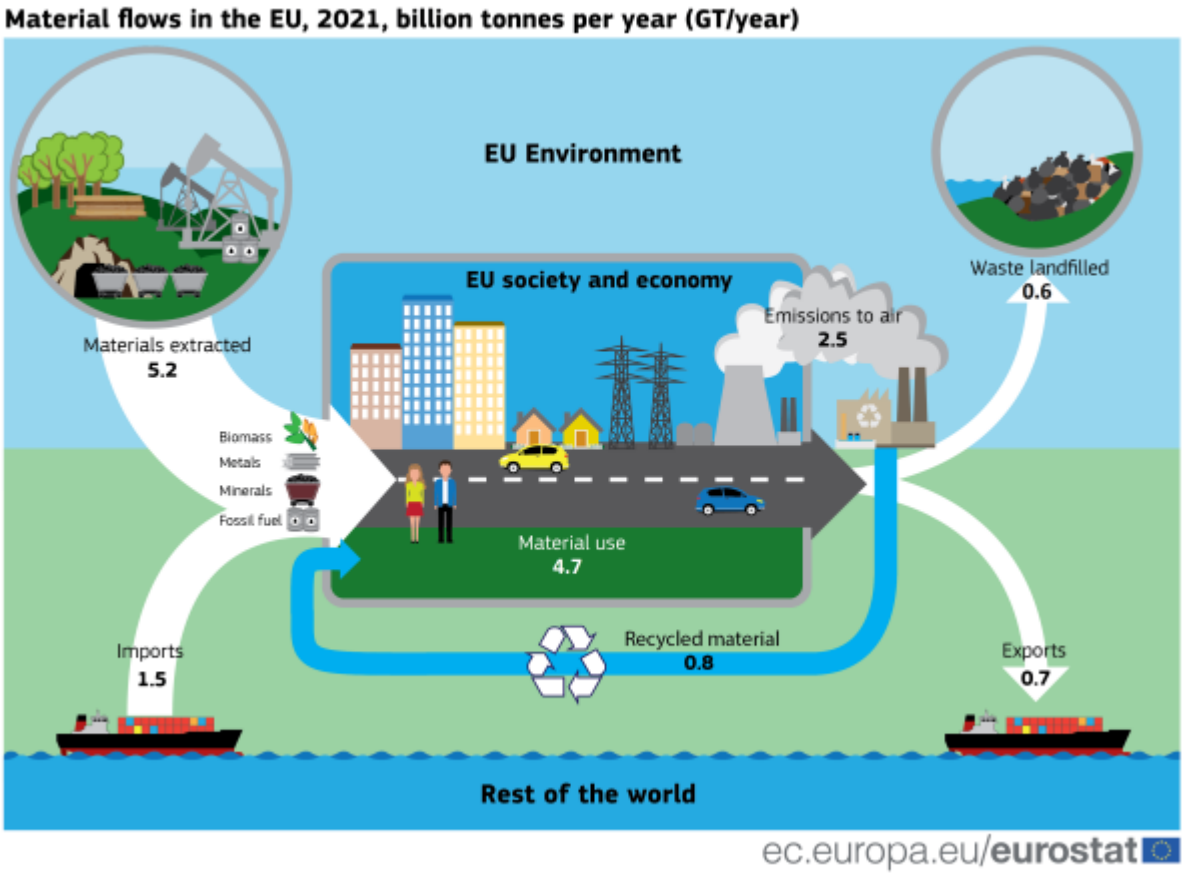
The concept of a circular economy has been seen as having significant potential in contributing to the attainment of several Sustainable Development Goals (SDGs) outlined in the 2030 Agenda for Sustainable Development. This agenda was established by global leaders during a momentous United Nations Summit in September 2015, as highlighted by Schroeder et al. (2018). The aforementioned Agenda, which became effective on January 1, 2016, consists of 17 Sustainable Development Goals (SDGs) and 169 associated goals. It serves as a comprehensive strategy in five overarching domains that are widely recognised as crucial for the well-being of humanity: individuals, the environment, economic well-being, peace, and collaboration. The concept of the circular economy has a significant correlation with many Sustainable Development Goals (SDGs), namely SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land). Specifically, objective 12.5 entails a significant decrease in the production of waste by means of prevention, reduction, recycling, and reuse by the year 2030.The user's text is too short to be rewritten in an academic manner.

LITERATURE REVIEW

Numerous research studies have been conducted on the subject of waste management, with a significant proportion employing optimisation models to scrutinise various facets of this matter. Several literature reviews on waste management models have been conducted by Beigl et al. (2008), Bing et al. (2016), Pires et al. (2011), Ghiani et al. (2014), and Smith and Ball (2012). Beigl et al. (2008) emphasise the prevalence of heterogeneous models in the literature for assessing municipal solid waste generation. These models incorporate various types of data, such as economic, socio-demographic, or management-oriented information. Bing et al. (2016) present a comprehensive examination of waste management strategies used in several European nations, juxtaposing them with existing waste management frameworks explored in scholarly literature.

The authors reach the conclusion that garbage recycling is a complex issue that requires attention at several stages of decision-making. Similarly, Pires et al. (2011) conducted a comprehensive literature analysis that examines several models and techniques to analyse the advantages and disadvantages of waste management practises in European Member States. In their publication, Ghiani et al. (2014) provide a comprehensive analysis of the existing body of operations research literature pertaining to the field of solid waste management. The authors emphasise that waste management issues have strategic, tactical, and operational aspects that may be effectively addressed through the application of operations research methodologies. Furthermore, the authors present a linear mixed integer programming framework aimed at minimising the overall costs associated with

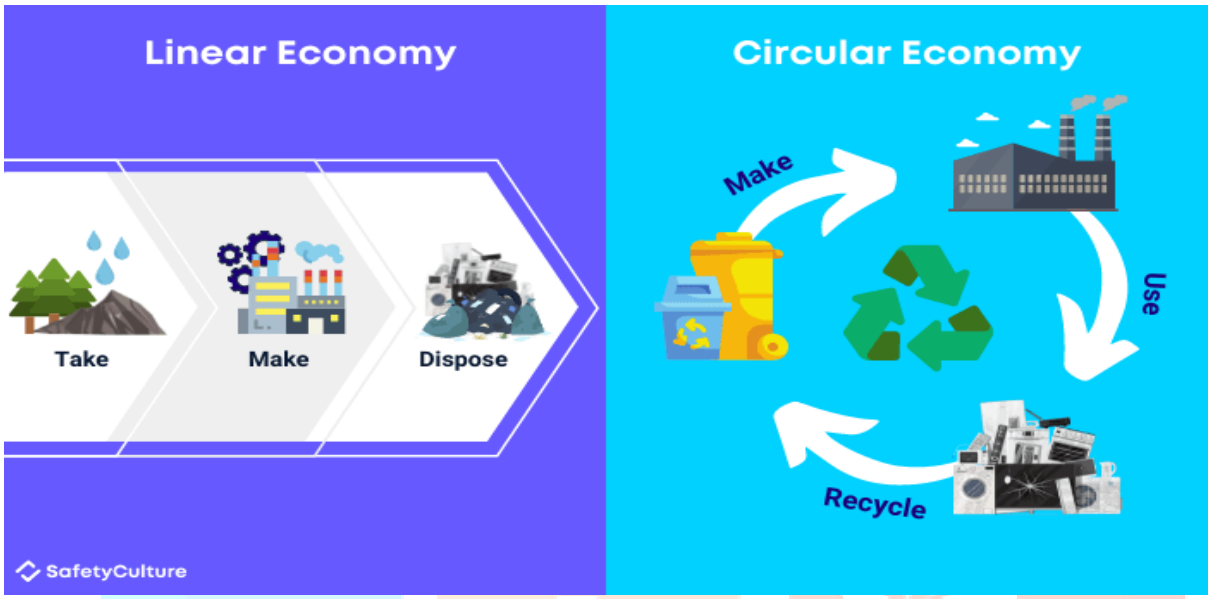
the management of the solid waste system. In this study, Smith and Ball (2012) aim to provide a set of principles for the modelling of material, energy, and waste process flows in order to facilitate sustainable manufacturing practises. The methodology employed in this study involved doing a comprehensive analysis of existing literature in order to determine the fundamental principles of sustainable manufacturing and the various strategies for their implementation.



This article examines a sustainable supply chain within the framework of the circular economy, focusing on the collection of garbage by municipalities and its partial reuse by a recycling firm for the generation of power, heating, and other commodities. In the present research, trash sorting, collecting, recycling, and dismantling are regarded as distinct stages within the waste management system. It is assumed that garbage is categorised by residents into certain groups and then collected by the corresponding municipalities. A portion of the material is deemed non-reusable, resulting in its immediate disposal in landfills by the responsible towns overseeing its deconstruction process. The entirety or a portion of recyclable garbage can be instead sold to a firm that engages in its transformation and afterwards sells the resulting goods to customers within their respective marketplaces. Within the category of recyclable trash, the categories that are often acknowledged are paper, glass, plastics, aluminium, and bio-waste, which encompasses the organic component.

A substantial body of literature exists pertaining to the many facets of the supply chain in waste management. Hicks et al. (2004) describe a functional modelling approach that aims to depict the movement of materials and the accumulation of costs throughout both internal and external supply chains in the context of waste management. In their study, Chang and Chang (1998) propose a nonlinear programming model that incorporates waste streams originating from various facilities such as landfills, transfer stations, and incinerators, where

energy recovery takes place. The optimisation problem under consideration assesses the ability of centralised presorting facilities to effectively manage trash intakes in order to satisfy the energy recovery and throughput criteria of the designated incinerators. The case study was done in the Taipei metropolitan region. In a similar vein, Costi et al. (2004) put forth a model based on mixed-integer nonlinear programming. This model aims to assist decision makers in a municipality by facilitating the formulation of integrated programmes for incineration, disposal, treatment, and recycling. The authors specifically focus on the city of Genoa in Italy as the reference region for their case study.



The authors Minciardi et al. (2008) have conducted a comprehensive investigation on waste management in the city of Genoa. Their study involves the development of a nonlinear multi-objective model, which aims to minimise many factors including economic expenses, unrecycled trash, sanitary landfill disposal, and incinerator emissions. The authors Santibañez-Aguilar et al. (2013) provide a novel multi-objective mixed integer linear programming formulation for the purpose of optimising the planning of a distributed system designed to handle municipal solid waste. This formulation takes into account both economic and environmental considerations. Diaz-Barriga-Fernandez et al. (2017) have established a multi-objective framework to facilitate the strategic planning of a municipal solid waste management system. This comprehensive model encompasses several aspects such as garbage collection, transportation, recycling, and the distribution of finished goods. The ultimate objective is to optimise the overall net earnings. In their study, Erkut et al. (2008) propose a multi-criteria mixed-integer linear programming model as a solution to the location-allocation problem of municipal solid waste management at the regional scale. The mixed-integer linear programming model proposed by Mohammadi et al. (2019) addresses the operational choices pertaining to trash supply chain networks, encompassing logistics, production, and distribution. The objective of the model is to optimise the overall profitability of the supply chain by effectively managing the many constraints related to demand, production, transportation, and inventory imposed by different organisations within the network.

All the previously mentioned studies operate under the assumption that a singular body is responsible for managing the various stages of the waste supply chain and overseeing the whole system. In practical application, it is common to observe many businesses or market participants involved in the waste supply chain, each assuming responsibility for distinct activities. Hence, the efficacy of the entire waste management system is contingent upon the interplay between these entities. The aforementioned articles do not address this particular aspect, and our objective is to address this research gap. This article aims to examine the correlation between two key stakeholders in a waste supply chain, specifically municipalities and recycling enterprises. A sequential optimisation model is developed from a mathematical perspective. Initially, the local governing bodies establish the pricing structure for recyclable garbage that is sold to recycling companies, as well as the tax burden imposed on people for waste management services, with the objective of optimising their financial gains. The recycling company incorporates offer prices as a parameter in its problem-solving process. This allows the company to determine the optimal quantity of recyclable waste to acquire from municipalities, ensuring the maximisation of profits from the sale of the newly produced goods. This decision-making process takes into consideration all costs incurred and technical limitations. Various algorithms can be employed to solve sequential models. The recycling company's problem is addressed using the decomposable penalty approach introduced by Konnov (2019), while the municipalities' problem is solved by employing a bisection type method.

The use of this sequential model enables us to examine the distinct responsibilities fulfilled by municipalities and recycling companies in the improvement of trash sorting, collecting, and recycling. This is accomplished by conducting a series of sensitivity analyses. This study focuses on examining the potential impact of an increase in the maximum quantity of collectable sorted waste on various factors, including the pricing of recyclable waste set by municipalities, the production of new goods by recycling companies, the tax burden on citizens, the net profits of recycling companies, and the net costs incurred by municipalities. An analogous examination is undertaken under the assumption of reduced expenses associated with garbage collection and transportation, as well as an augmented capacity of the recycling company's transformation activities. The aforementioned difficulties are examined via the use of numerical experiments carried out in the 12 Provinces of the Lombardy Region in Italy. These provinces encompass the waste output of around 10 million residents.

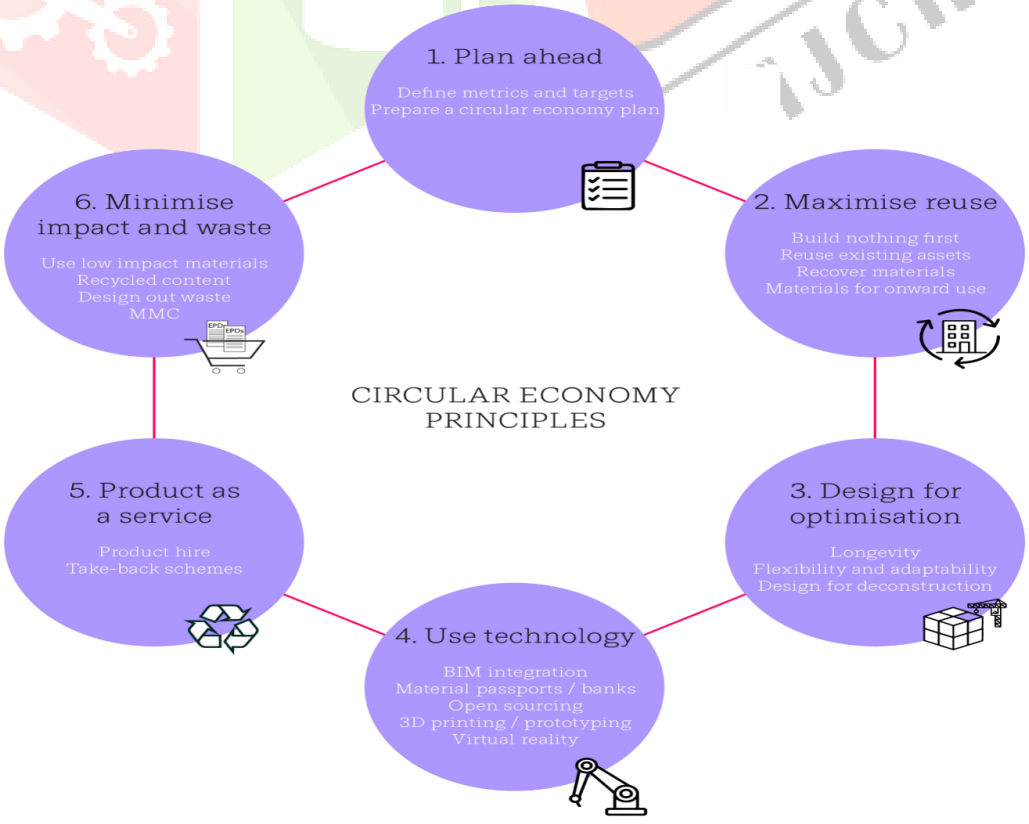
The potential risks associated with municipal solid waste are increasing and transcending the boundaries of local and regional jurisdictions. The issue has evolved into a global concern, with escalating implications for public health, the environment, society, and the economy. Based on a recent study conducted by the Independent Evaluation Group (IEG), it has been determined that the World Bank Group is at the forefront of addressing the issue of municipal solid waste. However, in comparison to its investments in other sectors, the bank's financial commitment to this particular area remains relatively modest. Furthermore, the adoption of a circular economy as a comprehensive and enduring solution is not yet a primary objective for the bank.

THE PROCESS

Improper management of waste can lead to the contamination of air, water, and land, hence facilitating the proliferation of disease-causing organisms. Individuals experiencing poverty are subject to a greater degree of impact as a result of their heightened likelihood of residing in close proximity to or being employed within waste disposal facilities, in comparison to individuals of higher socioeconomic status. Improper waste management has the potential to obstruct stormwater drains, hence causing floods that give rise to unsanitary and toxic circumstances. The incineration of waste leads to the release of harmful substances and particulate matter into the atmosphere, which can give rise to a range of health issues, encompassing respiratory and neurological disorders.

Insufficient management of solid waste at a global level is a significant factor in the exacerbation of climate change, accounting for around 5% of total global carbon emissions. Additionally, this mismanagement has led to the proliferation of plastic pollution, resulting in detrimental impacts on the marine ecosystem, with estimated annual costs up to $13 billion. Approximately 80% of the plastic present in the water is derived from Municipal Solid Waste Management (MSWM) systems that exhibit inadequate functionality.

The exponential growth of solid waste generation is a deeply concerning reality. According to projections, the population in large and medium-sized cities is expected to double by the year 2050, while in the world's poorest nations, it is forecast to triple. This issue is particularly worrisome because to the limited availability of sanitary landfills, recycling facilities, and incineration facilities in low-income countries. Consequently, a significant proportion of their waste is inadequately handled, lacking any form of treatment, and ultimately deposited in open landfill sites.



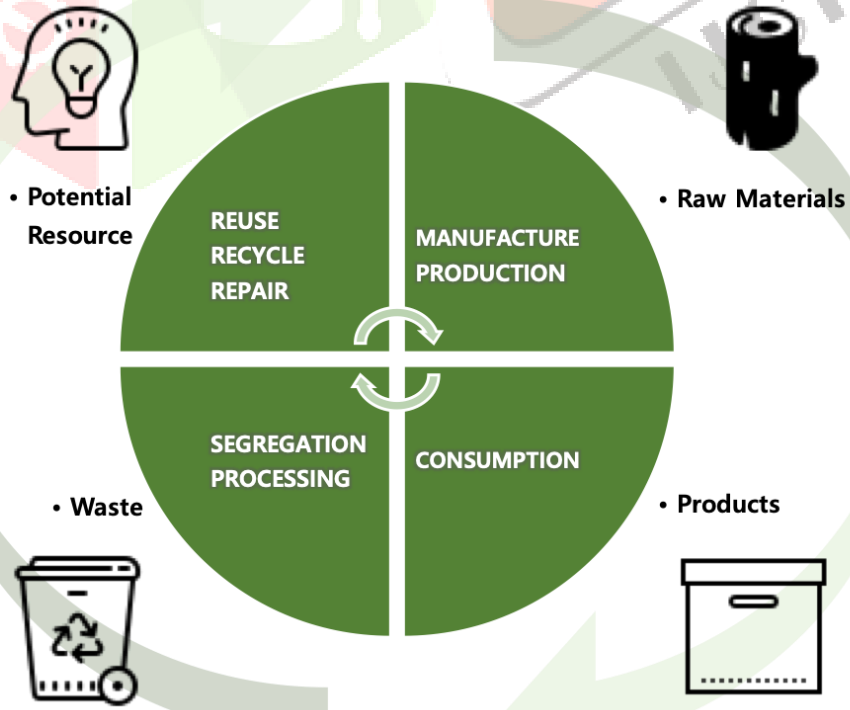
The study by the Independent Evaluation Group (IEG)

The study by the Independent Evaluation Group (IEG) examines the World Bank Group's support for municipal solid waste management in client countries throughout the period of 2010-2020. Its objective is to assess the efficacy of the World Bank Group's assistance in this area. The paper further delineates feasible resolutions to the prevailing issue and the obstacles impeding the implementation of those resolutions.

Responding to the problem by implementing measures. An emphasis on financial affairs and the concept of synergy.

There exists an urgent imperative to transition away from the current linear economic model, characterised by the take-make-dispose approach, and instead embrace established sustainable alternatives, such as the waste hierarchy and circular economy methodologies. The implementation of this shift is imperative as it will effectively mitigate the adverse environmental consequences associated with our prevailing economic framework.

A methodology that incorporates the waste hierarchy prioritises waste avoidance, reuse, recycling, and recovery over waste disposal. The concept of a circular economy involves advocating for the implementation of waste-reducing designs in goods, maximising the utilisation of products and resources for extended periods, and recycling materials from end-of-life items to reintegrate them into the economic system. This approach effectively closes the loop between the extraction of raw materials, the manufacturing process, and the ultimate disposal of these materials.



The proposed transition is anticipated to be a complex endeavour, necessitating more financial resources for the establishment of robust waste management infrastructure and the implementation of effective systems. Furthermore, its execution will rely on collaborative efforts from many stakeholders at the local, regional, national, and international levels.

In contrast to the money allocated to other urban services, the financial support provided by multilateral development agencies and the private sector for municipal solid waste management (MSWM) exhibits a very modest level. Based on a study undertaken by the International Solid Waste Association, the allocation of official development financing towards waste management was a mere 0.32% of the total between the years 2003 and 2012.

Furthermore, as per the information curated by the Public-Private Infrastructure Advisory Facility, the sector of municipal solid waste management received a total of one billion dollars in private investments during the calendar year 2020. In contrast, the water supply and sanitation sector attracted a significantly higher amount of private investments, totaling four billion dollars. Despite the substantial demand for funds in low-income nations, none of the aforementioned monetary resources were allocated to these regions.

The establishment of stronger collaborations among local, regional, and national governments is crucial to ensure that endeavours aimed at local financing and service supply are in line with the policy and regulatory priorities set at the regional and national levels. The administration of these synergies occurs at the local level.

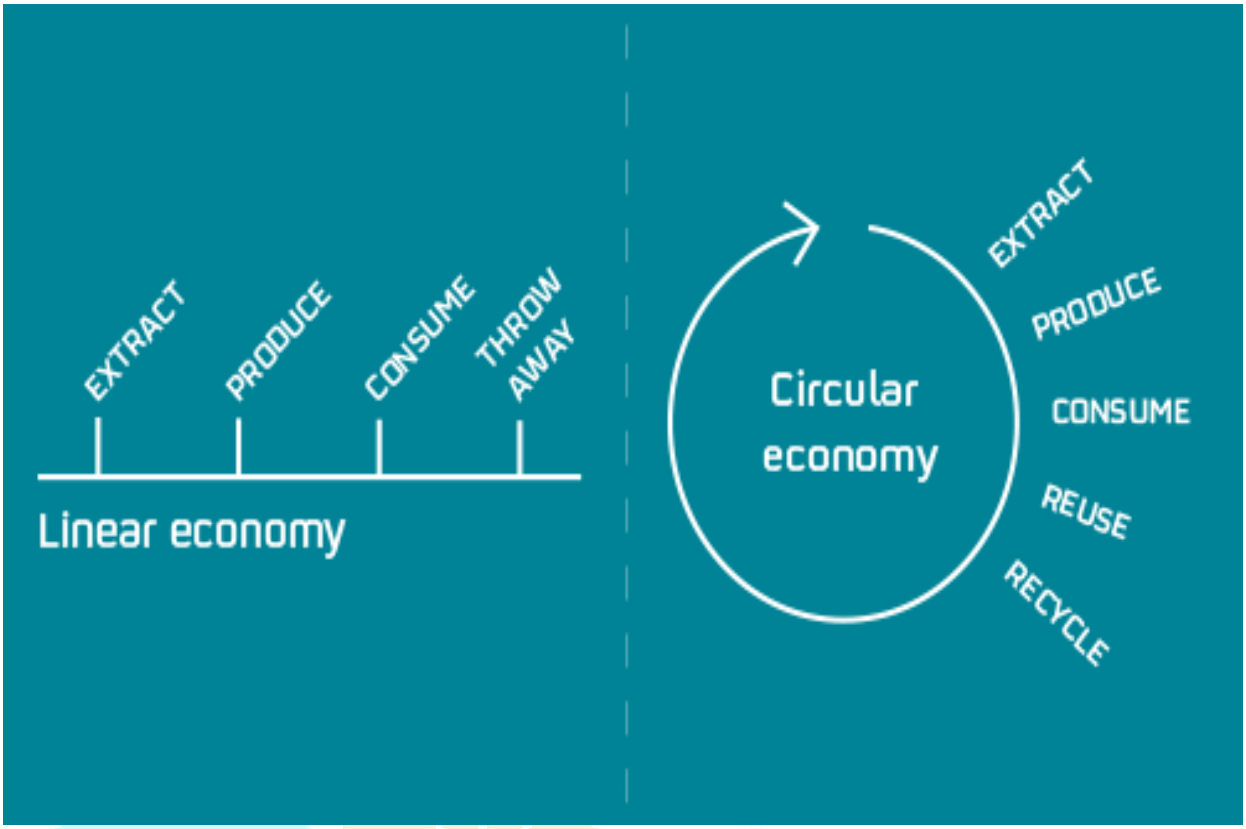
Moreover, the involvement of the government in collaboration with the corporate sector, civil society, and non-governmental organisations will enhance the effectiveness of service delivery, while also promoting enhanced methodologies and heightened accountability among service providers. Furthermore, the enhancement of support for the informal waste pickers' community is crucial in facilitating the collection and retrieval of recyclable and reusable materials.

THE WORLD BANK PERSPECTIVE

The efforts undertaken by the World Bank Group in regard to the management of municipal solid garbage.

The World Bank Group (WBG) is a leading institution among Multilateral Development Banks (MDBs) in the field of funding and expertise in solid waste management. The integration of waste hierarchy and circular economy approaches for municipal solid waste management (MSWM) into the aims and operations of various nations has not been fully realised, despite the recognition and advocacy of the World Bank Group in this regard.

The primary focus of the Bank Group is directed towards the provision of infrastructure and services. Although the Bank Group has achieved considerable success in this regard, the sustainability of projects in the long term might be impeded by challenges associated with maintaining their financial viability. Nevertheless, the World Bank Group (WBG) lacks consistency in its provision of many essential components necessary for the implementation of integrated waste management. The aforementioned components encompass the modification of laws, the preparation for cost recovery, the integration of the business sector, the incorporation of behavioural elements, and the inclusion of garbage pickers in the process.



The World Bank Group has allocated significant finance towards three primary infrastructure projects, including the closure of unauthorised dumpsites, restoration of existing sanitary landfills, and establishment of new landfills. These initiatives have consistently received substantial financial support from the organisation. There has been a notable dearth of emphasis on waste avoidance, waste sorting, recycling, and the recovery of resources.

If appropriate measures are not implemented, both human beings and the planet will incur significant consequences. The World Bank Group (WBG) institutions possess the capability to address this issue in a collaborative fashion and collaborate with other development finance institutions to support countries in attaining the necessary institutional enhancement and crucial financial resources.

Given that just 27% of the projects undertaken by the World Bank Group (WBG) have incorporated measures to encourage private sector involvement, there exists a potential for the WBG to further enhance the mobilisation of private capital for municipal solid waste management (MSWM).

The World Bank Group possesses the capacity to consistently tackle the growing challenge of waste management in low-income countries. These nations have been allocated less than 2% of the overall finance provided by the World Bank, and none of them have received any investments from the International Finance Corporation (IFC).

The World Bank Group has expressed its commitment to implementing the recommendations provided by the Independent Evaluation Group (IEG). Consequently, it is reaffirming its resolve to adopting waste hierarchy practises that align with the needs and capacities of its customers. This commitment involves using its leadership position to engage in collaboration and coordination with developmental partners, with the aim of enhancing the management of municipal solid waste and establishing a trajectory towards the implementation of a circular economy. This commitment also include the identification and mitigation of barriers to investments in municipal

solid waste management (MSWM) in countries with lower socioeconomic levels. Furthermore, this dedication encompasses the identification and mitigation of barriers that hinder investments in municipal solid waste management (MSWM) in nations with higher economic levels.