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Plastic Waste Recycling: Experiences, Challenges and Possibilities in a Circular Economy-A State-of-the-Art Review

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ABSTRACT

Worldwide, plastic products are essential items, transforming our everyday life. Demand and usage are gradually increasing. Subsequently, plastic waste generation also increased to 287 million tonnes in 2019. Despite several benefits from plastic products, the mismanagement of plastic waste and its detrimental effects on the environment, living species, and nonliving element is a global concern. The waste plastics are the cause of great nuisance. Recycling waste plastics is one of the best solutions to get rid of the pest. On the other hand, 4% of petroleum resources worldwide are used for plastic production. Many technologies have been introduced to recycle plastic waste in different applications such as energy generation, secondary plastic production, construction materials, road construction, composite materials, and others. Proper management of plastic waste through the circular economy principle is one of the sustainable approaches to increase the recycling possibilities of plastic waste in different productive applications leading to replenishing the depletion of natural resources, reducing the harmful effects on the environment, and improving sustainability in the plastic industries, at the same time policy formation is essential to control the mismanagement and misuse of plastic waste throughout the globe. This article has explored plastic waste recycling and application possibilities in a circular economy, replenishing nonrenewable resource depletion, reducing carbon budget, environmental pollution and increasing sustainable development.

List of Abbreviations and Symbols
CE: Circular Economy
CPCB: Central Pollution Control Board
GDP: Gross domestic product
GHGs: Greenhouse gases
LCA: Life Cycle Assessment
MSW: Municipal Solid waste
NGOs: Non-governmental organizations
NPW: Non-biodegradable plastic waste
PET: Polyethene terephthalate
PVC: Polyvinyl chloride
SBM: Swachh Bharat Mission
ULB: Urban local body
UN: United Nation
UNFCCC: United Nations Framework Convention on Climate Change

1. Introduction

1.1. General background (Plastic waste)

Globally, the exponential population growth and accelerating trend of urbanization caused an increase in the annual generation of municipal solid waste (MSW) to 2.01 billion tonnes in 2016, and it is expected to stand at 3.4 billion tonnes by 2050 (Reznikova et al., 2019; Gu et al., 2021). Waste plastic among the waste category accounted for 12% of total global waste (Law et al., 2020). Accumulating a colossal amount of plastic waste in the environment is a severe global concern because of its multidirectional and detrimental effects on biodiversity, ecosystems, ecology, marine species, and human & animal health, respectively (de Titto and Savino, 2019; Awasthi et al., 2021). The invention of plastic led to the improvement of the lives of human beings. It opened up other technological and economic advantages, such as plastic being a low-cost product, playing the role of a substitute for wood, ceramics, metals, and consumer products; in addition to that, plastic is light, durable, and acts as corrosion-resistant material (Vollmer et al., 2020; Rodrigues et al., 2019). Plastic products are lightweight, enduring & durable, low cost, and have unique engineering properties as well as mechanical and thermal properties. The versatile properties of different categories of plastic polymers, being non-porous, ductile, malleable, and water-resistant, making them suitable for a diverse range of products and applications, including medical science and space technology.

Due to its lightweight property, the plastic component can reduce energy consumption in many directions in the utility and industrial sectors. Despite the many advantages and benefits of plastic materials, on the flip side, critical challenges are faced by the global community due to the mismanagement of plastic waste disposal, causing severe environmental degradation (Babayemi et al., 2019). As plastic waste is not degrading efficiently and virtually does not degrade, it remains for hundreds of years after its disposal in the land and ocean. In the last 50 years, worldwide plastic production has surged with a compound yearly growth rate of 8.4%. It is 360 million tonnes in 2018 and is expected to stand at 500 million tonnes by 2025 (Zhang et al., 2021) and 1124 million tonnes by 2050 (World economic forum, Jan 2016). Subsequently, the world generated 242 million tonnes of plastic waste in 2016 (Law et al., 2020). Globally, only 9% of plastic waste is recycled (Schwarz et al., 2021; CPCB Report, 2020).

Table 1. The generation rate of plastic waste in a few major countries

Country/ Regions	Plastic waste quantity (Million tonnes/ per year)	Year of the data	References
China	49.71	2018	Liang et al., 2021
USA	38.00	2010	Taghavi et al., 2021
Germany	14.50	2010	Taghavi et al., 2021
Russia	6.00	2010	Taghavi et al., 2021
Egypt	5.50	2010	Taghavi et al., 2021
United Kingdom	5.00	2010	Taghavi et al., 2021
Asian countries	121.00	2016	Liang et al., 2021
Sub-Saharan Africa	17.00	2020	Ayele et al., 2020
India	17.66	2018	Liang et al., 2021
Japan	11.19	2018	Liang et al., 2021
Malaysia	2.65	2018	Liang et al., 2021
Singapore	1.24	2018	Liang et al., 2021
Thailand	5.96	2018	Liang et al., 2021
Turkey	6.28	2018	Liang et al., 2021
Indonesia	3.01	2018	Liang et al., 2021

The quantity of plastic waste increases in the biosphere only when it is not appropriately managed, such as disposal in waterways, open dumping, landfilling and open burning, and lack of recycling initiatives. There are many ways to reduce plastic waste, that is by proper LCA design, effective and optimize the consumption of plastic products, and effective management of plastic waste; on the other way it is essential to promote awareness among the public and societies through the active participation of stakeholder, NGOs, Government body, and ULB so that it can be possible to reduce the plastic in the environment and eliminate the adverse effect of its and increase reverse trend of sustainability (Schwarz et al., 2021). Introduce favorable policies to mitigate associate problems arising from unmanaged plastic waste in the biosphere. Promoting recycling facilities led to reducing the volume of plastic waste from the biosphere and eliminating the adverse effects of plastic waste. It is of utmost importance to adopt the 4R policy reduce, reuse, recycle, and recovery philosophy of the circular economy to reverse this trend and bring sustainability (Prata et al., 2019; SBM, 2019).

1.2. Global perspectives (Plastic waste)

In modern civilization worldwide, plastic materials are essential in many directions and cover various applications such as transportation, packaging, construction, healthcare, electronics devices, automobile, and airplane. Plastic's impressive success and utility are unparalleled by any competing materials, though about 4% of fossil fuel is used as raw material for producing plastic. The process is energy-intensive, including the consumption of resin having embodied energy of 62–108 MJ kg^{-1}, which is a much higher level than paper, glass, and few metals (Excluding aluminum) (Lebreton and Andrady, 2019). Technological advancement, economic development, and the unparalleled position of plastic products lead to increased plastic consumption. It has been expected that the demand for energy, fossil fuel, and associated carbon emissions will increase as the future demand for plastic increases (World Economic Forum, 2016). Lebreton and Andrady (2019) emphasize that *"by the year 2050, plastic industries may account for as much as 20% of the petroleum consumed globally and 15% of the annual carbon emissions budget"*. Plastic has been produced from fossil-based virgin resources, depleting nonrenewable resources. Continuous extraction of virgin resources and materials production results in depletion of nonrenewable resources, increased energy demand and produced GHGs, and reduced sustainability. To mitigate global warming, climate change, and environmental pollution and keep the global temperature within 2˚C (UNFCCC, 2015; Bose et al., 2022), there is an urgent need to promote a circular economy business model instead of the traditional linear economy model of production and consumption (Ferreira et al., 2020; Kornek et al., 2020), through the circular economy principle, recycling efficiency of the plastic waste can be possible to increase at maximum level, instead of 9% are recycled globally as on date, while reducing environmental pollution and energy consumption which in turn reduce the pressure on extraction and consumption of virgin resources.

Global plastic production annually 400 million tonnes in the year 2018; due to the lack of proper management, in most of cases, the plastic waste is dumped in the biosphere, which accounted for 9-12% directly dumped in the ocean, 79% for landfill purpose, 12% incinerated and only 9% recycled (Taghavi et al., 2021). More than 50% of the plastic produced globally is for single-user applications and becomes waste plastic following their initial applications (Ayeleru et al., 2020). Table 1 presents the generation of plastic waste by a few major countries.

Recycling waste plastic is a sustainable approach to reducing the consumption of nonrenewable resources and is most likely aligned with the circular economy principle. A wide range of plastic recycling processes and their diverse applications have already been proven in the present arena. Circular plastics economy is a sustainable way to enhance the economy, deliver better environmental outcomes, and minimize consumption of virgin resources (Schwarz et al., 2021); also effective circular plastics economy can drastically reduce the accumulation of plastics waste into marine and terrestrial environments, including other negative consequences, and decoupling it from fossil fuel feedstocks (World Economic Forum, January 2016).

2. Effects of Plastic Waste on the Environment

Plastic waste can travel throughout the world through the rivers and oceans and accumulate in marine and terrestrial environment. Accumulation of an enormous quantity of unmanaged plastic waste causes pollution in the environment, and it can take hundreds or even thousands of years to decompose and break down the same (Kumar et al.,2020; Goli et al., 2020), so the negative environmental consequences and damages are long-lasting, details of detrimental effects of plastic waste are described as section-wise below.

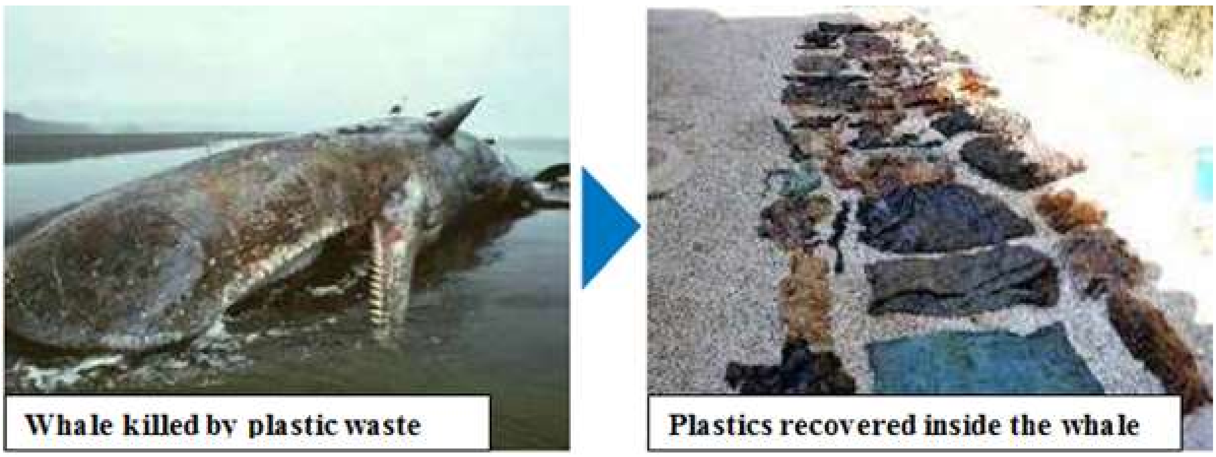

Fig. 1. Effects of plastic waste on marine species (SBM, 2019)

2.1 Effects of plastic waste on the terrestrial environment

Worldwide, 6300 million metric tons of plastic waste have been generated by 2015 (Geyer et al., 2017; Wang et al., 2019); the same has been assigned as four broad categories such as incineration, landfilling, recycling, and environmental release, respectively. Plastic waste accumulated in the environment had occurred for many decades when mass production of plastic started. Today, plastic contamination in the environment is now omnipresent across all major compartments of the environment (Hurley et al., 2020). The physical form of plastic waste that exists in the terrestrial environment has been categorized into four different sizes as macro plastic (>25 mm), mesoplastic (1.5 mm -25 mm), microplastic (1 µm-1.5 mm) and nano plastic (< 0.1 µm), respectively (Geyer et al., 2017; Hartmann et al., 2019).

2.2 Effects of plastic waste on the marine environment

Due to its biodegradation in nature, the plastic waste only fragments into smaller pieces. It will remain as it is in the environment for a long time, more than 100 years. It may be transported far away like land to lake, river, or ocean, and often the source of plastic is the ocean from fishing activities and coastal industrial disposal activities directly to the ocean (Li et al., 2016), is therefore exposed to chronic plastic pollution. Approximately 8 MT of plastic are annually accumulated into the ocean (Jambeck et al., 2015); Knight (2012), documented *that "around 165 MT of waste plastic were estimated to be present in the oceans of the world, in 2012*" The presence of plastic waste in the ocean environment has adverse effects on a wide range of marine species and organisms (fish, sea lions or seabirds), as they're exposed to chronic plastic pollution, mainly via plastic entanglement or ingestion. Fig. 1 is present as one example of the "effects of plastic waste on marine species" (SBM, 2019).

Some of the marine organisms, often associated with hydrophobic contaminants in their bodies, may also become entangled in the plastic, which can be harmful or fatal. In the marine environment, animals are mainly affected through entanglement and subsequent strangulation. Ingested plastic debris causes hindered growth, reduces the stomach's capacity, creates an intestinal blockage, and causes internal injuries. Entanglement of waste plastic with nets also causes a reduction of feeding efficiency, strangulation, and even drowning (Isangedighi et al., 2020).

3. Management of Plastic Waste

3.1 Circular economy principle towards managing the colossal quantity of plastic waste

The growing concern of environmental degradation, resource depletion, and energy optimization led to the research into renewable alternatives and waste recycling (Bose et al., 2021; Bose, 2021; Bose, 2022). With an increasing population, rapid urbanization, climate change, and environmental pollution worldwide, we must move towards a circular economy instead of the traditional linear model of production and consumption (Schröder et al., 2020). Adopting the circular economy path at the global level could bring substantial annual benefits, along with a significant reduction in resource depletion and pollution, which would consequently snowball effect on the economy (Domenech et al., 2019).

A circular economy (CE) concept is the continuous utilization of resources, and it is regenerative and restorative by design. In the CE concept, materials are constantly used and recycled along with a 'closed-loop system, rather than being used as a linear model and then discarded (Eriksen et al., 2019; Centobelli et al., 2020; Morseletto, 2020). Through the circular economy principle, we can maximize the recycling of plastic waste and simultaneously restore the value of plastic waste in the economy without creating pollution, reducing energy consumption, and increasing resource efficiency (Vollmer et al., 2020; Ferasso et al., 2020).

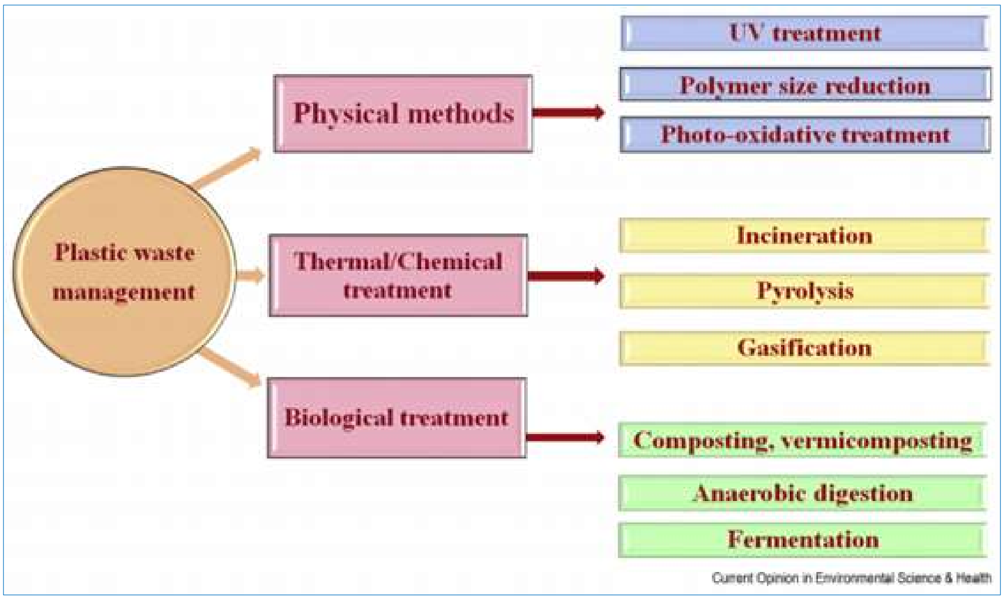

Fig. 2. Technologies options available for the treatment of plastic waste (Rajmohan et al., 2019)

3.2. Treatment processes of plastic waste

The proper management of plastic waste is one of the most crucial challenges. The growing demand for plastic causes a significant amount of waste plastic generated worldwide as 400 million tonnes in 2019. Generated plastic waste needs to be managed appropriately to prevent its detrimental effects on the environment and, at the same time, recover the maximum possible resources out of it.

Fig. 2 presents the different technologies option available for plastic waste treatment (Rajmohan et al., 2019). The various processes in managing waste plastic include recycling, reuse, materials recovery, energy harvesting, pyrolysis, incineration, and landfilling. In particular, recycling waste plastic would be successful with the proper management strategy and infrastructure in the process, such as collection, storage, recycling, and recovery. Global plastic production annually 400 million tonnes in the year 2018; due to the lack of efficient management, in most cases, the waste plastic is dumped in the biosphere, which accounted for 9-12% directly dumped in the ocean, 79% for landfill purpose, 12% incinerated and only 9% recycled (Taghavi et al., 2021).

4. Recycling Aspects of Plastic Waste

Recycling waste plastic has several advantages. It leads to reducing the extraction of nonrenewable resources, thus also a reduction of carbon dioxide emissions and other toxic gasses, and replenishing the depletion of virgin resources. There are several benefits to the recycling of plastic waste as follows.

- Reduces Environmental Pollution
- Energy savings of 40-100 MJ/kg (depends on the polymer)
- Economic Benefits
- Reduces demand for virgin polymer
- Preferred to Land Filling
- Generates Employment

- Reduces depletion of Fossil fuel reserves
- Reduced emissions of carbon dioxide (CO_2), nitrogen oxides (NOx), and Sulphur-dioxide (SO_2). Polymer

4.1. State of the art on recycling of plastic waste in different applications

A wide range of applications and products are developed from recycled waste plastic. Table 2 presents the different applications of waste plastic through the recycling process.

4.2. Recycling of waste plastic for different valuable applications

4.2.1. Pyrolysis methods for recycling of plastic waste to produce energy

4.2.1.1. Pyrolysis

"Pyrolysis is a common technique used to convert plastic waste into energy, in the form of solid, liquid, and gaseous fuels. Pyrolysis is the thermal degradation of plastic waste at different temperatures (300–900 °C), in the absence of oxygen, to produce liquid oil" (Rehan et al., 2017).

Table 2. Recycling of plastic waste in different applications (Present state of the art)

Description	Application	References
Recycling of PET bottles	Aerogel production, its application as a substrate in a "Triboelectric Nanogenerator (TENG)."	Roy et al., 2021
Recycling of PET bottles for energy production	Energy production	Zhang et al., 2021; Doğan-Sağlamtimur et al., 2019
Recycling of PET bottle building materials	Production of building materials	Perera et al., 2019; Vidales et al., 2014; Taaffe et al., 2014; Asadi, 2017
Recycling of PET bottles for virgin recycling	Direct recycling and reuse of PET bottle	Cámara-Creixell et al., 2019; Benavides et al., 2018; Welle, 2011
Pyrolysis	Alternate fuel Tribological products Lubricants Gasoline range aromatic oil Fuel Oil, Producer Gas, Char Liquid, Gas, Solid	Lee et al., 2015 Sikdar et al., 2020 Sikdar et al., 2020 Muhammad et al., 2015 Lee et al., 2015; Ghodrat et al., 2019 Ghodrat et al., 2019
Energy production from plastic waste	Electricity generation (1 tonne of plastics wastes generates 634 kW h of electrical power)	Khoo, 2019
Energy production from plastic waste	Fuel, gas	Khoo, 2019; Sajdak and Muzyka, 2014
Energy production from plastic waste	Energy recovery	Wichai-utcha and Chavalparit, 2019; Khoo, 2019; Sajdak and Muzyka, 2014
Recycling for concrete	Plastic fibre reinforced concrete	Sharma and Bansal, 2016
Recycling for building materials	Aggregate (course and fine both)	Ismail et al., 2008
Recycle E plastic	As a coarse aggregate in concrete	Kumar et al., 2015
Recycling of waste plastic bottles	Brick for building Construction	Mansour et al., 2015
Recycling for building materials	Cementitious composites	Awoyera and Adesina, 2020
Recycling for road pavement	Road pavement materials	Appiah et al., 2017
Recycling for road pavement	Modification of bitumen binder	Appiah et al., 2017
Recycling for soil improvement	Used for soil improvement	Ahmed et al., 2010; Yarbasi and Kalkan, 2020

Table 3. The calorific value of some significant plastics compared with standard fuels (Thanh et al., 2011)

Items	Calorific value (MJ/kg)
Polyethene	43.3–46.5
Polypropylene	46.50
Polystyrene	41.90
Kerosene	46.50
Gas oil	45.20
Heavy old	42.50
Household plastic waste mixture	31.8
Petroleum	42.3

4.2.1.2. Energy recovery through the pyrolysis process from non-recycled plastic waste

Energy as a form of oil from pyrolysis of non-recycled plastic is one of the sustainable approaches for recycling plastic as higher calorific value (Thanh et al., 2011), and can be achieved by this method of recycling even it is more than wood-based oil, in which comparable to conventional diesel.

Table 3 presents the calorific value of some significant plastics compared with standard fuels. Apart from the energy recovery through the pyrolysis process, several other pyrolysis products can be extracted from the waste plastic.

Qureshi et al. (2020) experimented on pyrolysis products through the recycling of different polymers (waste plastic) presented in Table 4.

4.2.2. Carbon recovery from waste plastic

Apart from the conventional recycling of plastic waste, the modern concept of carbonization is a sustainable way of converting polymer precursors to valuable resources like carbon materials for environmental protection and restoration, energy conversion, and storage. "*Chen et al. (2020) presented a systematic multi-perspective overview of carbonization as a feasible route of reuse of plastic wastes"* in Table 5.

4.2.3. Gasification of plastic waste as waste to energy

Gasification of plastic is one of the best approaches to recycling plastic waste and convert into a gaseous mixture of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), and hydrogen (H_2) via partial oxidation (Ranzi et al., 2001; Dogu et al., 2021). For unsorted and contaminated plastic, gasification is the best way to recycle and is considered as most promising and proven technology. The gasification process is typically carried out in the presence of air or pure oxygen and steam, within the temperature range at temperatures of 700 °C–1500 °C, and atmospheric pressure (Lopez et al., 2018; Arena, 2012; Dogu et al., 2021).

Table 4. Pyrolysis products from different polymers (waste plastic) (Qureshi et al., 2020)

Resin	Major origin of the waste	Low-temperature products (<400 °C)	High-temperature products (>700 °C)
PE	Household, industrial plastic packaging, agricultural plastic	Waxes, paraffin	Gases and light oils
PP	Household and industrial packaging, automotive	Waxes, oils	Gases and light oils
PS	Household, industrial plastic packaging, Construction, demolition, WEEE	Styrene, its oligomers	Styrene, its oligomers, PAH
PA-6	Automotive waste	ε - Caprolactam	
PMMA	Automotive, construction waste		MMA (methyl methacrylate)
PET	Household plastic packaging	Terephthalic acid	Benzene, benzoic acid, formaldehyde, acetaldehyde, CO_2, CO
PU	Construction, demolition, automotive	Di-isocyanate	Methane, CO, aromatics
PVC	Construction plastic waste	HCL, benzene Toluene	Toluene

Table 5. Carbon recovery from polymers (waste plastic) (Chen et al., 2020)

Polymers	Repeat Unit	Carbon content (wt %)	Carbon yield (w %)	Carbon recovery (wt %)	References
PE, LLDPE	C_2H_4	85.7	50-57 (1200 °C)	58.3-66.5	Choi et al., 2017
LDPE, DPE			72-75 (900 °C)	84-87.5	Postema et al., 1990
PS	C_8H_8	92.3	40% (900 °C)	43.3	Zou et al., 2010
PVC	C_2H_3Cl	38.4	16-20 (555 °C)	41.7-52.1	Qiao et al., 2004
PET	$C_{10}H_8O_4$	62.5	19-21 (750 °C)	33.4-33.6	Laszlo et al., 2003
Nylon	$C_6H_{11}NO$	70.1	40 (1000 °C)	57.1	Karacan and Tuncel, 2013

The steam gasification process is endothermic; the process requires air or oxygen to provide the required amount of heat in the reaction process, whereas gasification in pure air is less costly and environmentally friendly. Different types of gasifiers have different outcomes with advantages and limitations.

The air gasification process is most viable for a small and medium plant with a materials process rate of 1-100 kg/hour and capable of producing fuel gas of a heating value of 6-8MJ/Kg (LHVs) (Lopez et al., 2018; Dogu et al., 2021). H_2 reaches syngas and can be produced through steam gasification with a heating value of 15 MJ/Kg (Erkiaga et al., 2013; Wilk and Hofbauer, 2013). A dual-stage gasifier is also the best solution for plastic gasification in respect of recycling objectives of plastic waste (Wilk and Hofbauer, 2013; Dogu et al., 2021)

4.2.4. Torrefaction of waste plastic

The Torrefaction process of waste is mainly a mild pyrolysis process used to improve the fuel quality to become an appropriate solid fuel for different applications (Acharya et al., 2015). Torrefaction is mainly two types viz, dry torrefaction and wet torrefaction. Chen et al (2011) define as *"Dry torrefaction as a thermal process of waste treatment under atmospheric pressure and temperature ranges of 200°-300°. Wet torrefaction is defined as a treatment of waste in a hydrothermal medium (hot compressed water) within the temperature ranges of 180 °C-260 °C* (Chen et al., 2011; Tapasvi et al., 2012; Van der Stelt et al., 2011). Many authors have studied the torrefaction of plastic waste mixed in the MSW waste stream to produce solid fuel for different applications. Triyono et al. (2019), experimented with the wet torrefaction process with MSW, including plastic waste; in this process, no initial drying and sorting are required, and it found a sustainable approach.

4.2.5. The hydrothermal carbonization (HTC) (Plastic waste valorizations)

HTC is defined as the treatment of waste materials in water (subcritical or supercritical state) at a specified temperature and pressure to degrade the organic matter (Huang et al., 2019). *"It is a homogeneous reaction with advantages of fast reaction rates"* (He et al., 2018), the process has economic viability, and it is a proven technology to process waste to energy (Nobre et al., 2021).

Huang et al. (2019) conducted a *"Co-hydrothermal carbonization (Co-HTC) process with PVC and sawdust was performed in a 500 ml autoclave"*, The Recycling of plastic waste through the hydrothermal carbonization (HTC) process seems feasible; the higher heating value (HHV) of hydrochar was around 24–30 MJ/kg (close to bituminous coal) (Huang et al., 2019), and the energy yield was about 74–81%. The author also concluded that *"The scaling up of the lab-scale experiment could be utilized in the treatment of municipal solid wastes (MSW) and biomass wastes, both of which could be turned into clean fuel eventually"* (Huang et al., 2019).

4.2.6 Use of waste plastic for the water treatment process

The supply of purified water is essential for human health and for selective key industries, including food processing, pharmaceuticals, and electronics. To meet the demand of large volume of purified water to the societal and industrial context, many research studies have been performed to design the appropriate composite with economically viable for purification of water by utilization of different kinds of waste materials.

Plastic polymer is one of the best suitable waste materials available in considerable quantities in the plastic waste stream, having unique and tunable properties such as a high surface area for fast decontamination, selectivity to eliminate different pollutants, optical properties, and superb magnetic. Also, the water treatment process is incurred a meager cost (Santagata et al., 2020).

Chaukura et al. (2016) conducted a series of experiments to prepare the sulfonated polystyrene ion exchange resin and the composite material based on an adsorbent phase activated carbon and polystyrene. The author documented that the proposed composite materials can have a high affinity and capacity to remove multiple contaminants from water simultaneously. At the same, the process is very economical.

Table 6. Various policies are adopted by various organizations and countries (Global context) (Laskar and Kumar, 2019)

No	Country	Policies
1	Canada	An environmental protection act was introduced to ban microbeads' use in all cosmetic products completely.
2	China	It passed a Law in 2008, the consumer has to pay for the use of plastic bags, and within two years, usage of plastic bags dropped by 50%.
3	France	It passed a law ‘‘Plastic Ban’’ in 2016 to ban all plastic by 2020
4	India	Union Government of India banned the use of plastic bags below 50 μm in 2016, amended under Plastic waste Management rules 2016
5	Ireland	A bill was introduced in 2002 to charge a 10 cents fee for plastic bags and 4 cents if it goes for the recycling program again.
6	Rwanda	A small developing country in Africa passed a law to ban all non-biodegradable plastic and made the country free from plastic in 2008.
7	Sweden	It is the world's most extensive recycling nation. Less than 1% of Sweden's household waste goes to dumping yards. It recycles all most every waste.
8	USA	California is the first state to ban plastic shopping bags.
9	USA	San Francisco bans the sale of any kind of plastic water bottle.
10	USA	In 2015 a bill was passed to ban all cosmetics products that contain plastic microbeads.
11	USA	By introducing Assembly Bill 888’ against the use of microplastics beads in personal care.

Wang et al. (2019) introduced a novel approach to preparing a gel material (GM) by utilizing “waste thermosetting unsaturated polyester (WTUPR)” through the recycling process; the gel materials developed in the process can serve as a suitable and efficient metal ion carrier *for "catalytic degradation of organic pollutants in wastewater."* The process transformed into a value-added product, a very efficient, economical, viable, and sustainable way to purify wastewater.

5. Recommendations on the Policy Framework

The future policy options available to policymakers for managing plastic waste are to promote necessary schemes and facilities within the policy and regulation framework with the alliance of Industry partners and stockholders (Bose et al., 2021; Bose, 2021; Bose, 2022). The proper recommendation is essential to rebalance the policy and regulation toward plastic waste valorization to bring the reverse trend from linear to the circular economy and foster sustainable resource management. Few issues in managing plastic waste causing barriers, which need to be addressed at the earliest to promote sustainable development through managing plastic waste, are as follows.

- Strengthen the policy in respect of environment governing land issues
- Strengthen and reformation needs on existing policy so that private parties can join and develop process technology towards recycling and reuse of plastic waste
- Government should form a region-wise policy on plastic waste recycling, reuse, and utilization
- Policy on mandatory adoption/utilization of plastic waste reduces dependency on natural resources.
- Fixation of proper buying and selling price of plastic waste
- Reform market regulations and strengthen market functioning across states
- Reinforce existing policy initiatives already underway for the valorization of plastic waste
- Clarify roles and responsibilities at the Government level by bringing key policy areas under a single umbrella
- Strengthen coordination and cooperation among all ministries and agencies
- Flexible licensing systems to promote plastic waste recycling and processing plant
- Safely policy
- Favorable environmental law in respect of plastic waste recycling process
- Insurance scheme and start-up facilities
- Financing facilities to set up a plant
- Emerging circular economic concept
- Policy to Introduce code and Standard
- Policy to design LCA to reduce waste
- Policy for compulsory use of plastic waste as secondary products wherever applicable
- Policy for restricting the use of natural resources
- Policy for limiting the use of certain unsustainable methods or technology to specific Industries
- The special policy required penalties wherever applicable

5.1. Policy and regulations for managing plastic waste in the global context

The policy is made on behalf of the "public." The policy is oriented toward a goal or desired state, such as the solution of a problem in the management of plastic waste. With the vision of global environment conservation and resource optimization, a policy must be implemented to achieve our goal: the overall protection, safety, and development of the global environment and sustainability. Various policies toward managing plastic waste adopted by different organizations and countries are presented in Table 6.

5. Conclusion

The present study demonstrates that the entire plastic waste can be utilized for different valuable applications without much compromise on the properties and qualities of the end products. The rapid pace of urbanization will continue to exacerbating the pressure on nature. The consumption of natural resources for plastic production in a linear process is no longer sustainable, and recycling plastic waste to supplement some of them in a circular process is indispensable, the reuse and recycling of plastic waste supplement natural resources to some extent. With the elimination of plastic waste, all potential damage to the environment, flora & fauna, animals, and humans are entirely averted. Recycling plastic waste through the circular economy business model will lead to the employment of local people and improve the local economy. Thus, adopting the technology will provide environmental benefits, reduce the burden on the ecosystem, generate business and economic opportunities, and provide societal benefits. There is an urgent need for dedicated research to find out the hinders, barriers, knowledge gaps, and policy deficiency towards utilization of the full potential of plastic waste, leading to accelerating the valorization of plastic waste.

Under the current circumstances, globally, it has become imperative for all nations to devise policies to address the threat being created due to the generation of the enormous volume of waste plastic and its end disposal issues and help to mitigate the risks it imposes on biodiversity, including ecosystems and environment both. At the same time, proper management of plastic waste through the circular economy principle is essential to closing the circularity gap, optimizing the utilization of nonrenewable resources, and reducing the detrimental effects of plastic waste in the environment, leading to sustainable development, cleaner, and greener waste management practice.
The circular economy business model for recycling plastic waste has several benefits, and the advantages are as follows.

- Increase sustainability in the natural resources.
- Energy from plastic waste supplements nonrenewable energy.
- Replenish the depletion of natural resources
- Reduce environmental pollution (Marine and Terrestrial)
- Mitigate climate change issues
- Resource optimization
- Reduce energy consumption
- Plastic waste would be recognized as a wealth
- Economic and societal development
- Employment opportunities
- Rural development
- Increase GDP of the country
- Increase sustainability plastic industry.

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