Blockchain Technology and AI Facilitated Polymers Recycling: Utilization Realities and Sustainability

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Abstract

From the environmental perspective, efficient plastic utilization and its recyclability become significant issues that need to be resolved for deploying urban and sustainable technologies. It is estimated that approximately 400 million tons of plastic are produced each year for different applications. This number will be doubled by 2050, which is a serious problem. The primary issue that arises in a recycling process is associated with optimum supply chain management. The comprehensive and transparent supply chain methodologies will help stockholders to make conclusive policies and precise strategies. Transparency in supply chain management assists in captivating planning, pricing, purchasing, and inventory management decisions. Environmental sustainability requires recycling, which should have innovative concepts like Artificial Intelligence and Block-chain Technology. Manual methods of sorting and segregating the waste have outdated and not much efficient. The inclusion of AI and Blockchain Technology brought a revolution by increasing the efficiency and accuracy of the recycling process. This critical review focused on recycling plastics and plastic waste using artificial intelligence and blockchain technology. Various plastic regulation policies and AI utilization for plastic recycling are discussed. An overview of the blockchain and its classification for waste management or plastic recycling has been discussed. The utilization of Blockchain technology for a plastic circular economy, its types, and critical benefits has also been systematically demonstrated.

Keywords: Plastic Recycling, Blockchain Technology, Artificial Intelligence, Plastic Circular Economy.

1. Introduction

Growing Environmental concerns specifically related to using plastics have become a significant issue. Most researchers are working on efficient and sustainable plastic recycling and its utilization. But still, a major portion of plastic recycling is left untouched. It may be because of the manually operated conventional methods, e.g., grinding, washing, separating, drying, regranulating and compounding. The other important issue with these conventional methods is the selection/segregation of the thermoplastics from the available plastic wastes, which is the initial and most crucial part[1][2]. We can only recycle thermoplastics, not thermosets, as it requires a typical process or cannot be easily recycled. Currently, plastics and their products have become an unseparable part of everyone's life because of their properties and applications in almost every area [3]. But too much frequent use of plastics creates a problem and endangers human and animal lives [4]. Currently, approximately 400 million tons of plastics are produced per year for various applications, and a survey suggests that it will double by the year 2050[5]. These figures are distressful and are only because of avoidance of responsibility of the recycle chain members, who plan further steps for plastic waste management.

Nevertheless, currently waste tracking difficulty is the primary problem one can find in the confusing recycling chain process. On the other hand, China, a major importer of waste, creates more chaos in traceability by banning waste import, followed by other countries that imposed strict laws on waste import[6]. This has resulted in concealed volume flow of plastic waste that may go to or end up in the ocean. Also, it may lead to waste crime by disposing or dumping waste in other countries. This has become a profitable illegal business. In developing countries, the waste management is done by the street pickers, who are underpaid and work under very poor sanitation without any disclosed identities[7]. The frail awareness and least of cooperation recycle chain intensifies the chaos towards waste management. So, establishing a tracking system for tracing the waste and developing an incentive system is required. This is the area where Blockchain Technology fits and helps very well[8]. But no one thinks that if we produce such no. of plastics, where should we dispose of them? The conventional or manual method of recycling plastics became outdated because of the accuracy of the function [9][10]. Recycling plastics as valuable products should be promoted and appreciated[11]. Plastic recycling promotes sustainability and reduces environmental issues. Many researchers have utilized agricultural waste with recycled plastics and develops valuable products[12][13]. The circular economy is another way to dispense waste by increasing the product life and helps in minimizing waste generation[14]. Industry 4.0 and its advanced technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and Blockchain Technology not only improve productivity but also show the probability of ascertaining the technology like circular economy for the plastic waste[15][16][17]. Blockchain Technology showed great potential for recycling plastic waste. Some good organizations have started using Blockchain Technology to solve recycling problems[18]. Supply chain management, which gains so much attention, is a specific example of the Blockchain application in the waste management sector. The primary application of Blockchain Technology that specifically concentrated on (a) Incentivization, (b) Traceability. In incentivization, entry or deposition of waste may lead to give incentives or rewards that may be in the form of cryptocurrencies, exchange of goods or the digitized tokens. Plastic bank is doing great job by providing incentives to the plastic waste collectors with an objective to minimize plastic waste amount which flows towards the Oceans. The collected waste is brought to the waste station, where it is weighed. Blockchain Technology based bank made the transaction to the collector based on the weighing amount. The waste can be segregated and checked both by physically and automatically. Under traceability, the information based on the waste types is collected and subsequently recorded with the Blockchain Technology. The Blockchain Technology monitors and evaluates the quantity, its type, and location from where it was collected. This information can help to develop an efficient waste management system[19]. So, this is the time when one needs to go ahead and utilize modern technology so that the recycling of plastics can be done accurately and adequately. There are so many new technologies available that can be used for the recycling of plastics. Examples of these technologies are Artificial Intelligence, Internet of Things, Machine learning, Big data, Blockchain Technology, etc[20].

Saberi and co-workers suggest that Blockchain Technology can distribute cryptographic tokens to motivate the people, and plastic waste can be tracked for its secure disposal through this technology[21]. Blockchain Technology is a greener choice that promotes sustainability and improves lifecycle visibility[22]. Blockchain Technology can be applied to marine conservation to minimize ocean plastic pollution [23]. An optimization model has been developed that evaluates the cost of a Blockchain Technology based waste management system[24]. Artificial Intelligence (AI) helps manage plastic waste by identifying, sorting, and recycling. AI-based robots can sort the plastic waste based on their types and recyclability option. AI based robots works on an algorithm, which can be modify by using machine learning for more effective operations (https://www.allerin.com/blog/seeking-ai-assistance-in-reducing-plastic-waste).

Tapscott [25] has defined Blockchain as “an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value”. Blockchain is considered a distributed ledger or online ledger that utilizes the data structure to clarify how transactions can be initiated. Blockchain does not require any third-party intermediary for the transactions and permits the end users to become a part of this ledger. In a blockchain network, the data is stored in the blocks, and these blocks form the chain, so the name becomes Blockchain [26].

Geyer and co-workers [27] reported that around 60% of the plastic dumped in a depot, around 30% of the plastic burnt up and approximately 10% of the plastic was recycled. Careless dumping of plastic has led to increased marine and land pollution, which creates a severe problem [28]. Incineration of plastic waste is also found to be one of the useful techniques to produce energy. However, it is generally avoided due to certain disadvantages associated with this technology. Like incursion of the burnt feedstock derived from fossil fuel and petroleum may come back into the ecosystem [29].

Blockchain technology has become famous nowadays, which can be better understood concerning the various applications in which it is being used extensively. Blockchain technology comprises three versions: Blockchain 1.0, Blockchain 2.0, and Blockchain 3.0 [30]. Blockchain 1.0 was related to the area of cryptocurrencies. Similarly, Blockchain 2.0 and 3.0 have applications in smart contracts, computerized contracts, health and government sectors, etc.

Blockchain Technology, a distributed ledger, provides safe communication amongst untrusted things without any central controlling unit [31]. Additionally, the BCT generally operates in a decentralized manner which doesn't need to trust any other thing [32]. The global ecosystem showed the in three different classifications: in used plastic, after-used plastics, and urban litter [27].

Blockchain technology has also contributed to the supply chain industries, specifically in food items, seasonal production, transportation, and storage. In the food sector, safer food supply and its traceability are of greater importance from producer to consumer regarding the quality and conformity to the health and safety standards. Hence, traceability has become easier because of the utilization of Blockchain Technology [32].

In a letter to the industry, Sankaran [33] elaborates the "plastic" in two words, i.e., one is "Revolution" and the other is "Pollution". It means that "Plastics" has created both sorcery and chaos, both magnificent and agitating. Blockchain technology can be the one that can trace and sort out the different types of plastics from the wastes and transport them to the right place for recycling.

Patil and co-workers [29] have successfully connected AI (Multi sensor-based) and blockchain Technology to recover some crucial information related to plastic, like the plastics' physical and chemical properties. This data is then shared with blockchain technology to effectively separate plastics.

Peshkam and Dubois [34] reported that plastic waste management requires the public to restrict themselves from throwing packaging into the environment and develop and speed up innovative processes to create some applications by utilizing these wastes. The available advanced technology helped the waste management process from "asset creation and valuation" to "transfer and exchange". A great example of this technology can be seen in terms of the PLASTIC BANK, developed by a Canadian Company. People gave their plastic packaging to the plastic bank collection centres (as they buy all these wastes by their type and weight). The bank provides them with some credits in their blockchain-based app. Similarly, "Circularise", a Dutch-based company, has developed an app that buys the recycled materials at a fixed and accurate price and mentions there about the no. of times recycling the material they performed. Table 1 shows different industries utilize blockchain technology for plastic recycling.

Table 1: List of companies utilizing Blockchain technology, IoT, and Artificial Intelligence for Plastic Recycling.

Company Details	**Recycling Technology**	**References**
RecycleGo partnered with DeepDive Technology	Blockchain Technology for achieving 25% recycled content	https://www.recyclingtoday.com/article/recyclego-deepdive-technology-plastic-recycling-blockchain/#:~:text=RecycleGo%2C%20a%20New%20York%2Dbased,blockchain%20technology%2C%20the%20companies%20say.
Good Tech IBM	IBM Blockchain Platform and IBM-Plastic Bank activity	https://www.ibm.com/blogs/corporate-social-responsibility/2020/04/plastic-bank-recycling-ecosystems/#:~:text=At%20Plastic%20Bank%20waste%20has,school%20tuition%2C%20and%20health%20insurance.
Lush Brand (Cosmetic)	Artificial Intelligence (AI), Machine Learning	https://www.dell.com/en-us/perspectives/plastics-rethinking-the-cycle/
Agilyx	Artificial Intelligence (AI)	https://www.dell.com/en-us/perspectives/plastics-rethinking-the-cycle/
Terracycle	AI and Blockchain-enabled loop for recycling of plastics	https://www.dell.com/en-us/perspectives/plastics-rethinking-the-cycle/
Dell Technologies	AI, IoT for recycling	https://www.dell.com/en-us/perspectives/plastics-rethinking-the-cycle/

Klean Loop	Mobile app DApp interfaced with AI and Blockchain, which gives tokenized coins Kleancoin	[35]https://www.prnewswire.com/news-releases/kleanloop-a-decentralized-blockchain-dapp-for-creating-transparency-in-tyre-and-plastic-recycling-300918319.html
Block chain Development Company (BCDC)	Launched Blockchain-enabled incentives leading to recycling of plastics	https://www.prnewswire.com/news-releases/worlds-first-global-plastic-offset-scheme-launched-by-bcdc-657453753.html
BIOTA (German Based Association)	Combined Blockchain and IoT and launched the "DEPOSY" project for plastic waste incentivization	https://www.ledgerinsights.com/german-association-using-iota-dlt-to-incentivize-plastic-recycling/
BASF assisted Blockchain Project	The company has launched the ReciChain project to demonstrate the circular economy and traceability of recycled plastics	https://www.ledgerinsights.com/basf-blockchain-plastic-recycling-recichain/

Most of the researchers concentrated on the Blockchain concept for plastic recycling and explained its potential and possible outcomes based on its characteristics didn't explore the practical part of the solution. Significantly, the real waste management scenario is missing. It has been seen that the effective utilization of the Blockchain Technology and AI is missing. Still, more awareness needs to be developed amongst the people regarding the plastic waste recycling. Dumping plastics in the landfills or in the ocean should be stopped, if not, then it may result in a threatening repercussions that one may face one day for sure. The objective of the current review article is to fill the gap by responding to the following questions:

a. How the effective utilization and awareness of Blockchain Technology for plastic waste recycling can be ameliorated?
b. How do the plastic global law policies work together for its recycling?
c. How does the AI-enabled Blockchain Technology strategy help in plastic recycling or plastic waste management?
d. How does the circular economy of plastics help in recycling?

The current study aims to elaborate on the utilization of Blockchain Technology, its types, advantages, and disadvantages for recycling plastic waste into valuable applications/products, and how this technology help to enhance recycling efficiency. The remainder of this review is structured as follows: section 2 describes the global plastic situation and plastic law policies, section 3 discusses an overview of Blockchain Technology and its classification, section 4 describes the utilization of Blockchain Technology for plastic waste reduction and recycling, section 5 describes the challenges and benefits of the Blockchain Technology, section 6 and 7 shows the utilization of Blockchain on the circular economy, and plastic circular economy scenario, section 8 describes the need of AI for sustainability, and at last section 9 describes the use of AI and Blockchain together for a sustainability and plastic recycling.

2. Plastic Global situation and policies:

Plastic pollution has become a global concern. Due to the variety of plastic pollutants generated from industries and households, e.g., textiles waste, tire dust, plastic bottles, packaging, etc., a coordinated action must be executed by different stakeholders at various stages. Despite growing concern, no specific steps or agreements are available to target hostilities, mainly on neutralizing plastic pollution. After recognizing the issues related to the existing legal plan, a new opportunity is identified at the international level to resolve the issue. In 2017, at the 3rd session of UNEA (United Nations Environmental Assembly), different countries came together and passed a resolution on marine plastics and microplastics. Considering this, the Centre for International Environmental Law (CIEL) worked and strengthened the available regional and international instruments to address plastic pollution effectively. Plastic pollution is disastrous and an accelerated issue of concern that needs a mandatory global response. United Nations has set an enhanced global action for marine plastics. CIEL and its partners give assurance about including plastic's complete life cycle in all policy considerations. (https://www.ciel.org/issue/plastic-global-law-policy/)

2.1 Energy Policies and Regulation:

There is a steep rise in the legislation and regulation based on plastic use and its disposal. Basel Convention controls hazardous wastes and their removal across the transboundary movements. Plastic also comes across the sustainable development goals, ensuring "sustainable consumption and production patterns". The circular economy model also covers some definite targets under this goal: "substantially reduce waste generation through prevention, reduction, recycling, and reuse by 2030".

2.1.1 Circular Economy Level:

The circular economy level must be promoted and encourage society to adopt the "producing and consuming" plastic approach instead of "take, make, and dispose of".

European Union technical expert group delivered a system known as "Taxonomy", which shows a technical shortlisting standard for environment change alleviation, adaptation, and "do no significant harm" to other environmental goals in the legislative proposal. One of the environmental objectives is "transition to a circular economy, waste prevention, and recycling". In 2018, regulatory actions involved revised European legislation specifically for waste management. These legislative changes have set their target to reduce plastic waste by

50% by 2025, outlining minimum requirements for the producers to bear all the financial expenses related to waste management, sorting, and treatment operations.

2.1.2 Raw Materials:

Developing a policy for the raw materials obtained from bio-plastics or companies responsible for producing fossil fuel-based plastics is necessary. But some of the policies which ultimately impact these companies aimed to (i) recycling of plastics should be increased (ii) reduction on the dependency on fossil fuel (iii) reduction in greenhouse gas emissions. These policies may ultimately reduce the demand for fossil fuel production and motivate them to switch towards recycled materials instead of fossil fuels.

2.1.3 Manufacture:

It has been observed that most of the policies are aimed at the effective utilization of plastics in some suitable form; packaging is one of the great options to utilize or recycle plastics. But this is a big challenge for the manufacturers and packaging designers to think about the contents and perform the life cycle assessment of the plastics before manufacturing [36].

3. Blockchain Technology: An Overview

Blockchain, also known as the “distributed append-only time-stamped data structure”, permits the establishment of peer-to-peer networks. This network allows non-trusted members to interact genuinely without any third-party (trusted one) involvement [37]. Microsoft defines the blockchain (https://azure.microsoft.com/en-in/services/blockchain-service/) as “A novel process for Business, Industries, and the private organizations to immediately verify the transactions leading to streamlining of business activities, which saves money and ultimately reduces the fraud activities”.

The following sections elaborate on blockchain technology, i.e., its concept, history, parameters, types, advantages, and challenges.

3.1 Basis and Need of Blockchain:

The uncertainty in the financial transaction has developed an innovation known as Blockchain Technology. The uncertainty cannot be eliminated but can be lowered to some extent. The Blockchain aims to control this uncertainty and apply it in a safe and decentralized way, providing better certainty.

Decentralization and distributed ledger are the two essential things, making blockchain technology stronger and more irrepressible. It has been observed that decentralization is a stimulating feature of Blockchain. It can be attained by giving computation tasks to all the available nodes. Decentralization can also resolve serious problems like "single point failure" of the centralized system like in banking and railway reservations, where the risk of failure may occur at any moment. It has also been observed that the central server becomes unavailable in a well-architected network because of the heavy traffic, which makes the server unresponsive. This problem may sometimes result in the crashing or breaking down of the server. Blockchain technology, which supports decentralization, allows all the information related to the transactions, etc., to be stored in each node. These nodes behave as backup servers. This is possible by regularly updating the distributed ledger, which acts as a primary tool in blockchain technology.

The fundamentals of the blockchain lie in distributed computing, cryptography, software engineering, and game theory. The following objectives ultimately motivate the utilization of blockchain technology:

- Faster Settlement:

Blockchain technology significantly reduces the time of transactions as compared to the conventional transaction system.

- Security:

  It provides security in the transactions by involving cryptography functions and other protocols in it.

- Immutation:

  Modification of the blocks is complex because of their immutability. It is difficult to temper any information of the block.

- Transparency

  In the case of a centralized system, where third-party involvement is a must, it is not necessary at all due to the decentralized system of blockchain technology. Transparency can only be achieved in the system if each network owner takes part in the networking.

3.2 Terms associated with Blockchain Technology:

These terms were reported by Komalavalli and co-workers[38] related to blockchain as Nodes, Transaction, Address, Block, Chain, Nonce, Mining, Consensus, and Merkle Tree. Nodes are computers with a distributed ledger that are utilized in the blockchain architecture to validate transactions, which comprised of the details of the sender and receivers with the transaction value. It stored the information and data of the transactions into a block. The address is a public key that shows the senders and the recipients of the blockchain network. A block comprises various details related to the transactions, such as timestamp and interconnectivity with the preceding blocks (developed using the hash algorithm) stored in the block. Hash can be considered as a "fingerprint", which is different for each block. Chain is the sequential order of the blocks that make the chain of the network architecture. A nonce is an irregular number demanded by the miners to validate the hash value. This particular value combines the required information from that block for developing the valid value. When Miners found the suitable value, then they called it "MINING". The nonce value starts from 0 and increases value by 1 until the discovery of the valid hash. As the difficulty increases, then the number of valid hash decreases. Mining is the block transaction that can only be done by creating the hash. The verification of the transaction involves a tedious mathematical computation. Once the Miner verifies and validates the transaction, then it goes to a secure block. Consensus is a rule used to add the block in the network architecture. Merkle tree is a hash tree in which every node contemplates the hash of a block and non-leaf with the hash labels of its child nodes.

3.3 Blockchain Classification:

There are three types of blockchain, i.e., Public Blockchain, Private Blockchain, and Hybrid Blockchain. These are summarized as follows: [38]

3.3.1 Public Blockchain:

This is an open type of blockchain, also known as a "permissionless ledger". In this, anyone can participate or join the network without any permission. In this, participants may read or edit the network with a copy of the ledger. It works perfectly in an unauthenticated network because of its fixed nature of records.

3.3.2 Private Blockchain:

It allows only selected participants who have permission to join the network. In this, each participant of the network has all transaction records. Encryption is provided with a private key so that the data of the block cannot tamper. Only authorized users of the specific organizations have control over the network. Only trusted nodes are allowed to join any business network. An "identity management system" is used to validate the users.

3.3.3 Hybrid Blockchain:

Hybrid means a combination. This is a combination of the public and private blockchain, also known as "Consortium Blockchain". The structure of this blockchain is of "semiprivate" and "semi-decentralize". A hybrid network is supporting the properties of both "public and private blockchain". This blockchain may work with a distinct organization [38].

4. Blockchain: A sustainable utilization for plastic waste reduction and plastic recycling promotion:

It has been a great debate that manufacturers of plastic goods are not using secondary plastic to manufacture. They assumed recycled plastic generally has fewer properties and qualities than virgin plastics. But this does not seem right every time. Recycled plastics also have useful properties. The main thing is to sort the right plastic for suitable applications. The segregation of plastic should be done efficiently based on its type and quality. Blockchain Technology helps segregate these plastics by applying smart contracts, traceability, and AI (Artificial Intelligence).

Blockchain Technology can promote plastic recycling, integrate liabilities, and improve the efficiency of the plastic industry. The revolution in plastic recycling using blockchain technology can be realized by overcoming the following difficulties [39]:

- To control the government administration for overcoming the initiative shortcomings.
- Basic changes must be accommodated in the whole business.
- Digitalize the business, blockchain utilization for the advertisement, and remodel the plastic waste packaging.
- Collaborate with mechanical principles and technical standards to enhance a distinguished environment.
- Incentivize the tasks related to sorting, collecting, recycling, etc., to promote entrepreneurial activity.

Blockchain technology is used for plastic recycling by incentivizing the collection, disposal, and consumption. This can be achieved by converting the natural resources into tokens and assigning them a Digital ID to start trading using this ID. The plastic bank is an example of this, which provides digital tokens, and people can use these digital tokens at any partnered store. Figure 1 shows a blockchain model. Blockchain also stores the data, which can be obtained by the IoT devices or the RFID tags and can provide information about the quality of the plastic garbage [40].

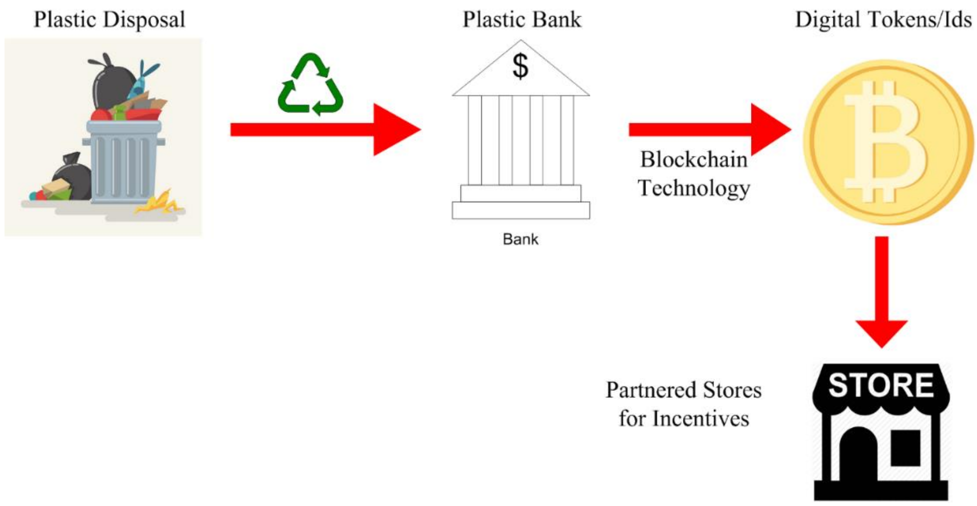

Figure 1: Blockchain Plastic Recycling Model for Incentives

Recently, RecycleGo and DeepDive Technology group has partnered for transparency and optimized decision-making in the recycling supply chain by utilizing Blockchain Technology. The primary concern of the recycling industry is optimum decision-making in the supply chain. Blockchain technology is the ultimate solution that helps in a plastic recycling supply chain that can be monitored, incentivized, and trusted. Blockchain can help identify and trace any recyclable material at any point of the recycling process and support the environment free from waste altogether [41].

Recently, BASF has launched a new project, reciChain, that combines blockchain with a digitized badge that improves the identification, tracing, and monitoring of plastics through the whole chain. With reciChain, it revitalizes the plastic value and noticeably enhances its circularity in the supply chain. The implementation of the reciChain has resulted in collaboration amongst the different stakeholders, such as plastic manufacturers, suppliers, and collectors, to enhance the plastic's circularity in the system [42].

Blockchain, a secured virtual ledger, stores and distributes the data without any third-party intervention. A plastic waste management process includes asset “creation and valuation” to “transfer and exchange”. A good example is Plastic Bank centres, which buy segregated wastes (based on weight and type). Participants carry plastic waste to one of the centres and receive points based on the blockchain-enabled app through smart contracts, which can be operated through smartphones. Circularise is another initiative with the objective of transparency. Through this action, one can get the exact pricing system for any type of recycled material and check how many times the same product is recycled.

The Norwegian start-up, namely Empower, presents another example. This start-up uses blockchain-enabled tokens, which encourage “donation-based recycling”. If any company donates an amount (e.g., 2000 Euros), Empower collects 2000 kg of their company’s plastic waste. The United Kingdom has proposed a new model, i.e., the “deposit-return scheme model”. This model added a small surcharge to the product's price and was redeemable when the consumer returned the empty packaging/container to the shop/store. This charge is in the form of “crypto-credit” in plastic packaging, and the customer is liable to dispose of the plastic packaging in a suitable container [34].

A team, “Deplastify the Planet”, using blockchain technology using the temper proof/distributed ledgers, which traces the plastics right starting from the ocean to the collectors/pickers and to the recycling units where these are converted into useful forms and sent to companies [43].

The following reasons explain why blockchain technology is an efficient technique for recycling [44]:

- It provides reliability, control, and safety.
- It helps to link with "crypto tokens" to plastic waste, which directly goes to the collectors/recycler account/wallets.
- Security and transparency can be maintained by using blockchain technology.
- It permits workers to collect these digitized tokens and exchange them into currencies or cryptocurrencies.
- It eliminates the mediator so one can get the full value of every recycling waste.

5 Advantages/Benefits and Challenges of Blockchain:

The advantages of Blockchain Technology are given below [45]:

- **Decentralized System:**

  Decentralization means there is no intermediary or third-party intervention for the transaction. This makes the system more secure as the threat of data loss or hacking is eliminated.

- **Trust and transparency**

  Trust and transparency can only be maintained by the "immutability" of the system. As each and everything will be transparent or available to each entrant of the network. They all have access to a distributed ledger.

- **Immutability**

  This is the other advantage of Blockchain Technology. No one on the network can edit or delete the information once available on the network.

- **Traceability**

  This is the main advantage of the blockchain, as if any problems occur in the network, they can be corrected simultaneously.

- **Simplification**

  All the information is available in a single ledger.

- **Fast Processing**

  This advantage is really an important one. In the conventional process, the transaction may be delayed because of any reason present at that moment, but Blockchain technology simplifies things very fast, even in seconds.

Following are the main challenges/barriers of Blockchain Technology [45] [38]:

- **High Energy Consumption**

  The frequency of utilization of the computers in creating the nodes and then doing transactions over the network causes too much consumption of power and wastage of energy. This is the main disadvantage of Blockchain Technology.

- **Perception**

  Perception is another challenge in Blockchain Technology. If the participant is not having good knowledge, it may decrease the efficiency of the Blockchain.

- **Legal regulations**

  This is a must for applying in the "Banking and the Financial Institutions".

- **Lack of skill**

  Blockchain Technology requires highly skilled persons who can solve the complex problems of the network.

6. Blockchain: A sustainable utilization in Circular Economy:

The minimal availability of natural resources has become a serious concern nowadays. This is due to the increasing global resource consumption, leading to material turnover and a corresponding increase in the product price. To overcome this problem, one must promote recycling, refurbishing, and remanufacturing to fulfil the shortage of resources [46]. The circular economy aims to eliminate and promote the reusability/recyclability of waste material [47].

The circular economy can be considered as the closed-loop ecosystem that follows numerous disciplined actions such as reuse, recycling, remanufacturing, etc., and improving their life cycle [33]. In addition, the circular economy reduces the waste into secondary raw material, ultimately diminishing the demand for the primary raw material. The major advantages of a circular economy include less demand for the primary raw material, recyclability, waste reduction, and improved economic growth [46].

The circular economy actively utilizes management tools such as "reverse logistics and supply chain activities". The circular economy also engages the consumers in sharing and servicing economy. New revenue resources are being developed with the help of the circular economy by minimizing waste and reusing material at the end of life. The knowledge of sources and markets are the prime parameters for an effective circular economy. A large-scale supply chain is the primary need of a circular economy, not only for the companies/industries but also for society and their households [48].

6.1 Seven Key elements of Circular Economy:

The seven key elements which are being considered for the circular economy are:

- Design: Design plays an important role. The design should be performed by keeping a few things, such as selecting the right material and designing for the extended lifetime.
- Incorporation: Digitization needs to be incorporated into the system, which ultimately optimizes the various resources used to strengthen the system. Few logistics and supply chain companies utilize drones and copters to supply the parcels, etc.
- Preserve and Reuse: Maintain, repair, and utilize resources very efficiently and even after their end of life.

- Rank regenerative resources: Non-toxic and renewable resources should be efficiently given utmost importance.
- Waste management and utilization: Waste management and utilization should be done efficiently to promote the use of secondary source material.
- Add greater value through Business models like commercialization and development of circular business models and socio-technological impact on plastic design.
- Collaboration: Work in collaboration via supply chain with organizations and Industries and establish the joint value. (https://www.circle-economy.com/circular-economy/7-key-elements)

Blockchain and the circular economy are useful approaches that can transform business and the global economy. These two emerging technologies are ultimately helpful in waste minimization/elimination and allocating and tracing their life cycle. There are many ways through which the blockchain's properties/abilities can be effectively utilized with the circular economy. Transparency, traceability, reliability, and automation are some blockchain components that help promote the circular economy objectives.

A distributed ledger, one of the significant features of blockchain technology, can register various information about the circular economy, such as material sources and their products, different processing techniques, amount of energy consumed, and life cycle assessment. For example, tracing the material can be achieved by providing the Global Positioning System, helpful all over their life cycle. The blockchain's prospective properties/characteristics help promote reusability, recyclability, and circularity management [47].

However, there are two sides to the coin. One is a positive side, and the other is a negative side. Until now, we have gone through only one side of the coin, i.e., the circular economy's benefits. There are numerous challenges to the circular economy available. Few of the concerns to the governance, economic, and organizational theory. The circular economy has diversified users and suppliers (of different products), who belong to various companies and sectors. It is sometimes difficult to manage the by-product (waste management) through blockchain technology. On the other hand, it is observed that because of some environmental concerns or regulations, the company stops making the product (product deletion), which is extremely crucial for circular economy and by-product management/waste management planning.

Uncertainties and the lack of scale are other challenges of the circular economy. The overall scale of waste may be large, but the dispersion of waste streams may find it hard to identify and attain circular economy material. It is difficult to manage the flow behaviour and dispersion of small-scale waste. A circular economy requires a wide range of supply chains among various industries and societies [49]. Although it sometimes happens that due to dispersion, diversified sectors sometimes face problems in identifying, developing, and sustaining the circular economy resources [48].

7 Plastic Circular Economy:

There are different factors for plastic classification. These factors are their constituents, processing, recyclability, and synthesis. According to the European Commission, plastics can be classified into three main groups, ‘recyclable’, ‘non-recyclable’, and ‘complex’ based on the circular economy. **Figure 2** shows these types of plastics.

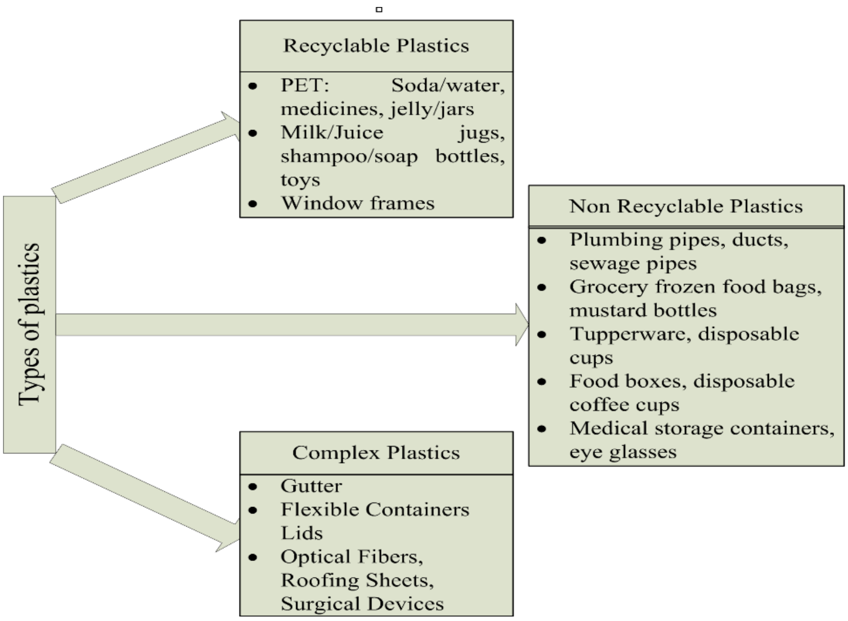

Figure 2: Different types of Plastics

Plastic, a superior material developed by scientists, plays a significant role in various sectors, such as medical, packaging, construction, textiles, devices, and even households. Plastic diversified applications made this material the necessity of life. Apart from its advantages, it has various challenges too. The main problem arises at the end of life of these products, i.e., their disposal. Reports show that it is assumed that plastic's utilization or production will increase by the year 2035, and by 2050, its production will reach four times the current value. Plastics Europe reported an annual plastic production rate from the year 2011 to 2019. Figure 3 shows that approximately 40-48% of plastics are non-recyclable, 19-30% are recyclable, and 20-27% come under the unknown classification. Until 2015, only 9% of plastic is recycled; the rest goes to landfills or into the sea. Scientists also predict that, if this is the scenario, we will have more plastics in the sea than the fish (by weight). Hence, one must understand the concern of plastic waste utilization [50].

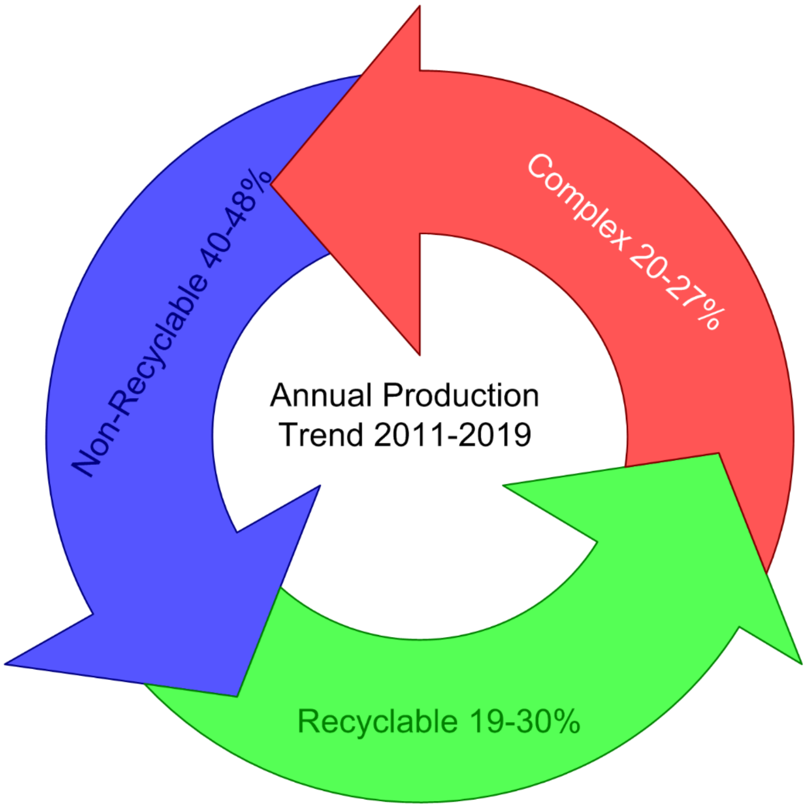

Figure 3: Global annual plastic production from the year 2011 to 2019

Under the circular economy, materials are designed so that nothing goes to waste stream. It means the system can be designed to effectively utilize the material without waste. The efficient application of a circular economy will result in satisfaction in both society and the environment. In January 2018, the EU made a first-ever strategy for plastics in a circular economy, suggesting how the plastic was designed, utilized, produced, and reused. The European Commission has made its policy for monitoring the progress of the circular economy through the circular economy performance index (CPI), which is the ratio of “Actual Environmental Benefit” to “Ideal Environmental Benefit”, following the quality. Ellen McArthur introduces “New Plastic Economy”, which states that plastic is never a waste material, as it can be useful for improving the economy. The new plastic economy synchronized with circular economy principles by providing three main objectives.

(https://www.ellenmacarthurfoundation.org/explore/plastics-and-the-circular-economy#:~:text=Recycling%20of%20plastics%20is%20one,the%20consumption%20of%20finite%20resources).

The first objective is to develop an efficient plastic end-of-life use by promoting recycling and re-utilization. Secondly, to lower the disposal of plastics into the ocean/sea. The third objective is to explore the renewable energy concept through waste [50].

Significant changes in the current policies and practices are required to attain the circular economy of plastics. These changes may be in design, refurbishing, maintenance, recycling, chemical conversions, etc. [51].

In December 2015, European Commission moved towards the first circular economy package and provided an action plan related to the same. According to this plan, a circular economy is described as "An economic system, in which the value of products and material is preserved as long as possible, resulting minimization/elimination of the waste" (EC 2019). The European commission establishes some measures to trigger the inclination of Europe toward the circular economy, which promotes the "close loop" product lifecycle by recycling and utilization. It provides benefits to both environment and the economy **(Figure 4)**. From figure 4, concerning the whole cycle, the plan first covers the Design of Products, i.e., The product should be designed so that it can be easily repaired and remanufactured. Under operations/processes, the production processes or operations should cover the utilization of the resources. Utilization/Consumption covers the proper utilization of the resources to avoid carbon footprints, easy availability of repair, and the parts or components. Management of waste is another step in the cycle that should be proper and more focused on reducing landfilling or incineration, and revising the legislation for waste management. At last, waste resource utilization covers the utilization of the secondary raw material to manufacture the product. (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614)

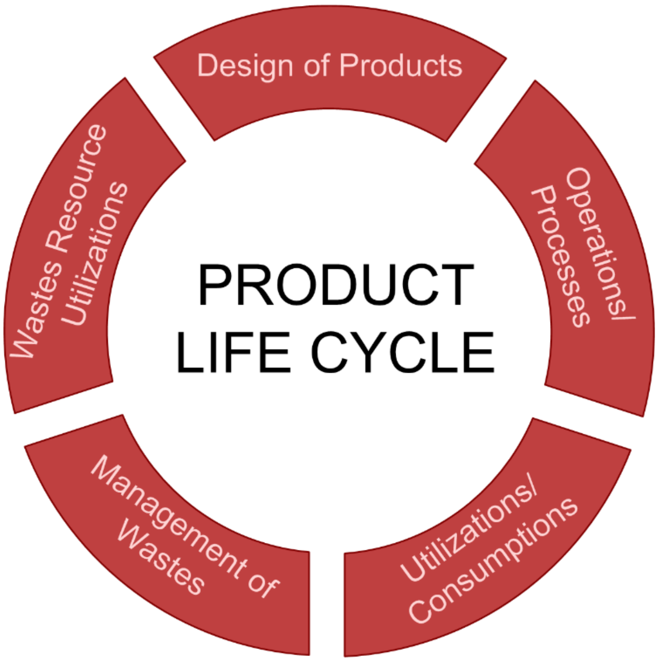

Figure 4: A basic product life cycle

As per the action plan provided by the European Commission (EC) in 2015, plastic is placed at a high priority level for the circular economy. In 2017, EC cleared that, by year 2030, whole plastic packaging would be completely recycled. But apart from this, Europe still needs to increase its speed for recycling plastics, which is still quite low compared to the recycling rates of the other material. As per the EC's report 2018, it is found that less than 30% of the total plastic is recycled (of the total production of plastics annually, i.e., 25.8 million tonnes) [52].

As per the reports of the European Commission, they define the following points about the vision of Europe's new plastics economy [53]:

- A proper design and production can help reuse, recycle, reduce greenhouse emissions, and boost European employment opportunities. Establishing sustainable plastic industries helps restrict the dependency on imported fossil fuels.
- The designing of the plastic should be done for excellent durability and good quality recyclability. They proposed that by 2030, all the plastic utilized in the packaging should be recycled or reusable.

- Changes in design and production allow the plastics' higher recycling rates for major European applications.
- By the year 2030, the capacity to sort and recycle plastics will become four times since 2015, resulting in approx. 200000 new jobs in Europe.
- Modified collection capacity has led to removing the poor plastic waste and providing beneficial feedstocks in recycled plastic.
- Chemical industries work together with plastic recycling industries to attain greater applications.
- Europe's dependency on petroleum or fossil fuel products will be significantly reduced and ultimately reduce CO2 emissions committed by the Paris agreement.
- Innovative material can be developed for efficient application and is capable enough compared to non-renewable sources.

7.1 Characteristics of Plastic Circular Economy:

Plastic circular economy (for plastic packaging) can be explained by the following six characteristics [54]. Figure 5 describes the characteristics of the plastic circular economy:

- **Elimination:** Eliminate and avoid unnecessary packaging by redesigning innovative models to get a circular economy.
- **Apply Reuse Models:** The reuse model should be followed to lessen the need for single-use of plastic packaging.
- **100% reusable and recyclable plastic packaging:** This requires innovation, redesign, materials selection, and processing methods to make the plastic 100% recyclable and reusable. Various reuse models can be used to achieve this objective.

- **Reusable, Recyclable, and biodegradable plastic packaging:** Landfills, Incineration, and energy production from waste are not the aim of the circular economy. This is the business's responsibility to promote or produce plastic packaging to ensure the recycling, reuse, and degradation of the same with time. Governments have to mandatorily establish the funding sources and regulatory policies for this purpose.
- **Avoid the utilization of hazardous chemicals for Packaging:** Hazardous chemicals for plastic packaging should be avoided/eliminated. Health and safety should be the priority concerning the workers and the environment.

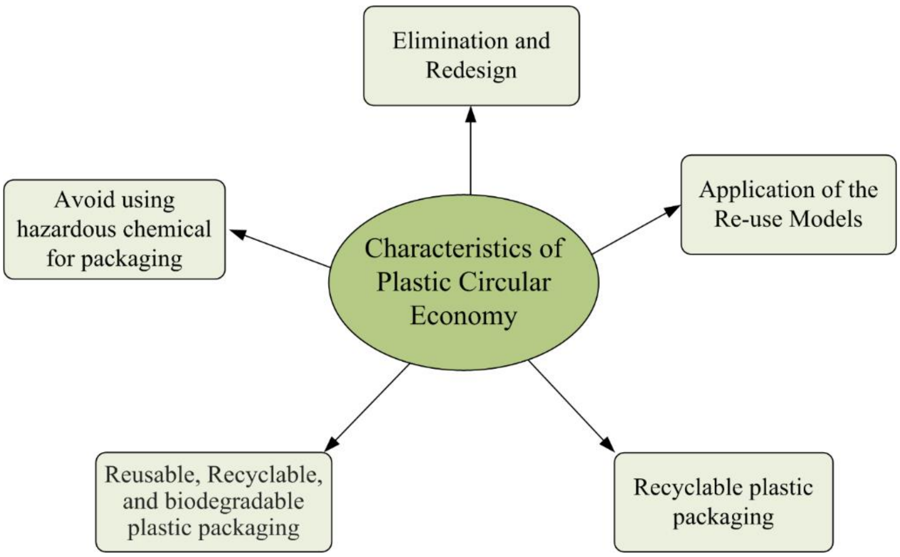

Figure 5: Characteristics of Plastic Circular Economy

8. The Need of Artificial Intelligence for a Sustainability:

Industrial modernization demands various Artificial Intelligence techniques such as Machine Learning, Deep Learning, the Internet of things (IoT), and Blockchain Technology. Their inclusion helps improve efficiency and helps in delivering things on time. Blockchain technology consists of a decentralized database that assists in sending information between fields that do not authenticate each other. The 3 “C”, which are essential in the decision-making process of Blockchain Technology, are cooperation, collaboration, and coordination. Various industries and sectors such as biomedical, agriculture, banking, and supply chains have now implemented blockchain technology to bring transparency and security in every manner [38].

It has been observed that most small and medium-sized enterprises SMEs create plastics in terms of leftover parts (during manufacturing and production), by-products, and unused parts, which are in such small quantities, give reasonable margins if opted for selling purposes. This can only be achieved by safely and reliably storing the data related to the material's quantity, quality, etc. Blockchain technology is one that can provide effective tracing and tracking to permit secured dispensing and authorization of the secondary plastic material.

Artificial Intelligence noticeably takes care of the waste management process by replacing manual operations with automated ones. An AI-based algorithm has been developed, followed by robots for sorting plastic waste. These robots work faster and more efficiently than the manual workforce. Some industries are already using AI-based robots for waste management. These robots can provide a more sustainable and healthier environment by managing and recycling waste through innovative technology. Another application of AI in waste management is the smart trash bins. Sorting plastic is another complex problem. It should be good if one can able to sort the plastic just nearby to its originating source. AI has solved this problem. AI segregates and sorts the plastic near its source of origin. AI robots are so trained that they recognize waste right at their origin and segregate it. This segregated waste then collected and smoothened the waste management process. AI-based trash bins can identify the type of waste or plastic with 90% accuracy. This AI-based trash bin's algorithm can be improved for identifying the various types of waste, like plastic waste for recycling (https://www.allerin.com/blog/seeking-ai-assistance-in-reducing-plastic-waste).

9. AI and Blockchain: A Prospective Utilization in Plastic Recycling and Sustainability

Artificial Intelligence (AI) is one of the useful techniques utilized in almost every field. The usefulness of AI in plastic waste recycling is observed under plastic waste segregation. It is difficult to segregate the plastic based on its type, colour, density, and weight from the waste. To solve this problem, a multi-sensor-based AI approach is explicitly utilized for segregation purposes [55]. The sensor detects and identifies the plastics' physical properties based on their color, shape, and size and separates them into the specified bins. Near infra-red diodes are also used for the segregation, which uses light infrared spectroscopy of plastics within the 300-3000 nm wavelength range. The resonant frequency of the various plastics can also be considered a parameter of differentiation based on the various plastics' resonant frequencies. The laser sensors easily differentiated the plastics based on their types, such as Polyethylene terephthalate (PET), Polyethylene (PE), Polyvinyl chloride (PVC), Polypropylene (PP), Polystyrene (PS), and Acrylonitrile Butadiene Styrene (ABS). Figure 6 shows an AI-enabled blockchain model for plastic recycling. It has been observed that the different plastic molecules have different resonant frequencies, so based on these frequencies, those plastics from the wastes can easily be differentiated [29].

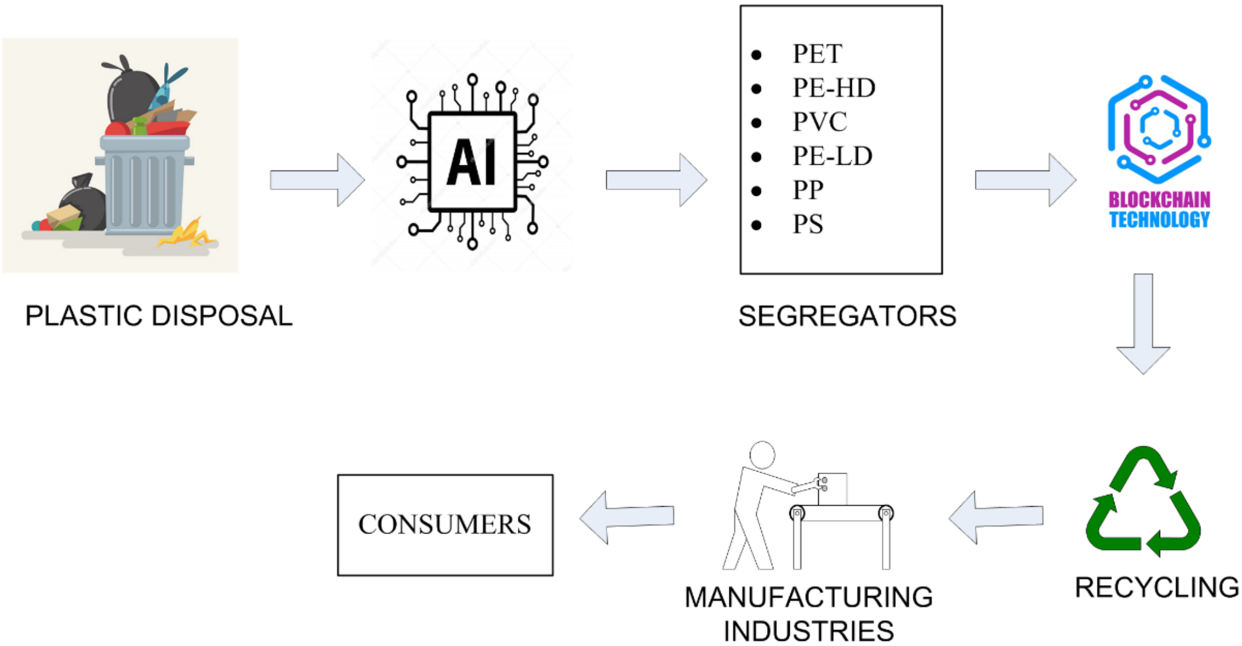

Figure 6: AI enabled blockchain model for plastic recycling

Recently, **Hailu and Saeedkia** [56] have developed an advanced tetra hertz technique to identify the plastics that precisely segregate the plastics from the wastes. Plastic segregation based on its colour is also a challenging task. So, these techniques are suitable for identifying the plastic and 99% accurate based on its colour. However, this technique shows around 95-98% accuracy if we talked about plastic segregation.

Utilizing AI for plastic waste segregation ultimately reduces the complexities and provides an efficient solution for plastic segregation. Through multiple sensors, we may be able to segregate plastics from wastes easily. It has been proved that recycling is proportional to the efficiency and reliability of segregating plastics into their types, depending on physical factors such as their density, colour, and origination. Chidepatil and co-workers [29] have developed a multi-sensor-based system for the segregation of plastics from plastic wastes. The segregation technique uses three types of sensors and is categorized based on their operating frequencies, such as VIS (Visual Frequency), NIR (Near Infra-Red), FIR (Far Infra-Rea) sensors. These sensors provide information regarding the plastics, such as their type, shape, physical and chemical compositions, colour, etc.

Ghoreishi and Happonen [57] studied the importance of AI in the circular economy and hastened its utilization to design a new product. Everyone is aware that the product design dramatically affects the sustainable ecology. Their study focuses on the different circular design tools and plans, which undoubtedly support the industries and organization's product design. Also, the product circularity can be improved further by the application of AI. AI helps identify the most accurate data about the specific materials and their availability, states, and receptiveness, by which tracking becomes more accessible and provides recycling opportunities. AI also helps remotely track the circular economy’s efficiency, both at the manufacturing and end of the product's life cycle.

European Commission [58] reported that financial supports should be given for digitization. Digitization applied AI, IoT, and Blockchain technology to improve the product or business model design specifically for the circular economy.

Merlinda and co-workers [59] reviewed some of the challenges and opportunities of blockchain technology in the energy sector. They showed that blockchain development companies have developed a coin, RecycleToCoin, and will be given to the users through a mobile app. The coin is given to the people to recycle plastic wastes, aluminium cans, etc.

Andrew Forrest and co-workers [60] showed how an industry would help drive the circular plastic economy to eliminate plastic pollution. They showed that industry could help restrict the plastic flow by converting used “used plastic” into a cashable commodity”, incentivizing people, and promoting polymer technology industries.

IISD [61] also reported that cryptocurrencies are developed by blockchain. These cryptocurrencies can be considered as tokens that can be further used for incentivization. These tokens are known as “Impact tokens”, representing socio-environmental impacts of particular activities.

Conclusion and Future Research Directions:

Plastic accumulation is an inevitable concern for the sustainable environment, and it can potentially create associated problems if this is not addressed properly within specific timeframes. Plastic recycling is a challenging task and needs specific implementation strategies. Plastic's manual segregation is an intricate process and has many issues, such as the identification and segregation of the plastics based on their types. Blockchain technology and Artificial Intelligence are the key techniques to manage plastic waste recycling. This article specifically comprises the demonstration of blockchain technology, the circular economy of plastics, and effective utilization for plastic waste management. The current article has also briefly introduced AI-enabled multi-sensor utilization for the segregation and collection of plastics from waste. The studies indicated that utilizing blockchain technology, AI, and circular economy, demonstrates an effective tool and solution for prospective plastics recycling.

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