Resource Recycling with the Aim of Achieving Zero-Waste Manufacturing

Omojola Awogbemi 1,*, Daramy Vandi Von Kallon 1 and Kazeem Aderemi Bello 2

Abstract: The management of the huge amounts of waste generated from domestic and industrial activities has continued to be a source of concern for humanity globally because of its impact on the ecosystem and human health. Millions of tons of such used materials, substances, and products are therefore discarded, rejected, and abandoned, because they have no further usefulness or application. Additionally, owing to the dearth of affordable materials for various applications, the environmental impact of waste, and the high cost of procuring virgin materials, there have been intensive efforts directed towards achieving the reduction, minimization, and eradication of waste in human activities. The current review investigates zero-waste (ZW) manufacturing and the various techniques for achieving zero waste by means of resource recycling. The benefits and challenges of applying innovative technologies and waste recycling techniques in order to achieve ZW are investigated. Techniques for the conversion of waste glass, paper, metals, textiles, plastic, tire, and wastewater into various products are highlighted, along with their applications. Although waste conversion and recycling have several drawbacks, the benefits of ZW to the economy, community, and environment are numerous and cannot be overlooked. More investigations are desirable in order to unravel more innovative manufacturing techniques and innovative technologies for attaining ZW with the aim of pollution mitigation, waste reduction, cost-effective resource recovery, energy security, and environmental sustainability.

Keywords: zero waste; waste minimization; manufacturing; 4IR; waste recycling

1. Introduction

Waste generation and disposal are two challenges faced by mankind in this century. Waste is generated by households, industry, schools, restaurants, farms, and, indeed, all human activities. Global waste generation, which was 2.02 billion tons in 2016, is projected to reach 2.59 billion tons in 2030 and 3.4 billion tons in 2050 (Figure 1) [1]. The rate of waste generation has been predicted to overtake the population growth rate by more than double during the same period. However, not all generated waste is collected. Although 96% of waste generated by high-income countries is collected, only about 39% of waste is collected in low-income nations. In terms of waste disposal and treatment, only 36.6% of waste generated ends up in one form of landfill or other, whereas 33% is dumped and burned in the open. A paltry 13.5% of global waste is recycled, whereas about 11% is incinerated [1]. Canada, Bulgaria, and the United States were the three largest per capita generators of waste in 2017, generating 36.1 metric tons (MT), 26.7 MT, and 25.9 MT of waste per capita (Table 1) [2].

In general terms, waste consists of materials, substances, or products that are produced but are no longer useful or are unable to meet their intended purpose. Because such materials have no further usefulness, they are discarded, rejected, thrown away, dumped,
or abandoned [3]. Waste is generated either as raw materials, intermediates, final products, or as remnants after the consumption of the final product or from human activities [4,5].

![Figure 1. Waste generation by region in 2016, 2030, and 2050 (millions of tons) Redrawn from [1].](image)

### Table 1. Top ten waste generators in 2017. Compiled from [2].

| Country          | 2017 Population (Million) | Annual Waste per Capita (MT) | Annual Total Waste (MT) | Waste Treatment Recycling (%) |
|------------------|---------------------------|------------------------------|-------------------------|-------------------------------|
| Canada           | 36.54                     | 36.1                         | 1,325,480,289           | 20.6                          |
| Bulgaria         | 7.102                     | 26.7                         | 189,141,945             | 19.0                          |
| United States    | 325.1                     | 25.9                         | 8,425,840,000           | 34.6                          |
| Estonia          | 1.316                     | 23.5                         | 30,912,409              | 24.7                          |
| Finland          | 5.503                     | 16.6                         | 91,698,449              | 28.1                          |
| Armenia          | 2.945                     | 16.3                         | 47,889,000              | ns                            |
| Sweden           | 9.995                     | 16.2                         | 163,199,471             | 32.4                          |
| Luxembourg       | 0.590                     | 11.8                         | 7,016,503               | 28.4                          |
| Ukraine          | 44.83                     | 10.6                         | 474,106,025             | 3.2                           |
| Serbia           | 7.021                     | 8.9                          | 62,269,603              | 0.8                           |

A huge quantity of materials is generated during every phase and in every facet of manufacturing activities. By definition, manufacturing waste consists of any materials left unused or left over after the completion of manufacturing processes. These materials are generated at every stage of manufacturing, and can be in either solid or liquid form. Common examples of manufacturing waste include solid waste such as scrap metals, plastics, polymers, wastepaper, glass, tires, ceramics, cardboard, packaging materials, other carbon-based materials, etc.; chemical waste such as acids, salts, electrolytes, etc.; and toxic waste such as wastewater, slag, lead, electronic waste, etc. [6].

In many countries, however, there are waste management regulations governing waste generation, collection, recovery, and reuse. Such countries have enacted specific legislations
on the percentage of recovered materials that are to be used in the manufacture of new products. Products such as sanitary tissue paper, building insulations, floor tiles, plaques, laminated paperboard, restroom dividers, office furniture, file folders, etc., are manufactured in their majority from materials recovered from waste. The aim of such regulations is to reduce waste generation and encourage waste reuse. However, enforcement of these regulations has not been very effective.

2. Zero Waste Manufacturing

At first glance, zero waste (ZW) means complete and total elimination or absence of waste. However, much more than that, ZW entails waste prevention and where all materials are reused. It is a philosophy that forbids sending any unused material to landfills, dumpsites, or incinerators. Under ZW, the keyword is conservation of resources. It involves responsible utilization, re-utilization, and recycling of resources to safeguard human health and preserve the environment [7]. The Zero Waste International Alliance (ZWIA), an organization working towards a world without waste, seeks to eliminate wastes by resisting incineration, landfiling, and dumping but by developing innovative ways of promoting resource conservation and waste conversion to use raw materials for the production process and for the sustainability of the environment [8,9].

Improved waste management, inappropriate waste disposal, open dumping of waste, and landfiling pollutes natural habitats (air, land, and water) and exacerbates health-related problems. Greenhouse gases such as carbon monoxide and methane generated from the refuse heaps at dumpsites promote air pollution, whereas the leachate formed in the landfills contaminates ground and surface water sources. Proper waste management strategies including waste prevention, minimization, remediation, and re-utilization can help solve many avoidable problems and safeguard the ecosystem.

Zero waste manufacturing (ZWM) entails the various techniques that promote a manufacturing system that utilizes minimum materials, generates minimum wastes, and encourages waste re-utilization. Though wastes cannot be completely prevented in manufacturing processes, strategies that allow waste prevention, minimization, recycling, redesigning, and re-use contribute towards ZWM processes. Waste generated from manufacturing can be substantially reduced by the adoption of methodologies that allow a product to be used for other applications after becoming obsolete or undesirable for its primary application. This means creating a product with multi-utility capability and a dependable service life across multiple utilization cycles is a way to achieve ZW in the manufacturing sector. Additionally, conventional manufacturing processing poses a great challenge to the concept of sustainable material utilization, lean material production, and minimum material removal during production. To achieve ZWM, innovative manufacturing techniques and pathways must be adopted and utilized.

Previous research has appraised how different technologies will ensure the attainment of ZWM. Notably, Singh et al. [10] carried out a multidisciplinary review on ZWM and concluded that new manufacturing technologies such as 3D printing, application of digital technologies including Internet of Things (IoT), big data analytics, Artificial Intelligence (AI), and cloud computing, etc. and an urgent attitudinal change are needed to achieve ZWM. Additionally, Kerdlap et al. [11] advocated the implementation of innovative technologies such as additive manufacturing, waste auditing, material recovery, and application of digital platforms for industrial symbiosis are the key ingredients for achieving sustainable ZWM. On their part, Singh and Hussain [12] submitted that waste-free manufacturing will not only benefit the manufacturing sector but help communities and societies to ensure clean, safe, and hygienic environments.

Despite all these efforts, the necessary question to ask is whether the subject of ZWM or waste-free manufacturing has been adequately tackled. Are the avenues for achieving ZWM been well interrogated bearing in mind the enormous waste emanating from the manufacturing sector? The current effort aims to interrogate innovative pathways for achieving ZWM through the conversion and utilization of some wastes. The objective is to
stimulate further investigations in the study area with a view to coming up with implementable actions. This intervention is limited to a desktop review of published research outcomes in the last decade. The various examples of technologies for recycling, utilization, and conversion for waste plastic, glass, paper, metals, tires, textiles, and wastewater are reviewed. Future prospects and sustainable conclusions are drawn.

3. Major Avenues for Achieving ZWM

Over the last decade, researchers, manufacturers, waste management experts, and environmentalists have put forwards various novel techniques, pathways, and technologies for achieving waste-free manufacturing. Some of these pathways involve the use of smart technologies, waste prevention manufacturing techniques, waste minimization, waste prevention, waste utilization, as well as waste recovery and conversion.

3.1. Application of Innovative Technologies

The advent of new technologies has led to improvement in every facet of the economy and lives. The performance of the manufacturing sector has been enhanced by the introduction of various innovative, fast and cost-saving technologies. The fourth industrial revolution (4IR) combines physical, digital, and biological technologies that improve the flexibility, agility, and pace of production systems to meet the rising demand for goods and services. The 4IR involves the application of notable technologies such as the IoT, big data, analytics, robotics, additive manufacturing, machine learning, lean manufacturing, AI, high-performance computing, among others, to produce high-quality products in a cost-effective, labor friendly and environmentally friendly manner [13]. The deployment of 4IR technologies in the manufacturing sector has enhanced productivity, improved product usefulness, reduced energy consumption, ameliorated emission of toxic gases, and led to waste reduction [14,15].

Various researchers have utilized technologies to improve manufacturing processes and outcomes to raise productivity while minimizing waste. In extant research, Lu [16] and Wang et al. [17] chronicled the application of 4IR technologies such as the Industrial Internet of Things (IIoT), cloud computing, big data analytics, robotics, etc. in the manufacturing sector towards improved efficiency, environmental sustainability, energy management, cost reduction, and waste minimization. There are many advantages derivable from the application of innovative technologies to ensure effective manufacturing systems though with obvious challenges (Table 2). The application of AI ensures automation and precision manufacturing thereby reducing waste when compared with human or traditional manufacturing processes [18,19].

Table 2. Benefits and limitations of 4IR technologies in manufacturing.

| Technologies | Benefits                        | Limitation                                      | Ref.   |
|--------------|---------------------------------|-------------------------------------------------|--------|
| AI           | Precision manufacturing         | High initial cost.                              | [18,19]|
|              | Automation                      | Requires maintenance and complex programming    |        |
| Robotic      | Higher output efficiency        | Lack of imagination, ingenuity, and personality | [20,21]|
|              | Precision manufacturing        | High initial financial investment                |        |
|              | Additive manufacturing         | Industrial robots require sophisticated operation, maintenance, and programming |        |
|              | Elimination of errors          |                                                |        |
|              | Repetitive operation efficiency |                                                |        |
|              | Enhance productivity and reliability |                                            |        |
Additionally, robotic technology helps in automation, performs hazardous jobs, and does repetitive jobs for a long duration with minimum errors due to fatigue thereby ensuring waste prevention and minimization [20,21]. The application of robotic machining has gained prominence in recent years with the obvious advantage of the elimination of defective products, waste prevention and minimization, and consistent production of quality products [22,23]. Big data analytics allows intelligent process monitoring, prediction of a machine breakdown, mass product customization, and attainment of error-free products through cybersecurity, the likelihood of identity theft, and high energy consumption are legitimate concerns [24,25]. Notwithstanding the few challenges associated with the adaptation of cloud computing technology in a manufacturing system, it has been found to reduce defects and wastages, maximize production efficiency and allow real-time monitoring of...
machines towards reducing downtown due to machine breakdown [26–28]. Additionally, Ooi et al. [29] and Fisher et al. [30] in their earlier studies, reported that cloud computing offers innovativeness, ensures flexibility, improves performance, and contributes to ZW in a manufacturing system.

The continuous application of novel technologies and manufacturing techniques holds the key to less waste generation, fewer product errors, and smarter products in the foreseeable future. Though the use of these technologies comes with increased cost, the benefit of their adaptation will be visible in reducing waste and waste management costs, lower cost of materials, and near abrogation of defective products. Effective man-computer symbiotic association, also called Augmented Intelligence can address some of the emerging challenges and increase production output at reduced cost and man-hour.

3.2. Total Waste Recycling and Reuse in Manufacturing

Waste recycling and reuse is a viable way of waste minimization, waste reduction, and waste management. Most of the items that are discarded by mankind and end up in dump-sites can be recycled and reused. Waste recycling and reuse reduces the number of wastes sent to landfills and incinerators, ensures conservation of natural resources, saves energy, reduce pollution and contamination, and supports the manufacturing sector. Recycling of wastes from the manufacturing sector reduces the use of new raw materials, minimizes environmental impacts of waste treatment and disposal, saves money, and ensures that minimum energy is consumed during product manufacturing. For sustainable wastes recycling systems, the waste generated must be collected, sorted, processed, converted to other usable items, and the consumers are encouraged to patronize items produced from recycled materials. Paper and cardboard, plastic, food, metals, rubber and leather, textiles, wood, stones and brick, glass, and ceramics are the common wastes that can be recycled and reused [31]. Although metal scraps can be converted into aluminum cans, nails, and other steel products, waste papers are transformed into egg cartons, cereal boxes, paper towels, newspapers, glass containers, laundry detergent bottles, etc. are made from waste glass.

3.2.1. Waste Glass

One of the most reported uses of waste glass is as a substitute for fine aggregates and concrete to reduce the cost and environmental impact of Portland cement production [32–34]. To further demonstrate this position, Tamanna et al. [35] and Lu et al. [36] investigated the deployment of crushed waste glass as a partial replacement for fine aggregates in concrete. The generated concrete exhibited better strength, durability, and improvements in other mechanical properties when used for building and road construction. Waste glass has also been recycled and converted to an architectural mortar with improved durability, compressive strength, and workability [37]. In extant research, Keawthun et al. [38] demonstrated the application of recycled waste glass when they recovered sodium silicate from recycled waste glass. The water glass finds applications as sealants, binders, emulsifiers, and buffers in pulp and paper as well as detergent industries. The waste glass was also converted to a high-capacity Lithium storage battery to store energy. The Li battery was found to be effective, last long, and is cost-effective [39]. When the waste glass was converted to low-cost polymetric tiles for use in the construction industry, it was reported the produced tiles possess improved compressive strength and better load carry capacity [40]. Since glass is not biodegradable, recycling is a practical and cost-effective strategy of minimizing glass wastes, reducing pollution and eliminating waste glass from landfills, and avoiding the harmful environmental impacts of waste glass.

3.2.2. Waste Plastic

Waste plastic is one of the major sources of environmental pollution. Because plastics are non-biodegradable, the impact of their inappropriate disposal and management is long-lasting and devastating. Plastic wastes are produced from industrial, commercial,
and household activities. In 2018, 46% of plastic wastes were generated from packaging, whereas textiles, consumer products, and transportation sectors generated 14.9%, 12.1%, and 5.6%, respectively (Figure 2) [41]. Global plastic production has been projected to grow by 3.8% by 2030 [42]. With this growth rate, more plastic wastes will be generated with its attendant environmental pollution. To reduce the incidence of waste plastic and move towards zero plastic waste, recycling plastic to other products is inevitable. One of the avenues for waste plastic recycling is the conversion of waste plastic to fuel. Various techniques have been adopted to convert waste plastic to petrol, diesel, jet fuel, and hydrogen fuels. The generated fuels are environmentally friendly, effective, and generate less harmful emissions when used to power internal combustion engines [42–44]. In other research, waste plastic has been converted to catalysts for biomass valorization [45], nanofoam for environmental remediation [46], and oil for engine lubrication applications [47]. In another research, Vidal-Barrigue et al. [48], investigated the use of waste plastic as a substitute for raw materials in the manufacture of construction materials. They reported that construction panels manufactured from waste plastic showed better elasticity, flexural strength, surface comfort, and shock-impact resistance. This further demonstrates the conversion of waste plastic for cost-effective building renovations and sustainable construction.

3.2.3. Waste Tire

About 1.5 billion waste tires are generated annually worldwide, but only about 100 million are recycled [49]. The low rate of tire recycling is due to the complexities involved in the process arising from their compositions (tires consist of natural and synthetic rubber, fiber, and wire). Since tires are not biodegradable, waste tires litter our major cities and populate dumpsites thereby constituting an environmental nuisance. Inappropriate dumping of waste tires causes open-air fires and pollutes aquatic and terrestrial habitats [50]. There has been renewed interest in the growing economic value of waste tires in recent years. In the year 2017, the global market for waste tires was USD 7.6 billion and has been projected to become USD 9.5 billion by the end of this year, 2022 [51]. Equally, there has been increased market value of the products generated from recycled waste tires. The market share of the waste tires recycling products that was USD 4.20 billion in 2019 is estimated to grow by 5.0% and become USD 6.21 billion by 2027 [52].

Recycled waste tires can be used for road construction, noise and vibration reduction in railways, production of chemicals, biofuel, and other bio-based products [50]. These products are achieved through various conversion techniques and technologies including
retreading, reclaiming, combustion, grinding, and pyrolysis [53,54]. Avenues for the utilization of waste tires for various applications have been well exploited and reported by researchers. Some of these applications offer low-cost, environmentally friendly, and waste conversion advantages in road and building construction, energy conversion, wastewater treatment, soil decontamination, and raw materials for the tire industry [55–61].

3.2.4. Wastepaper

The total global paper consumption was recorded as 422 million metric tons (MMT) in 2018 with China, the United States, Japan, Germany, and India leading the pack with 110 MMT, 72 MMT, 26 MMT, 22 MMT, and 15 MMT, respectively [62]. The global paper consumption has been projected to become 433 MMT, 444 MMT, and 461 MMT in 2025, 2027, and 2030, respectively [63]. In terms of market share, the global paper recycling market that was USD 5.5 billion in 2020 is estimated to reach USD 56.2 billion by 2025 [64]. Activity in the paper recycling sector has been propelled by numerous environmental, sanitation, and cost benefits derivable from the process. Besides, with the increase in the global literacy index, industrialization, and replacement of most plastic with paper products, the use of books and other paper products will continue to increase. Papers are used in the production of books, magazines, cardboards, stationaries, copying, commercial printing, and packaging. Application of waste papers includes production of bioethanol, butyric acid, cellulose nanofibers, fluorescent Carbon Dots, ceiling boards, and other chemicals and bioproducts [65–71]. The conversion of wastepaper into biofuels, building materials, chemicals, and other products are cost-effective, enhance sanitation, ensure appropriate disposal of waste paper, a green approach to waste management, and safeguards the environment.

3.2.5. Waste Metals

Metal recycling is the practice of collecting, sorting, cleaning, and melting metallic scraps to convert them into new products. Metals can be ferrous (contains mostly iron) and non-ferrous (does not contain iron) and can be used for various applications. Waste metals or scrap recycling has continued to grow in the past few years. The growth is being propelled by cost-effectiveness, increased demand, conservation awareness, and environmental concerns. Metal recycling allows builders, producers, and industrialists to get raw materials for the production of finished products without damaging their properties. According to recent reports, the global metal recycling market that was USD 52.1 billion in 2019 is estimated to grow to USD 76.1 billion in 2025 and further to USD 86.11 billion in 2027 [72,73].

There are huge prospects for metal recycling in meeting the dearth of adequate materials for the global industrialization drive. The major process for metal recycling includes collection, separation/sorting, cleaning, fragmentizing, weighing, and selling. The ferrous metals are separated from non-ferrous metals before selling. The collected metals are usually remelted and cast into bigots and sold to industries for further use. Sustainable end-of-life products of metal conversion include construction parts [74], automobile parts [75], fasteners such as machine screws, socket screws, bolt screws and rivets, bed frames, cooking pots and cutleries, tools, toys, bicycles, sinks and bathtubs, farm equipment, eyeglass frames, beverage containers, roofing and window frames, to mention but a few [76]. The numerous environmental, sanitary, and economic advantages of metal recycling make the process continue to receive attention. Recycling waste metals also ensures energy savings and slows landfill growth. However, a lot of time, resources, and energy are expended during the collection, sorting, and conversion of waste metals. Additionally, workers at the various recycling facilities are often exposed to unhealthy environments and toxins. The quality of some of the products of recycled metals is substandard and low in quality leading to failure during usage [77-79].
3.2.6. Waste Textiles

Due to increased population, modernization, increasing fashion awareness, and inclement weather conditions created by the depletion of the ozone layer, the use of clothing and other textile materials have continued to increase. Subsequently, the generation of worn-out textiles and out-of-fashion clothes has continued to rise. For example, about 134 million tons of waste textiles are expected to be generated globally by 2030 as against the current data of 92 million tons [80]. Despite this huge waste of generated textiles, only a paltry 15% of post-consumer textile waste was collected. In 2015, 15% was collected for reuse or recycling whereas the figure reduced to 14.7% in 2018 [80,81]. However, only about 1% of the collected waste textiles are recycled [82]. Discarded clothing and textile materials are one of the constituents of municipal and solid wastes and constitute about 22% of total global waste, ending up occupying 5% of all landfill spaces [83]. The textile industry itself generates about 10–11% carbon dioxide, 9–10% nitrogen oxide, 8.1% of global greenhouse gas emissions, and 20% of wastewater, globally [83–85]. Going by the current trend and reliable estimations, by 2050, the production of textiles from virgin sources will expend 300 million tons of oil and generate 26% of carbon emissions, an over 200% and 1200% increment compared to 2015 statistics, respectively [86,87]. According to health experts, the production of textiles from virgin sources aggravates the concentration of synthetic polymers in the atmosphere, exacerbates environmental pollution, and causes damage to human health [82,88].

It has been estimated that conversion and utilization of waste textiles can reduce the production of new textiles from new materials, improve sanitation, slow down the rate of filling of landfill spaces, and lessen the use of water, energy, and chemicals in the production chain. Compared with incineration and landfilling, textile recycling is more beneficial from the economic, health, social, wastes recovery, and environmental standpoints [89]. However, limitations and underdevelopment of the appropriate practical technologies for recycling various types of waste textiles, economic considerations, technical challenges relating to the complexities of clothes, and undeveloped markets have continued to hamper the recycling of waste textiles. Nonetheless, recent studies have enumerated the various avenues and products of textile recycling. According to Xia et al. [90], Zach et al. [91], Yousef et al. [92], and Saud et al. [93], waste textiles are converted into polyethylene terephthalate, thermal and acoustic insulation materials, polyester and carbon electrocatalyst, respectively, for various applications. Recycling waste textiles offers opportunities in material recovery, social, economic, and environmental sustainability.

3.2.7. Wastewater

Wastewater is the water that has been used in the domestic, commercial, or industrial sector and must be treated before being released into water bodies. Domestic sources of wastewater include water used for bathing, washing, water from lavatory, laundry, and dishwashing, whereas commercial sources of wastewater are laundry, food processing, beauty salon, auto body repair shop, car wash, furniture cleaning, markets, restaurants, irrigation sites, livestock houses, abattoirs, slaughterhouses and acid mine drainage. Industrial wastewaters are generated from paper and pulp industries, textiles industries, paints and dye industries, iron and steel industries, mines and quarries, food processing industries, and chemical industries [94]. A recent study puts the global wastewater generation at 359.4 billion cubic meters per annum (m$^3$/yr) out of which 225 billion m$^3$/yr was collected and 188 billion m$^3$/yr treated [95]. Improper disposal of untreated wastewater pollutes the soil, increases soil acidity, leads to a dearth of oxygen, and suffocates plants and animals. Untreated wastewater contaminates surface and underground water, and negatively impacts the lives of aquatic plants and animals. Consumption of untreated polluted water expose humans to preventable health risks and exacerbates cases of cholera, diarrhea, dysentery, hepatitis B, and other water-borne diseases [96,97].

In recent research, various adsorbents have been deployed for the purification of wastewater. Enaime et al. [98] developed biochar, whereas Jaspal and Malviya [99] devel-
oped biomass-based composites as low-cost adsorbents for decontamination of wastewater. Several other effective techniques have been developed and applied for the purification of contaminated water. Dimoglo et al. [100], Li et al. [101], and Ang and Mohammad [102] employed electrocoagulation/electroflotation, oxidation-filtration, and natural coagulants, respectively, for the purification of wastewater. The various techniques were found to be cost-effective, efficient, and sustainable for the removal of colored contaminants, organic and inorganic pollutants from contaminated water. The purified water was found safe, hygienic, and meets international water standards. Decontamination and recycling wastewater contributes to zero wastewater and increases the accessibility of safe water for social, economic, agricultural, commercial, and industrial applications.

Table 3 shows the summary of the conversion techniques, recovered products, and applications of the various wastes.

**Table 3. Recycling waste materials into new products.**

| Waste Material | Conversion Technique | Recovered Product | Uses | Ref. |
|----------------|----------------------|-------------------|------|------|
| Glass          | Crushing and mixing  | Reinforced concrete | Building and road construction industries | [35] |
|                |                      | Reinforced fine aggregate | Building and construction industries | [36] |
|                |                      | Architectural mortar | Building and construction industries | [37] |
|                | Hydrothermal and fusion methods | Sodium silicate (water glass) | Used as sealants, binders, deflocculants, emulsifiers and buffers | [38] |
|                | Crushing Addition of reducing agent | High-capacity Li storage materials | Li-battery energy storage system | [39] |
|                | Alkaline activation | Geopolymeric tiles | Building industry | [40] |
| Plastic        | Pyrolysis            | Petrol, Diesel and Gas | Power internal combustion engine | [42] |
|                | Catalytic pyrolysis  | Jet fuel and hydrogen | As fuels | [43] |
|                | Thermal conversion   | Fuel oil | Heating homes, fuel trucks, ships, and industrial power plants | [44] |
|                | Pyrolysis            | Catalysts | Biomass valorization | [45] |
|                | Catalytic decomposition | Photocatalytic Nanofoam | Environmental remediation | [46] |
|                | Thermal conversion   | Oil | Lubrication | [47] |
|                | Crushing, mixing, and testing | Construction panels | Building partitioning and construction | [48] |
| Waste Material | Conversion Technique | Recovered Product | Uses | Ref. |
|----------------|----------------------|-------------------|------|------|
| Tires          | Pyrolysis            | Pyro oil          | Diesel engine fuel, Carbon nanotubes | [55] |
|                | Pyrolysis            | Pyro char         | Energy storage, Wastewater treatment | [56] |
|                | Pyrolysis            | Pyro gas          | Fuel, liquefied synthetic natural gas, Hydrogen gas | [57] |
|                | Adsorption           | Pulverized waste tires | Soil decontamination | [58] |
|                | Combustion           | Carbon black      | Production of batteries, electronic devices, catalyst, pigments, concrete, and plastics, | [60] |
|                | Crushing             | Rubber granulate  | Concrete reinforcement | [61] |
| Paper          | Enzymatic hydrolysis and fermentation | Bioethanol | Fuel | [65] |
| Paper          | Pulping, flotation, washing, and grinding | Cellulose nanofibres | Electronics, packaging, and nanocomposites | [66] |
| Paper          | Carboxymethylation  | Carboxymethyl cellulose | Packaging materials | [67] |
| Paper          | Microwave-assisted hydrothermal degradation | Graphene oxide quantum dots | Value-added products | [68] |
| Paper          | Grinding, drying, and coating | Oil adsorbent | Remediation of oil spills | [69] |
| Paper          | Fermentation        | Butyric acid      | Biofuels and chemicals | [70] |
| Paper          | Grinding, pressing  | Ceiling board     | Interior roofing and decoration | [71] |
| Metals         | Hot extrusion       | c-channel         | Construction and fabrication of parts | [74] |
| Metals         | Casting             | Automobile bumpers | Automobile industry | [75] |
| Metals         | Various production processes | Doors and window frames, bed frames, automobile parts, mattress springs, farm implements, cooking pots, cutleries, locks, and doorknobs | Various households, agricultural, construction, industrial uses | [76] |
### Table 3. Cont.

| Waste Material | Conversion Technique | Recovered Product | Uses | Ref. |
|----------------|----------------------|-------------------|------|------|
| Textiles       | Melt pressing        | Polyethylene terephthalate | Flexible food and beverages packaging, plastic foils, balloon production, shopping bags, water bottles, etc. and for thermal insulation | [90] |
| Nonwoven       | Thermal and acoustic insulation materials | Polyester | Sound absorbers, asbestos, glass fibers, expanded perlite, fire protection, sound insulation in cars | [91] |
| Leaching, carbonization, filtration | Polyester | Manufacturing of bottles, industrial polyester fibers, threads, hoses, yarns, ropes, safety belts, home furnishing materials. | | [92] |
| Nonwoven       | Carbon electrocatalyst | Polyester | Replacement for platinum catalysts, fuel cell application, and metal-air batteries | [93] |

| Wastewater | Adsorption | Clean water | Water for irrigation | [98] |
|-------------|------------|-------------|----------------------|------|
|             | Adsorption | Decontaminated water | Water for carwash and other industrial purposes | [99] |
| Electrocoagulation/ electroflotation | Purified water | Laundry, lavatory, and irrigation purposes | [100] |
| Oxidation-filtration | Depolluted water | Industrial applications | [100] |
| Coagulation | Portable water | Agricultural and industrial purposes | [102] |

### 4. Implications

ZWM is achievable. However, necessary legislations, policies, and programs must be enacted and dutifully implemented. There is need for comprehensive and all-encompassing strategies with specific timelines respected by all stakeholders. The first step towards this is to intensify citizenship education geared towards behavioural change. The people must buy into and wholeheartedly support sustainable consumption. The adverse effects of unmanaged wastes on global climate change and human health are unambiguous and evident. Many people and communities are unwilling to imbibe sustainable behaviour and lifestyles that will mitigate the raging effects of environmental degradation. Governments at various levels must be willing to invest in sensitization, education, training, and research on innovative ways to achieve ZWM [103,104].

Producers of some non-biodegradable and hazardous products must be made to take some responsibility for the impact of their products on the environment. Producers must develop efficient strategies for product take-back to encourage consumers to return the product to them at its end-of-life. Manufacturers must develop innovative technologies that
allow the returned products to be refurbished, remodeled, resuscitated, reprocessed, and made anew. Such encouragements must include monetary rewards and other incentives such as discounts on the purchase of new products. This will promote producers’ and consumers’ responsibility, reduce indiscriminate dumping of used products by consumers, and ensure manufacturers produce products they can recycle [104,105].

Most countries have weak policies towards waste recycling and material recovery from waste. Enforcement of some of the waste management policies has been politicized in some countries. In the interest of sustenance of the environment, policies and legislations that promote 100% recycling of wastes, 100% recovery of resources from wastes, and zero landfills and incineration should be prioritized [104,106].

With the advantages of ZW including its cost-saving and economic capabilities, sanitary and environmental sustainability, waste management, material recycling, and resource recovery, it is best to adopt innovative technologies and approaches towards its realization. The use of eco-friendly and innovative technologies will ensure value for money, reduce the risk of infections and contaminations, and allow for metering and adequate record keeping. Some of the techniques and technologies for achieving ZW can be time-consuming, misleading, and difficult to achieve. In some cases, the cost of collection, sorting, and conversion of waste can be greater than the cost of developing new products [107]. Additionally, conversion and re-utilization of wastes can offend some social, religious, and cultural beliefs and practices [108]. Conversion and utilization of wastes are beneficial to the economy, community, and environment in the following ways:

4.1. Benefits of ZW to the Economy

Youths and women groups are engaged in waste collection, sorting, processing, wastes markets, and other recycling processes thereby creating jobs and additional income. Money that should have been used to procure new materials is diverted to other productive uses when some waste materials are converted and used at a cheaper price [109]. Jobs such as car rentals, tool sharing, Managers of local recyclers, waste depots, and compost facilities are created in the community thereby contributing to the local economy and poverty alleviation. ZW also contributes to the circular economy and assists in keeping the resources of the people within the local community rather than leaving the community to purchase imported goods and products [110]. Small and medium scale enterprises are incentivized to participate in waste recycling and make use of recycled products, thereby creating markets and empowering businesses within the local community.

4.2. Benefits of ZW to the Community

ZW benefits the communities by promoting social equity and cohesion, builds community capacity and improves the capability of the community dwellers, promotes community inclusiveness, and protects community well-being. Marginalized groups and small communities are assisted through redistribution of foods, furniture, materials, and other resources are assisted through community-based ZW approaches to reduce waste and cost, build capacity and participate in community development endeavors. ZW helps in environmental protection, reduces air pollution, water decontamination, and reduction in soil toxicity, as well as keeping wastes away from dumpsites and incinerators [111].

4.3. Benefits of ZW to the Environment

Bearing in mind that the inappropriate disposal of wastes affects the environment, it is noted that waste reduction, recycling, and re-utilization reduces GHG emissions. Huge amount of energy is consumed, and toxic emissions are generated during the production of food, goods, packaging materials, and waste disposal. Waste reduction, re-utilization, and recycling will conserve energy, considerably reduce carbon emissions and mitigate impact on the environment. ZW also conserves natural resources, minimizes pollution, and ensures sustainable consumption [106,112]. Waste recycling reduces the magnitude of wastes getting to landfills and incinerators thereby promoting material recovery.
5. Conclusions

The dearth of affordable materials for the smooth running of the manufacturing sector has become a major challenge that needs to be tackled. With the ever-increasing cost and environmental impact of making of virgin materials, waste minimization, reduction, conversion, and recycling approaches have been gaining attention. In this work, the technologies and practices for achieving ZWM and the contribution of innovative 4IR technologies in manufacturing have been highlighted. Various conversion techniques covering products from diverse wastes, and their applications are interrogated extensively. Benefits of ZW to the economy, community, and environment are discussed.

The application of innovative technologies and best practices should be allowed to play critical roles in waste collection, reduction, and management to build a sustainable circular economy. In the framework to achieving circular economy, adoption and implementation of economic policies, legal instruments, and digital technologies that minimize the use of virgin raw materials are crucial. Such interventions should encourage the use of recovered materials for optimal resource utilization and cost reduction. The implementation of policies that promote and support circular economy concept will ensure effective use of recovered resources, GHG emission reduction, and ensure the ZW approach for green environment is recommended.

The findings of this research will contribute to scholarship by enriching the quality of information available on waste management, conversion, and utilization. Researchers, environmentalists, manufacturers, materials developers, and policymakers will benefit from this research and use the information therein as a springboard for more investigations. Going forward, more targeted research is needed on the use of appropriate technologies and techniques to achieve ZW for effective environmental sustainability, cost-effective resource recovery, and accelerated industrial development. Additionally, concerted efforts aimed at developing novel technologies for eco-friendly waste collection, conversion, and utilization should be commissioned.

Author Contributions: Conceptualization, O.A., D.V.V.K. and K.A.B.; methodology, O.A., D.V.V.K. and K.A.B.; software, O.A., D.V.V.K. and K.A.B.; investigation, O.A., D.V.V.K. and K.A.B.; resources, O.A. and D.V.V.K.; writing—original draft preparation, O.A. and K.A.B.; writing—review and editing, O.A., D.V.V.K. and K.A.B.; supervision, project administration, O.A. and D.V.V.K.; funding acquisition, D.V.V.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. The Article Publishing Charges was paid for by the University of Johannesburg Library.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The authors acknowledge and appreciate the support received from the Faculty of Engineering and Built Environment, University of Johannesburg, South Africa.

Conflicts of Interest: The authors declare no conflict of interest.

References
1. Trends in Solid Waste Management. Available online: https://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html (accessed on 10 January 2022).
2. Canada Produces the Most Waste in the World. The US Ranks Third. Available online: https://www.usatoday.com/story/money/2019/07/12/canada-united-states-worlds-biggest-producers-of-waste/39534923/ (accessed on 10 January 2022).
3. Awogbemi, O.; Kallon, D.V.V.; Aigbodion, V.S. Trends in the development and utilization of agricultural wastes as heterogeneous catalyst for biodiesel production. J. Energy Inst. 2021, 98, 244–258. [CrossRef]
4. Awogbemi, O.; Kallon, D.V.V.; Aigbodion, V.S.; Mzozoyana, V. Property Determination, FA Composition and NMR Characterization of Palm Oil, Used Palm Oil and Their Methyl Esters. Processes 2022, 10, 11. [CrossRef]
5. Awogbemi, O.; Kallon, D.V.V.; Aigbodion, V.S.; Panda, S. Advances in biotechnological applications of waste cooking oil. Case Stud. Therm. Eng. 2021, 4, 100158. [CrossRef]
6. Shammas, N.K.; Wang, L.K. Treatment of Nonferrous Metal Manufacturing Wastes. In Waste Treatment in the Metal Manufacturing, Forming, Coating, and Finishing Industries; Wang, K., Nazih, K., Shammas, Y., Hung, T., Eds.; Lawrence CRC: Boca Raton, FL, USA, 2016; pp. 72–148.

7. Singh, S.; Ramakrishna, S.; Hussain, C.M. The realm of zero waste technology: The evolution. In Concepts of Advanced Zero Waste Tools; Hussain, C.M., Ed.; Elsevier: Amsterdam, The Netherlands, 2021; pp. 1–21. [CrossRef]

8. Zero Waste International Alliance. Available online: https://zwia.org/ (accessed on 10 January 2022).

9. Awogbemi, O.; Kallon, D.V.V.; Onuh, E.I.; Aigbodion, V.S. An overview of the classification, production and utilization of biofuels for internal combustion engine applications. Energies 2021, 14, 5687. [CrossRef]

10. Singh, S.; Ramakrishna, S.; Gupta, M.K. Towards zero waste manufacturing: A multidisciplinary review. J. Clean. Prod. 2017, 168, 1230–1243. [CrossRef]

11. Kerdlap, P.; Low, J.S.C.; Ramakrishna, S. Zero waste manufacturing: A framework and review of technology, research, and implementation barriers for enabling a circular economy transition in Singapore. Resour. Conserv. Recycl. 2019, 115, 104438. [CrossRef]

12. Singh, S.; Hussain, C.M. Zero waste manufacturing. In Concepts of Advanced Zero Waste Tools; Hussain, C.M., Ed.; Elsevier: Amsterdam, The Netherlands, 2021; pp. 45–67. [CrossRef]

13. Ahuett-Garza, H.; Kurfess, T. A brief discussion on the trends of habilitating technologies for Industry 4.0 and Smart manufacturing. Manuf. Lett. 2018, 15, 60–63. [CrossRef]

14. Frank, A.G.; Dalenogare, L.S.; Ayala, N.F. Industry 4.0 technologies: Implementation patterns in manufacturing companies. Int. J. Prod. Econ. 2019, 210, 15–26. [CrossRef]

15. Awogbemi, O.; Kallon, D.V.V. Impact of Fourth Industrial Revolution on waste biomass conversion techniques. In The Proceedings of the SAIIE32 Steps, Muldersdrift South, Africa, 4–6 October 2021; pp. 352–365.

16. Lu, Y. Industry 4.0: A survey on technologies, applications and open research issues. J. Ind. Inf. Integr. 2017, 6, 1–10. [CrossRef]

17. Wang, S.; Wan, J.; Zhang, D.; Li, D.; Zhang, C. Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination. Comput. Netw. 2016, 101, 158–168. [CrossRef]

18. Dolci, R. IoT solutions for precision farming and food manufacturing: Artificial intelligence applications in digital food. In Proceedings of the 2017 IEEE 41st Annual Computer Software and Applications Conference (COMPSAC), Turin, Italy, 4–8 July 2017; Volume 2, pp. 384–385.

19. Pimenov, D.Y.; Bustillo, A.; Mikolajczyk, T. Artificial intelligence for automatic prediction of required surface roughness by monitoring wear on face mill teeth. J. Intell. Manuf. 2018, 29, 1045–1061. [CrossRef]

20. Ramakrishna, S.; Khong, T.C.; Leong, T.K. Smart manufacturing. Procedia Manuf. 2017, 12, 128–131. [CrossRef]

21. Javaid, M.; Haleem, A.; Singh, R.P.; Suman, R. Substantial capabilities of robotics in enhancing industry 4.0 implementation. Cognit. Robot. 2021, 1, 58–75. [CrossRef]

22. Ji, W.; Wang, L. Industrial robotic machining: A review. Int. J. Adv. Manuf. Technol. 2019, 103, 1239–1255. [CrossRef]

23. Kim, S.H.; Nam, E.; Ha, T.I.; Hwang, S.H.; Lee, J.H.; Park, S.H.; Min, B.K. Robotic machining: A review of recent progress. Int. J. Precis. Eng. Manuf. 2019, 20, 1629–1642. [CrossRef]

24. Ur Rehman, M.H.; Yaqoob, I.; Salah, K.; Imran, M.; Jayaraman, P.P.; Perera, C. The role of big data analytics in industrial Internet of Things. Future Gener. Comput. Syst. 2019, 99, 247–259. [CrossRef]

25. Ren, S.; Zhang, Y.; Liu, Y.; Sakao, T.; Huisingsh, D.; Almeida, C.M.V.B. A comprehensive review of big data analytics throughout product lifecycle to support sustainable smart manufacturing: A framework, challenges and future research directions. J. Clean. Prod. 2019, 210, 1343–1365. [CrossRef]

26. Askary, Z.; Kumar, R. Cloud Computing in Industries: A Review. In Recent Advances in Mechanical Engineering; Kumar, H., Jain, P., Eds.; Springer: Singapore, 2020; pp. 107–116. [CrossRef]

27. Wan, C.; Zheng, H.; Guo, L.; Xu, X.; Zhong, R.Y.; Yan, F. Cloud manufacturing in China: A review. Int. J. Comput. Integr. Manuf. 2020, 33, 229–251. [CrossRef]

28. Siderska, J.; Jadaan, K.S. Cloud manufacturing: A service-oriented manufacturing paradigm. A review paper. Eng. Manag. Prod. Serv. 2018, 10, 22–31. [CrossRef]

29. Ooi, K.B.; Lee, V.H.; Tan, G.W.H.; Hew, T.S.; Hew, J.J. Cloud computing in manufacturing: The next industrial revolution in Malaysia? Expert Syst. Appl. 2018, 93, 376–394. [CrossRef]

30. Fisher, O.; Watson, N.; Porcu, L.; Bacon, D.; Rigley, M.; Gomes, R.L. Cloud manufacturing as a sustainable process manufacturing route. J. Manuf. Syst. 2018, 47, 53–68. [CrossRef]

31. Chen, F.; Luo, Z.; Yang, Y.; Liu, G.J.; Ma, J. Enhancing municipal solid waste recycling through reorganizing waste pickers: A case study in Nanjing, China. Waste Manag. Res. 2018, 36, 767–778. [CrossRef]

32. Nodhehi, M.; Taghvaei, V.M. Sustainable concrete for circular economy: A review on use of waste glass. Glass Struct. Eng. 2021, 1–20. [CrossRef]

33. Mallum, I.; Sam, A.R.M.; Lim, N.H.A.S.; Omolayo, N. Sustainable Utilization of Waste Glass in Concrete: A Review. Silicon 2021, 1–16. [CrossRef]

34. Johari, A.; Sharma, K. Use of Crushed Waste Glass (CWG) for Partial Replacement of Fine Aggregate in Concrete Production: A Review. In Advances in Geotechnics and Structural Engineering; Kumar-Shukla, S., Raman, S.N., Bhattacharjee, B., Bhattacharjee, J., Eds.; Lecture Notes in Civil Engineering; Springer: Singapore, 2021; Volume 143, pp. 399–410. [CrossRef]
35. Tamanna, N.; Tuladhar, R.; Sivakugan, N. Performance of recycled waste glass sand as partial replacement of sand in concrete. Constr. Build. Mater. 2020, 239, 117804. [CrossRef]

36. Lu, J.X.; Zhou, Y.; He, P.; Wang, S.; Shen, P.; Poon, C.S. Sustainable reuse of waste glass and incinerated sewage sludge ash in insulating building products: Functional and durability assessment. J. Clean. Prod. 2019, 236, 117635. [CrossRef]

37. Lu, J.X.; Duan, Z.H.; Poon, C.S. Combined use of waste glass powder and cullet in architectural mortar. Cem. Concr. Compos. 2017, 82, 34–44. [CrossRef]

38. Keawthun, M.; Krachodnok, S.; Chaisena, A. Conversion of waste glasses into sodium silicate solutions. Int. J. Chem. Sci. 2014, 12, 83–91.

39. Lee, S.S.; Park, C.M. Facile conversion of waste glass into Li storage materials. Green Chem. 2019, 21, 1439–1447. [CrossRef]

40. Rivera, J.F.; Cuárran-Cuárran, Z.I.; Vanegas-Bonilla, N.; Mejía de Gutiérrez, R. Novel use of waste glass powder: Production of geopolymeric tiles. Adv. Powder Technol. 2018, 29, 3448–3454. [CrossRef]

41. Phanisankar, B.S.S.; Vasudeva Rao, N.; Manikanta, J.E. Conversion of waste plastic to fuel products. Mater. Today Proc. 2020, 33, 5190–5195. [CrossRef]

42. Huo, E.; Lei, H.; Liu, C.; Zhang, Y.; Xin, L.; Zhao, Y.; Qian, M.; Zhang, Q.; Lin, X.; Wang, C.; et al. Jet fuel and hydrogen produced from waste plastics catalytic pyrolysis with activated carbon and MgO. Sci. Total Environ. 2020, 727, 138411. [CrossRef]

43. Olufemi, A.; Olagboye, S. Thermal conversion of waste plastics into fuel oil. J. Petrochem. Sci. Eng. 2017, 2, 252–257. [CrossRef]

44. Yeung, C.W.S.; Loh, W.W.; Lau, H.H.; Loh, X.J.; Lim, J.Y.C. Catalysts developed from waste plastics: A versatile system for biomass conversion. Mater. Today Chem. 2020, 21, 100524. [CrossRef]

45. De Assis, G.C.; Skovroinski, E.B.; Lette, V.D.; Rodrigues, M.O.; Galembeck, A.; Alves, M.C.; Eastoe, J.; De Oliveira, R.J. Conversion of “Waste Plastic” into photocatalytic nanofoams for environmental remediation. ACS Appl. Mater. Interfaces 2018, 10, 8077–8085. [CrossRef]

46. Ahmad, N.; Maafa, I.M.; Ahmed, U.; Akhter, P.; Shehzad, N.; Amjad, U.; Hussain, M. Thermal conversion of polystyrene plastic waste to liquid fuel via ethanolysis. Fuel 2020, 279, 118498. [CrossRef]

47. Vidalles-Barriguete, A.; Santa-Cruz-Astorqui, J.; Piña-Ramírez, C.; Kosior-Kazberuk, M.; Kalinowska-Wichrowska, K.; Atanes-Sánchez, E. Study of the mechanical and physical behavior of gypsum boards with plastic cable waste aggregates and their application to construction panels. Materials 2021, 14, 2255. [CrossRef]

48. Hu, Y.; Attia, M.; Isabet, A.; Mohaddespour, A.; Munir, M.T.; Farag, S. Valorization of waste tire by pyrolysis and hydrothermal liquefaction: A mini-review. J. Mater. Cycles Waste Manag. 2021, 23, 1737–1750. [CrossRef]

49. Martínez, J.D. An overview of the end-of-life tires status in some Latin American countries: Proposing pyrolysis for a circular economy. Renew. Sustain. Energy Rev. 2021, 144, 110932. [CrossRef]

50. Global Market for the Tire and Rubber Remediation and Recycling Industry. Available online: https://www.bccresearch.com/market-research/advanced-materials/ (accessed on 13 January 2022).

51. Global Tire Recycling Downstream Products Market Outlook (2019 to 2027). Available online: https://www.prnewswire.com/news-releases/global-tire-recycling-downstream-products-market-outlook-2019-to-2027 (accessed on 15 January 2022).

52. Sathiskumar, C.; Karthikeyan, S. Recycling of waste tires and its energy storage application of by-products—A review. Sustain. Mater. Technol. 2019, 22, e0125. [CrossRef]

53. Formela, K. Sustainable development of waste tires recycling technologies—Recent advances, challenges and future trends. Adv. Ind. Eng. Polym. Res. 2021, 4, 209–222. [CrossRef]

54. Karthikeyan, S.; Prathima, A.; Periyasamy, M.; Mahendran, G. Assessment of the use of Codium Decorticafum [Green seaweed] biodiesel and pyrolytic waste tires oil blends in CI engine. Mater. Today Proc. 2020, 33, 4224–4227. [CrossRef]

55. Subramanian, A.S.; Gundersen, T.; Adams, T.A., II. Technoeconomic analysis of a waste tire to liquefied synthetic natural gas (SNG) energy system. Energy 2020, 205, 117830. [CrossRef]

56. Shahrokhi-Shahraki, R.; Kwon, P.S.; Park, J.; O’Kelly, B.C.; Rezania, S. BTEX and heavy metals removal using pulverized waste tires in engineered fill materials. Chemosphere 2020, 242, 125281. [CrossRef]

57. Chen, C.; Sun, M.; Wang, B.; Zhou, J.; Jiang, Z. Recent Advances on Drawing Technology of Ultra-Fine Steel Tire Cord and Steel Saw Wire. Metals 2021, 11, 1590. [CrossRef]

58. Gómez-Hernández, R.; Panecatl-Bernal, Y.; Méndez-Rojas, M.A. High yield and simple one-step production of carbon black nanoparticles from waste tires. Helilogy 2019, 5, e02139. [CrossRef]

59. Svoboda, J.; Vaclavik, V.; Dvorsky, T.; Klus, L.; Zajac, R. The potential utilization of the rubber material after waste tire recycling. IOP Conf. Ser. Mater. Sci. Eng. 2018, 385, 012057. [CrossRef]

60. Global Paper Industry—Statistics & Facts. Available online: https://www.statista.com/topics/1701/paper-industry/#dossierKeyfigures (accessed on 18 January 2022).

61. Paper Consumption Worldwide from 2020 to 2030. Available online: https://www.statista.com/statistics/1089078/demand-paper-globally-until-2030/ (accessed on 18 January 2022).
64. Global Paper Recycling Market Report. 2020. Available online: https://www.globenewswire.com/fr/news-release/2021/02/02/2167874/28124/en/Global-Paper-Recycling-Market-Report-2020 (accessed on 18 January 2022).

65. Al-Azkawi, A.; Elliotson, A.; Al-Bahry, S.; Sivakumar, N. Waste paper to bioethanol: Current and future prospective. Biofuel Bioprod. Biorefin. 2019, 13, 1106–1118. [CrossRef]

66. Hietala, M.; Varrio, K.; Berglund, L.; Soini, J.; Oksman, K. Potential of municipal solid waste paper as raw material for production of cellulose nanofibers. Waste Manag. 2018, 80, 319–326. [CrossRef]

67. Adolfsson, K.H.; Hassanazadeh, S.; Hakkarainen, M. Valorization of cellulose and waste paper to graphene oxide quantum dots. RSC Adv. 2015, 5, 26550–26558. [CrossRef]

68. Liu, J.; Wang, X. A new method to prepare adsorbent utilizing waste paper and its application for oil spill clean-ups. BioResources 2019, 14, 3886–3898. [CrossRef]

69. Adolfsson, K.H.; Hassanzadeh, S.;切换to sustainability. J. Clean. Prod. 2020, 271, 11240–11256. [CrossRef]

70. Singh, Z.; Bhalla, S. Toxicity of synthetic fibres and health. Adv. Res. Test. Eng. 2017, 2, 1012.

71. Ekpunobi, U.; Ohaekenyem, E.; Ogbuagu, A.; Ojiako, E. The mechanical properties of ceiling board produced from waste paper. Br. J. Appl. Sci. Technol. 2015, 5, 166. [CrossRef]

72. The Global Metal Recycling Market. Available online: https://global-recycling.info/archives/4094 (accessed on 20 January 2022).

73. Liu, J.; Wang, X. A new method to prepare adsorbent utilizing waste paper and its application for oil spill clean-ups. BioResources 2019, 14, 3886–3898. [CrossRef]

74. Huang, J.; Dai, H.; Yan, R.; Wang, P. Butyric acid production from recycled waste paper by immobilized Clostridium tyrobutyricum in a fibrous-bed bioreactor. J. Chem. Technol. Biotechnol. 2016, 91, 1048–1054. [CrossRef]

75. Liam, T.; Pan, D.; Wang, W.; Wu, Y.; Zuo, T. Overview of the recycling technology for copper-containing cables. J. Clean. Prod. 2020, 271, 11240–11256. [CrossRef]

76. El Messiry, M.; Ayman, Y. Investigation of sound transmission loss of natural fiber/rubber crumbs composite panels. J. Ind. Text. 2021, 1–6. [CrossRef]

77. Zeeshan, A.; Liu, H.; Zhang, L.; He, Y.; Cao, H.; Liu, S.; Zheng, X.; Zhu, Z.; Lin, X.; Zhang, Y.; He, Y.; Cao, H.; Sun, Z. A Review on Metal Recycling from Spent Lithium Ion Batteries. J. Clean. Prod. 2019, 254, 120078. [CrossRef]

78. Roy, M.; Sen, P.; Pal, P. An integrated green management model to improve environmental performance of textile industry towards sustainability. J. Clean. Prod. 2020, 271, 122656. [CrossRef]

79. Li, L.; Liu, G.; Pan, D.; Wang, W.; Wu, Y.; Zuo, T. Overview of the recycling technology for copper-containing cables. Resour. Conserv. Recyl. 2017, 126, 132–140. [CrossRef]

80. Vadivel, R.; Nirmala, M.; Raji, K.; Siddaiah, B.; Ramamurthy, P. Synthesis of highly luminescent carbon dots from postconsumer waste silk cloth and investigation of its electron transfer dynamics with methyl viologen dichloride. J. Indian Chem. Soc. 2021, 98, 100181. [CrossRef]

81. Niinimäki, K.; Peters, G.; Dahlbo, H.; Perry, P.; Rissanen, T.; Gwilt, A. The environmental price of fast fashion. Nat. Rev. Earth Environ. 2020, 1, 189–200. [CrossRef]

82. Pacelli, F.; Ostuzzi, F.; Levi, M. Reducing and reusing industrial scraps: A proposed method for industrial designers. J. Clean. Prod. 2015, 86, 78–87. [CrossRef]

83. Yaashikaa, P.R.; Priyanka, B.; Senthil Kumar, P.; Karishma, S.; Jeevanantham, S.; Indraganti, S. A review on recent advancements in recovery of valuable and toxic metals from e-waste using bioleaching approach. Chemosphere 2022, 287, 132230. [CrossRef]

84. Joshi, G.; Naithani, S.; Varshney, V.K.; Bisht, S.S.; Rana, V.; Gupta, P.K. Synthesis and characterization of carboxymethyl cellulose in a fibrous-bed bioreactor. J. Chem. Technol. Biotechnol. 2015, 90, 106182. [CrossRef]

85. Leal Filho, W.; Ellams, D.; Han, S.; Tyler, D.; Boiten, V.J.; Paço, A.; Mooora, H.; Balogun, A. A review of the socio-economic advantages of textile recycling. J. Clean. Prod. 2019, 218, 10–20. [CrossRef]

86. Yousef, S.; Tatarians, M.; Tichonovas, M.; Klucininkas, L.; Lukošiūtė, S.I.; Yan, L. Sustainable green technology for recovery of carbon fibers and polyester from textile waste. J. Clean. Prod. 2020, 254, 120078. [CrossRef]
93. Sauid, S.M.; Kamarudin, S.K.; Karim, N.A.; Shyuan, L.K. Superior stability and methanol tolerance of a metal-free nitrogen-doped hierarchical porous carbon electrocatalyst derived from textile waste. *J. Mater. Res. Technol.* 2021, 11, 1834–1846. [CrossRef]

94. Thisani, S.K.; Kallon, D.V.V.; Byrne, P. Geochemical Classification of Global Mine Water Drainage. *Sustainability* 2020, 12, 10244. [CrossRef]

95. Jones, E.R.; van Vliet, M.T.; Qadir, M.; Bierkens, M.F. Country-level and gridded estimates of wastewater production, collection, treatment and reuse. *Earth Syst. Sci. Data* 2021, 13, 237–254. [CrossRef]

96. Garg, S.; Chowdhury, Z.Z.; Faisal, A.N.M.; Rumjit, N.P.; Thomas, P. Impact of Industrial Wastewater on Environment and Human Health. In *Advanced Industrial Wastewater Treatment and Reclamation of Water*; Roy, S., Garg, A., Garg, S., Tran, T.A., Eds.; Springer: Cham, Switzerland, 2022; pp. 197–209. [CrossRef]

97. Pratap, B.; Kumar, S.; Purchase, D.; Bharagava, R.N.; Dutta, V. Practice of wastewater irrigation and its impacts on human health and environment: A state of the art. *Int. J. Environ. Sci. Technol.* 2021, 1–16. [CrossRef]

98. Enaime, G.; Baçaoui, A.; Yaacoubi, A.; Lübken, M. Biochar for wastewater treatment—Conversion technologies and applications. *Appl. Sci.* 2020, 10, 3492. [CrossRef]

99. Jaspal, D.; Malviya, A. Composites for wastewater purification: A review. *Chemosphere* 2020, 246, 125788. [CrossRef] [PubMed]

100. Dimoglo, A.; Sevim-Elibol, P.; Dinç, Ö.; Gökmen, K.; Erdoğan, H. Electrocoagulation/electroflostation as a combined process for the laundry wastewater purification and reuse. *J. Water Process Eng.* 2019, 31, 100877. [CrossRef]

101. Li, N.; Lu, X.; He, M.; Duan, X.; Yan, B.; Chen, G.; Wang, S. Catalytic membrane-based oxidation-filtration systems for organic wastewater purification: A review. *J. Hazard. Mater.* 2021, 414, 125478. [CrossRef]

102. Ang, W.L.; Mohammad, A.W. State of the art and sustainability of natural coagulants in water and wastewater treatment. *J. Clean. Prod.* 2020, 262, 121267. [CrossRef]

103. Zaman, A. Zero-Waste: A New Sustainability Paradigm for Addressing the Global Waste Problem. In *The Vision Zero Handbook: Theory, Technology and Management for a Zero Casualty Policy*; Björnberg, K.E., Matts-Åke, B., Hansson, S.O., Tingvall, C., Eds.; Springer: Singapore, 2022; pp. 1–24. [CrossRef]

104. Zaman, A.U.; Lehmann, S. Challenges and opportunities in transforming a city into a “zero waste city”. *Challenges* 2011, 2, 73–93. [CrossRef]

105. Gaur, A.; Gurjar, S.K.; Chaudhary, S. Circular system of resource recovery and reverse logistics approach: Key to zero waste and zero landfill. In *Advanced Organic Waste Management*; Hussain, C., Hait, S., Eds.; Elsevier: Amsterdam, The Netherlands, 2022; pp. 365–381. [CrossRef]

106. Zhao, R.; Sun, L.; Zou, X.; Fuji, M.; Dong, L.; Dou, Y.; Geng, Y.; Wang, F. Towards a Zero Waste city—an analysis from the perspective of energy recovery and landfill reduction in Beijing. *Energy* 2021, 223, 120055. [CrossRef]

107. Demets, R.; Roosen, M.; Vandermeersch, L.; Ragaert, K.; Walgraevve, C.; De Meester, S. Development and application of an analytical method to quantify odour removal in plastic waste recycling processes. *Resour. Conserv. Recycl.* 2020, 161, 104907. [CrossRef]

108. Lee, R.P.; Meyer, B.; Huang, Q.; Voss, R. Sustainable waste management for zero waste cities in China: Potential, challenges and opportunities. *Clean Energy* 2020, 4, 169–201. [CrossRef]

109. Kurniawan, T.A.; Avtar, R.; Singh, D.; Xue, W.; Dzfaran Othman, M.H.; Hwang, G.H.; Iswanto, I.; Albadarin, A.B.; Kern, A.O. Reforming MSWM in Sukunan (Yogyakarta, Indonesia): A case-study of applying a zero-waste approach based on circular economy paradigm. *J. Clean. Prod.* 2021, 284, 124775. [CrossRef]

110. Gu, B.; Tang, X.; Liu, L.; Li, Y.; Fujiwara, T.; Sun, H.; Gu, A.; Yao, Y.; Duan, R.; Song, J.; et al. The recyclable waste recycling potential towards zero waste cities—A comparison of three cities in China. *J. Clean. Prod.* 2021, 295, 26358. [CrossRef]

111. Awasthi, A.K.; Cheela, V.R.S.; D’Adamo, I.; Iacovidou, E.; Islam, M.R.; Johnson, M.; Miller, T.R.; Parajuly, K.; Parchomenko, A.; Radhakrishnan, L.; et al. Zero waste approach towards a sustainable waste management. *Environ. Dev. Sustain.* 2021, 3, 00014. [CrossRef]

112. Rajadesingu, S.; Deepankara, V.; Dowlat, M.J.H.; Karuppannan, S.K.; Arunachalam, K.D. Modern society and zero waste tools. In *Concepts of Advanced Zero Waste Tools*; Hussain, C.M., Ed.; Elsevier: Amsterdam, The Netherlands, 2021; pp. 181–213.