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REVIEW PAPER

Urbanization and Benefit of Integration Circular Economy into Waste Management in Indonesia: A Review

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Abstract
Urbanization is a global problem but is more pronounced in developing countries. Population growth in developing countries is in line with population movement from rural to urban areas due to easy access to jobs, welfare, and the economy. Indirectly, urbanization will burden urban areas in various vital sectors and contribute directly to waste generation. Unscientific waste handling causes health hazards and urban environmental degradation. Solid Waste Management is a formidable task in Indonesia that will become more complicated with increasing urbanization, changing lifestyles, and increasing consumerism. Several current obstacles related to waste management have made the situation even worse. Current inappropriate waste disposal practices have created severe environmental and public health problems. The purpose of this paper is to critically review the impact of urbanization on waste generation, what is currently being done, and the benefit of integrating a circular economy into waste management to address the waste problem in Indonesia. This review provides an overview of urbanization trends, the projected increase in waste due to urbanization, solid waste status, and current waste management in Indonesia. An integration circular economy approach provides an overview of the benefits of implementing this approach in five crucial sectors in Indonesia. The circular economy approach is expected to be one of the future solutions to the problem of waste management in Indonesia.

Keywords Urbanization · Circular economy · Waste management · Benefit · Impact

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Introduction

The rise of development in big cities in Indonesia can spur economic growth. As a result, these cities will become magnets for residents looking for work and a place to live, often referred to as urbanization. Urbanization and waste management problems are two essential aspects closely related to sustainable development goals. The phenomenon is characterized by population concentration in urban areas, followed by urbanization's modernization of other aspects of life [94]. Indonesia continued to experience an increase in the proportion of the urban population from 30.9% in 1990 to 43.1% in 2005 and sharply to 53.12% in 2015 [12]. United Nations Habitat [83] states that in Indonesia, 65% of urban population growth is due to migration and reclassification, while around 35% is due to the natural growth of the urban population.

This excessive urbanization has caused various problems in Indonesia. Not only causing trouble in the destination city but also causing trouble in the abandoned village. One of the problems due to urbanization is the significant increase in urban solid waste in Indonesia [89]. In addition, the increase in people's purchasing power for various types of basic materials and technological products also contributes significantly to the quantity and quality of the waste produced [25]. The types of basic materials and technology products typically consist of kitchen waste, yard waste, paper and cardboard, plastics and rubber, metals, glass, e-waste, inert materials, and miscellaneous waste [58]. Kitchen waste and yard waste together comprise the organic fraction of solid waste [15]. Among all waste components the most heterogeneous include textiles, fabrics, biomedical waste (e.g. sharps and glass), personal hygiene products, health care items, cosmetics, pharmaceuticals, pet waste, leather, rubber, and polymer residues. Solid waste has shown a positive correlation with urbanization on a global scale [5]. The solid waste generated globally in 1997 was about 0.49 billion tonnes, with an estimated annual growth rate of 3.2–4.5% in developed countries and 2–3% in developing countries [38]. Research conducted in the developing city of Limpopo Province, South Africa, shows that the waste in this city is increasing by 30% every year [61]. Waste management in Beijing, China, shows that economic development and population growth have increased waste generation from 2.96 million tons in 2000 to 6.20 million tons in 2007, fluctuating to 6.35 million tons in 2010 [88].

It should be emphasized that this topic has not been discussed in-depth in the literature review, particularly in Indonesia. However, issues related to waste use are becoming increasingly crucial as urbanization increases. The purpose of this paper is to critically review the impact of urbanization on waste generation, what is currently being done, and the benefit of integrating a circular economy into waste management to address the waste problem in Indonesia. This review provides an overview of urbanization trends, the projected increase in waste due to urbanization, solid waste status, and current waste management in Indonesia. An integration circular economy approach provides an overview benefits of implementing this approach in five crucial sectors in Indonesia.

Urbanization in Indonesia

Urbanization is a symptom of a multi-sectoral process in nature, seen from the causes and consequences it causes [13]. Urbanization is also complex, including social, economic, political, and geographical factors [81]. There are important things to note about the difference between urbanization and urban growth related to the concept of urbanization.

Urban growth is one mechanism to see urbanization through the natural growth of the urban population. Urban growth can be seen by comparing the number of urban residents from time to time. In contrast, urbanization is seen by comparing the relative number of urban residents with the total population from time to time [19]. Three things make up urbanization: increased natural population, rural–urban migration, and reclassification [50]. Uncontrolled population growth will cause various problems and obstacles to efforts made, because high population growth will cause a rapid increase in the number of workers, while the ability of the region to create new job opportunities is very limited [73]. In relation to rural–urban migration, the relationship is usually found that when urban and rural inequality is sharpened, the attractiveness of the city will be stronger, which in turn will result in increased in-migration to the city [76]. The increase in urban population is not only due to in-migrants and births in cities but also due to the number of villages that are classified as urban because they can qualify based on criteria that change every year in classifying rural and urban areas [91].

As in most developing countries in Asia, urbanization in Indonesia is triggered by economic development, especially in the industrial and service sectors, which tend to be located in big cities. This development is due to the availability of utilities such as water, electricity, ports and airports, and places of concentration of skilled labor and markets. Urbanization and economic development in most of Indonesia are driven by domestic and foreign investment in large urban areas. In 1950, only Jakarta City had over one million people. Thirty years later, in 1980, there were three new cities with over one million population: Surabaya, Bandung, and Medan.

Furthermore, in 1990, Semarang, Palembang, and Makassar had over one million people. And in 2010, the number of cities with a population of more than one million people became eleven with the addition of Bekasi, Tangerang, Depok, and South Tangerang cities. The latter cities have developed due to the mega-urbanization process of Jakarta, forming the megacities of Jabodetabek (Jakarta, Bogor, Depok, Tangerang, and Bekasi), where Jakarta's urban activities have overflowed to its periphery. Urban physical development extends beyond the city and urban boundaries, spreading along the main roads and spreading randomly in all directions [69]. Urbanization that occurs in Indonesia is triggered by various factors both in the form of push factors which include poverty, lack of facilities in rural areas, low living standards, and limited employment opportunities, as well as pull factors which include adequate city facilities and high living standards [48]. Both the push and pull factors of urbanization are related to factors triggered by natural processes, migration, economic conditions, socio-economic facilities, infrastructure, accessibility, industry, and government policies [29]. Improved quality and quality in various aspects can trigger urbanization.

The trend of urbanization is predicted to continue to increase from year to year (Table 1). Various factors can cause the increasing trend of urbanization; academics have outlined several factors that lead to urbanization. For example, Jiang and Oneill [36] reveal that urbanization and urban growth are caused by various reasons related to rural–urban migration, natural population increase, and incorporation. Furthermore, Turok and McGranahan [81] explained that the growth of a metropolitan area depends on its economic structure, human resources, quality of life factors, historical trends, and location. Furthermore, urbanization is also integral to the three pillars of sustainable development: economic development, social development, and environmental protection [51].

The expansion of urban development, including industrial and non-industrial drivers, is driving change in peri-urban areas. In defining the drivers of urbanization, two forces must be considered: centripetal (internal driving) and centrifugal (external driving) forces in an urban expansion [70]. Centrifugal forces in middle-income countries include manufacturing

Table 1 Urbanization trend projection in Indonesia

Year	Population in million			% of total population		% increase in urban population
	Total	Urban	Rural	Urban	Rural	
2010	238,5	118,7	119,8	49,8	50,2	–
2015	255,4	136,1	119,3	53,3	46,7	3,5
2020	271	153,6	117,4	56,7	43,3	3,4
2025	284	170,4	113,6	60	40	3,3
2030	296,4	187,9	108,5	63,4	36,6	3,4
2035	305,6	203,5	102,1	66,6	33,4	3,3

Source: [11, 12]

investment, the rapid development of expressways, and urban land markets, where urban land prices are lower in the suburbs. Cultural preferences also play a role in the sense that high-income people expect to live in the suburbs, as is found in North America and Australia, despite housing offerings close to the core city. In comparison, centripetal forces may be related to the economic structure that drives urbanization. Include specific sectors, such as services that tend to be concentrated in particular areas. However, cultural factors and choice limitations can also play a role, similarly to centrifugal forces. Shin and Kim [72] found that speculative activity can also be considered a factor in urban change.

Solid Waste Status in Indonesia

Waste generation in Indonesia continues to increase from year to year in line with population growth and urbanization. In metro and big cities, waste generation is estimated to reach > 500 tons/day on average, while in medium cities with a population of < 500 people/ha, the middle waste generation is 100–300 tons/day [11]. The composition of Indonesia's waste is organic waste (food waste, wood branches, and leaves) at 57%, plastic waste at 16%, paper waste at 10%, and others (metal, textiles, leather rubber, and glass) at 17% [77]. The average percentage of waste processed by composting for cities in Indonesia by means of 16.2%, about 11 million tons/year [55]. Improvements do not match this increasing waste generation in waste management infrastructure and efforts to reduce waste at the source (application of the 3R concept: reduce, reuse, and recycle). The quality of service is still limited (regarding costs, human resources, facilities, infrastructure, and community participation). From an institutional perspective, the roles of operators and regulators are unclear. Landfill as a place for the final waste processing often gets public protest and rejection. As a result, environmental quality is decreased, especially in urban areas.

The volume of waste increases from year to year due to population growth, technological improvement, and socio-economic activities of the community, as illustrated in Table 2 regarding the projected increase in waste based on population [1]. The same opinion was expressed by Liu et al. [45],the growth of the volume of waste is closely related to the rapid increase in population from rural to urban areas. In addition, landfill is still the primary choice in waste management in Indonesia. Most waste is directly transported and disposed of in landfills without pre-treatment; only about 10% of the waste is used [55].

Table 2 Projected increase in waste volume based on total population

Year	Projected total population in million	Waste generation projection (liter/day)	Waste generation projection (m^3/day)	Waste generation projection (m^3/year)
2010	238,5	150.255.000	150.255	54.832.125
2015	255,4	160.902.000	160.902	58.729.230
2020	271	170.730.000	170.730	62.316.450
2025	284	178.920.000	178.920	65.305.800
2030	296,4	186.732.000	186.732	68.157.180
2035	305,6	192.528.000	192.528	70.272.720

Source: [11, 12]

The rapid population growth in urban areas has increased the amount of waste generation. From studies and evaluations that have been carried out in cities in Indonesia, it can be identified the main problems in the management of municipal solid waste, including [17]:

a. Urban population growth provides a logical consequence of the increasing complexity of the solid waste problem.
b. Increasing population density demands better methods/patterns of waste management.
c. The heterogeneity of the urban population's socio-cultural level adds to the problem's complexity.
d. The situation of funds and the relatively low priority of handling from local governments is a common problem on a national scale.
e. There are shifting food handling techniques, including the use of non-biodegradable materials like plastic for packaging.
f. Limited appropriate human resources are available to deal with the waste problem.
g. Progress in the design of waste equipment has been slow.
h. Community participation, in general, is still not well-directed and well-organized.
i. The waste management concept is sometimes unsuitable to be applied, and the possibility of modifying the idea is not open in the field.

Until now, the paradigm of waste management used is collect-transport and throw away. In contrast, the main mainstay of a city in solving waste problems is landfilling. The government tends to pay less serious attention to landfills, so there are cases of landfill failure. The government seems to think that its landfills can solve all waste problems without paying proportional attention to these facilities; landfills can be a time bomb for the government. Landfill operations in Indonesia are mostly still in an open dumping system. Clause 44 of Law Number 18 of 2008 concerning Waste Management mandates that no later than 2013, every regional/city government will have a representative landfill that meets technical and environmental principles (sanitary landfill).

In the early 1990s, the Indonesian Ministry of Public Works introduced the transition method using a controlled landfill system, especially for small and medium-sized cities, by delaying the closing time to 5 to 7 days. However, most waste managers in districts/cities still consider this method expensive. A landfill that has been designed and prepared as a sanitary landfill will quickly turn into open dumping if the landfill manager does not consistently apply the applicable regulations. In addition, another challenge faced in developing a solid waste management system in Indonesia is the low level of access to dependable

waste services. There is still a gap in waste services between the SDGs targets in 2015, 70%, with the existing achievement of 56.2%.

According to data [55], access to solid waste services in Indonesia at the national level reaches 86.73% (this value includes total waste management: fulfilling and not fulfilling). Table 3 shows the achievement of access to waste management in Indonesia, consisting of rural, urban, and national accomplishments. In addition to the low coverage of waste services in several cities, the Government of Indonesia is also still facing challenges, including the lack of facilities and infrastructure, the absence of a management agency that handles explicitly waste, the lack of budget allocations provided by the local government as a result of this sector not being become a priority in regional development, the behavior of people who have not implemented clean and hygienic living behavior, and weak law enforcement. Law Number 18 of 2008 concerning Waste Management mandates reducing and handling waste. It was reinforced by the Regulation of the Minister of Public Works Number 3 of 2013 concerning the Implementation of Facilities and Infrastructure for Handling Household Waste and Types of Household Waste which mandates sorting and storage from the source of the waste.

Based on the Medium-Term National Development Plan (RPJMN) 2015–2019, the Government of Indonesia has set a universal access target in the sanitation sector, namely increasing population access to proper sanitation (domestic wastewater, garbage, and environmental drainage) to 100% at the level of basic needs. In solid waste, the targets are reducing waste by 20–35% and transportation and final waste processing by 65–80%. In achieving the target of universal access, appropriate policies and strategies are needed by involving the active role of the community and development partners, including the private sector and donors from abroad, to obtain alternative sources of financing, in addition to those available from the Revenue Expenditure State Budget (APBN) funds.

Current Practices of Waste Management in Indonesia

Waste management in industrialized countries is often defined as control over the generation of waste, starting from the storage, collection, transfer, transportation, processing, and final disposal of waste, with the best principles for health, economy, engineering, conservation, aesthetics, environment, and also to the attitude of society [24]. The success of management does not only depend on technical aspects but also includes non-technical aspects, such as how to regulate the system so that it can function, how the institution or organization should manage it, how to finance the system, and last but not least how to involve the waste-producing community in handling the waste. A waste management system must involve various disciplines, such as urban planning, geography, economics, public health, sociology, demography, communication, conservation, and materials science [31]. Before Law Number 18 of 2008 was issued, urban waste management (issued by the Ministry of

Table 3 Achievements of access to waste handling in Indonesia

Access to waste handling achievements	2010	2013	2018
Rural	73.70%	72.60%	82.00%
Urban	87.40%	87.00%	91.43%
National	80.50%	79.80%	86.73%

Source: Ministry of Health of the Republic of Indonesia, 2018

Public Works) in Indonesia positioned that urban waste management was a system consisting of 5 subsystem components (Fig. 1), that is [2].

However, if you pay attention, this concept applies to the approach to solving the waste problem and to other sectors that are generally related to community services. Therefore, the five components are more accurately described as essential aspects that affect solid waste management.

Regulations/Laws

The regulatory aspect is based on the fact that Indonesia is a state of law where life joints rely on applicable laws. Municipal solid waste management in Indonesia requires strength and a legal basis, such as forming organizations, collecting levies, public order, and so on [66]. The regulations needed in the implementation of the waste management system in urban areas are those that regulate:

a. Public order related to waste handling
b. Waste management master plan for cities
c. Form of management institutions and organizations
d. Procedures for implementing management
e. The number of service fees or levies
f. Cooperation with various related parties

The legal umbrella related to waste management in Indonesia is Law Number 18 of 2008 concerning Waste Management. Furthermore, it is also elaborated in several Government Regulations and Ministerial Regulations such as the Minister of Public Works Regulation Number 3 of 2013 concerning the Implementation of Facilities and Infrastructure for Handling Household Waste and Waste Similar to Household Waste which mandates sorting from the source. Regional Regulations (Perda) on waste management are also already owned by several regions. However, the socialization of these regulations has not been carried out, so the

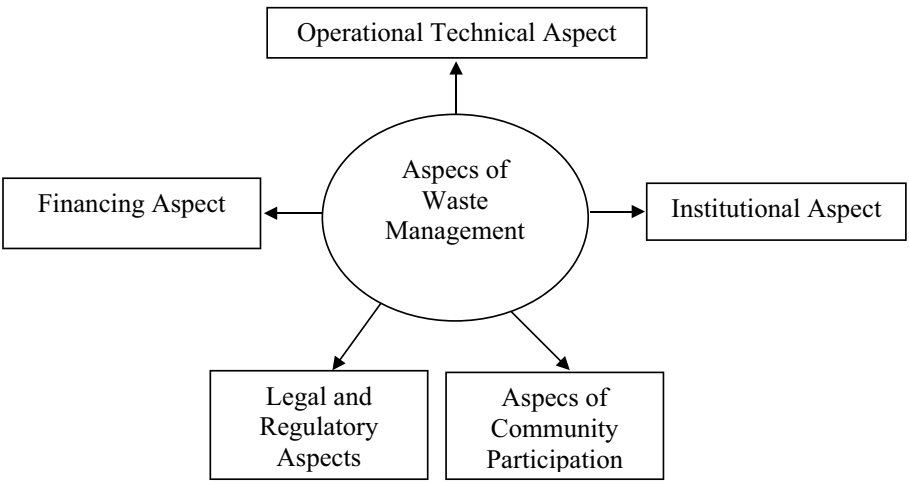

Fig. 1 Aspects of urban waste management

implementation of these regulations has not been optimal. For example, sanctions for violations and law enforcement that have been stipulated in the local regulations have not been fully implemented. Likewise, the things regulated by the Law on Waste Management have not all been implemented, such as the provisions on landfills with sanitary landfill systems or minimal control landfills and the implementation of consumer obligations to manage their waste or better known as Extended Producer Responsibility (EPR).

Institutions and Organizations

The aspect of organization and management is a multi-disciplinary activity based on technical and management principles concerning the economic, social, cultural, and physical conditions of the city area and pays attention to the parties served, namely the city community [78]. The design and selection of the organizational form are adjusted to the following:

a. Government regulations that foster it
b. The pattern of the operating system applied
c. Working capacity system
d. Scope of work and tasks to be handled

Waste management institutions in Indonesia are still multi-sectoral. At the central level, the Ministry of Environment and the Ministry of Public Works are the leading sectors in waste management, especially in preparing the required standards, norms, and regulations. Meanwhile, the waste management process in each region is the responsibility of the local government. Until now, there has been no institutional standardization related to waste management. Therefore, the institutional form of waste management in the district/city can be in the form of agencies, tribal agencies, sections, and even regional companies. In addition, there is no separation of functions between operators who carry out waste management activities and regulators who make policies and supervise their implementation.

The existing organizational structure is also not supported by adequate human resource capacity and capability. The process of transferring and changing the structure of positions in the local government often causes the transfer of human resources who are capable and have good knowledge in waste management. As a result, the waste management institution again loses qualified human resources. Likewise, unclear work procedures between administration and field implementers, and various authorities, be it waste transportation, retribution collection and budget allocation, make the implementation of waste management activities constrained. The lack of coordination and cooperation between waste sector agencies, as well as the inflexible form of the institution, also hampers the implementation of waste management in terms of budget allocation, budget utilization, and accountability.

Operational Technical

Based on the Indonesian National Standard (SNI) 19-2454-2002, the operational and technical procedures for urban waste management include the basics of planning for the following:

a. Service area
b. Service level
c. Operational technical, starting from waste container, waste collection, waste removal, waste transport, waste processing and sorting, and final disposal of waste

Sorting and recycling activities are carried out as much as possible from the collection to the final disposal of the waste. Waste generation in Indonesia continues to increase from year to year and is not proportional to the quality of waste management. Currently, the reference for waste management specifications is Indonesian National Standard (SNI) No. 19-2454-2002 concerning Waste Management Procedures in Settlements. This waste management operational technique is integral, integrated in a chain and sequential manner, namely, storage/containerization, collection, transfer, and transportation to disposal/processing.

Landfill operations if referring to Law Number 18 of 2008 in sanitary landfill have been implemented, but in reality, until now, only control landfill systems have been carried out in several regions, and most landfills in Indonesia are still operating in open dumping. The financing factor is the main obstacle in implementing sanitary landfill. Another obstacle is the limited land for landfills, so in some places, a regional landfill system is implemented.

Financing/Levies

As with other activities, the financing component of a municipal solid waste management system is ideally calculated based on the following:

a. Investment costs
b. Operation and maintenance costs
c. Management fee
d. Cost for development
e. Cost of counseling and community development.

The financing aspect is a driving resource so that the city's waste management system's wheels can move smoothly [93]. It is hoped that Indonesia's solid waste management system will lead to self-financing, including forming local companies. This financing sector involves several aspects, such as the following:

a. The proportion of Revenue Expenditure State Budget (APBN) or Revenue Expenditure Regional Budget (APBD) for waste management, retribution, and waste management costs
b. Cost for salaries, transportation, maintenance, education and development, and administration
c. The proportion between retribution and community income
d. Applicable levy structure and withdrawal

A waste levy is a concrete form of community participation in financing the waste management program. The structure of retribution is justified if the implementation is a formal body authorized by the government. A major obstacle to waste management in Indonesia is limited funding, including sources of funding for investment, operations, and maintenance of waste equipment and other facilities. In some regions, waste management has not been prioritized by the head of the region and the legislature so that the budget allocation for waste management is very minimal, which is mostly only <5% of the Revenue Expenditure Regional Budget (APBD).

Cooperation with the private sector both in the form of investment and Corporate Social Responsibility (CSR) has been carried out in several regions. For example, CSR from

several companies in the form of infrastructure assistance (waste bins, transportation equipment, and waste management training to the community). However, cooperation in the form of investment is still constrained by several things, such as private investment in landfills (TPA) and integrated waste disposal sites (TPST) which cannot take place continuously due to resistance from residents. Then when viewed from the waste tariff/retribution, the current retribution has not been based on adequate calculation and data collection, both in terms of the amount of waste generated and the amount of potential payment. The tariff calculation has also not been optimized based on the type of waste generator, which can be in the form of waste from residential houses, commercial sector waste, or industrial sector waste. The realization of retribution collection is also still low nationally, still around 20%. This causes the government's burden in financing waste management to be very large.

Community Participation

Without the participation of the waste-producing community, all planned waste management programs will be in vain. One approach to the community to assist government programs in cleanliness is to familiarize the community with behavior following the program's objectives, which includes, among other things, the following:

a. How to change public perception towards orderly and orderly waste management
b. Local social, structural, and cultural factors
c. Habits in waste management

According to Damanhuri et al. [17], the problems that occur are related to community participation in waste management, including the following:

a. Unequal distribution of population
b. There is no desire in the community to protect the environment
c. There is no standard method for community development that can be used as a guideline for implementation
d. There are still many cleaning managers who have not included counseling in their programs
e. Managers are concerned that community initiatives will not be compatible with existing management concepts

Communities that have been generating waste play an important role in waste management, especially when the waste is still at the source. Low public awareness in waste management is one of the obstacles in Indonesia. Although in some places there are already community groups that care about waste, but in general, community participation in waste management is still relatively low. Disposal of waste out of place (even into rivers and waterways) is a common occurrence. Regulations and Standard Operating Procedures (SOPs) that have been made regarding waste management have not been fully informed to the community.

The government continues to encourage people to start managing waste from their homes in various ways. For example, 3R promotion, composting, and waste banks. Waste banks are a well-established activity that has been participated in by several community groups in various parts of Indonesia. The business world and academia are part of the community. So far, the synergy of roles between the central government, provincial government, district/city government, private sector, community, and universities has not been

optimal. As a result, it has not been able to produce a reliable waste management system. Private investment is still low, CSR utilization is also not optimal. Waste-producing producers (in this case the business world) have not yet implemented EPR.

Technical Waste Management in Indonesia

The waste management operational system also includes a waste processing and processing subsystem, which needs to be developed in stages by considering processing that relies on reuse, either directly, as raw materials or as energy sources [7]. The implementation of the waste management system currently carried out in Indonesia.

Open Dumping

This method of processing waste is straightforward; it is often used in developing countries [95]. Usually used to cover indentations in the ground, swamps, or ravines, garbage is dumped there without covering the ground. With this way of processing waste, there will be environmental pollution such as odor pollution, outbreaks of disease due to the breeding of fly or mosquito populations, and pollution of surface water and groundwater by leachate due to rinsing waste heaps rainwater.

Composting

Composting is carried out to process waste and, simultaneously, get results from the compost [4]. Waste must be separated to be composted, for example, organic waste leaves, food scraps, and other waste that can rot. Waste as fuel has the following features:

a. Change the state of the soil to be like hummus.
b. Return collected organic materials.
c. Enriching substances N, P, K, and Ca are essential for plants.
d. The fertilization process takes place slowly and lasts a long time.

Burning (Incineration)

Burning waste must be done very carefully because burning waste can cause air pollution [9]. This way, by-products are produced in scrap metal and steam, converted into electrical energy. Other advantages of using this tool include can reduce the volume of waste by 75–80% from the source without a sorting [44]. The method of burning requires a high cost of about three times; therefore, the waste that is burned is waste that can no longer be used for other purposes. Ash or slag from combustion residues is dry enough and free from decay so that it can be taken directly to landfills in vacant land, swamps, or low-lying areas as backfill material. A large enough incinerator with a capacity of about 300 tons/day can be equipped with a power plant so that the electrical energy produced can be used to reduce process costs. The types of incinerators include the following:

a. High temperature
   Suppose the waste is not separated between combustible and non-combustible waste—temperature between 800 and 1000°C.

b. Semi-high temperature
   If the waste is not separated, more garbage is burned.
c. Low temperature
   Used for combustible waste. The temperature is between 650 and 750°C.

Sanitary Landfill

A sanitary landfill is a reasonably good way of processing waste; it is done by placing the waste in the ground and then covering it again with soil [3]. This method will require extensive land if all waste is processed. Therefore, processed waste is waste that really cannot be used for any purpose. This method is widely used in developing countries. The principle is as follows:

a. Waste is dumped in the basin
b. Waste is compacted
c. Waste is covered with soil

Circular Economy

The circular economy (CE) approach refers to an economic system designed to be restorative and generative [14]. More specifically, it maintains the value of products, materials and resources in the economy for as long as possible and minimizes the production of waste (European [23]. As such, the CE approach has received recent attention as a step towards a more sustainable economic model [67]. CE theory suggests that increased resource efficiency and reduced waste during the life cycle of manufactured goods are actually unexplored economic opportunities that have the potential for economic growth [26].

Circular economy is often discussed through the 3R principles of reduce, reuse and recycle [97]. The reduce principle implies the use of minimal inputs of energy, raw materials, and waste by, for example, applying better technologies, simplifying packaging, and using power-efficient equipment [75]. The principle of reuse refers to the use of fewer resources, less energy, and less labor than would be required to produce a new product from new materials or even to recycle and dispose of the product [10]. The principle of recycling or recycle refers to recovery operations where waste materials are reprocessed into products, materials, or ingredients, either for their original or other purposes. It includes reprocessing of organic materials but excludes energy recovery and reprocessing into materials to be used as fuel or for landfilling operations. Recycling is often discussed almost in the same breath as CE, and waste policy includes a strong focus on increasing recycling rates.

Circular economy is a system designed to be restorative and regenerative, where restoration replaces the concept of "end-of-life" for products, energy systems are shifted to renewable technologies, toxic chemicals that interfere with reuse are eliminated, and waste is eliminated as much as possible through improved materials, products, and system design [22]. Circular economy provides an economic system with an alternative flow model that is cyclical in nature [21]. The idea of material cycles dates back to the early days of industrialization [43]. The idea has also been put into practice with the argument that it reduces negative environmental impacts and stimulates new business opportunities [18]. Unlike traditional recycling, practical policies and business-oriented circular economy approaches emphasize the reuse of components and materials, remanufacturing, refurbishing, repairing, developing, and upgrading as well as energy utilization and product waste [8].

The circular economy concept is depicted in Fig. 2. The point of the figure is that the circle depicts product reuse, remanufacture, and repair, demanding less resources and energy and more economical than conventional recycling of materials that make low-quality goods [52]. The time the resource spends/life cycle inside the circle should be maximized. Materials should first be recovered for reuse, renewal, and repair, then for remanufacturing, and only then for raw material utilization, which has been the main focus in traditional recycling. According to CE, energy combustion should be the second to last option while disposal to landfill is the very last option. In this way, the product value chain and life cycle can maintain the highest value and quality for as long as possible and also be as efficient as possible.

Government Policies to Encourage Circular Economy Implementation in Indonesia

The Indonesian government has established a policy to encourage the implementation of a circular economy in the context of sustainable economic development and environmental quality improvement. This is contained in the narrative of the 2020–2024 National Medium-Term Development Plan (RPJMN), which contains plans for the preparation of an

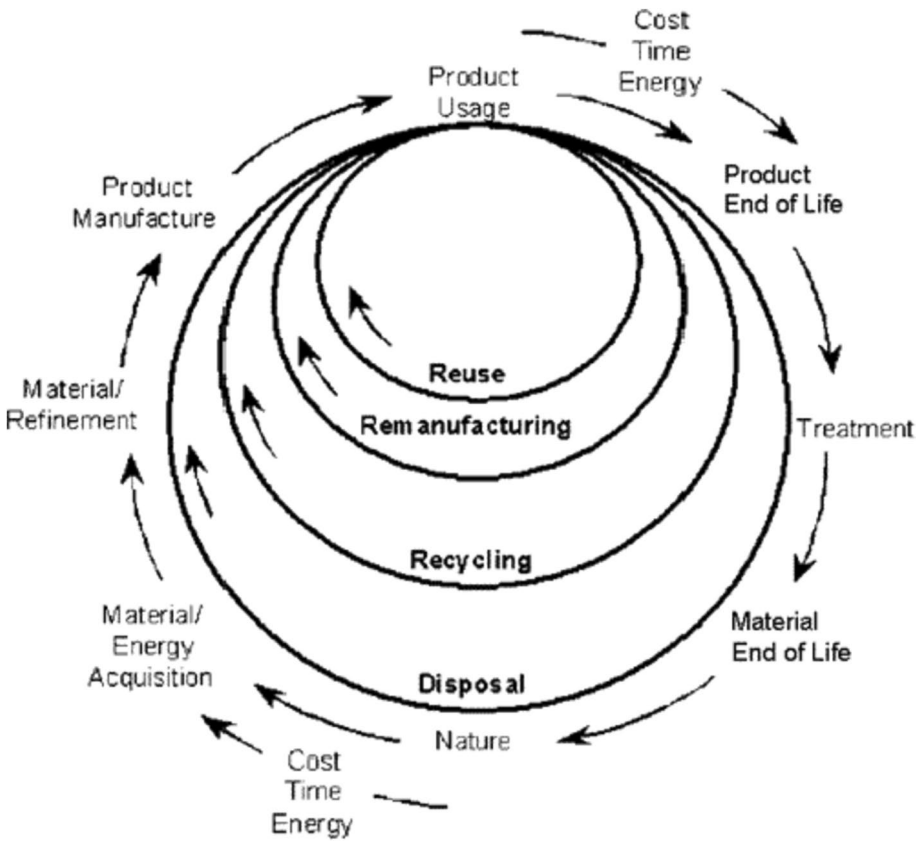

Fig. 2 Circular economy concept

integrated waste management system from upstream to downstream, and the development of green industries [64]. Based on a report by the Ministry of National Development Planning, there are several industrial sectors in Indonesia that will be the focus in implementing the circular economy, namely, food and beverages (packaging), clothing or textiles/garments, construction services, plastics, and electronics [39]. The purpose of this policy is also to achieve target 12 (sustainable consumption and production) which overlaps with targets 6, 7, 8, and 15 of the Sustainable Development Goals [39].

In addition to the RPJMN, based on information from the Indonesia Circular Economy Forum (ICEF), there are government policies that encourage the implementation of the circular economy, namely Presidential Regulation Number 97 of 2017 concerning National Policy and Strategy for the Management of Household Waste and Waste Similar to Household Waste (Perpres Jaktranas) [62]. Broadly speaking, the Perpres Jaktranas contains two things, namely, the policy direction for reducing and handling household waste and similar household waste, and strategies, programs, and targets for reducing and handling household waste and similar household waste [62]. The policy target based on the Perpres Jaktranas is the reduction of household waste and similar household waste by 30 percent or 20.9 million tons and the handling of household waste and similar household waste by 70 percent or 49.9 million tons in 2025, compared to the projected waste generation of 70.8 million tons [62]. To realize this, the appendix of the Presidential Regulation on Jaktranas contains several policy scopes, strategies, and programs that involve multi-stakeholders, namely, ministries and institutions at the central level, and regions (provinces, cities/districts) in a synergistic manner.

Waste management policies are also regulated in Presidential Regulation No. 83/2018 on Marine Debris Handling. In this Presidential Regulation, there is an Action Plan for Handling Marine Debris 2018–2025 which is embodied through strategies, including a national movement to increase awareness of stakeholders; management of land-based waste; coastal and marine waste management; financing mechanisms, institutional strengthening, supervision, and law enforcement; and research and development. The existence of this policy is a follow-up to the government's commitment to tackle marine plastic waste by 70 percent by 2025 [63].

In its development, the National Action Plan (NAP) on circular economy is currently being developed. This development is urgently needed because the implementation of circular economy is not solely a business matter but also requires a framework that is supported by policy makers, namely the government [82]. In the formulation of circular economy policies, there are three main scopes of regulation formulated, first, product manufacturing which includes managing the process of reuse, repair, recycling, providing added value within the framework of the manufacturing business; second, support for research and innovation of environmentally friendly technology; and third, the provision of an environmentally friendly product market ecosystem [53]. In addition, due to its relationship with environmental conservation efforts and social aspects, the formulation of policies requires the application of risk mitigation [37].

Circular economy implementation policy is multi-sectoral and requires synergistic involvement of relevant stakeholders as it requires an upstream to downstream regulatory scheme [42]. Stakeholders in policy making consist of government, business/industry, academia, and civil society within the framework of the quadruple helix model [33]. The government functions as a regulator in providing support for legal frameworks, financing mechanisms, and governance. Academia functions in research activities and innovation of environmentally friendly technologies and scientific recommendations. The business sector, industry functions in the development of business models, products, and the

application of sustainable production. Civil society functions in information literacy to the public, liaison of cooperation networks, and monitoring and evaluation of policies. The model is illustrated in Fig. 3 [16].

Implementation of Circular Economy

One example of a circular economy that could include food waste, natural yarns, wood products and biopolymers would create "biological nutrients" (compost) while another could include non-organic materials such as polymers (plastics) and electronic materials that become "technical nutrients" for next generation products (X. [46]. The concept was originally introduced in the 1970s by Swiss architect and economist, Walter Stahel, who proposed that materials be processed in a "closed loop" and "waste" become resources. Stahel defined this as a "Cradle-to-Cradle" system and the Linear model was defined as Cradle-to-Grave [27]. It also identifies the need to extend product life through repair and remanufacturing, which is also now seen as an integral part of the circular economy [74]. Cradle-to-Cradle is also a design method used by William McDonough (architect) and Michael Braungart (environmental chemist) who stated that it would facilitate "design for abundance" and as a consequence they developed the C2C benchmark to support and promote products that meet this standard [49]. Dematerialization (reducing material inputs while maintaining performance) and alternative business models such as leasing and service provision (which includes maintenance for example) are also integral parts of the circular economy [84].

The product life cycle consists of four main stages: (1) extraction of raw materials and processing, (2) manufacture, (3) use, and (4) end of use. It has been explained that, in a linear economy, at end-of-use, materials are treated as waste and either sent to landfill or incinerated. Besides using land that could be used for housing or agriculture, the decomposition process in landfills or incineration can produce emissions, toxins, and other pollutants. In contrast, the circular economy reduces supply risks by keeping materials in

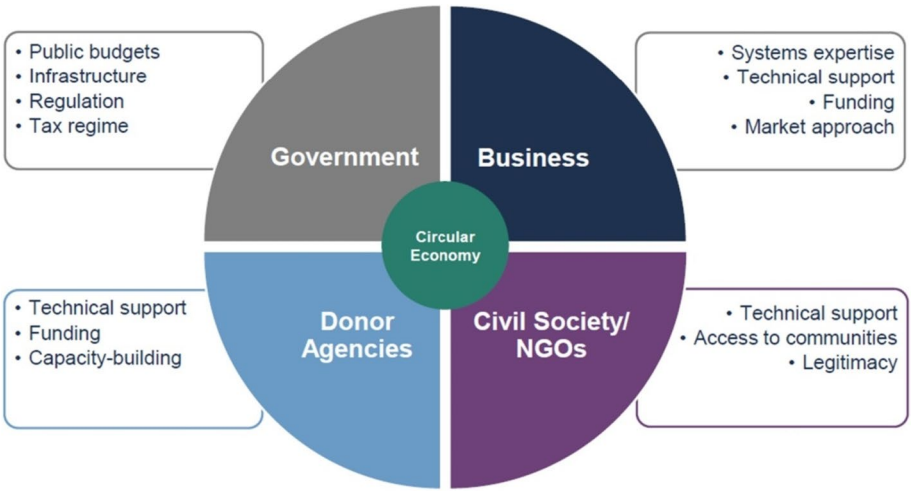

Fig. 3 Quadruple helix model in circular economy implementation

circulation, and although energy and resources will still be required for decomposition and recycling, eliminating the initial lifecycle stage (extracting and processing large quantities of materials) also reduces the amount of damage, up to 75% of the energy and water involved, associated emissions, and environmental and other impacts [92].

Extending the life of products, purchasing services (such as replacing physical CDs with MP3 format and online music services, e-books, and digital format reader apps), and leasing also contribute to the circular economy and are profitable as the manufacturer has control over products that can be easily maintained, repaired and upgraded throughout their life. Furthermore, at end-of-life, suppliers have control over reprocessing and recycling and can manage the outcome in open or closed material cycles (where materials are remade into different products or the same products). In addition to reducing resource supply risks, the circular economy also has the potential to reduce corrupt and unethical practices, which will promote sustainable development as it will be much easier to conduct accurate supply chain audits and select ethical suppliers and/or encourage unethical suppliers to change their practices [68].

Some large manufacturers (e.g. Rolls Royce, Philips, and Caterpillar) and some smaller ones (e.g. Closed Loop which recycles and re-assembles plastic bottles and The Bond Group which manufactures commercial refrigeration equipment) are developing alternative businesses on their way to a circular economy. However, the majority of businesses are not doing so due to a lack of knowledge and understanding of circular economy concepts. Some concerns and barriers are practical (e.g., availability of networks and/or supply chains for dismantled products and components and materials for recycling have not been established) while other barriers are perceptual (there is a general belief that remanufactured/reengineered components and recycled materials are inferior to virgin materials). Furthermore, currently most products in circulation are not designed for disassembly or recycling and as a result the process can damage components and materials while the cost and complexity of disassembly is relatively high. These and other constraints are being addressed by several UK government and non-government bodies including APSRG (the All-Party Parliamentary Sustainable Resource Group), Innovate UK, the Ellen MacArthur Foundation, and the Royal Society of Arts' Great Recovery project which all promote and support research into the benefits and business opportunities associated with aspects of the circular economy.

Benefit of Integration Circular Economy into Waste Management

Increased production has created a problem that requires landfills. The material flow in society is schematically depicted in Fig. 4. Waste is generated when extracting raw materials and during the production process. The most effective way to reduce the waste problem is to reduce the amount and toxicity of the waste. But with the increasing desire for a better standard of living, humans are becoming more and more consuming and generating more waste. Consequently, the community must look for effective waste management methods and ways to reduce the amount of waste that needs to be disposed of in landfills. Following Law No. 18 of 2008, waste management aims to improve public health and environmental quality and make waste a resource.

The increase in waste resulted in increasingly complex problems for managing waste. Solid waste management is complex because it includes many technologies and disciplines. Includes technology associated with control over the generation, storage, collection,

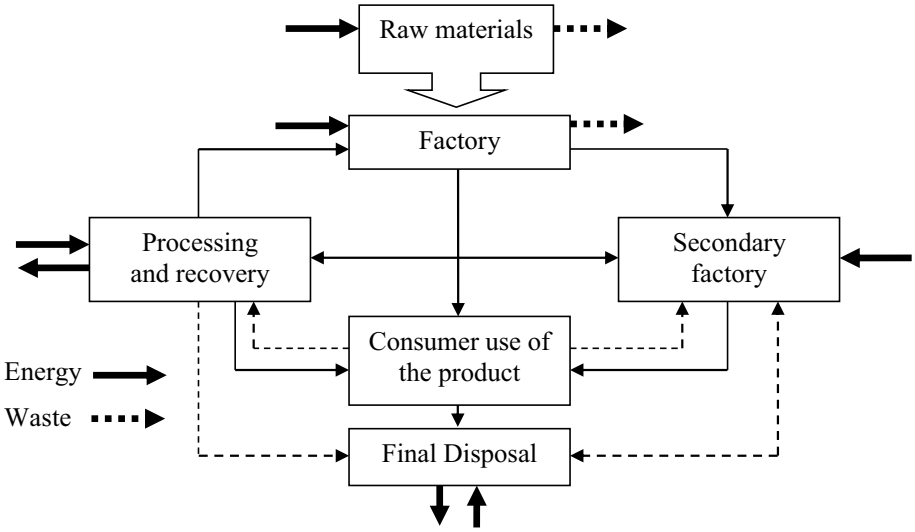

Fig. 4 The flow of materials and waste in industrial society

transfer and transportation, processing, and disposal of waste, which is acceptable and by the principles of public health, economics, engineering, aesthetics, and other environmental considerations, including responsiveness to the general public [80].

According to Yukalang et al. [96], waste management will fail when too much waste is in the wrong place, is not close enough to sell, or is not recycled enough. The solution lies in redesigning products, packaging, and processes suitable for input into the value chain. Initiatives and tools can also support successful sustainable waste management strategies. One example of a developing waste management strategy is the circular economy approach [86]. The circular economy aims to generate economic growth by maintaining the value of products, materials, and resources in the economy for as long as possible, thereby minimizing the social and environmental damage caused by the old linear economic approach [85]. Not just better waste management with more recycling, a circular economy encompasses a broad range of interventions across all sectors of the economy [40]. Circular economy activities are focused on the 5Rs: Reduce, Reuse, Recycle, Refurbish, and Renew (Table 4).

Five Priority Sectors Offer Great Potential for a Circular Economy Approach in Indonesia

Applying a circular economy in Indonesia has potential in five sectors: food and beverage, textiles, construction, wholesale and retail trade (focusing on plastic packaging), and electrical and electronic equipment [39]. These sectors play an essential role in the Indonesian economy. Based on data published by the [12], these five sectors contributed more than 30 percent of Indonesia's GDP and employed more than 43 million people or a third of Indonesia's workforce in 2019 (Table 5).

These five sectors generated a significant amount of waste in 2019. Food wastage and waste, excluding food waste during production, amounts to nearly 57.4 million tonnes. Waste volume is expected to increase to 82 percent by 2030 in several sectors (Fig. 5) [39].

Table 4 A circular approach consisting of 5R

Reduce	• Eliminating waste in production and supply chains (such as 3D printing) • Virtualization of products and services (such as e-books) • Reducing energy use (such as improving energy efficiency) • Redesign the product to use fewer inputs (such as the use of solid steel in construction)
Reuse	• Sharing existing assets (such as houses, cars, and other equipment) • Use of second-hand goods • Improve asset use by offering products as services
Recycle	• Reusing existing materials • Anaerobic digestion and biochemical extraction for organic waste
Refurbish	• Remanufacture products or components • Longer life cycle with product maintenance
Renew	• Prioritizing renewable energy and materials (such as replacing plastic packaging with paper-based ones)

Source: [21]

The increase in a waste generation comes from physical waste, such as food scraps or textile waste, and structural destruction, such as empty office space or inefficient energy use. Two key factors will likely drive waste generation growth in the next decade. First, by 2030 there will be an additional 90 million Indonesians who will join the class of consumptive society, which will drive demand for basic consumer needs (e.g., packaged food) and discretionary consumer products (e.g., electronics and clothing) [59]. Second, by 2019 and 2030, more than 35 million people will live in urban areas (Haikun [87]. According to government estimates, by 2045, around 67 percent of Indonesia's population will live in urban areas [54]. To minimize this, the Indonesian government has made various efforts. One of them is moving the national capital from Java Island to Kalimantan Island which aims to equalize development. In addition, there are several policies that are currently prioritized by the Indonesian government. First, efforts to improve the education aspect in villages can be done by promoting vocational secondary education. Vocational secondary education will certainly be very helpful in developing the talents of students who are practical in accordance with the desired specialization. In addition, this aspect can also be used to encourage the emergence of an entrepreneurial spirit so that it can provide jobs in the village. Of course, the presence of jobs in the village will reduce the rate of urbanization that occurs. Secondly, the accessibility aspect (in terms of transportation) in the village is an important factor to support

Table 5 The five focused sectors contribute ~ 33% of GDP and employ over 43 million people

Sectors	GDP in 2019 (Indonesian trillion)	Percentage of total (%)	Workforce in 2019 (million)	Percentage of total (%)
Food and drink	1014	9,3%	13,1	10,1%
Textile	146	1,3%	1,2	0,9%
Construction	1108	10,1%	7,6	5,9%
Wholesale and retail	1168	10,7%	19,8	15,3%
Electrical and electronic equipment	204	1,9%	1,6	1,3%
Total	3640	33,2%	43,3	33,5%

Source: [11, 12]

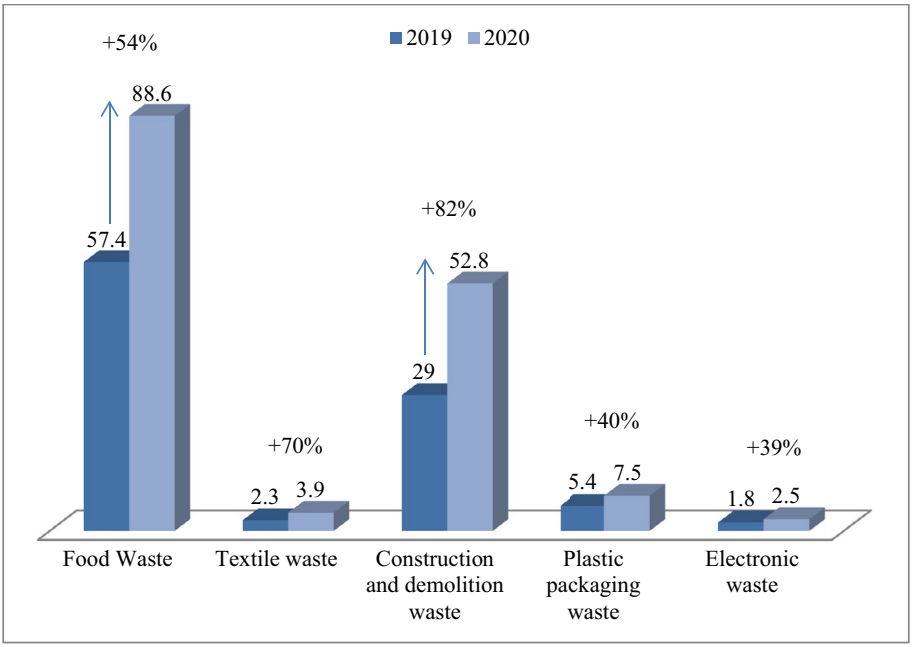

Fig. 5 A predicted increase in waste generated by five key sectors

economic activities, despite the fact that many villages in our country still have poor accessibility. This accessibility serves as a connecting route for the flow of goods and services (economic activity). Through the improvement of accessibility in villages, such as the construction of roads and bridges as well as telecommunication facilities, the empowerment of potential resources in the village can be optimally developed. The ease of access can also be a pull factor for the government and the private sector to partner and develop the superior aspects of the village concerned. Third, empowering the main potential of the village can be done to reduce urbanization. One way to develop the potential of the village can be done in accordance with existing resources such as agribusiness potential and tourism aspects. The agribusiness potential in the village can be developed and marketed in a more "selling" way so that the potential can be empowered. Urbanization drives demand for consumer products and the construction of houses and other public infrastructure, generating waste.

A Waste Track in Five Sectors Is an Opportunity for a Circular Economy

Based on the potential and opportunities of 5R circularity in each sector, prioritization can be done in each sector (see Table 6). These opportunities are identified based on available evidence that they can make the most impact in the sector and then revised in consultation with stakeholders. For example, "Reduce" and "Recycle" have the most significant opportunity for the food and beverage sector. As a result, four opportunities are prioritized, namely as follows: (1) reducing food wastage after harvest, (2) reducing wastage and waste in the food supply chain, (3) reducing food waste generated by consumers, and (4) reducing food waste and waste in the production process. Impact of each prioritized opportunity, an estimate of the current adoption rate in Indonesia, is used. For example, the recycling rate of e-waste in Indonesia is estimated at 5 percent [47].

Table 6 Potential and opportunities for 5R circularity in every sector

5R	Food and Drink	Textile	Construction	Wholesale and retail trade	Electrical and electronic equipment
REDUCE	Reduce food wastage at the postharvest stage	Reduction of waste at the production stage	Reduce waste with existing processes	Reduce the use of plastic packaging	Virtualization and dematerialization of physical goods
	Reducing food wastage in the food supply chain		Reduce waste with new processes		
	Reduce consumer food waste		Optimization of building use		
REUSE		Product reuse	Reusing materials	Reusing plastic packaging	Product reuse
RECYCLE	Process materials from food waste during the processing stage	Recycle materials	Recycle materials	Redesigning plastic packaging so that it can be recycled	Recycle materials
				Increase the recycling rate of plastic packaging	
REFURBISH					Increase product life and reduce product obsolescence
					Product repair
RENEW		Using materials that are more environmentally friendly	Using materials that are more environmentally friendly	Using materials that are more environmentally friendly	
			Design and build buildings that are more resource-efficient		

Source: [39]

High potential

Medium potential

Low potential

Estimates of the potential for each circular economy opportunity are made based on national and international references that can be applied to Indonesia in 2030. Indonesia can increase its e-waste recycling rate and match India's e-waste recycling rate of 21 percent by 2030 [71]. Case studies elsewhere are also used to understand this potential further. Pilot projects in Benin, Cape Verde, India, and Rwanda have documented a reduction in food wastage of more than 50 percent during field trials with various storage techniques and low-cost handling practices [41]. Thus, it can be assumed that if Indonesia invests in improving infrastructure and food handling (e.g., temperature control during storage), it can reduce postharvest food wastage by as much as 50 percent by 2030.

A successful transition to a circular economy can help Indonesia reduce waste production at the source and increase recycling rates. A circular economy can also reduce waste by up to 50 percent by 2030 (compared to a "business as usual" scenario). Depending on each sector type, recycling rates can also increase by 4–17 percent compared to the business as usual scenario. The analysis shows that the circular economy can contribute significantly to government efforts to reduce waste in five sectors (Fig. 6) [39].

a. Indonesia can reduce food waste and waste by 50 percent and recycle as much as 4 percent of its remaining food waste and waste compared to the business as usual scenario.
b. Indonesia can reduce textile waste by 14 percent and recycle 8 percent of the remaining textile waste.
c. Indonesia can reduce construction and demolition waste by 5 percent and recycle the remaining 15 percent of construction and demolition waste.
d. Indonesia can reduce plastic packaging waste by 21 percent and recycle 17 percent of the remaining plastic packaging waste.
e. Indonesia can reduce e-waste by 13 percent and recycle 16 percent of the remaining e-waste.

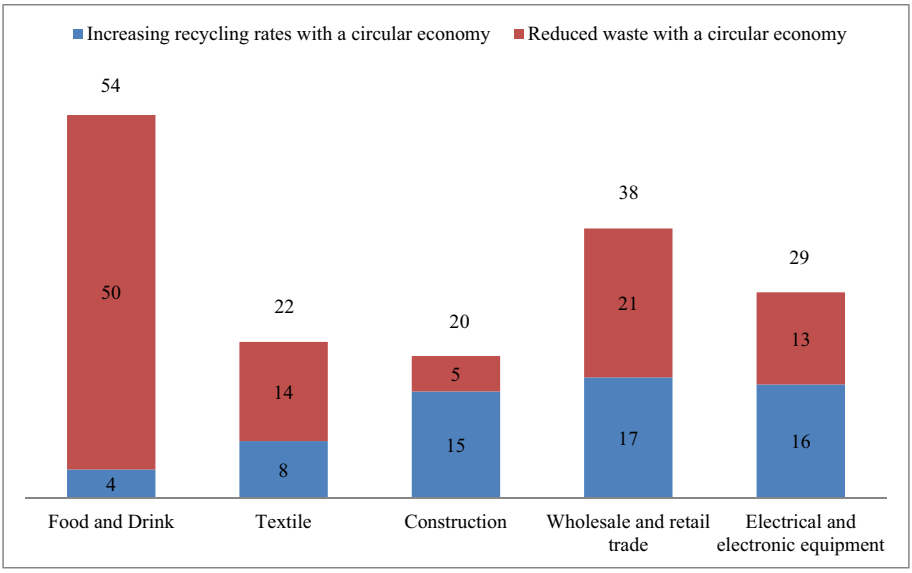

Fig. 6 Prediction of the circular economy's contribution to waste reduction in Indonesia

Potential Significant Economic Impacts from the Implementation of a Circular Economy

Generating less and recycling more waste can significantly impact the Indonesian economy (Fig. 7). Based on two methodologies (model based on the IO table and the Incremental Input–Output Ratio), the transition to a circular economy could increase Indonesia's gross domestic product (GDP) by IDR 593–638 trillion (equivalent to USD 42–45 billion) in 2030 (equal to 2.3 to 2.5 percent of projected GDP in 2030) [12]. Economic value can be more significant than the "business as usual" scenario in which Indonesia does not actively implement a circular economy.

There are two essential aspects of the analysis. The latest government estimates show Indonesia's GDP will decrease by 1.6 and 2.2 percent in 2020 [57]. The International Monetary Fund (IMF) projects Indonesia's GDP to grow as high as 6.1 percent in 2021 [35]. However, the relationship between GDP growth and waste volume in the five priority sectors cannot be directly assessed, and COVID-19 may have a more significant impact on waste and circular opportunities (which is difficult to quantify) than the current linear economy. For example, declining household income could decrease the demand for electronic goods, reducing e-waste. There is an increase in the percentage of formal workers working from home, and digitalization can potentially increase the volume of electronic waste [20]. Other results are also uncertain whether reducing the volume of e-waste caused by a decrease in income can outweigh the increase in the volume of e-waste caused by digitalization. It is essential to update this analysis once the impact of COVID-19 on the Indonesian economy and the volume of waste is known. It aims to determine the potential of the circular economy after COVID-19.

The five sectors derive broad economic benefits from adopting circular economic opportunities. These economic benefits are derived from reducing waste in critical sectors, where savings can be utilized in other sectors (health, education, recreational services, etc.). It is important to note that although the economy will benefit significantly from the adoption

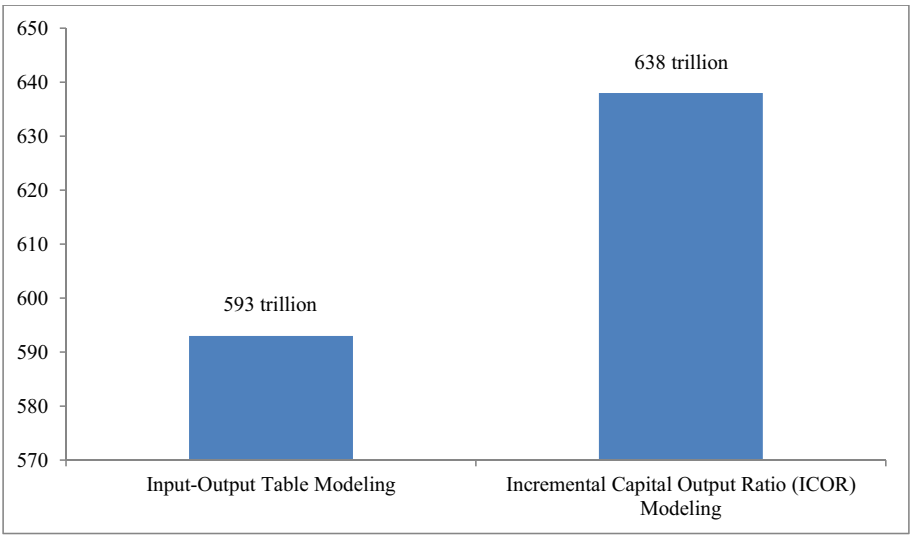

Fig. 7 The impact of the circular economy on Indonesia's GDP in 2030

of a circular economy, it does not mean that the economic output of these five sectors will be higher. Understanding the exact financial impact in each sector is problematic because it depends on how businesses and consumers take advantage of the savings resulting from adopting a circular economy. For example, if consumers reduce their food waste (which causes their food spending to also decrease due to the food savings they make) and decide to use the excess spending money to buy food of higher quality and price, then the impact on the food sector and drink to be positive. However, if the savings are used in other sectors, the effect on the food sector can be damaging. Adopting business efficiency opportunities linked to a circular economy can generate significant returns to GDP and employment growth in the industry. However, if adopting a circular economy causes a decrease in consumer demand, this will drive economic growth to slow down compared to business-as-usual conditions. The results of this study need to be studied further, especially the impact on the broader economy, especially on spending caused by savings from the circular economy. However, these findings reinforce the importance of understanding the existence of winners and losers in the transition process to a circular economy. Businesses and policymakers must prepare themselves to ensure that the transition that is carried out prioritizes the principles of justice and does not harm several things in the Indonesian economy and society.

Indonesia's micro, small and medium enterprises (MSMEs) can also be essential in supporting the economic transition. In 2018, there were 64 million MSMEs in Indonesia, employing around 61 million people (equivalent to almost 90 percent of the total workforce) [30]. MSMEs also contributed nearly 60 percent of Indonesia's GDP in 2017 [79]. A circular economy can reduce MSME production costs with greater production efficiencies and waste reduction and result in new business models, such as a focus on recycling and recovery, which can provide significant opportunities for MSMEs (Plant [65]. In addition, MSMEs can play a better role than large companies in adopting a circular economy. MSMEs are also better positioned to adopt a circular business model that requires a decentralized production system, such as a business model that focuses on reusing, recycling, and repurposing resources locally. MSMEs have great opportunities to be close to ending consumers than large companies [6]. However, most MSME companies are still micro or small in Indonesia. According to the Central Bureau of Statistics, micro and small enterprises contributed 98% of all MSMEs in 2016 [12]. Small and medium enterprises have limited knowledge regarding adopting a circular economy, so the government will need a policy concept that is adaptive to business variations in MSMEs. To support micro and small enterprises, the government could consider these enterprises part of supply chain partnerships that have proven effective in Europe.

A Circular Economy Can Reduce Carbon Emissions and Clean Water Use Significantly

There is great potential for reducing carbon dioxide emissions, other greenhouse gases (CO_2e), and consumption of clean water, which can help Indonesia achieve its low-carbon and sustainable development targets. For example, based on a document submitted by the Government of Indonesia to the United Nations Framework Convention on Climate Change (UNFCCC), Indonesia is committed to reducing CO_2e emissions by 29 percent from the "business as usual" scenario with its resources up to 41 percent with international assistance by 2030 [56]. Based on this analysis, a circular economy can help Indonesia achieve around 15 percent of its lowest target to reduce CO_2e emissions and approximately 11 percent of its highest target of reducing CO_2e emissions by 2030 relative to a "business as usual" scenario.

The reduction in CO_2e emissions is driven by several factors, including lower waste generation, alternative feedstocks that are more energy-efficient, and increased resource lifetime. Emissions released during various products related to the five focus sectors (e.g., food, textiles, and plastics) are expected to account for the emissions that could be avoided if Indonesia adopted circular opportunities. A circular economy can offer several other environmental benefits besides preventing carbon emissions. For example, increasing the reuse of textile products can reduce the production of textile materials and reduce the negative impact of wastewater pollution from textile factories. Increased food waste recycling through composting can help avoid land degradation and reduce the need to clear new land in pursuit of fertile agricultural land elsewhere [4].

A Circular Economy Can Create 4.4 Million Green Jobs Cumulatively and Significant Savings on Household Expenditure

Opportunities in a circular economy across five sectors could generate 4.4 million net jobs between 2021 and 2030 in Indonesia. The additional jobs generated from the circular economy could contribute to Indonesia's target of generating three million jobs annually as stated in Law No. 11 of 2020 concerning Job Creation (Omnibus Law) [39].

It is important to note that there will be winners and losers in this job transition. For example, some jobs upstream (such as mining or manufacturing) are likely lost. However, new jobs were created in the downstream sector (e.g., in other manufacturing or service sectors). The direct impact on employment in the five sectors could vary from − 14 to 2.5 million jobs under different scenarios. Policies are needed to support job transition by retraining sector-shifting workers to create new jobs. The action plan preparation will review this required policy response in detail. Despite its direct impact on employment, a circular economy limiting carbon emissions and reducing environmental pollution is an investment in human capital, health, and productivity. A report from Pollution and Health Metrics by the Global Alliance on Health and Pollution revealed 232,974 pollution-related deaths in Indonesia [28]. By reducing the demand for raw materials directly from nature, a circular economy can reduce deaths related to this pollution.

In addition, the circular economy can also contribute to reducing gender disparities in Indonesia. According to the Organization for Economic Co-operation and Development (OECD), the poor labor conditions faced by the female workforce and situations that force them to be exposed to more hazardous products and chemicals are examples of why women are disadvantaged in a linear economy [60]. Even plastic pollution has a disproportionate impact on women. Women are more likely to be exposed to the adverse effects of plastic pollution than men, such as direct exposure to emissions from incineration or waste disposal because they are more likely to be responsible for household tasks that expose them to waste pollution. Furthermore, women workers in the informal waste treatment sector often face health and safety risks and violence and discrimination in the workplace [90].

The circular economy can also create significant economic opportunities for Indonesian women. According to the International Labor Organization (ILO), the emergence of "green jobs" can offer opportunities for women's empowerment [34]. Particularly relevant for the textile sector in Indonesia, where women account for 58 percent of employment [32]. The data illustrates the significance of circular economy to create benefits for gender equality in Indonesia. Therefore, calls for a women-centered and proactive approach to policy development.

Based on this analysis, 75 percent of the total net employment created by the circular economy in Indonesia in 2030 can empower women. Potential for job transfer from sectors

that are generally male-dominated (e.g., construction, where women only occupy two percent of total employment) to jobs that will be created in sectors that women dominate typically (e.g., education, human resources, health, and social work, which allows households to have a more significant allocation of storage that can be reinvested).

Conclusions

Population growth and rapid urbanization have resulted in high waste generation in Indonesia. The composition of waste changes significantly along with people's consumption patterns. The current waste management system is not enough to solve the waste problem, and more planned efforts need to be made to overcome the waste problem. Sustainable waste management in developed countries goes through several stages: (1) reducing waste production from the source, (2) recycling and reuse, (3) processing waste into energy resources, and (4) avoiding waste disposal to landfill or to a minimum. The waste management system involves the entire community, government, and the private sector to be responsible for realizing zero waste with strict regulations and fines for violators. Another solution that can be done is to use a circular economy approach. It is proven from several existing analyses that circular economy provides significant benefits to the waste problem in Indonesia.

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Data Availability The corresponding author's data supporting these study findings are available upon reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

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