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Germany is Ahead to Implement Sustainable Circular Economy

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Abstract: *This study tries to discuss aspects of the application of circular economy (CE) in Germany. Since the start of the First Industrial Revolution (start in 1760), more than 260 years ago, there becomes enormous development in global linear economy (LE) on the basis of 'take, make and dispose'. Modern various technologies, such as automobiles, electricity, telephones, mobile phones, transistors, airplanes, computers, and the internet have brought enormous change in production and consumption. But unsustainable side effects of LE are; loss of biodiversity, deforestation, environmental pollution, climate change, etc. On the other hand, CE represents a sustainable economy. It keeps resources and materials, as long as, possible. The purpose of this study is to show the importance and beneficial effects of a realized CE on the economic, environmental and social sectors for the success of global sustainable development and the contribution of CE in Germany. Germany is the first country in the world that tries to implement CE by using technologies of waste and resource management.*

Keywords: Circular economy, Germany, sustainable development, waste management

JEL Codes: H4, I31, F6

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1. Introduction

Germany is a democratic, federal parliamentary republic (Federal Republic of Germany, Deutschland) led by a Chancellor (the Federal President), where federal legislative power is divided between the Bundestag, the parliament of Germany, and the Bundesrat, the representative body of regional states. Its capital and largest city are Berlin. It is located in the heart of Europe. Its area is 357,580 km^2 consisting of 16 Länder (states) with populations 83,900,473 (Figure 1). It borders Poland and the Czech Republic to the east, Austria and Switzerland to the south, France, Luxembourg, Belgium, and the Netherlands to the west, and the North Sea, the Baltic Sea, and Denmark to the north. Additionally, it shares maritime borders with Sweden and the UK. It has the largest economy in Europe, the world's 4th largest economy by nominal GDP, and the 5th largest by PPP. It follows the civil law tradition with three types of courts: ordinary courts, specialized courts, and constitutional courts [Fulbrook, 2014; Country Profile, 2021]. In 2015, the nominal gross domestic product (GDP) of Germany was $3.358 trillion compared with $3.237 trillion (revised) in 2014 with an increase of 3.7% [Perez, 2019].

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Figure 1: Map of Germany. Source: Country Profile [2021].

Global primary raw materials, such as oil, gas, metal, etc., are limited and in the future will become scarce. On the other hand, pollutants in waste will have a negative impact on the environment and human health. Hence, waste management (WM) policy must be handled efficiently so that today's products will be tomorrow's resources. Germany is the first country in the world that tries, and takes attempts to recycle wastes, and succeeds [BMU, 2006].

The circular economy (CE) is an alternative to the traditional linear economy (LE). CE indicates how to turn waste into a resource and bring it back into the economic cycle. The product with its resources and materials is kept in the economical circle for as long as possible is CE (Figure 3). It represents a sustainable economy, which guarantees a life cycle from cradle to cradle. It optimizes the products and minimizes the wastes [Ellen MacArthur Foundation, EMF, 2013]. Three main principles of the CE are [EMF, 2016a]; i) preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows, ii) optimize resource yields by circulating products, components, and materials, and iii) foster system effectiveness by revealing and designing out negative externalities. CE could help enable developing countries to industrialize and developed countries to increase wellbeing and reduce vulnerability to resource price shocks [Preston, 2012].

In LE outputs are produced from raw materials, sold, used, and then incinerated or discarded as waste, i.e., it follows "*take, make, waste*" policy (Figure 2). Hence LE only contains the steps of production, consumption and disposal. Unsustainable side effects of LE in the global environment are loss of biodiversity, deforestation, environmental pollution, climate change, etc. On the other hand, CE strictly follows 3R's principles: reduction, reuse and recycle [Preston, 2012]. Recent sustainable CE consists of a closed-loop based on the 7R's: Reduce, Reuse, Renew, Repair, Recycle, Recover, and Redesign. At present, the world economy is only 9.1% circular but in Germany, it is 14% [Weber & Stuchtey, 2019].

Sustainable development is becoming essential globally in every sector. CE tries its best to keep resources and materials in the economical circle for as long as possible for sustainable development. At

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present reusing and recycling, any kind of product and material is influencing almost every process of production of goods. The aim of every nation is to optimize of products and minimize of wastes, which is the main idea of CE [European Commission, 2015]. Our resources and raw materials are limited, but consumption of them is growing more throughout the world. So our primary resources can be saved to avoid creating waste and more dumps, and CE can help in this regard [Brüggemeier, 2017].

The CE is increasingly perceived as an important concept with ecological and economic goals. Policymakers, businessmen, NGOs, large companies, science, and civil society stressed CE. Germany has a high need for raw minerals and most of them come from abroad. For example, metal ores are almost entirely imported. CE can reduce the dependence on imports of raw minerals. A CE minimizes both material input and waste generation by resource-saving product design and by recycling and reusing products and materials [Neligan, 2018]. It is estimated that 12 of the 17 Sustainable Development Goals (SDGs) directly provide CE by the sustainable use of natural resources and increase resource efficiency [Ekins et al., 2017].

To keep natural and manmade materials in a circular flow of use, CE is implemented in the EU. It pays attention to plastics, construction and demolition products, waste electronic devices, food waste, and biomass and bio-based products [European Commission, EC, 2015]. In the world, most of the countries of the EU for the first time have followed the principles of CE. Germany is one of the first European countries to formulate a comprehensive CE. The CE is a top priority for environmental policy in the country. The German Federal Ministry of Education and Research (BMBF) is funding the development of CE in Germany [Weber & Stuchtey, 2019]. There is no national WM planning in Germany, rather each of 16 Federal States (*Bundesländer*) develops its own WM plan [European Economic Area, EEA, 2009]. Some other countries outside Europe, such as Japan, the USA, Canada, Italy, and BRICS (Brazil, Russia, India, China, and South Africa) have also been following the CE principles [Mohajan, 2020].

At present populations of the world have become more than 7.85 billion and estimate of reaching as many as 8.6 billion by 2030, 9.8 billion by 2050, and 11.2 billion by 2100; with about half will be located in Africa and Asia. If the current rate of production and consumption continues, the stress on the limited resources of the world will become dangerous [Mohajan, 2018; Worldometer, 2021]. Global consumption currently needs resources of 1.5 planet earth to sustain. If everybody in the world consumes at the UK and the US level the world needs 2.5 and 4 planet earth respectively. Clearly, the LE model in its current form is not sustainable in the long run [Hieminga, 2015]. Four of the nine planetary boundaries have already been exceeded [Mohajan, 2015].

As the resource is limited, resource efficiency is necessary for sustainable economic development. Resource efficiency comprises economic, social, and ecological aspects which are actions for sustainable development policy, both at the national level and international cooperation. CE helps to meet global responsibility for ecological and social impacts of resource use. It saves natural resources, secures jobs, possibly even lowers costs, limits negative environmental impacts, and leads to lower energy consumption [EMF, 2013].

The CE in Germany mostly focuses on the waste management (WM) policy. It is playing a pioneering role in the implementation of CE in the country. The government of Germany (GOG) laid the foundation stones for environmental protection which are still deeply rooted in the industrial landscape. The country has a strong WM sector, ultra-modern refuse incinerators. It is a pioneer in environmental engineering, such as refuses to sort, waste2energy, pre-treatment of waste for landfill, hydroelectric power, the bio-based economy, etc. [Country Profile, 2021].

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Bio-economy deals with bio-plastics, and compost is one of the most resource-intensive in Germany. It is one of the most vocal discussions on the CE. To explore how the bio- and circular economies could share an integrated, sustainable path it is needed bio-based industries. Germany is one of few European countries with government policy that actively supports a bio-economy. The GoG focused on bio-products potential to feed into the Earth's biogeochemical cycles of elements and resources [D'Amato et al., 2017].

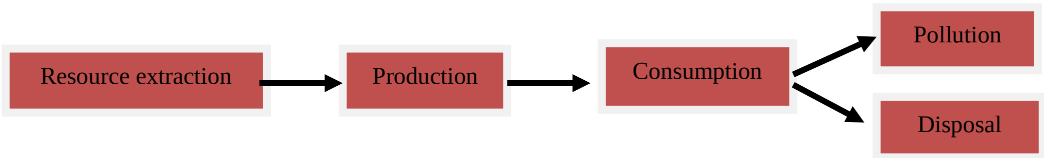

Figure 2: Linear economy. Source: (EMF, 2016b).

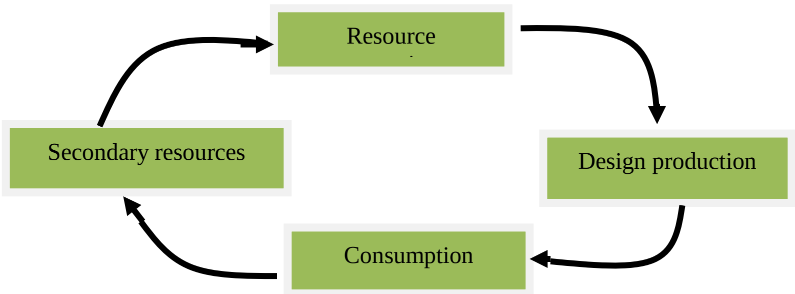

Figure 3: Circular economy. Source: (EMF, 2016b).

According to the Federal Office for Building and Regional Planning, Germany requires about 350,000 new housing units per year by 2021 with an estimated cost $91.28 billion. In 2018, the GoG announced its plan to construct around 1.5 million housing units by 2021 [Technavio Research, 2018].

2. Literature Review

The Ellen MacArthur Foundation, a nonprofit organization, developed the refinement and development of the concept of CE as regenerative design, performance economy, cradle to cradle, biomimicry, and blue economy. According to it, CE is the transformation and use of natural resources in such a manner as to maintain and preserve the ecologic equilibrium and economic growth [EMF, 2013]. Oliver Lah has discussed the CE policies and strategies as an indicator of the energy efficiency of the German economy from environmental and economic perspectives. He has indicated that the strong environmental framework makes the country a pioneer in sustainable economic development [Lah, 2016]. Borris Haupt has compared the construction industries in the Netherlands and southern Germany. He has revealed that CE in the Dutch construction industry might be ahead of Germany [Haupt, 2019].

Elena Brüggemeier has overviewed the term of CE to a more detailed look at waste management and soil management, as waste can have significant effects on the environment and soil. In the study, the author tries to discuss the methods of reusing or recycling and legislation in terms of CE [Brüggemeier, 2017]. M. Nelles, J. Grünes, and G. Morscheck show that the new German Closed Cycle Management Act

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(Kreislaufwirtschaftsgesetz, KrWG) to turn the WM into resource management. Germany has adapted WM policy in the last 25 years based on closed cycles. As a result, citizens of Germany become more conscious of the necessity to separate waste, which led to the introduction of new disposal technologies, and increased recycling capacities [Nelles et al., 2016]. A. Schüch, G. Morscheck, A. Lemke, and M. Nelles have mentioned that the WM policy has been adopted in Germany over the past 25 years that is based on closed cycles and assigns disposal responsibilities to manufacturers and distributors of products. They have expressed that biodegradable waste is collected separately, recycled, and ecologically and economically used [Schüch et al., 2016].

Peeranart Kiddee, Ravi Naidu, and Ming H. Wong have warned that e-waste contains a variety of toxic substances which can contaminate the environment and threaten human health. They have provided several tools, such as Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Multi Criteria Analysis (MCA), and Extended Producer Responsibility (EPR) to manage e-wastes in developed countries [Kiddee et al., 2013]. Dorothea Hansen and his coauthors have tried to discuss healthcare WM in Germany. They have shown that healthcare WM is different and complex from general WM [Hansen et al., 2014]. Elina Merta has discussed German municipal waste (MSW) management performance, indicators, and possible future trends during 2001-2014 in some detail [Merta, 2016].

Selman Karagoz and his coauthors have mentioned that at present automotive is one of the most critical sectors worldwide that is increasing rapidly. End-of-life vehicles (ELVs) create hazardous waste in the environment. Therefore, ELV management becomes of vital importance for environment conservation, circular economy, and sustainable development [Karagoz et al., 2020]. Risto Pöykiö, Gary Watkins, and Olli Dahl have discussed the importance of physical and chemical properties of municipal sewage sludge and compared them to the requirements of the Finnish Fertilizer Product Act and Fertilizer Product Decree to assess the potential utilization of this byproduct as a fertilizer [Pöykiö et al., 2019].

3. Methodology of the Study

Research methodology provides us the principles for organizing, planning, designing, and conducting good research. Hence, it is the science and philosophy behind all researches [Legesse, 2014]. The methodology of this study is to discuss the contribution to the implementation of CE in Germany. In this study, we have used secondary data sources. For the collection of secondary data we have used both published and unpublished data sources.

The published data are collected from books of famous authors, national and international journals, various publications of foreign governments or international bodies and their subsidiary organizations, various research reports of research scholars, research notebooks, handbooks, theses, websites, and public records and statistics, historical documents, and other sources of published information. The unpublished data are collected from diaries, letters, unpublished biographies, and autobiographies, and also from scholars and research workers, trade associations, and other public/private individuals and organizations.

4. Objective of the Study

The main objective of this study is to discuss CE implementation policy in Germany. Other specific objectives are as follows:

- to show CE strategy policy of Germany, and
- to indicate the source of waste and proper management of it in Germany.

5. German CE Strategy

Germany has no overall policy on CE. It took the first significant step towards a CE in the context of closed-loop resource management. It has strong waste management (WM) sector, ultramodern refuse incinerators, etc. The country is a pioneer in environmental engineering, such as refuses sorting, waste2energy, pre-treatment of waste for landfill, and renewable energy (e.g., hydroelectric power, bio-based energy, etc.) [FES, 2016]. Germany follows a combination of a top-down and bottom-up approach of CE. Landfilling was the first controlled WM until recycling, reuse, and prevention were applied for WM [Brüggemeier, 2017].

Germany followed CE in early 1976 with the Waste Disposal Act. It has been adapted the WM policy over the past 30 years. The CE in Germany mainly focuses on the WM characteristic. A cornerstone of the German recycling policy framework is the packaging law (Verpackungsverordnung); adopted in 1991, which requires manufacturers to recycle all packaging materials it sells. In Germany, the waste legislation is mainly determined by the Kreislaufwirtschaftsgesetz (KrWG) which could be translated as the CE law. The first law "*The German Closed Substance Cycle and Waste Management Act*" for WM was enacted in 1994 and replaced in 1996 by the Kreislaufwirtschafts- und Abfallgesetz (KrW-/AbfG), "*Closed Substance Cycle and Waste Management Act*" [Bio Intelligence Service S.A.S., 2011; EEA, 2009]. The law was amended and renamed in 2012 to the Kreislaufwirtschaftsgesetz (KrWG), "German Resource Efficiency Programme (ProgRess)" CE law. This law takes care of natural resources; protect human beings and the environment, and develop recycling and sustainable process of waste. This Act will also enhance CE activities to conserve natural resources and to ensure the protection of human health and the environment in the generation and management of waste [Kreislaufwirtschaftsgesetz, 2012; BiPro and CRI, 2015]. It increased the responsibility of producers and makes them responsible for coordinating the handling and utilization of the waste they produce. It stresses on 5-step waste hierarchy as, i) waste prevention, ii) preparation for reuse, iii) recycling, iv) energy recovery, and v) disposal [Haupt, 2019]. It provides WM in a closed cycle and ensures environmentally compatible waste disposal [Su et al., 2013]. These five steps are adopted from the European Waste Framework Directive (2008/98/EC) which has highly influenced the German regulations [Kreislaufwirtschaftsgesetz, 2012].

In 2013, the federal cabinet has decided on the program for the avoidance of waste (Abfallvermeidungsprogramm) with the contribution of the federal states, which determines systematic and comprehensive approaches of public administrations for waste avoidance providing specific recommendations, instruments, and approaches. In 2016, the Federal German cabinet decided on the "German Resource Efficiency Programme II (ProgRess II)" for instance sustainable construction and urban development [Jaron & Flaschentreher, 2012; Haupt, 2019]. At the beginning of 2019, the German Federal Ministry of Education and Research (BMBF) has funded a CE project "*The Circular Economy Initiative Deutschland*" [Weber & Stuchtey, 2019].

In 2018, CE has annual earnings of about €76 billion in Germany and employs about 290,000 people in some 11,000 companies. With a gross value of about €21.5 billion, it is an important economic sector to Germany. The construction industry is a major target for circular approaches as it consumes 50% of the natural resources (550 million tons), is responsible for 40% of the energy consumption and 30% of the water usage. In Germany, about 40% of the waste produced (200 million tons) and 35% of the CO_2 emissions happen from the construction industry [Haupt, 2019].

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6. Source of Waste in Germany

The WM system in Germany is carried out in a dual system: residual waste and organic waste. Many wastes are produced in Germany, such as waste oil, bio-waste, sewage sludge, mineral wastes, polychlorinated biphenyl (PCB) and polychlorinated terphenyl (PCT), packaging, batteries, containing capacitors, plastics containing brominated flame retardants, mercury-containing components (e.g., switches, the backlight of notebook), CFC, HFC, hydrocarbons, printed circuit boards, toner cartridges, removal of fluids, end-of-life vehicles, e-waste, etc. In Germany, glass, old clothes, compost and bio-waste, paper, packaging, bulky waste, and specialist waste are collected separately by private households before they are recycled [BMU, 2006].

In 2013, total waste in Germany was about 339,132 million tons; about 49,570 million tons (617 kg per person) was a municipal solid waste, about 57,577 million tons was production processes and commercial waste, about 202.735 million tons was construction and demolition waste, and about 29,250 million tons was mining rubble. The recycled rate was 79% of total waste, 62% of municipal waste, 67% of household waste, 70% of commercial waste, and 90% of construction and demolition waste [EEA, 2013].

6.1 Packaging Waste

The packaging is used to cover and protect food and some other valuable materials. The main constituents of packaging are valuable raw materials, such as paper, plastic, aluminum, glass, tin plate, cardboard, wood, etc. In 1991, the GoG enacted the Packaging Ordinance (VerpackV) that aims to put extended producer responsibility into practice by extending the manufacturers' and distributors' responsibility their products. Later the ordinance has been amended various times. Until 31 December 2018, retailers selling to the German market were required to comply with the German packaging law VerpackV. On 01 January 2019, the VerpackG replaces VerpackV [VerpackG, 2019]. The legislator's aim is not only to make sure companies contribute more to environmental costs but above all to generally reduce packaging waste as much as possible. In 1991, private households and small businesses produced 15.6 million tons of packaging waste, that figure dropped to 13.7 million tons in 1997, but then returned to a higher rate of 15.5 million tons in 2003. Recovery of used packaging has been continuously increased from 6.1 million tons in 1991 to 10.3 million tons in 2003 [BMU, 2006]. In 2010, packaging waste achieved a total recovery rate of about 85% in Germany. Circulations of these conserve natural resources save energy and reduce GHG emissions. In Germany, about 97% of all packaging waste was recycled in 2015 [Nelles et al., 2016].

6.2 Bio-Waste

Bio-waste can be divided into two types [European Commission, EC, 2016]: i) food and kitchen waste from households and household-like commercial waste, e.g., from restaurants, retail premises, etc., and ii) green waste, e.g., biodegradable garden and park waste. The Ordinance on the Utilisation of Biowastes on Land used for Agricultural, Silvicultural and Horticultural Purposes (Ordinance on Biowastes–BioAbfV) of 21 September 1998 was amended in April 2012 and was promulgated in the Federal Law Gazette of 8 April 2013 [Schüch et al., 2016]. It applies to treated (compost, digested) and untreated bio-waste that is used on land for agricultural, silvicultural, and horticultural purposes, and also in bio-waste production, collection, transport, treatment, and use [Dollhofer & Zettl, 2017].

In Germany, biodegradable waste is collected from bio-bins, biodegradable garden and park waste, market waste, and other biodegradable waste of diverse origins. In Germany, about 100 million tons of

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biodegradable wastes arise from forestry, agriculture and waste management. Of these, about 65% are technically and ecologically sensible usable [Schüch et al., 2016]. In 2015, about 13.85 million tons of biodegradable waste was treated in composting and digestion plants/biogas installations. Of these, 7.37 million tons were consigned to 868 composting facilities, and 6.48 million tons to 1,392 digestion plants that are used to produce around 3.96 million tons of high-quality compost and 4.09 million tons of fermentation substrate for use in various sectors as fertilizers (nutrients) or soil improvers [BMU, 2018].

In 1982, the first pilot project for the separate collection of bio-waste in so-called "bio-waste bins" started in Witzenhausen city of Germany but was not included in German legislation. In 1986, the German Waste Act stipulated the separate collection of waste for the first time but on a household, level was not compulsory throughout Germany [Fricke et al., 2003]. Since 2015, a separate collection of bio-waste is mandatory. For example, yellow bins are used for the collection of packaging wastes, such as plastics and metals [BiPro and CRI, 2015].

6.3 Medical Waste

Medical waste includes all wastes produced in healthcare or diagnostic activities [ICRC, 2011]. Over the last few decades, hazardous medical waste is increasing worldwide very rapidly. Medical waste creates during the diagnosis, treatment, and immunization of humans and other animals [Visvanathan, 2006]. Hazardous medical wastes are anatomical waste, chemical waste, heavy metals, sharps, infectious waste, Cytotoxic waste, pharmaceutical waste, radioactive waste, etc. [ICRC, 2011].

Waste production at healthcare sites are; hospitals, physician's offices, dental practices, blood banks, laboratories, clinics, research centers, dispensaries, home patients, etc. Therapeutic activities, such as cobalt therapy, chemotherapy, dialysis, surgery, delivery, resection of gangrenous organs, autopsy, biopsy, para-clinical exams, etc. are performed continuously in medicals [Prüss et al., 2014]. But healthcare providers and related people have to face a great challenge, as these wastes are infectious, hazardous, radioactive, etc. For example, cytostatic drugs used in cancer therapy are highly hazardous [Hansen et al., 2014].

Bio-medical wastes collection, segregation, packaging, storage, transportation, treatment, and disposal should be very carefully and safely. About 85% of the global healthcare waste is general waste and non-hazardous, the remaining 15% of waste can be infectious, toxic, or radioactive [WHO, 2014].

6.3.1 Non-infectious Waste

Non-hazardous wastes create from administrative, kitchen, and housekeeping functions at healthcare facilities. About 75-90% of medical waste, such as filter bags, papers, and newspapers, beverage bottles, glass package, fruit bowls, sweepings, the content of ashtrays, etc. created in the medical site is similar to domestic waste [Prüss et al., 2014].

Healthcare wastes, such as bandages or dressings, plaster casts, contaminated medical disposables, gloves, swabs, masks, gowns, diapers, etc. which are contaminated with blood, body fluids, and secrets or excretes but do not carry infectious parasites, can be disposed of as domestic waste [WHO, 2014].

6.3.2 Infectious Waste

Hazardous waste may cause mortality or serious illness or pose a substantial hazard to human health and the environment if improperly managed. Infectious waste contains various pathogens, such as bacteria, viruses, parasites, or fungi in sufficient concentration. It capable of producing infectious disease is contaminated with pathogens, which can be disseminated and cause serious diseases if it is thrown away as usual public waste. It is collected in special proofed containers and labeled with the biohazard symbol [Health Care without Harm, 2004].

Sharps, such as used needles, auto-disable syringes, scalpels, infusion sets, pipettes, broken glass, knives, blades, etc. can cause cuts and puncture wounds if handled improperly. These wastes can also carry infectious diseases. Strong and efficient sharps management practices help in reducing infections [ICRC, 2011].

Chemical waste, such as laboratory chemicals, film developer, solvents, spent disinfectants, fixatives, broken thermometers, blood-pressure gauges, formalin, expired chemicals, etc. can be hazardous for toxic, corrosive, flammable, explosive, or oxidizing properties. These can be collected in leak-proof containers which have to be clearly labeled [Hansen et al., 2011].

Anatomical wastes, such as human organs, human tissues, body parts, unused blood products, fetuses, etc. have to respect ethical standards. These could be considered a subcategory of infectious waste but are often classified separately; especially when special methods of handling, treatment, and disposal are used. Especially proofed and labeled containers are necessary to carry those [Ayliffe et al., 1992].

6.4 Sewage Sludge

Sewage contains not only human feces waste but also products and contaminants from homes, industries, businesses, stormwater, landfill leachate, and contaminants leached from pipes [Harrison et al., 1999]. Sewage sludge can contain all heavy metals, such as Cd, Cu, Cr, Pb, Hg, Mo, Ni, Zn, etc., and organic and inorganic pollutants, such as polychlorinated biphenyls, dioxins, persistent pharmaceuticals we use in daily life [Harrison et al., 2006]. Sludge is rich in nutrients, such as nitrogen (N), phosphorous (P), and micronutrients, and also contains valuable organic matter that is potentially useful for the improvement of soils. The processing of sewage sludge offers a good opportunity to recycle P [Brod et al., 2012].

The German Environment Ministry has updated the Sewage Sludge Ordinance of 1992. About 1.8 million tons of phosphorus-rich sewage sludge is used as a fertilizer in agriculture (25%) and in landscaping (10%) and the rest (65%) is incinerated. The Government of Germany (GOG) and the Federal States (Länder) have jointly passed an Ordinance on 3 October 2017 to use all sewage sludge in agriculture over the next 15 years [BMU, 2018].

6.5 E-Waste

In our daily life e-products, such as mobile phones, laptops, computers, electric bulbs, television sets, etc. are essential and ultimately these become waste. At present e-waste is one of the fastest-growing waste streams worldwide. The global annual growth rate of e-waste is 4 to 5% [Mishra, et al. 2017]. E-waste is generated from several sources, such as industries, institutions, and households. The toxicity of e-waste can contaminate the environment and is very dangerous to human health if these are not managed appropriately [Eguchi et al., 2012, Lucier & Gareau, 2019].

In 2016, about 50 million tons of e-waste were generated globally, but only 20% was recycled and 4% was sent to landfill sites [Baldé et al., 2017]. European countries generate about 8.3 to 9.1 million tons and the USA alone generates about 10 million tons of e-waste per annum [Wu et al., 2015]. More than 53.6 million tons of e-waste (an average of 7.3 kg per capita) is generated globally every year due to increased population, economic prosperity, technological development, dropping of IT products, and increase of non-durable products. The global generation of e-waste grew by 9.2 million tons since 2014 and is projected to grow to 74.7 million tons by 2030; almost doubling in only 16 years. Much of these e-wastes incinerates or throws in landfill that causes environmental pollution, human health hazards and the loss of valuable finite resources [Forti et al., 2020].

The lifetime of almost all electronic devices has been substantially shortened globally due to advancements in electronics, attractive consumer designs, and marketing and compatibility issues. For example, in the USA more than 130 million computers, monitors, and televisions become out-of-date annually [Bushehri, 2010]. Develop countries export large amounts of e-waste to developing countries (most of them are in Asia and Africa) that bear toxic chemicals [Robinson, 2009].

E-waste contains various toxic metals, such as lead (Pb), barium (Ba), cadmium (Cd), beryllium (Be), mercury (Hg), cobalt (Co), chromium (Cr), hexavalent chromium (Cr(VI)), copper (Cu), iron (Fe), lithium (Li), lanthanum (La), manganese (Mn), molybdenum (Mo), nickel (Ni), silver (Ag); persistent organic pollutants (POPs), such as dioxin, brominated flame retardants (BFRs); polycyclic aromatic hydrocarbons (PAHs); polychlorinated biphenyls (PCBs); polybrominateddibenzo-p-dioxins and dibenzofurans (PBDD/Fs); Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs); and polyvinyl chloride (PVC) [Kiddee et al., 2013]. For example, the presence of significant concentrations of these toxic substances is found in blood, serum, hair, scalp hair, human milk, and urine who live near recycling factories [Asante et al., 2012].

6.6 Waste Batteries

A battery is a transportable electrochemical device able to convert the stored chemical energy into electrical energy with high efficiency and no gaseous emissions [Scrosati & Sun, 2011]. Old batteries contain not only valuable raw materials but also substances that are environmental and health hazards. Valuable secondary raw materials, such as lead, zinc, steel, mercury, ferromanganese, cadmium, plastic, etc. can be recovered from waste batteries and reused. In 2006, more than 40,000 tons of portable batteries and accumulators are collected [BMU, 2006]. CCR REBAT is the largest take-back system for portable batteries in Germany. It collects used batteries at over 16,000 locations in Germany and ensures that they are recycled safely [BMU, 2018].

Directive 91/157/EEC was adopted on 18 March 1991 to reduce these hazards by harmonizing EU member states' laws. The European Battery Directive 2006/66/EC was adopted in Europe from 26 September 2006 [Battery Directive, 2006]. The Batteries Act (BattG) came into force in Germany on 01 December 2009. It governs the sale, return, and disposal of batteries and accumulators and transposes the European Directive 2006/66/EC into national law [BMU, 2018]. Directive 2006/66/EC was amended by Directive 2013/56/EU of 20 November 2013 [Battery Directive, 2013].

6.7 Municipal Waste

Every year, more people are joining the cities; consequently, the pressure on cities is increasing. For example, 72% of people in the EU now live in cities, towns, and suburbs. It is expected that the figure will reach 80% in 2021 [McQuibban, 2020].

In Germany, large quantities of commercial wastes are generated by more than 3.6 million businesses every year, with about 6.4 million tons of mixed municipal commercial wastes (MSWs). In recent years, only around 45% of this mixed MSW was pretreated in sorting facilities and 55% was used directly for energy recovery. Only about 0.4 million tons of 2.6 million tons of pretreated mixed waste was segregated and recycled, i.e., only 7% of 6 million tons of mixed MSW of commercial origin was recovered for materials [BMU, 2018].

MSW recycling continued to increase steadily from 52% (52.8 million tons) in 2001 to 64% (50.1 million tons) in 2014. MSW recycling covers different trends in material and organic recycling. In 2001–2014, material recycling increased from 19.6 million tons (38%) to 23.3 million tons (47%); while organic recycling increased only from 7.6 million tons (15%) to 8.6 million tons (17%). MSW generation decreased during 2001-2006 from 632 to 564 kg per person but then increased steadily to 618 kg in 2014 [Merta, 2016; Eurostat, 2016].

The new Commercial Wastes Ordinance enacted on 01 August 2017 that made the mandatorily separate collection of paper, board and cardboard, glass, plastics, metals, wood, textiles, bio-waste, and other production-specific waste fractions and from 01 January 2019 it is mandatory recycling rates of 30%; the Gewerbeabfallverordnung (GewAbfV) regulation governs the handling of these wastes [Auflage, 2020].

During the last 10 to 15 years, awareness and recognition of the importance of zero waste have grown rapidly. In 2007, the first zero-waste municipality was born in Capannori, Italy (led by a primary school teacher, Rossano Ercolini, later Goldman Environmental Prize Winner). About 400 European municipalities have committed to Zero Waste Cities Programme in Brussels to make waste zero very soon for a sustainable future. In 2019, Svilengrad (Bulgaria) and Kiel (Germany) became the first zero-waste cities in their countries. At present, 1.77% of the collective EU, UK, and Ukraine's population live in a zero-waste city. In 2020, the spread of COVID-19 global pandemic has created a great challenge for zero waste strategies [McQuibban, 2020].

6.8 End-of-life Vehicles

On 18 September 2000, the EU passed the End-of-Life Vehicle Directive [ELV Directive, 2000]. The Directive can be broken down into six basic parts as; i) prevention, ii) collection, iii) reuse and recover targets, iv) treatment, v) information gathering and dissemination, and vi) implementation [Konz, 2009]. ELVs contain various hazardous elements, such as mercury, cadmium, hexavalent chromium, anti-freeze, brake fluid, and oils, which are harmful to the environment [Simic, 2013].

On 5 December 2001, the GoG passed the bill for the "law on the disposal of end-of-life vehicles (end-o-life vehicle law)" and an explanatory statement on the bill. The End-of-Life Vehicle Ordinance enacted in 21 June 2002 allows consumers to return end-of-life vehicles to their manufacturer or importer free of charge [BMU, 2006]. It aims at material flow reductions through changes in product design. The End-of-life Vehicle Ordinance achieved on 01 January 2015 is currently the main prospective driving force for material flow innovations in the automotive industry [Karagoz et al., 2020].

In 2006, there are 46 million passenger cars on the roads of Germany. Every year, 3.3 million new cars are registered. About half a million cars and light utility vehicles are scrapped each year in Germany. In 2009, a record 1.78 million cars were scrapped. During 2006-2014 end-of-life vehicles (ELVs) recycling rate was 80% and the recovery rate was 85%. In 2015, these targets were raised to 85% and 95% respectively [BMU, 2018].

According to OECD, the total number of registered vehicles in OECD countries has grown by 4% a year within the period of 2014–2018 [OECD, 2019]. In 2006, there were 600 million cars in the world, with 49,886,549 being produced in 2006 alone [Konz, 2009]. The automotive sector generates about 5% of industrial waste in the entire world [Simic, 2013]. As the number of ELVs is estimated to increase to about 80 million units globally per year by 2020, ELVs WM is necessary for the environment and CE [WRME, 2014]. In the EU, some 15 million vehicles reach their end of life every year due to accidents and old age

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[Johnson, 2002]. The number of ELVs arising in the EU-25 to be about 14 million in 2010, compared to 12.7 million in 2005 [Schneider, 2010].

6.9 Mineral Waste

In 2015, the most important mineral commodities (valued at $14.87 billion) were bituminous and lignite coal, crude petroleum (90.5 million tons), natural gas (115.4 million cubic meters) and petroleum gas, peat, and the processing and manufacture of metals, such as lead, nickel, and steel. In 2015, the country also imported 7,277 kg of enriched uranium and exported 21,589 kg, imported 1.16 million tons of copper concentrate, imported 283,098 tons of zinc concentrate and exported 91,689 tons of zinc metal, imported 19,397 tons of tin metal, imported 42 million tons of iron ore and concentrates, imported 12,177 tons crude steel and exported 4,045 tons, imported 162 tons of tungsten ore and concentrate and exported 62 tons, imported 61 tons of tungsten metal, imported 1,249 tons ferrotungsten [Perez, 2019]. Berlin's Waste Management Strategy includes ambitious climate protection targets, featuring an additional annual reduction of 1.1 million tons of CO_2e by 2020. In 2017, more than 275 million tons of mineral wastes are produced in Germany [BMU, 2018].

7. German WM Strategy

WM has evolved substantially since the early 1970s in Germany. German policy on WM is to achieve a recycling-based economy that conserves resources and reduces adverse impacts on the environment [Eurostat, 2014]. In the mid-1980s the political credo of the so-called waste hierarchy "*avoid, reuse, and dispose of*" gained acceptance. Recovery of metal, textiles, paper, and other recoverable materials were to be recycled through the separate collection, sorting, and reuse [BMU, 2006]. Circular Economy Act and Packaging Act are the best contributors to German WM policy. Avoiding waste through prevention, reduction, recycling, and reuse enhances the idea of a CE [UN, 2015].

Recently Germany has achieved remarkable progress in WM. In Germany, waste recovery and recycling rates reach 81% and 69%, respectively in 2018. In 2015, it has 1,143 landfills, 76 incineration plants, and 2,171 recovery facilities [Schroeder & Jeonghyun, 2019]. The GoG has taken WM policy efficiently to achieve a recycling-based economy that conserves resources and reduces adverse impacts on the environment. It attempts to optimize the efficient use of raw materials, maximize recovery quotas, and permanently remove from the environment any residual waste which can no longer be used. The German WM system has no subsidies and the producer has to pay for waste treatment or disposal [Nelles et al., 2016]. In Germany, since 01 June 2005 waste may no longer be dumped in landfills without any pre-treatment and non-recoverable waste must be disposed of safely, without harming the environment or human health [BMU, 2018].

Germany followed the "Waste Disposal Act" in early 1976. The new "German Closed Cycle Management Act" took steps to turn the WM into resource management. It indicates that waste can be a useful source of raw materials and energy [Nelles et al., 2016]. In Germany, WM is also striving towards a closed-loop economy. The German Waste Prevention Programme (Abfallvermeidungsprogramm) was launched in 2013 with the contribution of the federal states. To implement CE, Germany employed about 200,000 people in 3,000 companies and turnover €40 billion per year in 2013. In 2018, the corresponding figures became 290,000; 11,000 and €76 respectively [BMU, 2018].

The National Sustainability Strategy was confirmed from 2002 to increase raw material productivity by 100%. The strategy aims for an economical productive, socially balanced, and ecological compatible development. In 2012, the second strategy is the German Resource Efficiency Programme (ProgRess). In 2016, the Federal German cabinet decided on the German Resource Efficiency Programme II (ProgRess II). The German Federal Ministry of Education and Research (BMBF) recently funded R&D projects on resource-efficient CE [Kreislaufwirtschaftsgesetz, 2012; Country Profile, 2021]. At present recoverable substances are being separated before landfilling and the energy from the wastes is being utilized [Nelles et al., 2016]. Landfill greenhouse gas, such as methane (CH_4) is about 21-25 times more harmful to global warming than carbon dioxide (CO_2) [Mohajan, 2012].

In Germany, more than 30 organizations from the private sector, academia, civil society, and government institutions launched the Prevent Waste Alliance in May 2019. More than 15,500 WM facilities help to conserve resources through recycling and other recovery operations. Objectives of it are to minimize waste, eliminate pollutants and maximize the reutilization of resources in the economy worldwide. They work together for waste prevention, collection, and recycling, as well as, the increased uptake of secondary resources in low and middle-income countries. In the last 30 years of attempts of CE efforts, German citizens obtained huge benefits and eager CE applications should be continued in the future. In 2017, there were 68 waste incineration plants in Germany with a capacity of about 20 million tons, as well as, 32 substitute fuel plants with a combustion capacity of about 5 million tons [BMU, 2018; Country Profile, 2021]. In Germany, Act KrWG-2012 aims to prevent waste, recovery of waste, disposal of waste, and other activities of WM [Kreislaufwirtschaftsgesetz, 2012].

In 2006, more than half of municipal and production waste is recycled in Germany; for example packaging, more than 80%. Total volumes of waste recovered are; 28 million tons of municipal waste, 30 million tons of production and industrial waste, and 163 million tons of construction and demolition waste, i.e., three tons of waste is recovered for each resident in Germany [BMU, 2006].

E-waste is hazardous to human health, with documented risk to the brain nervous system, lungs and kidneys, as well as, links to certain cancers. It also contaminates the soil, air and water [Forti et al., 2020]. The WEEE Directive was adopted in 2003 to institute harmonized European regulations for e-waste. The directive was transposed into German law via adoption of the 2005 Elektro- und Elektronikgeräte-Gesetz (ElektroG) law. An amended version of the directive, known as WEEE II, was enacted in July 2012. This directive was transposed into German law via the amended version of the ElektroG law, which was passed in 2015 [Kazancoglu et al., 2020]. In 2016, only 20% of e-waste was recycled globally. Often e-waste is mixed with residual waste and incinerated, placed in a landfill, or exported to developing countries (Western Africa and parts of Asia) [Forti et al., 2020]. Between 2006 and 2015, some 7.2 million tons of WEEE were collected and treated in Germany. In 2018, about 853,124 tons of e-wastes were collected; 772,934 tons of it from households (per capita 9.31 kg per year), and the remaining 80,190 tons from businesses [Kazancoglu et al., 2020].

Collection of packaging waste, either door-to-door or through collection points is free of charge for citizens and is funded by EPR schemes. But all drink containers excluding wine, fruit juice, milk, sparkling wine, or spirits have a deposit fee [Gibbs et al., 2014]. In 2012, about 94 waste incineration plants were operating in Germany to conduct residual waste and 60 mechanical biological treatment (MBT) plants of various types and configurations [Federal Statistical Office, 2015].

In Germany, biodegradable waste is collected separately; recycled efficiently and ecologically, and economically [Schüch et al., 2016]. The German recycling policy framework the packaging law (Verpackungsverordnung), was adopted in 1991 [EEA, 2013]. In Germany, annual raw material consumption (RMC) for 2010 is stated to be around 15.3 tons; about half of this is from non-metallic minerals, one-third

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from fossil energy carriers, and about one-fifth from biomass [UBA, 2016]. In Germany, resource efficiency is the major policy to foster recycling. The recycling rate of demolition waste is more than 90% in the country although it is usually not circular [Haupt, 2019].

In 2001, Germany had already recycled 52% of municipal waste (MSW), whereas about 26% was landfilled and 22% was incinerated. In 2014, the level of recycling had increased to 64%, landfilling was as low as 1% and incineration had increased to 35% [Eurostat, 2016]. To control e-waste it is necessary to collect e-waste properly, recover and recycle material by safe methods, develop eco-design devices, dispose of e-waste by suitable techniques, forbid the transfer of used electronic devices to developing countries, and raise awareness of the impact of e-waste [Kiddee, 2013]. There is little household and public awareness about the precautions and proper management of e-waste in many developing countries because large proportions of their populations are relatively unaware of the precautionary measures necessary for handling and disposing of e-wastes [Sivanthanu, 2016].

8. Benefits of the CE

The environmental benefits of the CE in Germany are the benefits of the soil, water, air, and climate. The benefits for the CE are to create a high number of new jobs and reduce harmful emissions significantly. If products are designed for reuse over a longer period waste is avoided. From the economic point of view the implemented CE has turned out in 2016 as a successful new economic field with about 200,000 employees, 6,000 companies, and €40 billion of turnover per year [Bau und Reaktorsicherheit, BMUB, 2016]. In 2018, the corresponding figures become 270,000; 11,000, and €70 billion respectively [BMU, 2018].

Act KrWG-2012 also created the opportunity to introduce an obligatory, nationwide “uniform recycling bin”. CE has considerable positive potential in Germany. It is estimated that in Europe net social benefits of CE will be €900 billion per year by 2030 [Weber & Stuchtey, 2019]. In 2019, about 9.3 million tons of e-waste are collected and recycled, which is 17.4% of generated e-waste. E-waste also contains gold, silver, copper, platinum, palladium and other recoverable materials. In 2016, it is estimated that the country can earn €55 billion by recovering these metals from e-waste [Forti et al., 2020].

9. Conclusions and Recommendations

In the last 45 years, Germany has taken various remarkable steps to develop CE through the WM policy. The country still faces some problems and some new problems are arising. Since 01 January 2015, more recyclable wastes are collected and recycled. In the study, we have observed that Germany has benefited from the implementation of CE. Germany has earned a lot of money by recycling, a large number of people have employed in the CE projects, stress on import of raw materials has reduced, reduces greenhouse gas emissions, reduces emissions of seriously harmful for human health, etc. In the study, we have observed that CE strategies are 3Rs principle (such as recovery, reuse, and recycling of resources), circular supply-chains, new business models, product life extension, and deep technological innovations. There are major problems between the municipal and the private WM policy. The collection of all organic wastes has not been realized nationwide. Still, many wastes are incinerated.

On our planet resources are limited and CE is the best way to move toward a sustainable world for tackling the growing populations. Germany must use its existing skills and structural strengths to implement CE, and in the future, it will apply new technologies through R&D for the development of CE in future.

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