1 Circular Economy Catalysing Decarbonization

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Abstract

Experts, scholars, and policy makers worldwide have proved and accepted that global warming is real with scientific evidence. The Paris Agreement sets the goals of keeping global warming to well below 2 °C and as close to 1.5 °C as possible compared to pre-industrial levels. On the other hand, the extraction rates of natural resources are increasing at a higher rate. Actions are very much required to control all these issues. Circular economy thinking is a recognition that we can no longer be indifferent to the finite resources of the globe. New business models and tools have been developed that will support a more resilient future. Circular economy will help reducing the extraction of natural resources with its regenerative concepts. Decarbonization can refer to moving away from energy systems that produce carbon dioxide (CO_2) and other greenhouse gas emissions or it can refer to removing carbon build up and carbon deposits from internal combustion engines. Both the processes have the same objectives of removing carbon, but in different ways. Energy decarbonization involves shifting the entire energy system to stop carbon emissions from entering the atmosphere before they are ever released and part of that process also involves using carbon capture technologies to remove CO_2 from the air after it has already been released. This involves decarbonizing power grids, decarbonizing supply chains, and utilizing carbon sequestration in the pursuit of net-zero emissions and a carbon neutral global economy. Circular economy will help making longer life

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cycle of products, conserve resources leading to zero wastage and help decarbonization by reducing carbon footprints. The sustainable development goals encourage the implementation of circular economy and decarbonization with an integrated approach by all stakeholders in the society. This article studies how the circular economy catalyse the decarbonization.

1.1 Introduction

We are in the middle of a climate crisis. The climate crisis is featured every day in the media reporting the images of floods, melting of ice, droughts, forest fires, and the damage these disasters inflict on local populations, particularly the downtrodden people in the society. The 2020 was set to kick-start the "decade of action" for the UN Sustainable Development Goals ("Sustainable Development Goals", https://www.un.org/sustainabledevelopment/decade-of-action/). To date, thousands of experts and scholars worldwide have proved that global warming is real with all kinds of scientific evidence (Fawzy et al. 2020). The Paris Agreement sets the goals of keeping global warming to well below 2 °C and as close to 1.5 °C as possible compared to pre-industrial levels, making all economies resilient to climate impacts, and ensuring that financial flows are consistent with these objectives (UNFCCC 2015). The task is enormous: the transformations needed will require realigning 7–19% of GDP worth of private and public spending every year. The 2020 Circularity Gap Report recorded a bleak, first-time milestone of 100 billion tons of materials enters the global economy every year. These materials are funnelled through our economy and allow us to continue our way of life. However, of this massive amount, only 8.6% is recycled and returned to the economy reducing the extraction of natural resource. The towns and cities are a major source of the greenhouse gas emissions (GHGs) that aggravate the climate crisis. The report entitled, "Circular Cities Impacts on Decarbonization and Beyond" in its January 2022 edition commented that, "with global projections indicating that there will be another two billion on the planet by the time we reach the 2050 target for Net Zero, it is clear that we need to tackle the GHGs in the built environment if we want to have any chance of mitigating the worst of the climate impacts to come". The same is also true to India, where the highest population of 1.42 billion in the globe resides as in April 2023. To reach its temperature goals, the Paris Agreement and the subsequent decisions of its parties give central importance to emission reduction strategies, decided by and for individual countries, following the principle of common but differentiated responsibilities and respective capabilities. This can take the form of Nationally Determined Contributions (NDCs) or Long-term Low-emission Development Strategies (known as LEDS, LT-LEDS or LTS). More than 50 countries globally, including 11 in Latin America and the Caribbean—have enacted targets to reach net-zero carbon or greenhouse gas (GHG) emissions, and more than 140 other countries have announced or are considering similar targets (Net Zero Tracker 2022; Andreas et al. 2022).

Circular economy concept is a recognition that we have to concern about the finite resources of the globe. New business models and tools have been developed that will support a more resilient future. It has been studied and observed by several researcher that circular thinking is already driving practical change, showcasing some of the success stories that demonstrate that significant difference can be made access to the right tools and a willingness are demonstrated to take action.

In last centuries, the global consumption and resource use can be described as "epcd2" (extract-produce-consume-dispose-deplete), or, "take-make-use", a linear economy approach (Ghosh et al. 2022). There are no questions about the growth that took place during last centuries with the *epcd2* approach but with the rates of increase in global extraction of natural resources, the scientists, environmentalists, and the policy makers were worried about the sustainability. Moreover, the processes following epcd2 involved huge over-consumption to the detriment of planetary health. The evolution of the concept and practice of the new circular economy models opens up the eyes of the global community and encourage to have the focus from "epcd2" with a paradigm shift to "zero-waste" and resource conservation focus of circular economy. Instead of depleting the resources at the end-of-life time of the intended use of a product. It is considered as a secondary raw material for a second production process. A circular economy is restorative and regenerative by design and aims to eliminate the concept of waste as per Ellen MacArthur Foundation. The "epcd2" process involves more carbon footprints than that of the processes following "Zero-Waste" model of circular economy as per Ghosh et al. (2022). This way the circular economy contributes to the extraction of natural resources and decarbonization in the processes. These characteristics present new ways to reduce consumption-based emissions while creating added value in terms of resilience and quality of life.

Seven core societal needs, namely, Housing, Nutrition, Mobility, Communications, Services, Consumables, and Healthcare have been identified in The Circularity Gap Report 2021 which have a big potential to cut down attributed emissions and resource use once circular economy concepts are implemented. A consensus has been reached that the surge in human-caused carbon emissions is the primary cause of global warming. The concept of carbon neutrality is designed to control global temperature rise (Chen 2021). Three key human needs, housing, mobility, and nutrition, are responsible for almost 70% of global emissions. Only 8.6% of the whole economy is circular which needs to be almost double to 17% to keep the planet sustainable. Circular strategies can "drastically reduce" the amount of minerals, fossil fuels, metals, and biomass consumed by the world's economy. Climate change and environmental restoration are top priority for the nations and local governments around the world. Cities account for 70% of global carbon emissions, 60% of resource use, and produce 50% of global waste and in this context, they are a part of the problem (Enel 2022).

COP27 is another crucial milestone to a net-zero world. In last few years companies were focusing on addressing direct emissions from company-owned and controlled resources from activities at the firm level, as well as emissions related to the generation of purchased energy, steam, heat, and cooling. The more we know about how the supply chains work, the more focused approaches can be adopted to close loops and concentrate on resilience. The planetary temperature continues to rise due to the heat-trapping nature of the greenhouse gas (GHG) emissions, more people and infrastructure are at risk, costing our economy heavily. Hence, it becomes necessary to adopt practices to reduce or zero down the carbonization from the firm level activities. To discuss about the decarbonization, it is pertinent to discuss about the Carbon Footprints. The next section will elaborate on Carbon Footprint and greenhouse gases.

1.2 Carbon Footprints and Greenhouse Gases

Carbon footprint has become a widely used term and concept in the public debate on responsibility and abatement action against the threat of global climate change and an essential concept for assessing the impact of human activities on the ecological environment (Wiedmann and Minx 2008a, b). It is mainly used to measure GHG emissions (Hammond 2007). While the term itself is rooted in the language of Ecological Foot printing (Wackernagel and Rees 1996), the common baseline is that the carbon footprint stands for a certain amount of gaseous emissions that are relevant to climate change and associated with production or consumption activities.

Nowadays, the carbon footprint has become combining the concept of carbon footprint with other energy research objects to study the effect of Carbon emission (CE_m) on the ecological environment from different perspectives, such as fossil energy footprint (Wiedmann and Minx 2008a, b), nuclear energy footprint (Stoeglehner and Narodoslawsky 2009), clean energy footprint (Chen and Lin 2008), wind energy footprint (Santhanam 2011), and solar energy footprint (Brown 2009). The popular method for determining the carbon footprint involves calculating the CE amount from energy utilization or converting CE amount into an equivalent bioproductive land area (Galli et al. 2012; Bonfiglio et al. 2020)

Several researchers have developed the definition of Carbon Footprints (CF) for better understanding. As per the dictionary, carbon footprints (plural noun) are the amount of carbon dioxide released into the atmosphere as a result of the activities of a particular individual, organization, or community. Carbon footprint is defined as the measure of the total greenhouse gas emissions released into the atmosphere. These emissions are caused by the choices and actions of an individual, company or a nation. Carbon footprint is measured in terms of carbon dioxide emissions (CO_2). In other words, Carbon footprint is the amount of carbon dioxide (CO_2) emissions associated with all the activities of a person or other entity (e.g., building, corporation, country, etc.). It includes direct emissions, such as those that result from fossil fuel combustion in manufacturing, heating, and transportation, as well as emissions required to produce the electricity associated with goods and services consumed. In addition, the carbon footprint concept also often includes the emissions of other greenhouse gases, such as methane, nitrous oxide, or chlorofluorocarbons (CFCs) (Selin 2023a, b). Table 1.1 demonstrates a few definitions of Carbon Footprints proposed by different researchers and organizations. Most researchers and organizations in defining CF dealt with the question of how much carbon dioxide emissions can be attributed to a certain product, company or organization, although none of them provides unambiguous definition of the term carbon footprint. In the definitions it has been observed that "carbon footprint" is used as a generic synonym for emissions of carbon dioxide or greenhouse gases expressed in CO_2 equivalents.

ISO 14067: 2018 has also defined as the partial carbon footprint of a product as the sum of GHG emissions and GHG removals of one or more selected process (es) in a product system, expressed as CO_2 equivalents and based on the selected stages or processes within the life cycle. A partial CFP is based on or compiled from data related to (a) specific process(es) or footprint information modules, which is (are) part of a product system and can form the basis for quantification of a CFP. More detailed information on information modules is given in ISO 14025:2006, 5.4. "Footprint information modules" is defined in ISO 14026:2017, 3.1.4. The results of the quantification of the partial CFP are documented in the CFP study report expressed in mass of CO2e per declared unit.

As per ISO 14067: 2018, carbon dioxide (CO_2) equivalent, CO_2e is the unit for comparing the radiative forcing of a GHG to that of carbon dioxide. Mass of a GHG is converted into CO_2 equivalents by multiplying the mass of the GHG by the corresponding GWP (Global Warming Potential) or GTP (Global Temperature Potential) of that gas. In the case of GTP, CO_2 equivalent is the unit for comparing the change in global mean surface temperature caused by a GHG to the temperature change caused by CO_2 (Source: ISO 14064-1:2006).

It is essential to understand greenhouse gases (GHGs) while discussing carbon footprint. GHGs are responsible for keeping our planet warm. Without them, the earth would be uninhabitable. Water vapour, methane from natural gas, nitrous oxide from soils and oceans, ozone, and carbon dioxide are its main constituents. Greenhouse gases protect us from the sun's radiation and regulate the internal heat on the planet. But a significant increase in greenhouse gases also represents a risk. Greenhouse gases (GHGs) act like a blanket insulating the Earth and warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb energy (their "radiative efficiency"), and how long they stay in the atmosphere (also known as their "lifetime").

1.2.1 GWP (Global Warming Potential) and GTP (Global Temperature Potential)

While discussing the carbon footprints and greenhouse gases (GHGs), two terminologies—Global Warming Potential (GWP) and Global Temperature

Table 1.1 Definition of carbon footprints

Definition	Reference
Carbon footprint of product is the "sum of GHG emissions and GHG removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change"; A CFP can be disaggregated into a set of figures identifying specific GHG emissions and removals. A CFP can also be disaggregated into the stages of the life cycle. The results of the quantification of the CFP are documented in the CFP study report expressed in mass of CO_2e per functional unit	ISO 14067: 2018 Greenhouse gases—carbon footprint of products-Requirements and guidelines for quantification
The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product	Wiedmann and Minx (2008a, b)
"The carbon footprint is the amount of carbon dioxide emitted due to your daily activities—from washing a load of laundry to driving a carload of kids to school"	
The carbon footprint was calculated by "measuring the CO_2 equivalent emissions from its premises, company-owned vehicles, business travel and waste to landfill"	British Sky Broadcasting (Sky)
". . . a methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions)". ". . . a technique for identifying and measuring the individual greenhouse gas emissions from each activity within a supply chain process step and the framework for attributing these to each output product (The Carbon Trust will refer to this as the product's 'carbon footprint')"	
". . . the full extent of direct and indirect CO_2 emissions caused by your business activities"	Schneider Electric (2021)
". . .the 'Carbon Footprint' is a measure of the impact human activities have on the environment in terms of the amount of greenhouse gases produced, measured in tonnes of carbon dioxide"	
"The demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion"	Global Footprint Network (2007)
"A carbon footprint is a measure of the amount of carbon dioxide emitted through the combustion of fossil fuels. In the case of a business organization, it is the amount of CO_2 emitted either directly or indirectly as a result of its everyday operations. It also might reflect the fossil energy represented in a product or commodity reaching market"	Grubb and Ellis (2007)
"A 'carbon footprint' is the total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product. It is expressed as grammes of CO_2 equivalent per kilowatt hour of generation (gCO_2eq/kWh), which accounts for the different global warming effects of other greenhouse gases"	Parliamentary Office of Science and Technology

Potential (GTP) must be discussed for easy understanding. Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. GWP is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. The time period usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers and scientists to compare emissions reduction opportunities across sectors and gases.

An alternate metric of GWP is the Global Temperature Potential (GTP). The GTP is a measure of the temperature change at the end of that time period relative to CO_2, whereas GWP measures the heat absorbed over a given time period due to emissions of a gas. The calculation of the GTP is more complicated than that for the GWP, as it requires the modelling for how much the climate system responds to increased concentrations of GHGs (the climate sensitivity) and how quickly the system responds (based in part on how the ocean absorbs heat) (USEPA 2023). Table 1.2 demonstrates the GHG components, their estimated GWP, their estimated lifetime, and other related information.

The Carbon Emission (CE_m) of power generation mainly refers to the Carbon Emission of coal, oil, natural gas, and other fossil fuel combustion in the process of thermal power production. In addition to the direct CE_m of production process, the CE_m of power generation also includes the implicit CE_m (Stoeglehner and Narodoslawsky 2009; Zhang et al. 2017). In decarbonising certain industry segments and long-distance transport, hydrogen could play a significant role in European Union. The associated technologies are largely at an early stage of deployment and are not very competitive with fossil fuel alternatives. This may be noted that the hydrogen consumed today is mostly derived from fossil fuels. In particular, the European Union and its Member States have recently reasserted their intention to implement Contracts for Difference (CfDs) to support hydrogen production (Bouacida 2023). Some hydrogen technologies are key to the decarbonization of industry, including electrolysis for hydrogen production and the direct reduction of iron ore with hydrogen for steel production (Bouacida and Berghmans 2022; IEA 2019; Ueckerdt et al. 2021). Currently, although alkaline electrolysis and polymer electrolyte membrane (PEM) electrolysis are fairly mature technologies, they remain sparsely deployed; while other electrolysis technologies, such as solid oxide electrolysis (SOEC), are still not at the commercial stage but could significantly contribute to decarbonization (IEA 2023).

In 2019, the transport sector accounted for 23% of total CO_2 emissions from energy and industrial processes, with passenger cars at 9%, or just over 3 $GtCO_2$ (IEA NZ 2021). The passenger car emissions need to decrease by 11% per year for the next 30 years according to the IEA's Net Zero Emission (NZE) scenario by 2050. Only 16% of the NDCs submitted by October 2021 by different nations included transport emission reduction targets, with the vast majority of measures discussed focusing only on reducing fuel consumption, developing low-carbon fuels, and electric vehicles (OECD/ITF 2021). NDCs also need to be developed in conjunction

Table 1.2 GHG components, estimated GWP, and lifetime

The GHG components	Estimated GWP	Lifetime	Remarks
Carbon dioxide (CO_2)	GWP of 1 regardless of the time period used, because it is the gas being used as the reference	CO_2 remains in the climate system for a very long time: CO_2 emissions cause increases in atmospheric concentrations of CO_2 that will last thousands of years	
Methane (CH_4)	GWP of 27–30 over 100 years	CH_4 emitted today lasts about a decade on average, much less time than CO_2. CH_4 absorbs much more energy than CO_2	Net effect of shorter lifetime and high energy absorption is reflected in GWP. CH_4 GWP accounts for some indirect effects, e.g., CH_4 is a precursor to ozone, which itself is a GHG
Nitrous oxide (N_2O)	GWP 273 times that of CO_2 for a 100-year timescale	N_2O emitted today remains for more than 100 years, on average, in the atmosphere	
Chlorofluorocarbons (CFCs)	Called high-GWP gases	For a given amount of mass, CFCs trap substantially more heat than CO_2	GWPs can be in the thousands or tens of thousands
Hydrofluorocarbons (HFCs)	Called high-GWP gases	For a given amount of mass, HFCs trap substantially more heat than CO_2	GWPs can be in the thousands or tens of thousands
Hydrochlorofluorocarbons (HCFCs)	Called high-GWP gases	For a given amount of mass, HCFCs trap substantially more heat than CO_2	GWPs can be in the thousands or tens of thousands
Perfluorocarbons (PFCs),	Called high-GWP gases	For a given amount of mass, PFCs trap substantially more heat than CO_2	GWPs can be in the thousands or tens of thousands
Sulphur hexafluoride (SF_6)	Called high-GWP gases	For a given amount of mass, SF_6 traps substantially more heat than CO_2	GWPs can be in the thousands or tens of thousands

with long-term low GHG emission development strategies, to achieve the ambition level to commensurate with what is needed to reach net-zero in 2050 (Waisman et al. 2019). Currently, 50 countries have submitted such long-term strategies (UNFCCC 2022), providing coverage for more than 40% of global CO_2 emissions (IEA NZ 2021), and only ten countries mentioned a 2050 transport targets (SLOCAT 2021).

Transport sector is one of the significant sectors that has higher carbon footprints. In Brazil, India, Indonesia, and South Africa, passenger transport emissions accounted for 4–7% of national GHG emissions in their baseline years (2019 in Brazil, 2012 in India, 2010 in Indonesia, and 2017 in South Africa). However, while the population and access to mobility continues to grow in all countries, analyses highlight possible pathways for a low-carbon transition of the passenger transport sector. Passenger transport emissions could be reduced by 35–90% between 2050 and the baseline years 2012 and 2017 in India and South Africa, respectively, reaching less than 0.04 tCO_2eq/capita, around 0.1 tCO_2eq/capita in Indonesia and around 0.2 tCO_2eq/cap in Brazil (Yann et al. 2023). On a per passenger kilometres travelled (pkm) basis, emissions are reduced by 66–92% in 2050 relative to the baseline years, reaching less than 8 gCO_2eq/pkm in India and South Africa and around 12gCO_2eq/pkm in Indonesia and Brazil. It should be noted that the average passenger domestic transport emissions per capita in non-OECD countries lies around 0.5 tCO_2/cap, while OECD countries have values of around 3 tCO_2/cap (OECD/ITF 2021). The share of passenger mobility by cars or motorized two-wheelers seen today varies considerably between countries (Fig. 1.1).

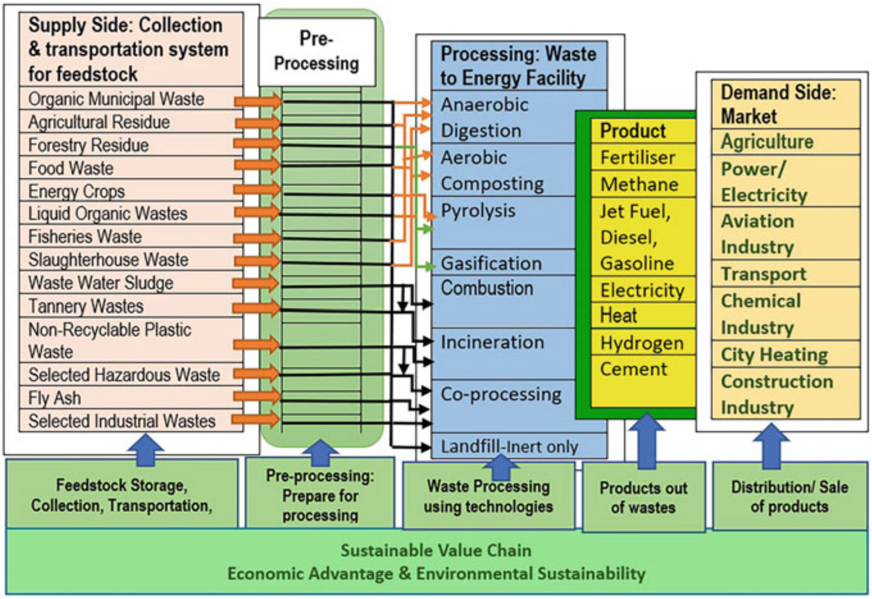

Fig. 1.1 Share of private motorized mobility (car and motorized 2-wheelers) in total mobility (% Gpkm), 2020–2050 (Source: Adopted from Yann et al. 2023)

In the figure, it is observed from the data in combination these represents more than 53% of passenger mobility in Indonesia representing a larger share of motorized 2-wheelers (35%) and a lack of public transport. While it accounts for less than 30% in India, public transport is highly subsidized by the government to support the lower- and middle-class population (70% of the total population), who therefore travel more by public transport. The objective of the nations is to allow people with more incentives continue preferring public transport.

1.3 Direct and Indirect Carbon Emissions Accounting

Carbon accounting, also known as a carbon or greenhouse gas inventory, is the process of measuring the amount of carbon dioxide, or other greenhouse gas (GHG), an organization emits help the entity in understanding its climatic impact. Carbon accounting is very important in the business today. The process helps organizations highlight and target high GHG emitting operations with emission reduction strategies. As such, in 2022, 81% of S&P 500 companies reported their own emissions (scope 1), and the emissions of the electricity they bought (scope 2). In addition, globally, over 22,000 companies disclosed environmental data with a focus on business emissions to the Carbon Disclosure Project (CDP) in 2022. The business houses need to understand sources of emissions are coming from and the volume exuded, to then devise and implement an effective GHG reduction program.

The first meeting of the Conference of the Parties (COP1) held in 1995 in Berlin, which launched strict and precise commitments to mitigate climate change in the name of, "Kyoto Protocol" while COP28 to the UNFCCC is scheduled during November–December 2023 in the United Arab Emirates. The protocol sets binding and measurable objectives for combating climate change for the first time, stipulating global ceilings for GHGs. COP21 took place in Paris in 2015, and marked a new momentum for climate action duly signed the Paris Agreement on Earth Day (April 22, 2016), at the UN headquarters in New York by 192 states and the EU—representing 98% of global GHG emissions. It outlined the action necessary to limit global temperature rise this century below 35.6 °F (2 °C) (which is warmer than pre-industrial levels), and to cap further temperature increases to 34.7 °F (1.5 °C).

However, scope 1, scope 2, and scope 3 for Carbon accounting and reporting need to be understood. The Greenhouse Gas (GHG) emission accounting is divided into three scopes while calculating (https://greenbusinessbureau.com/green-practices/energy/what-is-carbon-accounting/). Carbon footprint is categorised under three scopes:

1.3.1 Scope 1 Emissions

Scope 1 or Direct Emissions, as defined by the GHG Protocol, are GHGs released directly by the business in question by the burning of fossil fuels onsite. Personal vehicles and gas stoves are examples of scope 1 emissions. For simplicity, when defining scope 1 emissions, think "*burnt*". Emissions from chemical production in owned or controlled process equipment falls under scope 1. Direct CO_2 emissions from the combustion of biomass shall not be included in scope 1 but reported separately. GHG emissions not covered by the Kyoto Protocol, e.g., CFCs, NOx, etc. shall not be included in scope 1 but may be reported separately.

1.3.2 Scope 2 Emissions

Scope 2 or Indirect Emissions, as defined by the GHG Protocol, are indirect GHGs released due to the energy purchased by the business in question. Energy purchased are referred to the electrical energy (purchased or acquired electricity, steam, heat, and cooling, called "scope 2 emissions"). Companies that emit carbon, but purchase electricity are examples of scope 2 emissions. For simplicity, when defining scope 2 emissions, think "*bought*". Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated. These emissions physically occur at the facility where electricity, steam, and cooling or heating are generated. But as a user of the energy, the consuming party is still responsible for the Greenhouse Gas Emissions that are being created.

1.3.3 Scope 3 Emissions

Scope 3 or Other Indirect Emissions, as defined by the GHG Protocol, are indirect GHGs released across an organization's value chain. For simplicity, when defining scope 3 emissions, think "*beyond*". All indirect emissions which are the result of a companies' activities fall under Scope 3 emissions, such as the production of goods, transportation of purchased fuel, and at an individual scale; using those produced goods. Scope 3 is an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company but occur from sources not owned or controlled by the company. Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services.

In very simple understanding,

Scope 1: Emission from Gas and company car fuel used.

Scope 2: Emission from purchased Electricity Consumed by the company

Scope 3: Everything else. Split in to 15 sub-categories. Emission from other than scope 1 and 2.

Scope 1 is direct while scope 2 and scope 3 are indirect. Scope 3 includes the carbon emission takes place in any of the activities which are purchased by the company but not the own activities. Carbon footprints for the company in scope 3 is 80–90% of the total carbon footprints of the company. The GHG Protocol outlines 15 categories that fall under scope 3 emissions (Fig. 1.2). These categories are grouped as either upstream or downstream activities (Greenhouse Gas Protocol 2011). The overview of scope 1, 2, and 3 and possible associated activities in the value chain of a company as per the GHG protocol are demonstrated in Fig. 1.3 and

Fig. 1.2 Scope 3 emissions—15 categories as per GHG Protocol outlines

Fig. 1.3 Overview of GHG protocol, Scope 1, 2, and 3 and emission in value chain (partially adopted from Greenhouse Gas Protocol 2011 developed by authors)

Table 1.3. Scope 1, scope 2, and scope 3 are mutually exclusive for the reporting company, such that there is no double counting of emissions between the scopes.

1.3.4 Carbon Neutrality and Net-Zero Goals

The global carbon neutrality goal requires countries to go beyond incremental transformations, often resulting from past trends, to consider systemic transformations with "rapid and far-reaching transitions in energy, land, urban, and

Table 1.3 Overview of the scopes (Adopted from Greenhouse Gas Protocol 2011)

Types of emission	Scope	Specification	Examples of activities/entity
Direct emissions	Scope 1	Emissions from operations that are owned or controlled by the reporting company; these sources are owned or controlled by the reporting company	Emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment
Indirect emissions	Scope 2	Emissions from the generation of purchased or acquired electricity, steam, heating, or cooling consumed by the reporting company. The sources are owned or controlled by the reporting company	Use of purchased electricity, steam, heating, or cooling
Indirect emissions	Scope 3	All indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions, which are the consequence of activities of the reporting company, occur at sources owned or controlled by another company	Production of purchased products, transportation of purchased products, or use of sold products

infrastructure (including transport and buildings), and industrial systems" (IPCC 2018a, b). Despite the momentum of decarbonization, organizations are still found slow to act on climate change and decarbonization. As of early 2020, only 23% of the Fortune 500 had set meaningful commitments to carbon neutrality, climate action, or both. Progress in European head quartered Fortune Global 500 companies has been slightly more promising, with 42% taking action or publicly committed. Several theories and postulates are being evolved and proposed by researchers and policy makers for decarbonization. The report "Achieving Net-Zero Prosperity...... (2022)" demystifies what financing the transition to net-zero emissions means. It gives a guideline for the transition towards carbon-free prosperity. Fifteen transformations (Table 1.4) in different areas have identified that rely on existing technology can help deliver deep emission reductions, acting on electricity; transport; agriculture, forestry and land use; buildings; industry; and waste management (Andreas et al. 2022). It is necessary to understand the difference between carbon neutral vs. net-zero goals. Often carbon neutral and net-zero goals are used interchangeably, the terms *carbon neutral* and *net-zero* actually represent very different approach to decarbonization and combatting climate change.

Carbon Neutrality was first proposed in 1997 by the UK's Future Forests as a business planning concept that focuses on pathways to Carbon Neutrality from an energy technology perspective in areas of transport, tourism, family life and personal behaviour. It offsets carbon emissions by buying certified carbon credits. The British

Table 1.4 Fifteen potential transformations that can help deliver deep emission reductions

Major transformations area	Transformation serial numbers	Description of transformation
Electricity	Transformation 1	Accelerate carbon-free variable and flexible electricity generation through sources such as solar, wind, geothermal, and hydropower
	Transformation 2	Phasing out all fossil fuel electricity generation, such as coal, natural gas, and diesel
Transport	Transformation 3	Reduce individual motorized transport and increase public transport, walking, and biking
	Transformation 4	Replace diesel and gasoline passenger vehicles with electric and zero emission vehicles
	Transformation 5	Shift freight transport to rail, water and low- or zero emission technologies
Agriculture, forestry and land use	Transformation 6	Modernize farming practices to reduce emissions of methane and nitrous oxide
	Transformation 7	Pursue conservation of forests and other high-carbon ecosystems and farmland restoration
	Transformation 8	Reduce consumption of beef and dairy
Buildings	Transformation 9	Achieve the highest possible energy efficiency for building shells and appliances
	Transformation 10	Electrify building appliances
	Transformation 11	Deploy solar electricity and hot water generation on buildings
Industry	Transformation 12	Electrify low heat industry
	Transformation 13	Replace all fuels and feedstocks in heavy, high-heat industry with lower-emissions alternatives
Waste	Transformation 14	Work towards a circular economy
	Transformation 15	Reduce food loss and waste and implement active methane management for organic material disposal

Standards Institute (BSI) defines carbon neutrality as a phenomenon in which a product (or service) does not cause a net increase in greenhouse gas emissions to the atmosphere over its life cycle. Carbon neutrality is a voluntary behaviour that emphasizes the transformation of economic structure and energy structure. Moreover, it includes the need to accelerate innovative application of low-carbon and zero-carbon technologies, focusing on energy conservation and energy efficiency. Carbon neutrality emphasizes on accelerating the application of renewable energy, expanding the construction of forests and carbon sinks, and promoting the balance between greenhouse gas emissions and absorption of the earth. The transportation sector accounts for nearly 60%of oil consumption. Under the background of carbon neutrality, the exploration and practice of traditional fossil energy transformation in the field of transportation has become an important part of green transportation.

In 2019, the UK government became the first major economy to pass a net zero emissions law. With it, a target that will require the UK to bring all greenhouse gas emissions to net zero by 2050. Net zero means that any carbon emissions created are balanced (kind of cancelled out) by taking the same amount out of the atmosphere. Therefore, net zero can be reached when the amount of carbon emissions we add is no more than the amount taken away. There are many ways to remove carbon from the atmosphere, for example, you can plant trees which absorb CO_2 and release oxygen. When carbon (CO_2 or carbon dioxide) and other heat-trapping emissions are released into the air, they act like a blanket, holding heat in our atmosphere and warming the planet. Traditional energy sources such as coal and gas produce carbon dioxide among other gasses when they are burned to fuel power stations. Zero carbon means that no carbon emissions are being produced from a product or service (for example, a wind farm generating electricity, or a battery deploying electricity). Energy sources like wind, nuclear and solar do not create carbon emissions when they are used to produce electricity—we refer to these sources as zero-carbon (NGESO 2022).

Net zero is all about "balancing" or cancelling out any carbon we produce. We reach net zero when the amount of GHG we produce is no more than the amount taken away. Zero carbon concerns the emissions produced from a product or service—it means no carbon is given off at all. In the context of energy generation, one example would be a wind turbine creating electricity which does not give off any carbon.

1.3.5 Carbon Offsets and Carbon Credits

The overall goal of the carbon mechanisms, carbon offsets and carbon credits are to reduce emissions, and to remove the greenhouse gases that have already been emitted to the atmosphere. When a company reduces its GHG emissions, it can earn carbon credits which may then be traded to other companies which need to offset their own emissions. A carbon credit gives the purchaser permission to emit a specified amount of carbon, because another entity has emitted less carbon pollution and effectively has a credit that they can sell. A carbon credit represents the right to emit one metric ton of carbon dioxide. These credits are used by companies, industries, and governments. The majority of carbon credits are bought and sold through cap-and-trade systems between different companies and brokers. The goal of carbon credits is to make emitting carbon more expensive, incentivizing companies to work towards emitting less on their own.

Carbon Offsetting: The practical process that give rise to a carbon credit. Carbon Offsetting involves a project - such as a renewable energy project or a tree planting event- that removes atmospheric GHG emission.

Carbon Credits: A tangible measure illustrates how much CO_2 or other GHG has been removed from the atmosphere via a given Carbon Offset project – with one Carbon Credit representing one metric ton reduction of CO_2.

This system presents opportunities for investors as well. Individuals can invest in the carbon credit market in a few different ways, including direct investment in low-carbon companies or via exchange-traded funds (ETFs). Companies and individuals buy carbon offsets in the voluntary market in order to "offset" their carbon footprint. A carbon offset cancels out the CO_2 emissions that were produced in one place by reducing them in another place. A carbon offset represents one metric ton of carbon emissions. The purchase of an offset goes directly towards emissions reduction projects. When someone purchases an offset, that means a ton of carbon was removed or not emitted. This could be through installing solar panels or wind power system, direct air capture, or another method typically involving renewable energy.

The main difference between carbon credits and offsets is that a carbon credit gives one entity the right to emit carbon through the use of a "credit" purchased from another source. A carbon offset represents a more direct reduction of emissions, where the removal of carbon pollution by one entity helps offset the carbon emissions of another (Laurel Tincher 2023).

Quality offsets are certified by third parties who ensure that the carbon emissions being avoided or removed are legitimate. Requirements for certification are stringent to ensure that the offsets actually have a real impact. Examples of carbon offset projects might include solar power projects, wind farms, methane recapture operations, reducing deforestation, reducing the use of wood burning stoves and many such others. The negative side of carbon offsets is that they don't reduce one's own emissions and basically give people and companies permission to keep emitting carbon.

There have been long-standing concerns around the integrity of carbon credits. The Integrity Council on the Voluntary Carbon Market (IC-VCM), a multi-stakeholder and widely respected body, was set up as a successor to the Taskforce on Scaling Voluntary Carbon Markets (TSVCM), and tasked with defining a market-wide benchmark for high-integrity carbon credits, known as the "Core Carbon Principles" (CCPs). A first draft of the CCPs were published for consultation in mid-2022, with a final version published in late March 2023. The IC-VCM hopes credits can start to be assigned a CCP label from late 2023 (https://trove-research.com/commentary/core-carbon-principles-alignment-with-troves-carbon-credit-integrity-assessments/)

1.3.6 Carbon Sequestration, Carbon Sinks and CO_2 Equivalent

Carbon sequestration is the process of capturing, securing, and storing carbon dioxide from the atmosphere. The idea is to stabilize carbon in solid and dissolved forms so that it does not cause the atmosphere to warm. The process shows tremendous promise for reducing the human "carbon footprint". There are two main types of carbon sequestration: biological and geological (The Greenhouse Gas Protocol 2004). Carbon Sequestration refer to the storage of carbon that has the immediate potential to become carbon dioxide gas. Carbon Sequestration is the removal of carbon dioxide from the atmosphere and storage in another system, such as vegetation. If the carbon dioxide sequestered is more than the carbon dioxide emitted, the store is increasing and is known as a carbon sink. carbon sequestration is the long-term storage of carbon in plants, soils, geologic formations, and the ocean. Carbon sequestration occurs both naturally and as a result of anthropogenic activities. Significant interest has been drawn to the possibility of increasing the rate of carbon sequestration through changes in land use and forestry and also through geoengineering techniques such as carbon capture and storage (Selin 2023a, b).

Reservoirs that retain carbon and keep it from entering Earth's atmosphere are known as carbon sinks. For example, deforestation is a source of carbon emission into the atmosphere, but forest regrowth is a form of carbon sequestration, with the forests themselves serving as carbon sinks. The Kyoto Protocol under the United Nations Framework Convention on Climate Change allows countries to receive credits for their carbon sequestration activities in the area of land use, land use change, and forestry as part of their obligations under the protocol.

CO_2 equivalent is another important entity in the discussion of carbon emission. Eurostat Statistics explained, "A carbon dioxide equivalent or CO_2 equivalent, abbreviated as CO_2-eq is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential". In other words, a CO_2-eq is a standard unit for counting greenhouse gas (GHG) emissions regardless of whether they are from carbon dioxide or another gas, such as methane. As we know, GHG emissions are mainly CO_2. However, there are other GHGs that contribute significantly to human-induced global warming such as methane (CH_4), nitrous oxide (N_2O), refrigerant gasses (HFCs, PFCs, and CFCs), sulphur hexafluoride (SF_6), water vapour (H_2O), and ozone (O_3) (https://greenbusinessbureau.com/green-practices/energy/scope-1-emissions/).

CO_2-eq are commonly expressed as million metric tons of CO_2-eq, abbreviated as MMTCDE. The CO_2-eq for a gas is derived by multiplying the tons of the gas by the associated GWP:

$$\text{MMTCDE} = (\text{million metric tons of a gas})^{*}\ (\text{GWP of the gas}).$$

For example, the GWP for methane is 25 and for nitrous oxide 298. This means that emissions of 1 million metric tons of methane and nitrous oxide respectively is equivalent to emissions of 25 and 298 million metric tons of carbon dioxide (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent#:~:text=A%20carbon%20dioxide%20equivalent%20or%20CO2%20equivalent%2C%20abbreviated,carbon%20dioxide%20with%20the%20same%20global%20warming%20potential).

1.4 Decarbonization

Decarbonization means a decrease in the specific amount of carbon (or CO_2) emitted per unit of primary energy consumed. Decarbonization is not only about limiting GHG emissions and conserving natural resources; it is increasingly just good business. Hence it becomes essential to reduce carbon emission. Decarbonization reduces the amount of gaseous carbon compounds released in an environment or process. “The word decarbonisation refers to all measures through which a business sector, or an entity—a government, an organisation—reduces its carbon footprint, primarily its greenhouse gas emissions, carbon dioxide (CO_2) and methane (CH_4), in order to reduce its impact on the climate”.

In the EU, the transition to a low-carbon economy is estimated to create 1.2 million additional jobs by 2030 as per the European Commission, “Employment and Social Developments in Europe”, 2019. Rewiring America, “Mobilizing for a Zero-Carbon America” reported that the decarbonization via mass electrification could create as many as net 25 million American jobs over the next 15 years”. Decarbonization takes a relatively straightforward path which is not so easy. Each step in the path can pose significant challenges and requires technological, financial, organizational, and governance capacity. Fortunately, new solutions and financing models make decarbonized technologies more accessible, effective, and affordable than ever.

Achieving the Paris Agreement goal of limiting global warming to well below 2 °C requires a rapid decarbonization of the economy. According to most climate-economic models, this can only be done with the use of costly carbon-removal technologies (Fuss et al. 2020; IPCC 2018a, b). Decarbonization of industry and material production, in particular, requires technological and organizational change and large investments into new energy infrastructure and factories (Rissman et al. 2020; IEA 2020). GHG emissions from material production have risen from 5 Gt CO_2-equivalents (CO_2-eq) in 1995 to 11.5 Gt in 2015 (Hertwich 2021) and represent about 23% of global GHG emissions (Pauliuk et al. 2021).

Decarbonization helps organizations in the following ways that has been observed.

- Conserve resources and boost bottom lines
- Satisfy investors and other key stakeholders
- Ignite innovation and technological progress

- Stimulate organizational growth
- Grow industry influence, reputation, and brand
- Hire and retain top talent
- Building image in the society and set examples for others.

Increasingly, institutional investors, boards, and leaders see the value in decarbonization. Pressure is mounting for organizations to respond. For many organizations, the difficulty comes when asked to implement decarbonization strategies at scale. It is one thing to aspire to carbon neutrality or net-zero emissions and something else entirely to get there. Most organizations already understand why decarbonization is important while the key is to help them understand how to move from ambition to action (Schneider Electric 2021).

Given the anticipated slow pace of decarbonizing material production, the reduction of material demand through (1) more efficient use of materials at all stages of the material cycle and (2) the decoupling of services, such as mobility, from the number of material-intensive products, such as vehicles, may result in more immediate emission reductions.

Organizations must understand, from the beginning, what is their present status on carbon emission on the decarbonization pathway and what it is they aspire to achieve. Leaders across an organization must align on the vision and the strategy to achieve that vision. This is a foundational element to any program of change. Figure 1.4 demonstrates four phases of decarbonization pathway.

More and more people are switching to electric vehicles each year, which do not require decarbonizing at all, and modern internal combustion engines are seeing less carbon build up as fuel efficiency continues to increase and carbon residue in fuels continues to decrease.

Decarbonizing electricity and energy usage is a complicated challenge that will require a global effort to achieve. This will involve deep decarbonization, utilizing out-of-the-box energy resources and creating entirely different systems for how we generate and consume not just electricity but also energy in general. However, the electric vehicles and hydrogen fuels, etc. can fuel up the decarbonization transition at a faster rate.

In the building sector, decarbonization can be achieved through the energy efficiency measures focused on reducing the energy demand, reducing the energy consumption and increasing the use of low-carbon technologies, such as renewable energy sources. Decarbonization in the building sector involves the materiality of the built environment throughout their whole life cycle, users' energy habits and the performance and efficiency of the building and neighbourhood systems (European Commission 2019).

Fig. 1.4 Four phases of closed loop decarbonization pathway

1.5 Low-Carbon Technology

Energy efficiency refers to using less energy to perform the same task, that is, eliminating wastage of energy. Energy efficiency possess wider variety of benefits: reducing GHG emissions, reducing demand for energy imports, and lowering costs on a household and economy-wide level. It has been observed that 66% of industrial energy consumption spent in the heat applications, but the focus is often on electricity. With increasing energy intensity, the importance of heat applications for decarbonization in companies increases. For decades, the energy efficiency has been largely overlooked in early periods of energy transition planning. The energy efficiency should be more focused in the manufacturing and production context, as the sectors not only manufacture goods efficiently but also take into consideration its impact on other sectors and intended users. Low-carbon emitting technologies (LCET) are referred to as innovative technical solutions that are characterized by a low emission intensity, compared to state-of-the-art alternatives with a focus on environmental impact. They should act as an economic substitutional technology while fulfilling the initial promise of performance.

1.6 Circular Economy

Circular economy concept at present attracted the global attention as it is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible.

Circular economy promoted the use of materials at the end of its life cycle of its intended use. This helps in reducing the extraction of natural resources for new production processes. In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible. These can be productively used again and again, thereby creating further value. This is a departure from the traditional, *linear* economic model, which is based on a take-make-consume-throw away pattern or *epcd2*, means, extract-produce-consume-dispose-deplete. This model relies on large quantities of cheap, easily accessible materials and energy. In a circular economy, things are made and consumed in a way that minimizes our use of the global resources, cuts waste, and reduces carbon emissions.

In the traditional practice for long time, materials from the Earth are extracted, products are made from them, consume them as per its intended use, and eventually throw them away as waste and deplete the resources—the process is linear. In a circular economy, by contrast, we stop waste being produced in the first place. The circular economy is a systems solution framework that tackles global challenges such as climate change, biodiversity loss, waste, and pollution.

Circular economy is a systems solution framework that tackles global challenges such as climate change, biodiversity loss, waste and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature. Circular Economy could be understood in details with the definitions by researchers. There is no standard definition of circular economy, however, the most appropriate acceptable ones are compiled in Table 1.5. Circular economy must start at the conceptual level of a product or process. The materials, processes, products, resources required must be designed keeping the focus of longer lifetime of the product, minimum resources, namely, electricity, fuel, steam, heat, water, compressed air, to be required, with maximum productivity, tending to zero loss/rejection/wastes in process, sub-processes and products, effective reverse logistics and recycling, integration of supply and demand sides, utilisation of secondary raw materials in the same process, and a different process with a close loop materials cycles.

1.7 Case Studies: Circular Economy Implementation and Decarbonization by Carbon Footprint Reduction

It is clear that Circular Economy and decarbonization are complimentary to each other. If the concepts of circular economy are implemented, decarbonization will take place, on the other hand, the decarbonization process will stimulate the implementation of circular economy initiatives. The same may be observed in the following case studies.

Table 1.5 Definitions of circular economy (Source: Ghosh et al. 2022, p. 5–7)

The definition	Keywords	Reference
Circular economy is a systems-level approach to economic development and a paradigm shift from the traditional concept of linear economy model of extract-produce-consume-dispose-deplete (epcd2) to an elevated echelon of achieving zero-waste by resource conservation through changed concept of design of production processes and materials selection for higher life cycle, conservation of all kinds of resources, material and/or energy recovery all through the processes, and at the end of the life cycle for a specific use of the product will be still fit to be utilized as the input materials to a new production process in the value chain with a close loop materials cycles that improve resource efficiency, resource productivity, benefit businesses and the society, creates employment opportunities, and provides environmental sustainability	Systems-level approach; paradigm shift; epcd2; elevated echelon; zero-waste; resource conservation; changed concept of design and process; higher life cycle; conservation of resources; close loop materials cycles; resource efficiency; resource productivity; businesses and society; employment; environmental sustainability	Ghosh et al. (2022, p. 5)
The circular economy is an economy "where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste minimized". The transition to a more circular economy would make "an essential contribution to the EU's efforts to develop a sustainable, low-carbon, resource-efficient, and competitive economy"	Value of products, materials, and resources; as long as possible; waste minimized; transition; sustainable; low-carbon; resource-efficient; competitive economy	European Commission (2018)
The circular economy as "an industrial system that is restorative or regenerative by intention and design. It replaces the "end-of-life" concept with restoration, shifts toward the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models". The overall objective is to "enable effective flows of materials, energy, labour, and information so that natural and social capital can be rebuilt"	Restorative; regenerative; replaces "end-of-life" concept with restoration; renewable energy; reuse; elimination of waste; superior design; effective flows of materials, energy, labour and information; natural and social capital, rebuilt	Ellen MacArthur Foundation (2013, p. 7)

1.7.1 Case 1: Going Global Partnership—Industry Academia Collaborative Grant Research Project for adoption of Circular Economy in SMEs to Reduce Carbon Footprints

The authors as the India Coordinator from ISWMAW have developed an innovative idea to involve the Small and Medium Sized industries in the Going Global Partnership - Industry Academia Collaborative Grant Research Project (GGP-IACGRP), funded by British Council and Aston University, UK. The personnel involved in the group activities, named, CESIP (Circular Economy Small Improvement Project) group develops the scopes from improvement in the Small and Medium Sized Enterprises (SME) based on the process mappings and data analysis in consultation with the Academic and Industry partners. CESIP group is a cross functional team may consist of 3–7 persons who are involved in the improvement project as well as one or two from the partner organization. The India Coordinator and the UK PI are the permanent member of each CESIP Group. Sixty SMEs are working in the project from West Bengal, Andhra Pradesh, Maharashtra, and Delhi in India and five SMEs in Birmingham, UK. Each of the SMEs will identify the leakage/loss/weakness in different areas e.g., wastes generation, cycle time, energy spent/wastes, water utilization, recycling, reverse logistics, substitution of expensive materials, material flow, changing processes to smarter ones, waste and WIP utilization, fuel used, boiler operation, steam, emission, system of closing the loop, productivity, green purchase, layout, space utilization and illumination, etc. develops at least three CESIP. The CESIPs are being developed based on the improvement area identification in process maps and components in Table 1.6. Most of the CESIPs will reduce carbon footprints. However, the calculation of carbon footprints will be carried out for each CESIP to understand the reduction in carbon footprints though it is a complicated one.

The project will run till the month of December 2023 when assessment of the extent of CE implementation measuring resource efficiency and reduction of carbon footprints (CF) with a total target of 10% reduction of CF from the February 2023 level in the SME units. Eleven number of academic institutions and industry/researchers' associations have been working in the project as the partners, namely, Aston University, UK, International Society of Waste Management, Air and Water (ISWMAW), Kolkata, Jadavpur University, Kolkata, Federation of Small and Medium Industries (FOSMI), Kolkata, K J Somaiya Institute of Management (KJSIM), Mumbai, Sri Venkateshwara University, Tirupati, AP, Sri City Pvt. Ltd., Tirupati, AP, GITAM deemed to University, Visakhapatnam, Godavari Biorefineries Ltd., Mumbai, Centre for Responsible Business (CRB), New Delhi and Techno India University (TIU), Kolkata. The SMEs have already identified the CESIPs and started the improvement initiatives. A review is carried out each month for follow-up and monitoring the progress. It is expected that at least 70% of the targets of reduction of carbon footprints will be achieved. It is expected that each of the 60 SMEs will institutionalize the culture of adopting the circular economy concepts and will start getting benefits as applicable.

Table 1.6 Possible areas of CESIPs in circular economy implementation and decarbonization

Prevent big losses/leakages • Reduce breakdowns • Organized setup and adjustments • Reduce small stops • Increase speed • Reduce startup rejects • Zero production rejects • Zero-waste and reverse logistics • Zero emission • Reduce energy consumption • Reduce materials consumption • Reduce spillage • Reduce machine downtime • Reduce rejection • Reduce cycle time • Reduce process/machining time • Train on circular economy • Train on processes	Specific *defect* reduction by • Robust quality control Effective machine repair • Proper Effective documentation • Process standards • Understand customers' need • Accurate inventory levels Prevent environmental damage • Maximize waste treatment • Encourage recycling and reduce littering • Zero consumption of coal, HSD • Increase use of solar and other renewable energy sources • Increase resource circularity • Reduce waste and increase waste utilization
Reduce loss of *waiting* • Plan downtime or idle equipment • Reduce delayed set-up times • Improve process communication • Strengthen process control • Produce as per requirements • Remove idle equipment OR increase equipment utilization	Reduce *transportation waste* • Improve layouts—avoid large distance between operations • Effective material handling systems • Smaller batch sizes • Reduce multiple storage facilities • Robust design production systems
Reduce wastes due to *motion* • Improve workstation layout • Effective production planning • Improve process design • Dedicated equipment and machines • Clean operations • Appropriate production standards	Reduce *overproduction* • Unreliable process • Unstable production schedules • Inaccurate forecast and demand information • Customer needs are not clear • Long or delayed set-up times
Reduce *inventory waste* • Reduce overproduction • No delays in production • Zero defects in inventory • Reduce transportation	Encourage innovation • Poor communication • Involve people in workplace design and development • Lack of or inappropriate policies • Team training and retraining
10 Real-world industry 4.0 technologies Below are the top digital transformation technologies brought about by Industry 4.0: 1. Big data and analytics; autonomous robots 2. Simulation/digital twins; horizontal and vertical systems; industrial IoT (IIoT); cybersecurity technology; cloud; additive manufacturing; AI; augmented reality	

1.7.2 Case 2: Circulation of Waste as Secondary Raw Materials to Produce Different Products Including Cement Reducing Carbon Footprints

Citizens use different materials and generate municipal wastes comprising of different types of dry and wet wastes. Through a flow chart (figure a model is presented for understanding the circularity of products from the extraction of natural resources to the utilisation of the products when reaching at their end-of-lifetime).

Based on Fig. 1.5, the case study on coprocessing is described. Alternative fuels and raw materials (AFR) from waste can play an important role in contributing towards reducing the use of fossil fuel and costs while conserving natural resources, lowering global CO_2 emissions, and reducing the need for landfills. Co-processing in cement kilns is a technology that is practiced globally on large scale for environmentally sound and ecologically sustaining management of wastes from agricultural, industrial, and municipal sources. Wastes from households, shopping complex, gated community, commercial and business houses are collected by the municipal waste collectors daily using hand cart, motorized carts in municipalities in Odisha and west Bengal. Figures are shown from the collecting vehicles and materials recovery facilities in ward number 115, Ukil para, Paschim Putiary, Kolkata, and Rourkela city in Odisha.

The waste collectors visit each of the houses and collect dry wastes and wet wastes separately. The dry wastes are taken to the material recovery facility and each of the categories of wastes are separated manually stored in separate bins or locations. All the dry wastes separated in nearly 18–22 categories depending on the availability of wastes. The non-recyclable plastics and other wastes are also stored separately which has calorific value. Sometimes if those are little wet, are taken for drying in the sun. Each of the recyclable wastes, such as, plastics, papers, cans, textiles, metals, glass, cardboard and cartons, and many others are sold to the recycling plants. The non-recyclable plastics and other wastes are sent to cement plants to produce appropriate Refuse Derived Fuel (RDF) in the pre-process plants in

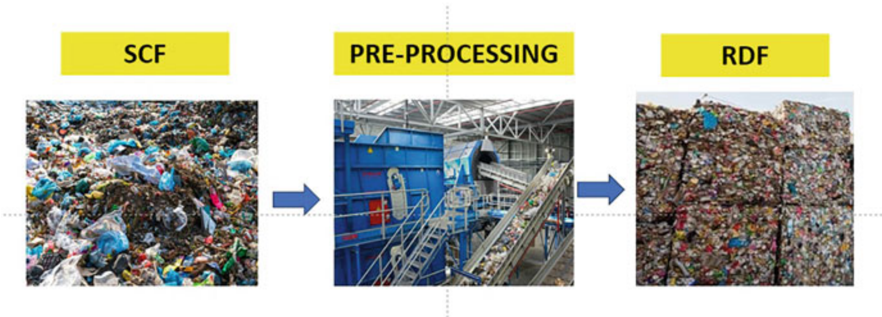

Fig. 1.5 Model to demonstrate the implementation of Circular Economy and Decarbonization (Source: Developed by the authors)

Fig. 1.6 Waste those may be co-processed in cement plants for cement production (Source: Ghosh et al. 2022)

the cement industries. Co-processing is an important technology for the sustainable management of hazardous and non-hazardous wastes derived out of Municipal, Industrial and Agricultural sources (Ghosh et al. 2022). Different types of wastes as demonstrated in Fig. 1.6 as available were separated for sending to the cement plants for co-processing. These materials go for pre-processing and coprocessing in the cement plants.

Pre-processing and coprocessing may be defined here for better understanding. Pre-processing may be defined as when alternative fuels and/or raw materials not having uniform characteristics must be prepared from different waste streams before being used as such in a cement plant. The preparation process, or pre-processing, is needed to produce a waste stream that complies with the technical and administrative specifications of cement production and to guarantee that environmental standards are met (UNEP 2011). Co-processing supports 3Rs and the waste hierarchy starting from waste reduction and least priority to landfilling. Co-processing is eco-friendly resource recovery option in waste management and comply with the Basel and Stockholm Conventions (Source: Guidelines on co-processing Waste Materials in Cement Production 2006). Alternative fuels are the wastes with recoverable energy value, used as fuels in a cement kiln, replacing a portion of conventional fossil fuels such as coal. Other terms include secondary, substitute, or waste derived fuels (UNEP 2011). Alternative fuels and raw materials (AFR) Inputs to clinker production derived from waste streams that contribute to energy and raw material requirements in the clinker manufacture.

Figure 1.7 demonstrate the photographs of wastes and RDF collected at bio mining sites and well as the Materials Recovery Facilities (MRF) in different municipalities in Odisha and West Bengal. There is the demonstration of commitment to implement circular economy and decarbonization using wastes.

There are huge number of examples of implement circular economy and decarbonization implementing water recycling, recycling and reducing waste materials in the process, materials and energy recovery, reducing energy usage,

Fig. 1.7 Dry wastes segregated at Rourkela biomining site (1) and MRF (2, 3, 5); and Jharsuguda Municipality MRF (3) for recycling and RDF preparation. and their sources those may be co-processed in cement plants for cement production (Source: Ghosh et al. 2022)

Fig. 1.8 Different wastes and their sources those may be co-processed in cement plants for cement production (Source: Ghosh et al. 2022)

Fig. 1.9 Different wastes and their sources those may be co-processed in cement plants for cement production (Source: Ghosh et al. 2022)

reducing machine idle running time, reducing cycle time, and changed processes and many other ways.

1.8 Conclusion

The transition to circular economy and net-zero emissions economies by decarbonization is a complex and difficult one, that cannot be solved by a handful of government agencies or using only one or two policy instruments. It would instead require a "whole-of-government" approach, where every ministry and all levels of governments, including states and cities, play a role. However, these are possible with pentagonal cooperation and desire of the governments, industries, academic and research organizations, non-government organizations, and general citizens. Implementation of circular economy and net-zero emissions economies by decarbonization need the understanding, awareness, and participation of multi-stakeholders in a nation. The policy, regulation, standard system, and effective governance are essential drivers for the transformation from traditional practices to the elevated echelon of requirements for circular economy and decarbonization which will lead to a sustainable society and environment.

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