7-11-2023

Industry 4.0 and Circular Economy: Opportunities of MENA Countries on the Path to the Sustainable Development

Suzanna Elmassah

Zayed University; Cairo University, suzanna.elmassah@zu.ac.ae

International Journal of Economy, Energy and Environment
2023; 8(4): 59-81
http://www.sciencepublishinggroup.com/j/ijeee
doi: 10.11648/j.ijeee.20230804.11
ISSN: 2575-5013 (Print); ISSN: 2575-5021 (Online)

Industry 4.0 and Circular Economy: Opportunities of MENA Countries on the Path to the Sustainable Development

Suzanna Elmassah[1, 2]

[1]College of Business, Zayed University, Abu Dhabi, United Arab Emirates

[2]Economic Department, Cairo University Faculty of Economics and Political Science, Cairo, Egypt

Email address:

Suzanna.elmassah@zu.ac.ae

To cite this article:

Suzanna Elmassah. Industry 4.0 and Circular Economy: Opportunities of MENA Countries on the Path to the Sustainable Development. *International Journal of Economy, Energy and Environment*. Vol. 8, No. 4, 2023, pp. 59-81 doi: 10.11648/j.ijeee.20230804.11

Received: April 7, 2023; **Accepted**: May 27, 2023; **Published**: July 11, 2023

Abstract: For decades, countries have strived to boost their economies through industrial expansion at the expense of natural capital, resulting in major environmental risks. The Sustainable Development Goals (SDGs) have switched the emphasis on resilient economic development that consider environmental sustainability. Against this backdrop, the circular economy has emerged as a vital tool for rectifying industrial progress regarding environmental sustainability. Integrating digital technologies (e.g., Industry 4.0) into circular economy applications has recently gained enthusiasm as a solvent for sustainability and climate change challenges. The current study examines approaches to integrating Industry 4.0 technologies and innovations into the circular economy to fully realize the benefits of both tackling climate change and attaining sustainable development goals in MENA countries. This is done through examining the associations between the circular economy, climate change, and sustainable development, as well as their associated indicators, followed by a scrutiny of the role of the Industry 4.0 pillars in applying the circular economy, a discussion of the challenges and obstacles to applying Industry 4.0 techniques to the circular economy, and finally an examination of Egypt's efforts to integrate the circular economy into the industrial system, as a representative of the MENA region. The article delivers an obvious array of policy implications through thoroughly investigating the Egyptian case, including: developing a comprehensive national strategy for Egypt's industrial revolution; developing traditional industrial cities; establishing the Egyptian Council for the Circular Economy; and establishing a legal and tax structure that fosters the transition to a circular economy, among several others.

Keywords: Circular Economy, Industry 4.0, Sustainable Development, Environmental Sustainability, MENA

1. Introduction

The development of industry in the world began in the eighteenth century with the start of the use of mechanization and steam engines in Britain and the United States, announcing the first industrial revolution. Since then, the industry has become the locomotive of economic growth and the main reason for the progress and backwardness of countries. In the second half of the nineteenth century, the second industrial revolution was inaugurated with the use of electric power and increased manufacturing capabilities with economies of scale. The sixties of the twentieth century marked the beginning of the development of electronics, communications, and computers and the emergence of the first generation of robots that brought the world to the digital revolution, which is the third industrial [1]. During the last decade, the features of *Industry 4.0* began to take shape with the great technological development and the integration of digital, physical, and biological technologies and became an integral part of the daily lives of individuals. Industrial development and transformation of production structures have been accompanied by a steady depletion of natural resources and non-renewable energy, in addition to the disruption of the planet's ecosystem due to the pollutants left by the industrial sector, the most important of which are the greenhouse gases (GHG) that cause climate change. Humans have released 2.5 thousand Giga-tons of carbon dioxide (CO_2) into the atmosphere from 1850 to 2020 [2].

Based on the shared responsibility for the planet, in 1992, 196 countries signed the United Nations Framework Convention on Climate Change (UNFCCC), intending to prevent negative human interference in the bio-system of the planet. Since then, the countries of the world meet annually at the Global Climate Summit, or what is known as the Conference of the Parties (COP). In 1995, the world's countries began serious negotiations to enhance the global response to climate change. Two years later, they reached the declaration of the Kyoto Protocol, which stipulated legal obligations to reduce emissions of a variety of greenhouse gases for both groups of developed and developing countries. Countries reached the "Paris Agreement" as the first global climate agreement during the Twenty-first Conference of the Parties (COP21) in 2015. The agreement aims to stabilize the concentration of greenhouse gases in the Earth's atmosphere at a level that allows the ecosystem to adapt naturally to climate change to ensure environmental sustainability that protects future generations from the risks of water and food shortages. The agreement sets a quantitative goal to contain global warming by no more than 2, preferably to 1.5 degrees Celsius, compared to the levels of temperatures recorded before the industrial revolution [3]. This target puts increasing pressure on countries to increase their commitments to climate change and reduce carbon emissions, as all signatories to the agreement commit to submitting ambitious targets to reduce greenhouse gas emissions every five years to limit global warming to 1.5°C [4].

During the recent COP26 Conference of the Parties in Glasgow, countries pledged to mobilize climate finance to achieve the goals of the Paris Agreement with more than $100 billion annually. 137 parties have committed to stop encroaching on lands by 2030. This commitment was coupled with an estimated $12 billion from the public sector and $7.2 billion from the private sector funding, with the CEOs of more than 30 financial institutions pledging to stop investing in activities related to deforestation around the world. More than 40 countries have agreed to move away from the use of coal, which is the main source of carbon dioxide emissions. 500 global financial services companies have agreed to align 40% of global financial assets with the goals of the Paris Agreement, including reducing global warming. The United States and China also pledged to strengthen climate cooperation over the next decade. More than 100 parties have signed the Glasgow Declaration on Cars and Vans, aiming to stop selling internal combustion engines by 2035 in leading markets and around the world by 2040. 103 countries have signed the Global Methane Pledge, which aims to reduce methane emissions by 30% by 2030 compared to 2020 levels. Added to this is the commitment of 13 countries to stop selling heavy vehicles powered by fossil fuels by 2040.

In this context of the commitment that has become imposed on all countries, circular economy applications can play a major role in reducing emissions in a way that enables countries to fulfill the Paris Agreement and achieve sustainable development goals. A study by *Circle Economy Institute* indicates that circular economy scenarios can reduce resource extraction by 28% and global carbon emissions by 39% [5]. Circular economy applications provide an opportunity to correct the course of industrial development about climate change and environmental sustainability and support the role of industry in achieving sustainable development goals. The circular economy allows the separation of economic growth from the use of natural resources by preserving the use of materials, products, equipment, and infrastructure for a longer period with a minimum rate of depreciation, thus improving the productivity of these resources and reducing pressure on them. This would provide an opportunity to reconsider and reduce the current demand for resources, as well as enhance the ability of systems to deal with crises by reducing pressures caused by resource shortages and dependence on imports. For example, the Netherlands aims to reduce its imports by applying resource circularity, which represents a self-renewal model through which materials are reused in successive production operations while reducing waste to the lowest level. As part of the production process waste becomes an entry point for another production process [6].

On the other hand, the term *Industry 4.0* (Fourth Industrial Revolution) was introduced for the first time at the Hannover Fair in 2011 and was officially announced as a German strategic initiative in 2011 to revolutionize manufacturing industries [7]. The term has gained great momentum due to the various technologies accompanying its emergences, such as the Internet of things, big data, cloud computing, and others. The technologies of the *Industry 4.0* have imposed themselves as a mean to raise the efficiency of the production process through the enormous capabilities of storing and retrieving huge amounts of information, linking and establishing relationships and interconnections between them in a way that raises the levels of productivity, quality, and efficiency.

It can be said that there is a mutual link between *Industry 4.0* and the circular economy, as the revolution brought about structural changes in the traditional linear economy and introduced radical changes not only in the form of industries and methods of production but also in the cognitive perspective of individuals. The modern technology and innovative solutions open the way for the emergence of innovative circular economy mechanisms in an easier and faster way.

This paper studies the means of implementing the technologies and innovations of *Industry 4.0* to the circular economy to maximize the benefits of both facing climate change and achieving sustainable development goals. The paper begins by addressing the development of *Industry 4.0* and an analysis of the technological pillars upon which it is based, followed by the indicators that monitor this revolution. Then the section of analyzing the linkages between the circular economy, climate change, and sustainable development and their associated indicators. The next section there is an analysis of the role of the pillars of *Industry 4.0* in applying the circular economy, with a review of the challenges and obstacles facing the application of the techniques of *Industry 4.0* to the circular economy. In the fourth section, the paper analyzes Egypt's efforts to integrate the circular economy into the industrial sector and extracts the available opportunities in this regard. The study ends with the conclusion and some suggested policies.

2. The Development of Industry 4.0

The emergence of the Fourth Industrial Revolution was preceded by three industrial revolutions, as shown in Figure 1. The term Fourth Industrial Revolution was first introduced at the Hanover Fair in 2011, and in the same year, the German government officially announced it as a *German Strategic Initiative* to revolutionize the manufacturing industries. The term has gained increasing momentum due to the continued emergence of technological technologies such as the Internet of things, big data, cloud computing, and others. In 2016, Klaus Schwab used the term "Fourth Industrial Revolution" in a report he submitted to the World Economic Forum and published a book with the same title, in which he discussed the concept of the fourth industrial revolution, its challenges, and its positive and negative effects on humanity.

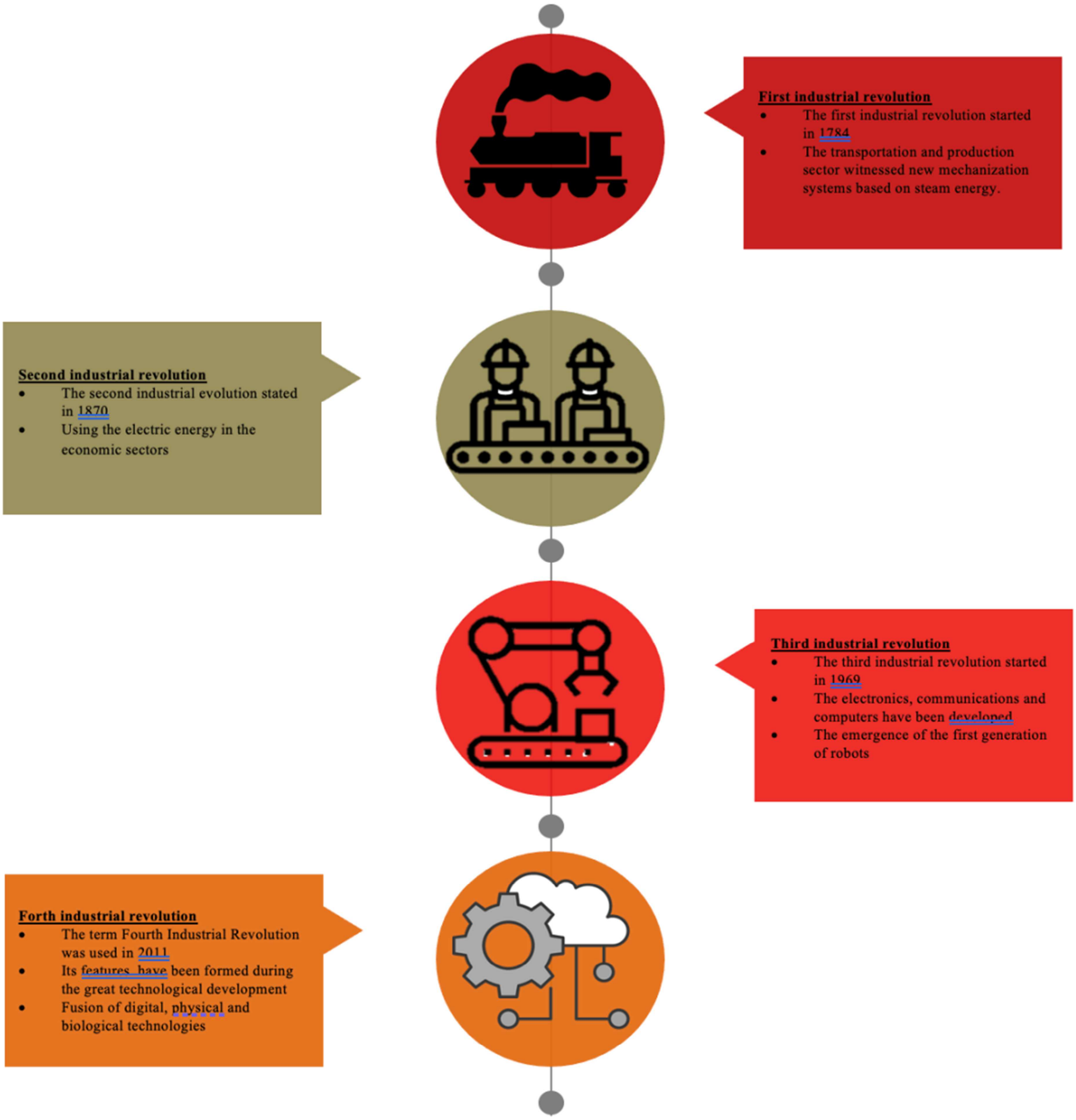
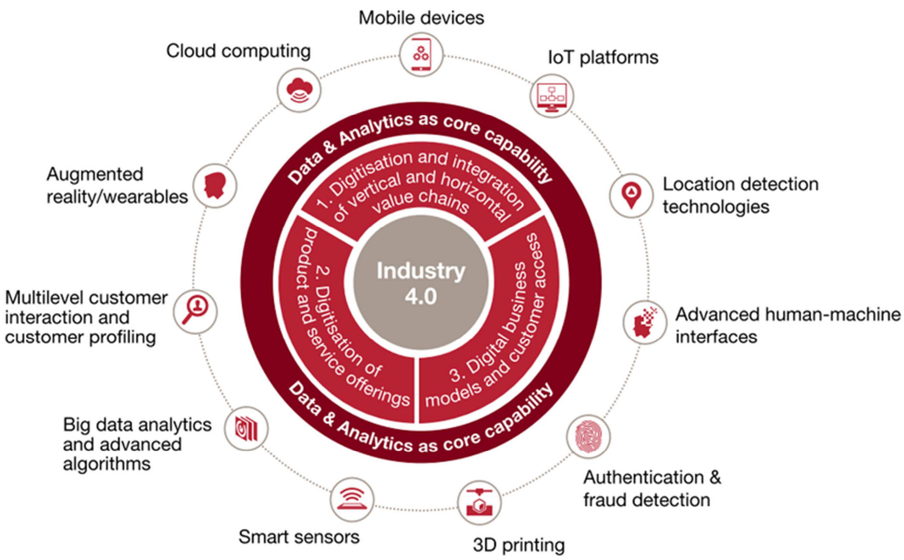


Figure 1. *The Industrial Revolution.*

Industry 4.0 is mainly based on major technological developments in various fields, including artificial intelligence, the Internet of things, self-driving vehicles, 3D printing, cloud computing, and big data. It relies on developing the foundations of industrial production by integrating digital technologies and Internet of things technologies with traditional industry methods to increase the efficiency of the industrial production process. Figure 2 illustrates the frame of the Fourth Industrial Revolution and the associated digital transformation technologies.



Source: [8]

Figure 2. *Industry 4.0 and Digital Technologies.*

The technologies of the *Industry 4.0* have imposed themselves as a means to raise the production process's efficiency, relying on technology and limiting the role of human intervention to only monitoring. The methodology of this revolution adopts more ability to store and retrieve huge amounts of information and to link and establish relationships and interconnections between them in a way that raises the levels of productivity, quality, and efficiency. The close convergence between artificial intelligence and big data in the early 2000s resulted in achieving better results than expected, which prompted its use in various fields, including, for example, the development of programs to discover new drugs. Countries worldwide are competing to make achievements on the road to *Industry 4.0* as a new opportunity for human development and achieving higher levels of growth to build a better future for people. The link between *Industry 4.0* and sustainable development is evident in the technologies the first offers, which considers the three dimensions of sustainable development: economic, environmental, and social. The ninth goal of the Sustainable Development Goals clearly expresses the link between innovation in the industrial field and countries' progress on the path of sustainable development.

In 2018, the World Economic Forum launched the *Future of Production Readiness Initiative* to measure countries' readiness to adopt the mechanisms of the Fourth Industrial Revolution. The arrangement of countries was based on two main pillars: the production structure and production engines. Each pillar is divided into several sub-pillars: technology and innovation, human capital, global trade and investment volume, and sustainable production. The classification of 100 countries comes into four groups based on the degree of each country on a scale from zero (the least prepared) to ten (the most prepared), as follows [9]:

The first group is the "leading countries": they are those countries that enjoy high levels of production, the highest levels of invested capital, in addition to their high evaluation scores in all aspects under evaluation. European countries accounted for about 60% of the top ten positions leading the future production readiness index for the year 2018. The ranking of the first ten countries came in a row: Japan, South Korea, Germany, Switzerland, China, the Czech Republic, the United States of America, Sweden, Austria, and Ireland [10].

The second group is "legacy countries": countries with a high primary production level but at risk in the future due to weaknesses in some of the assessed fields.

The third group is "countries with high potential": countries with limited primary production but enjoying a good performance in the rest of the assessed pillars.

The fourth group is "emerging countries": these are the countries with limited primary production, which also show low and weak values in the rest of the assessed pillars.

The World Economic Forum also partnered with the Economic Development Board of Singapore in the September 2020 Smart Industry Readiness Initiative as a global benchmark for *Industry 4.0*. This initiative provides an indicator that measures the extent of adopting advanced technology in the industrial sector for more than 600 industrial companies in about 30 countries so far. The report for 2022 indicated that the five most digitally mature industries are semiconductors, then electronics, then pharmaceuticals, then energy and chemicals, and finally, logistics [11].

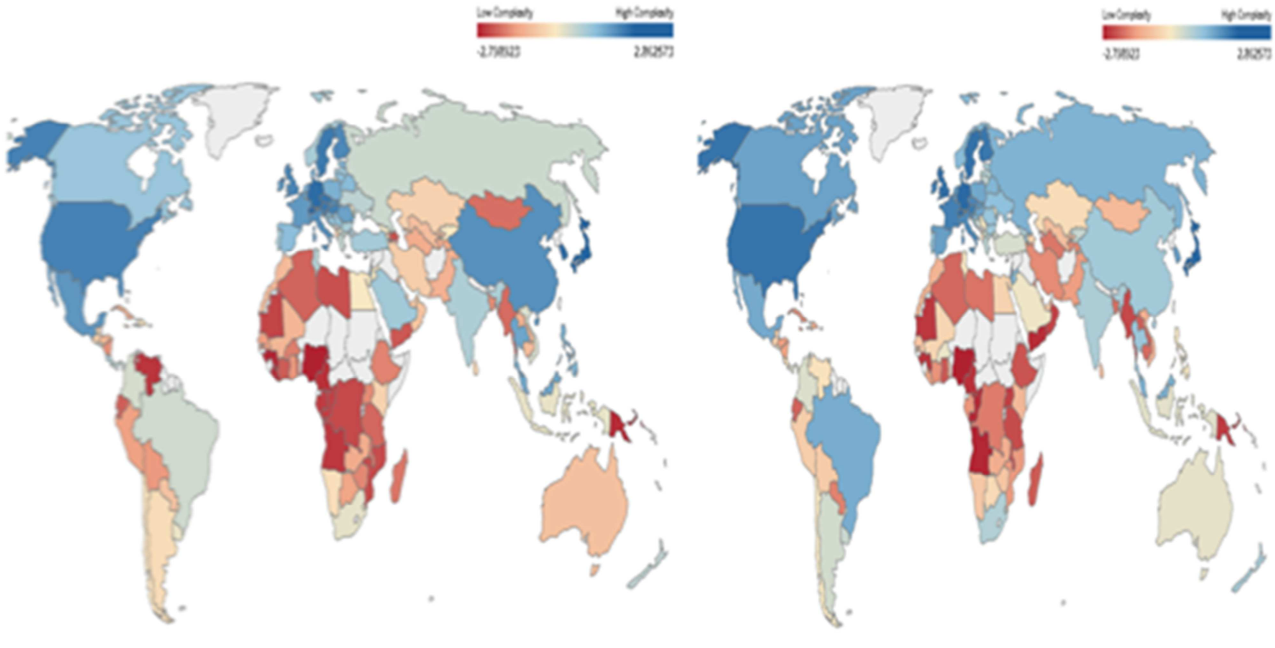
On the other hand, the ranking of countries in the world and the evaluation of their performance related to *Industry 4.0* is also shown through statistics such as the rate of development of production operations, the level of automation, and the global innovation index or through several sub-indicators included in composite indicators. For example, the World Bank's[1] ease of doing business index

1 In September 2021, the World Bank announced that it would stop issuing Doing Business report.

assesses the business environment in 190 countries around the world [12]. The index includes an assessment of 12 fields for regulating business activities within each country, including a sub-index that measures the performance of countries in relation to the Fourth Industrial Revolution. It shows the dominance of European countries on the first ten centers of the index in addition to Singapore, Hong Kong, and South Korea [13].

It is also possible to evaluate the performance of countries during the fourth industrial revolution in terms of the complexity of their production structure and their possession of productive capabilities that enable them to produce advanced commodities. "The Economic Complexity Index – ECI [14] measures a country's structural transformation level by estimating the amount of knowledge reduced to exports. Harvard Growth Lab ranks 6,000 products and services worldwide according to their degree of complexity (PCI), expressed in the diversity of knowledge required to produce the product [15]. Products with a high PCI value (more complex products that only a few countries can produce) include electronics and chemicals. Products with a low PCI value (the least complex product that almost all countries can produce) include raw materials and simple agricultural products.

In general, Japan tops the list of the most complex countries since the launch of the index, while the performance of other countries varies up and down. The blue color in the map, Figure 3, varies according to the degree of complexity, reaching (ECI = 2.862573), which indicates the most complex economies, as well as the red color, reaching (ECI = -2.798923), meaning the least complex economies. Most countries maintained approximately the same levels of complexity between 2000 and 2019, with some exceptions for some countries whose levels of economic complexity declined despite their high levels of income, which is largely due to their specialization in the production of uncomplicated commodities. One of the most prominent of these exceptions is the decrease in the complexity rate in Russia from ECI = +0.766974 in 2000 to ECI = + 0.12 in 2019, dropping its ranking from 28th in the world to 52nd. The same thing happened in Brazil, where its rank fell from 26th in the world to 53rd place. The level of complexity of Australia's economy also declined sharply between 2000 and 2019 [16].



Economic Complexity Index 2019 — Economic Complexity Index 2000

Figure 3. *Economic Complexity Index in 2019-2000.*

The top ten countries as well as the ten least complex countries also witnessed a difference in the global ranking, while Japan continuing to lead the top of the most complex economies. Some countries disappeared from the ranking of the ten most complex in 2019, such as the United Kingdom, Finland, Ireland, and France, and other countries appeared at the top of complexity, such as South Korea, China, and Singapore, which reflects the success of those countries in diversifying their economy and specializing in more developed commodities to achieve better performance during the Fourth Industrial Revolution. It is also evident that the United States has fallen from fifth in 2000 to tenth place in 2019. Less complex countries continue to remain in the same rank within the African continent, such as Nigeria, Papua New Guinea, and the Democratic Republic of the Congo.

It is expected that *Industry 4.0* will contribute to raising income levels and achieving inclusive growth that includes the various aspects of society by creating additional revenues, reducing costs, and increasing the efficiency of the production process through several channels shown in Table 1.

***Table 1.** Industry 4.0 channels for higher income and inclusive growth.*

Revenue generation channels through production process	Cost saving and efficiency channels through production process
Digitizing existing products and services	Increase the efficiency of quality operations by taking advantage of big data applications
Introducing new digital products and services	Increase the flexibility of the different stages of production
Creating new business areas	Increasing the efficiency of the overall planning of production operations, and taking advantage of cloud technologies to computerize the execution
Presenting and analyzing huge amounts of data by "Big Data Applications"	Digitizing production operations, thus efficient human resources utilization
Designing new products that suit society's demand	Horizontal integration to increase logistics efficiency
Increasing market shares of basic products	Vertical integration using sensors improves the efficiency of machines and production equipment and reduces the time to complete production operations.
	Algorithms predictions raise the efficiency of preventive maintenance operations

Although Industry 4.0 aims to raise income levels and achieve inclusive growth that includes all aspects of society, it poses several challenges at the local and international levels. First: Industry 4.0 is associated with new and complex inventions and innovations with a high technological component, which are monopolized by large, high-income countries, which leads to widening gaps in production and competitiveness between countries due to the inability of countries to have equal access to modern technologies and puts many peoples of the world in the circle of poverty and dependence. Second: Industry 4.0 relies on full automation, which threatens the human role in creating the added value of GDP and negatively impacts job opportunities. Third: Industry 4.0 is a double-edged sword regarding environmental sustainability. The complexity of production operations accompanying Industry 4.0 causes a steady increase in energy consumption and, thus, an increase in greenhouse gas emissions, which are the main cause of climate change. On the other hand, technological development contributes to providing new technologies and solutions to preserve the environment and achieve sustainability in a parallel way, perhaps the most important of which is circular economy practices. The applications of the circular economy allow for raising the efficiency of resource use by adopting zero-waste circular production and consumption patterns, and the innovations of Industry 4.0 allow information and technological technologies, and therefore it has become difficult to talk about either of them in a separate way from the other.

3. Circular Economy and Sustainable Development

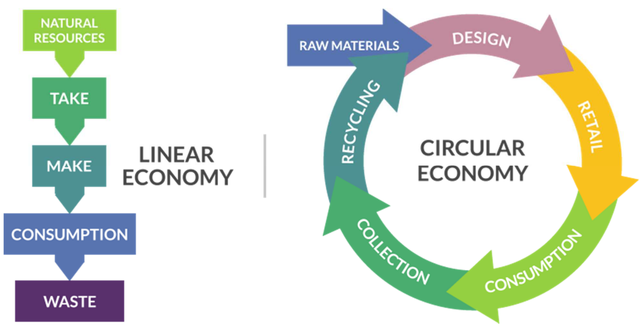
The unsustainable use of natural resources poses an explicit threat to the sustainability of development and the opportunities for future generations to obtain life opportunities, especially considering the continuing pace of population increase around the world. Scientists expect that the continuation of the current paths of production and consumption will intensify the global use of fossil fuels, metals, and minerals, which will lead to more pollution and loss of biodiversity and deepen the problems of climate change. The industry mainly accounts for CO_2, accounting for nearly 30% of global emissions [17]. The production of just four materials – cement, steel, plastic, and aluminum – generates more than 55% of total industry emissions. For this reason, searching for possible solutions to increase production by using fewer resources has become an urgent necessity.

Source: [19]

***Figure 4.** The Circular Economy.*

The circular economy system allows for economic growth to be separated from using natural resources and endowments, enabling economies to achieve high growth rates without the need for intensive depletion of natural resources. The idea of the circular economy is based on maintaining natural resources by preserving them for the longest possible period [18], and reducing waste in all forms by using it as new input in production operations. It is a term that describes an economic system based on business models that replaces the term "end-of-life" by reducing usage, recycling, and recycling and resources recovery in production, distribution, and consumption, as shown in Figure 4.

The application of circular economy strategies in the cement, steel, plastic, and aluminum industries is expected to reduce global emissions by about 40% [21]. Circular economy applications aim at rationalization in the use of products, equipment, and infrastructure in a way that extends the period of benefit from them and raises their marginal productivity. It is considered an innovative, multi-disciplinary approach, as it improves industrial performance for the benefit of society and business owners by understanding all waste streams and converting them into value-added commodities. The more resources move through different processing operations or through reuse, repair, redesign, or remanufacturing; the less new raw materials are needed, and thus the less waste.



Source: [20]

Figure 5. *The Circular Model Versus the Linear Model.*

The circular economy activates the principles and tools of an ecological perspective of industrial operations through sharing utilities and sharing of by-products as part of a closed-loop system. This leads to a decrease in the total waste of industrial operations, in addition to reducing the total amount of virgin resources consumed by industrial activities. Thus, the circular economy becomes a self-renewal model that maximizes the utilization of all raw materials, metals, energy, and resources in their various forms by launching recycling, use, re-manufacturing, and development operations instead of waste and waste disposal. The material circularity aims to comprehensively redesign supply chains to manufacture products that can be reused, refurbished, remanufactured, and recycled by advocating a restructuring of the manufacturing, consumption, and disposal methods of expendable products currently in the linear model, as shown in Figure 5. The applications of the concept of material circularity are not limited to consumer products only but extend to fixed assets and services, such as delivery services, in addition to the extension of the applications of this concept to the rehabilitation of existing buildings instead of constructing new buildings on new lands using new raw materials, which supports the sustainability of current urban development models.

Accordingly, the circular economy can redevelop health and consumer systems, define the value of things and the importance of effective use, and reduce the negative effects of traditional economic patterns. It can also contribute to creating better economic and investment opportunities for companies and institutions, in addition to the environmental and social benefits. Thus, circular economy applications create opportunities and gains at the facility level (the micro level), at the local spatial level (environmental industrial clusters), and at the macro level (industry strategies at the state level). Business owners make economic gains by converting waste from a burden and cost into sales and income. The prosperity of the circular economy sector would create more job opportunities - reaching about 700,000 job opportunities in the European Union alone by 2030 [22] and the applications of the circular economy stimulate innovation and allow for enhancing the competitiveness of companies, which supports the GDP growth rates of countries by about (0.5%) [23]. On the other hand, circular economy applications hold opportunities in the industrial sector to reduce waste, the most important of which are greenhouse gas emissions that are mainly responsible for climate change. Thus, the circular economy provides an opportunity to place industrial growth alongside the goals of sustainable development, bringing them together as one path adopted by countries to achieve growth and quality of life for the benefit of current and future generations.

Despite the novelty of the term circular economy, its practical application appeared in the sixties of the last century on the land of a small Danish city called Kalundborg. This assembly began with the spatial (geographical) localization of the circular economy through four main industries: a coal-fired power station, an oil refinery, a pharmaceutical factory, and a gypsum factory, in addition to a group of other small businesses. The assembly has now expanded to include about 13 public companies. They depend on each other's waste products and convert them into useful inputs [24]. Over the course of six decades, this gathering has been able to achieve remarkable success on the economic and environmental levels. The companies participating in the gathering achieve several economic and environmental benefits on an annual basis, including achieving bottom-line savings of about 24 million euros annually, as well as reducing CO_2 emissions by 635,000 tons, saving about 3.6 million cubic meters of water and 100 Gigawatts of electricity, plus 87,000 tons of raw materials [25]. It is also mentioned that Switzerland called for the circular economy for the first time in 1976 as an economic model that aims to reduce waste of materials, goods, and energy in the form of waste, by simplifying operations and supply chains, preserving the value of products, managing inventory and the natural, human, manufacturer, and financial capital in conjunction with the global trend to shift from individual ownership. To the idea of a "license of use and sharing of services", the use of technology helps to create products and systems in which materials are reused, recycled, or remanufactured and move towards sharing resources instead of owning them [26].

Table 2. *Sustainable development goals related to the circular economy.*

Goals	Indicators	Countries performance in 2021
SDG8 (Decent work and economic growth)	17 sub-indicators, including: Annual growth (real GDP per capita) Percentage of informal employment out of total employment, Unemployment rate Percentage of youth (between 15 and 24 years) outside the education, employment and training department Percentage of children (between 5 and 17 years of age) involved in the child labor market.	🟢 Only three countries achieved this goal: Slovenia, Cuba and the Czech Republic. 🟡 37 of 193 countries faced challenges, including Canada, Japan, UK and Qatar. 🟠 61 countries faced significant challenges, like France, Switzerland, Italy, the USA and China. 🔴 76 countries faced major challenges, including UAE, Jordan, Algeria, Brazil, and Egypt. ⚫ 16 countries for which information is not available, like Andorra, Dominica and Grenada.
SDG9 (Industry, innovation and infrastructure)	12 sub-indicators, including: manufacturing value added share in GDP CO_2 emissions per unit of added value Share of R&D in GDP, She of medium and advanced technological industry out of total value added.	🟢 Four countries achieved this goal: Sweden, UK, Japan, and Singapore. 🟡 18 of the 193 countries face challenges, including USA, Canada, UAE and France. 🟠68 countries face significant challenges, including Kuwait, Portugal, Czech Republic, Greece, China and Egypt. 🟠103 countries face major challenges, including Libya, Cuba, Mexico, Italy and India.
SDG11 (Sustainable cities and local communities)	18 sub-indicators, including: economic losses directly attributable to the disasters comparing to the GDP Percentage of urban solid waste collected and managed in controlled facilities out of total urban waste generate, Damage to the basic vital structures Number of disruptions to basic services due to disasters	🟢 No country has yet been able to achieve this goal 🟡 51 out of 193 countries face challenges, including UAE, Japan, Finland, Sweden and the USA. 🟠 69 countries face significant challenges, including Denmark, Greece, Italy, China and Egypt. 🔴 60 countries face major challenges, including Iran, Iraq, Ghana, Lebanon and India. 🔴 13 countries for which information is not available, including Barbados, Dominica and the Marshall Islands.
SDG12 (Responsible consumption and production)	18 sub-indicators, including: Number of countries developing, adopting or implementing policy instruments aimed at supporting the transition to sustainable consumption and production, Food loss index, Food waste index, National recycling rate, tons of material recycled, Hazardous waste per capita, proportion of hazardous waste treated, Capacity of renewable energy generation established in developing countries (watts per capita)	🟢 25 countries achieved this goal, including Morocco, Senegal and Ghana. 🟡 48 193 countries face challenges, including Ukraine, Iraq, Egypt and China. 🟠 51 countries face significant challenges, including Japan, Italy, Russia and Saudi Arabia. 🔴 52 countries face major challenges, including Kuwait, Germany, France, Canada and the USA. 🔴 17 countries for which information is not available, including the Marshall Islands, Dominica and Guinea-Bissau.
SDG13 (Climate Action)	11 sub-indicators, including: total greenhouse gas emissions per year, Number of countries adopting and implementing national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015-2030.	🟢 67 countries achieved this goal, including Morocco, Ghana, Kenya and Syria. 🟡 38 countries face challenges, including Tunisia, China, Brazil, Jordan and Egypt. 🟠 29 countries face significant challenges, including Ukraine, Russia, Malaysia and Algeria. 🔴 53 countries face major challenges, including Bahrain, Kuwait, USA, Italy, Canada, UK, and Japan. 🔴 6 countries for which information is not available, including Monaco, the Marshall Islands and San Marino.
SDG17 (partnerships to achieve the goals)	25 sub-indicators, including: The percentage of the local budget funded by local taxes, Wired broadband Internet subscriptions per 100 population according to speed, The percentage of people using the internet, The weighted average of tariffs around the world, The dollar amount allocated to companies between the public and private sectors in the field of infrastructure.	🟢 Only one country in the world has achieved this goal, and that is Norway. 🟡 32 of the 193 countries face challenges, including Denmark, Russia, Sweden and Germany. 🟠 92 countries face significant challenges, including France, Finland, Italy, Egypt, UAE and China. 🔴 51 countries face major challenges, including the USA, Japan, Canada and India. ⚫ 17 countries for which information is not available, including Bahrain, Cuba, and Qatar.

🟢: The goal is achieved; 🟡: There are challenges; 🟠: There are significant challenges; 🔴: There are major challenges; ⚫: No available information

Source: Global indicators framework for the goals and targets of the 2030 Agenda for Sustainable Development

Several studies and applications indicate that the adoption of circular economy mechanisms is linked to achieving a set of sustainable development goals [27, 28], including decent work and economic growth (SDG8), industry, innovation and infrastructure (SDG9), sustainable cities and communities (SDG11), and responsible consumption and production (SDG12), climate work (SDG13), and partnerships to achieve the goals (SDG17). Table 2 reviews the sub-indicators of these goals and the performance of countries in 2021.

The circular economy offers opportunities and applications that improve the performance of sustainable development indicators, especially those related to the industrial sector. This has given the term circular economy interest by many governments and institutions as one of the mechanisms to support sustainable development. This methodology allows for consistently achieving alignment between desired growth levels and addressing environmental sustainability challenges. However, the success of the overall circular economy policy requires the adoption of a comprehensive vision and coordination between the various economic sectors and the actors in them, as well as the existence of the political will to deal with the common global goals of sustainable development and climate change.

4. Activating the Circular Economy in the Industry Strategy: The International Experience

China's pioneering experience in formulating an industrial strategy around the circular economy ideology can be considered (Box 1). Chinese policymakers have adopted the concept of the circular economy since the 1990s as an effective model for aligning economic development objectives with environmental preservation. China accredited the Circular Economy Law in 2008, becoming the first country to legislate for the circular economy. The law is based on three pillars of the circular economy: *Reduce*, *Reuse*, and *Recycle*. Accordingly, China launched its industrialization strategy on three main bases: environmentally friendly production, industrial ecology, and development/ecological modernization. The Chinese government's drive towards a circular economy over the past four decades has helped achieve unprecedented levels of economic growth, doubling per capita GDP by more than 25 times and lifting nearly 700 million people out of poverty.

Box (1): China's industrial strategy and the circular economy

The industrial sector in China constitutes the most important sectors generating GDP, accounting for 40%. However, the superior industrial performance in China over the past decades was associated with heavy environmental losses, as the industrial sector bears more than two-thirds of environmental pollution in China. China has joined the international commitments to sustainable development on reducing carbon emissions by 2030 and achieving carbon neutrality by 2060. China accredited the Circular Economy Law in 2008, becoming the first country to legislate for the circular economy. The law is based on three pillars of the circular economy: reduce, reuse, and recycle. Accordingly, China launched its industrialization strategy on three main bases: environmentally friendly production, industrial ecology, and development/ecological modernization. After announcing the 17 Sustainable Development Goals, the country set, in its 13th Five-Year Plan (2016-2020), a top priority for building an "environmental civilization" that includes a clear vision for transforming the industrial sector into a sustainable sector through several strategies that adopt the circular economy methodology, the most important of which is the transformation of the traditional industrial clusters into eco-industrial parks. This strategy went through three phases: 1. Modifying the industrial structure of traditional communities through technological innovation to raise the efficiency of resource use. 2. Developing closed-loop supply chains through circular use of energy and circular use of waste and by-products that enable these complexes to coexist with industrial and shared use of infrastructure. 3. Achieving integrated and coordinated development between economy, environment and employment through comprehensive planning and strict management. In the same context, China approved five basic laws with the aim of transforming to the circular economy for the economic activities, which are: the Environmental Protection Law, the Environmental Impact Assessment Law, the Cleaner Production Promotion Law, the Circular Economy Promotion Law, and the Environmental Protection Tax Law. The success of the transformation towards the circular economy was demonstrated in the reduction of energy consumption per unit of industrial added value by about 32.7%, the rationalization of water consumption by about 33.6%, the increase in the rate of water reuse in the industrial sector to 90%, and the increase in the rate of use of industrial waste to 94% during the period 2011-2015. China has recently launched a new five-year plan (2021-2025), which includes ambitious goals in the field of circular economy, represented in replacing fossil fuels with renewable energy sources, reducing water consumption by 13.5%, and reaching 16% in water use per unit of GDP by 2025.

It is also indicated that the European Commission adopted the Circular Economy Action Plan (CEAP) in 2015, targeting the leading production chains in packaging, plastics, and textiles, which included reducing waste and promoting recycling and sustainability of products. As a result, the European Union was able to generate approximately (155) billion euros in 2017 because of reuse and recycling operations, in addition to a growth in employment rates of about (6%) in the recycling and reuse sectors and the financial leasing sector [29].

Furthermore, in 2013, the European Union funded the

SwitchMed initiative in eight countries of the southern Mediterranean, including Egypt, implemented by the United Nations Industrial Development Organization (UNIDO) and the United Nations Environment Program (UNEP). The initiative aims to accelerate the adoption of more sustainable production and consumption patterns in these countries. As a result, the initiative managed to reduce annual production costs by about (41.7) million euros and reduce carbon dioxide emissions by more than (197) thousand tons [30].

The Dutch experience is one of the most prominent successful experiences of the circular economy, as the circular economy in the Netherlands in 2020 reached nearly a quarter of the size of the Dutch economy [31]. In 2016, the Netherlands developed a national strategy to transform the circular economy by 2050 as part of its commitment to the European Union's Circular Economy Action Plan. The strategy aimed to reduce the use of raw materials from minerals and fossils by 50% by 2030 [32]. In 2015, the city of Amsterdam developed a sustainability agenda, which reflects the city's ambition to become a leader in the transformation towards the circular economy. In addition to being the first city to conduct a comprehensive material flow survey to determine the economic returns from applying the circular economy mechanisms. In this context, this study focused mainly on two chains of materials used in the local economy: construction and vital materials and food. The survey results showed that the construction sector alone could save 500 thousand tons of materials, avoiding about half a million tons of carbon dioxide yearly. Accordingly, the city has developed a roadmap for circular buildings. It has already taken several executive measures to implement that vision, including applying circular standards in four tenders and more than 70 projects [33]. By 2019, there will be 85,000 activities in the Netherlands, generating 420,000 jobs related to the circular economy, according to estimates from the Netherlands Environmental Assessment Agency [34].

Elsewhere in the world, South Korea [2] has adopted several procedures to transform towards a circular economy to achieve greater security and sustainability of resources. On top of these procedures, the enactment of several legislations aimed at transforming the circular economy, including the Resources Circulation Act (FARC), the master plan for resource circulation covering the period 2018-2027, and the master plan for resource development for the period 2020-2029. Colombia has also adopted several strategies targeting the transformation towards the circular economy through the circular use of waste, such as converting waste into energy, recycling raw materials, and the trend towards using renewable energy sources [35]. In Africa, the Western Cape government in South Africa launched the Industrial Symbiosis Program (WISP) in 2013, which aimed to recycle resources. As a result, the program was able to recycle more than (104) thousand tons of waste, which contributed to the generation of more than (8.5) million dollars and created about (218) job opportunities [36].

The Middle East and North Africa region (MENA) has opportunities to activate circular economy mechanisms and benefit from their outputs in facing challenges that impede sustainable development, such as waste management, addressing resource scarcity, and most countries' dependence on imported goods resources. Organic food waste represents about 55% of solid waste, followed by paper and cardboard (13%) and plastic (12%) [37]. According to the World Bank, the region can recycle 10% of plastic, 3% of metals, 1% of wood, and 3% of glass provided proper separation is applied, and there is adequate resource recovery infrastructure [37]. The average recycling rate in MENA countries is at most 9%. This low rate is primarily due to the small number of compulsory segregation and the absence of fees to cover the cost of waste collection and management [37].

Although governmental entities in the region's countries are entrusted with implementing laws related to waste management, these legislations and regulations are limited to the requirements of segregation, recycling, and waste reduction at the source in general. The lack of waste infrastructure is a significant challenge to implementing circular economy strategies. The economic viability depends on the quantity and quality of the segregated waste, and it is often challenging to implement circular economy strategies without strict government intervention. For example, it is logical for many companies to get rid of old manufacturing machines and replace them with new ones if the new ones are of higher productivity. These companies should pay more attention to the fate of the old machines but rather look for the least expensive way to get rid of them, without regard to the possibility of using them for other purposes, whether as scrap or otherwise. This behavior seems logical from an economic point of view, as companies look first for the accounting profit. The same applies to individuals, for example. In many cases, getting rid of a car involved in a traffic accident is less expensive than repairing it, but the environment is the most affected by these actions. Therefore, government intervention is required in many cases; in the form of approving regulations that encourage companies and individuals to benefit from recycling and raising their awareness level or imposing penalties on violators or incentives that encourage them to recycle and reduce the consumption of natural resources.

Many international organizations seek to encourage discussions about ways to involve all aspects of society in implementing the circular economy mechanisms. For example, the United Nations Conference on Trade and Development "UNCTAD" began to focus on the circular economy concept in 2015, in cooperation with the MacArthur Foundation, regarding resource recycling potential in several large economies such as China and India.

Interest in the circular economy is not limited to national

2 Korea is a resource-scarce country.

governments and international organizations only. Still, it extends to the work of many companies interested in improving their social and environmental footprints in parallel with achieving cost savings. Among the most important of these companies is *Philips Health Technologies*, which produces large and small medical equipment and home care devices. The company employs about 80,000 and achieved about 19.5 billion euros in 2020. Its products are distributed in over 100 countries, and its vision is based on circularly providing health care. The company embeds circular economy practices in all stages of production by developing business models that enable it to decouple the growth from its consumption of natural resources, like the Product-as-a-service model, take-back schemes, and others. Philips adopts several policies to achieve circular production of health equipment, including closing the loop on equipment, which enables customers to renew used medical devices. And this strategy has already begun to be applied in large hospitals on some devices, such as magnetic resonance imaging devices, and the company's policy is moving towards expanding to include smaller medical devices during the next five years. Refurbished Systems Policy is a system adopted by Philips to provide refurbished devices as new, with the company's guarantee of quality performance. Philips is also introducing new business models that allow the provision of medical devices and technologies with service contracts, with the company retaining ownership and responsibility for the device. Philips also provides smart health services that allow better use of resources and reduce emissions, for example, remote interaction between patients and care providers.

5. Circular Economy Indicators

Despite the importance of the circular economy in achieving sustainable development goals, it currently reaches only 8.6% of the global economy [38]. Moreover, given the complexity of the circular economy applications, no single composite indicator has yet been calculated to measure the performance of countries adopting circular economy policies. While it is possible to rely on several indicators to express countries' progress during the circular economy, these indicators relate to the sustainability of resource management (like a physical footprint and recycling rates). And other indicators related to social behavior (such as the percentage of citizens who prefer sustainable consumer alternatives, the number of published scientific research on the circular economy, the number of companies, and the size of employment in repairing devices). In addition to indicators related to business management operations (such as the obstacles faced by companies when adopting circular economy mechanisms, the sources of funding allocated to the operations of transformation to a circular economy, the number of companies that facilitate the operations of recycling products after their use, and the number of companies that introduce recycled products or resources into new production operations).

The literature indicates three primary levels at which the measurement of the circular economy performance is conducted: the micro level (such as a product or firm), the meso level (such as eco-industrial parks and industrial symbiosis), and the macro (such as a city, county, district, or village). Between 2018 and 2020, the Organization for Economic Co-operation and Development monitored 474 indicators related to the circular economy at the macro level. The aggregated indicators belong to 29 circular economy studies, of which eight are applied at the national level, eight at the regional level, and 11 at the local level. These indicators are a dynamic tool updated frequently and regularly given the progress countries, regions, and cities make in developing circular economy strategies and related measurement frameworks. It is also a source of inspiration for other governments wishing to develop or use similar indicators to improve policies related to the circular economy. Circular economy indicators can be categorized into five main categories, of which 474 indicators are distributed in the percentages shown in (Figure 6). The most significant percentage of circular economy indicators are related to the direct impact on the environmental balance (39%), such as emissions, energy saving rate, raw materials saving rate, recyclable raw materials percentage, waste segregation rate, and total waste recycling operations. At the same time, 34% of the indicators are related to governance, such as education, capacity building, and organization, expressed in the number of patents related to recycling, the applied recycling initiatives, the number of researchers in the field of the circular economy, the legislative amendments about laws regulating waste, and the removal of legislative obstacles that prevent the implementation of the circular economy mechanisms. Economic and commercial indicators are 14% of the circular economy performance indicators. They are related to the added value of the circular economy and public investment in the circular economy projects, in addition to focusing on the activities carried out by companies, such as the indicator on the amount of savings resulting from recycling, savings resulting from reducing waste, and total investment in the circular economy projects. 8% of the indicators are related to the framework of infrastructure and technology through the monitoring and measurement of tools and technologies that enhance the circular economy in the economy, such as the number of recycling centers in each city, environmentally friendly products and services, and the number of restaurants with a “no plastic” label. In addition, a set of indicators related to employment and human resources (5%), such as green jobs and the number of new jobs in circular economy sectors.

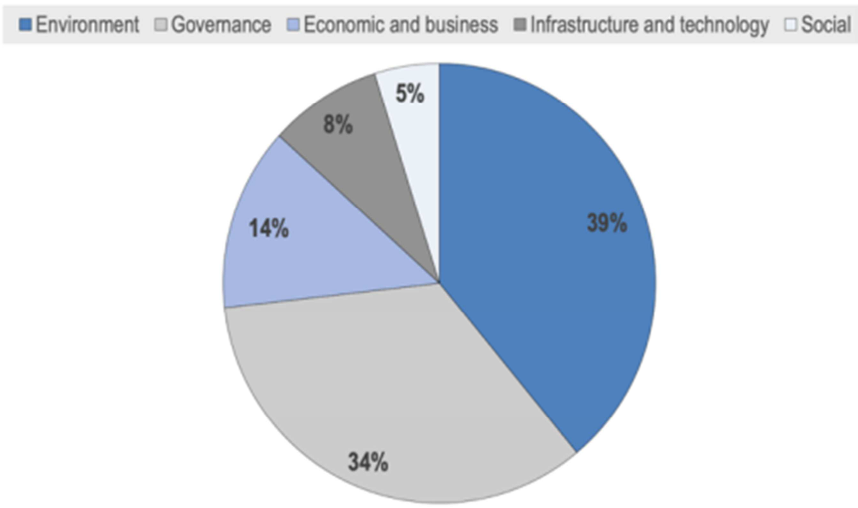


Figure 6. *Categories of Circular Economy Indicators.*

In a similar context, the Kingdom of Saudi Arabia (KSA) introduced the concept of a circular carbon economy during its presidency of the G20 as a framework for building an economy based on carbon recycling [39]. The concept shown in Figure 7 includes four axes: reducing carbon emissions, reusing carbon, recycling carbon, and carbon removal [40].

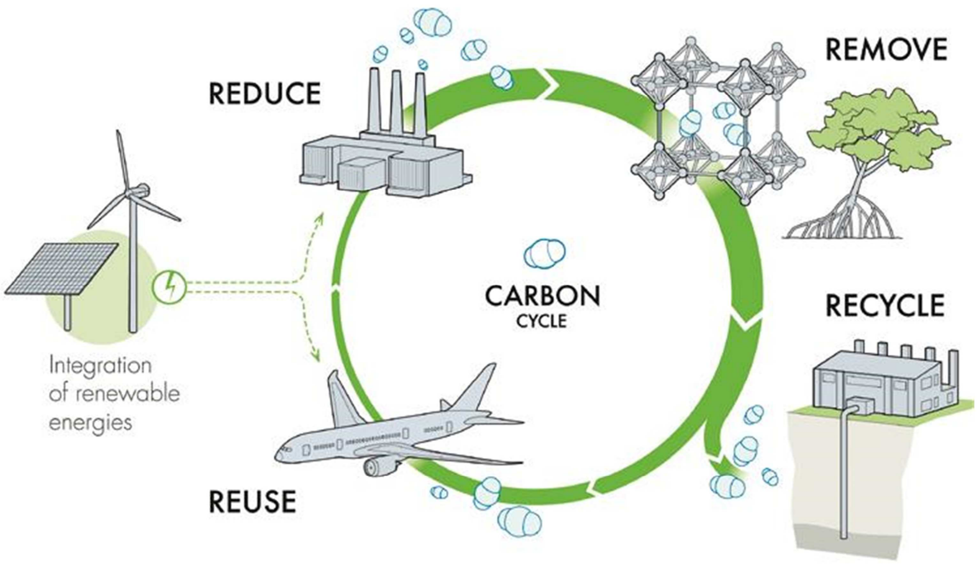
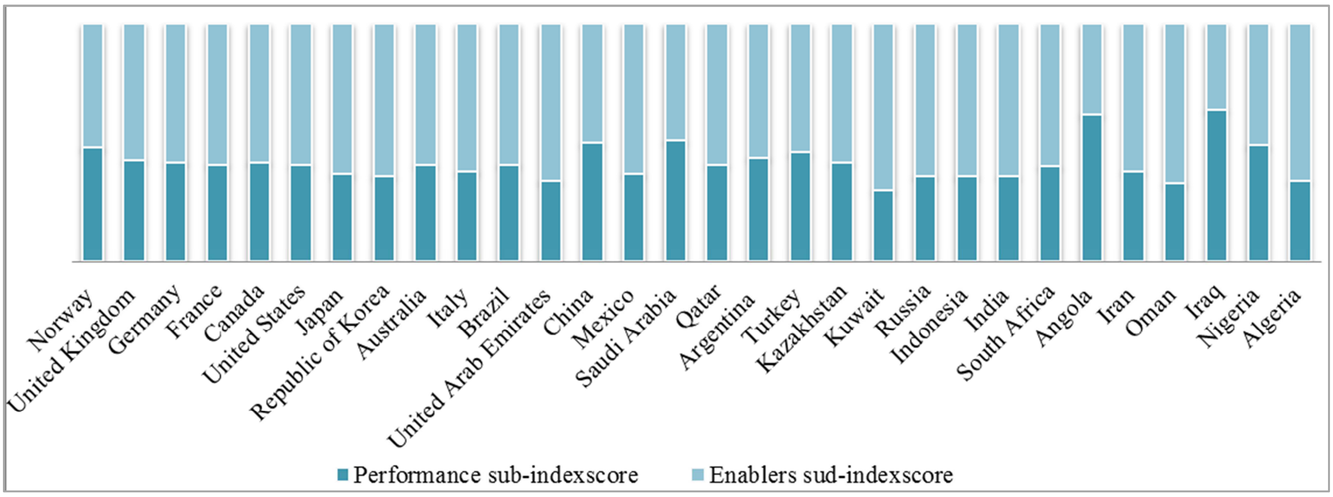


Figure 7. *KSA's Concept of Circular Economy.*

In the same context, the King Abdullah Petroleum Studies and Research Center introduced the Carbon Circular Economy Index (CCE Index) as a composite index that measures each country's different dimensions of the circular carbon economy. The index value ranges from zero (the lowest value) to 100 (the highest value) for the measured country's transformation towards a circular carbon economy. The Circular Carbon Economy Report for the year 2021 included the results of the index for thirty countries of the world [41], 11 countries from the MENA, 8 European countries, 6 Asian countries, and five countries from the Americas. Figure 8 shows the performance of the 30 countries and their ranking in the index, led by European countries in the first four positions, recording an average value of the index at 65, which is close to two-thirds of the maximum for this indicator. Much of the European progress in the course of the circular economy can be attributed to the help of modern technology and innovative solutions provided by the fourth industrial revolution that supports the activation of circular economy applications more efficiently and quickly. The next section of the study discusses the opportunities Industry 4.0 offers to support circular economy paths for sustainable development.



Source: [42]

Figure 8. *Carbon Circular Economy Index for 2021.*

6. Integrating Industry 4.0 with the Circular Economy for Sustainable Development

The integration of both the circular economy and Industry 4.0 holds opportunities for the world to reach the desired economic growth rates without prejudice to future generations' rights by supporting sustainability in its environmental, economic, and social dimensions [43]. Most of the industry technologies today pose a major threat to sustainability, as they are responsible for producing about 30% of GHG emissions [17], which are the leading cause of climate change. Transforming into the circular economy requires three main principles, *Reduce, Reuse, and Recycle*. Technology and innovation are important requirements for achieving these principles efficiently by a sustainable global society. The need for technology and innovation appears in: First, regarding the advanced collection, sorting, and recycling. Second, efficient handling of resources. Third, the circular design of products. Fourth, the interactive platforms.

Industry 4.0 introduces increasing technologies and advanced technological pillars, including artificial intelligence, 3D printing, Big data, and the Internet of Things, that support the principles of transformation toward the circular economy in a highly efficient way—improving production chains' efficiency and providing dynamic mechanisms to meet the volatile market requirements. It also provides effective mechanisms to reach sustainable production and consumption operations based on balancing the economic, social, and environmental dimensions. As it is possible to take advantage of electronic applications, sensors, and robots in advanced recycling, it is also possible to rely on artificial intelligence to raise resource processing efficiency in line with the circular economy mechanisms. For example, the circular design of products can benefit from 3D printing. Furthermore, interactive platforms can benefit from the *Internet of Things* and developing electronic applications and websites, as well as the possibility of helping from databases, which contributes to increasing the efficiency of the entire production system [44].

A set of examples and technologies – but not limited to – can be observed that indicate ways to benefit from Industry 4.0 in supporting the growth of the circular economy:

1) *Supply Chain Automation*: Industry 4.0 provides technologies to automate supply chains. The use of these technologies by companies enables them to reduce costs, the possibility of tracking products remotely and in real time, and obtain data on the volume of resources used. Radiofrequency identification devices can also be used in the reverse logistics management of used resources to detect waste that can be recycled and turned into valuable resources for new production cycles.
2) *Digitization*: The digital transformation operations introduced by Industry 4.0 provide alternatives to traditional industrial operations by relying on artificial intelligence, which contributes to managing transaction data and exchanging surpluses and wastes more efficiently. This enhances the efficiency of decision-making stages and the flexibility and rapid adaptation of manufacturing processes in circular economy practices at the micro and meso levels.
3) *Smart Factory*: Structures based on the integration of Industry 4.0 technologies contribute significantly to reducing waste and increasing the efficiency of operating systems and processing operations, which can greatly benefit when transforming into a circular economy.
4) *Deep learning* is based on algorithms that allow machines to teach themselves. This can support the circular economy by understanding customers' behavior when using websites and enabling the use of data collected about customers to improve websites and provide technical support to customers automatically and remotely.
5) *Big data*: Big data allows data to be virtualized,

bypassing all physical limitations associated with managing collected data, which contributes to increasing the efficiency of storage operations and improving the speed and reliability of data acquisition.

6) *Machine learning*: Machine learning enables computers to learn by linking various data in the form of images, numbers, maps, etc., and is highly compatible with massive databases.
7) *Advanced manufacturing*: It is based on adopting innovation strategies that support continuous technological development in production operations such as artificial intelligence, cloud computing, big data, collaborative robots, crowdsourcing, the Internet of Things, additive manufacturing, 3D printing, new energy sources, nanotechnology, biotechnology, and genetics. This achieves the integration of production and assembly lines into the manufacturing process and remote control of production operations. It also raises the efficiency of logistical systems that guide the introduction of fundamental changes in production lines, as any information related to production processes is exchanged immediately without human intervention, which reduces the possibility of error.
8) *Artificial neural network* is the most widely used method for developing artificial intelligence applications in a software attempt to simulate how the human mind works. These networks can be used to identify new patterns of tracking products available in the market. It is also necessary to create databases that provide information about final product disposal, strategic points for collecting used resources, and strategic areas for setting up waste recycling plants.
9) *Smart sensors*: These devices are sensitive to movement and temperature changes. They can be used as security devices and as automatic notifications via smartphones. In addition, these devices contribute to monitoring operations, which enhances the speed of decision-making. Therefore, it can be used in transforming operations to the circular economy to track industrial indicators and generate data in real-time to make effective decisions.
10) *Radio-frequency identification*: This short-range communications technology can automatically read radio frequencies with sensors. This technology can be used in various medical and financial fields (such as in developing electronic payment systems via phones and collecting fees). It can also be used to track shipments.
11) *Convolutional neural network*: The application of these networks focuses on processing and analyzing digital images. Convolutional neural networks can be used in the circular economy to capture a picture of products and to obtain product aspects and characteristics, which allows manufactured products to be distinguished and compared with reused raw materials.

At a time when Industry 4.0 is facilitating its technologies to transform into a circular economy and contribute to solving social and environmental problems, it is exposed to several internal challenges related to (1) financing and investments, (2) Research and development, and several other challenges facing public policy: (1) Managing the negative externalities of Industry 4.0, (2) Ensuring a fair distribution of the proceeds of adopting these technologies, (3) Ensuring human leadership of Industry 4.0 and being its centerpiece [45]. Data control is at the top of the external challenges of Industry 4.0. As the technologies offered by Industry 4.0 made data the new currency, and the accumulation and monopoly of that data in a limited number of giant digital companies limit fair competition between companies. Cybersecurity [46] is a significant and growing external concern, as reported in the 2018 [46] World Economic Forum Global Risks Report, which imposes enormous costs on countries to protect it. In 2017, about 300,000 computers in 150 countries were exposed to a cyber-attack known as the WannaCry attack, which imposes enormous costs on governments to protect it.

On the other hand, cyber-physical systems[3] deal with big data and several heterogeneous devices, which makes them very complex. Therefore, reaching the application of unified standards and specifications for these cyber-physical systems represents a significant challenge that requires continuous research and development [47]. In addition to these challenges, substantial investment costs are needed to establish smart factories that support the circular economy in addition to the costs and complexities related to unifying the infrastructure required to adopt the technologies of the fourth industrial revolution, which depends mainly on adopting disruptive technologies[4] within production operations, which is one of the most difficult challenges facing the transformation into smart factories.

As for the unequal distribution of the benefits of the technologies of *Industry 4.0*, it should be noted that the same thing happened in the previous industrial revolutions, and in this regard, there are many fears that *Industry 4.0* will lead to a widening gap in distribution.

7. The Egyptian Efforts to Integrate the Circular Economy into the Industry

The Egyptian state launched a national strategy to achieve the 17 SDGs in February 2016, which is "Egypt's Vision 2030,"; which included a balance among the economic pillar, the social pillar, and the environmental pillar while preserving the rights of future generations. This vision reflects Egypt's international commitment to sustainability and inclusive growth while giving particular importance to building an integrated and sustainable environmental system that enhances the country's ability to confront the growing environmental risks [48]. In its first axis, the strategy indicated that the energy sector must meet the requirements of sustainable development by efficiently using traditional and renewable resources to contribute to economic

3 Intelligent systems that integrate, monitor, and control physical, computer, and network operations in a system

4 Which refers to improved technologies that replace traditional technologies

growth, competitiveness, social justice, and environmental preservation. The third pillar of the vision also touched on the need to integrate the environmental dimension in all economic sectors to preserve natural resources and support their efficient use and investment while guaranteeing the rights of future generations in a way that leads to diversifying production resources and economic activities, supporting competitiveness, providing new job opportunities, eliminating poverty, and achieving Social Justice.

Egypt witnessed a steady increase of 32% per capita primary energy consumption from 1990 to 2014 [49]. Although Egypt ranks 25th globally in oil production, it is facing increasing rates of declining reserves [50]. The industrial sector controls 37% of energy consumption in Egypt [49], which is higher than the share of the same sector in the European Union. Water scarcity risks also constitute a significant challenge to the development strategy. The increasing demand for water from agriculture, industry, and household consumption resulting from population increase puts pressure on the limited water resources in Egypt in light of the limited water re-treatment. The water deficit is estimated at 30 million cubic meters [51], and the annual per capita share of water is 570 cubic meters [52], which is less than the global water poverty limit.

The manufacturing sector is the largest consumer of natural resources and the main contributor to environmental degradation in Egypt. Egypt has established several cities and industrial complexes as part of its path towards industrialization, with the absence of implementation mechanisms for effective environmental protection policies [53], which creates three sources of challenges that impede the ability to grow and sustain, which are: industrial waste management, used water treatment, and energy efficiency achievement. The industrial sector used about 5.4 billion cubic meters of water in 2017 [54]. Most untreated industrial wastewater is disposed of in waterways or public sewage networks, posing environmental and health risks. Half of all wastewater produced in Egypt is treated, and 0.7% is officially reused for irrigation [55]. In addition, the industrial sector in Egypt was responsible for 9.7% of CO_2 emissions in Egypt in 2016 [56]. Despite the lack of recent data on solid waste, 2012 data indicates that Egypt produced approximately 89 million tons of solid waste, six million tons of which are non-hazardous industrial waste, and hazardous industrial waste ranges from 260 thousand to 500 thousand tons [57].

Egypt has formulated several goals within its sustainable development strategy, including that 80% of municipal waste is regularly collected and managed with 90% efficiency and that waste in water treatment plans be limited to less than 10% by 2030. It should be noted that Egypt has achieved several achievements in dealing with waste and surpluses in the industrial sector. In 2020, the number of garbage recycling factories in Egypt reached 51, and the total garbage amounting to about 32.5 million tons was disposed of. The total number of treated sewage treatment plants reached About 421 stations, bringing the amount of treated sewage to 4436.7 million m3. The total amount of agricultural waste during 2019 was about 2422 thousand tons in six governorates (Daqahlia, Sharqia, Qalyubia, Kafr El-Sheikh, and Gharbia), to be recycled about 1308 thousand tons, Which represents about 54% of the total of those wastes generated, in addition to that, about 7.4 billion m^3 of wastewater were reused during the year 2020/2021, in seven governorates (Sharqia, Daqahlia, Menoufia, Gharbia, Kafr El-Sheikh, Behairah, and Giza) [58].

However, these dealings and achievements still need to be made available. They do not guarantee the maximum utilization of resources. At the same time, the inclusion of circular economy applications provides opportunities for Egypt to achieve the goals related to reducing environmental degradation in the face of rapid population growth and high consumption patterns, to reach the goals of sustainable development with a higher degree of efficiency. In 2021, the Circularity Gap Report ranked Egypt among six other “grow countries” along with China, Indonesia, Brazil, Mexico, and Vietnam. Developing countries are manufacturing centers responsible for 47% of global emissions and 51% of global resource extraction. This report annually covers 176 countries around the world in line with the World Economic Forum in Davos. It aims to direct decision-makers in economically developed countries' attention to the importance of adopting circular economy strategies for a better future for all people. Therefore, these countries should give high priority to sustainable agriculture; circularity of resource efficiency, transforming towards renewable energy sources, and establishing infrastructure to extend the material efficiency cycle [5]; Hence the importance of Egypt's adoption of the circular economy strategy, taking advantage of the industrial development witnessed by the world towards the applications of the Fourth Industrial Revolution.

7.1. The Institutional and Legal Framework Related to the Circular Economy in Egypt

The Environment Law No. 4 of 1994 is Egypt's primary environmental legislation. In addition, there are three sets of other laws and policies related to the circular economy in Egypt. First: Solid waste management laws, second: Water treatment laws, and Third: Laws pertaining to energy use. Waste management is based on the provisions contained in the Environment Law, amended by Law 9 of 2009, as well as Law 38 of 1967, as amended by Law 31/1976, which is the fundamental law related to solid waste management and regulates the collection and disposal of solid waste from homes and the commercial and industrial establishments [59]. Moreover, in October 2020, several legislations were issued, including the Waste Management Regulation Law No. 202[5] of 2020, according to which a public authority called the Waste Management Regulatory Authority was established, and its powers include regulating, monitoring, and evaluating waste activities, developing investment opportunities, issuing

[5] Law No. 202 of 2020 issuing a law regulating waste management. (2020), Official Gazette No. 41 bis (b) on October 13, 2020, https://docs.google.com/viewerng/viewer?url=https://manshurat.org/sites/default/files/202_30.pdf

the necessary licenses and permits; as well as creating a national strategy to improve waste management and recycling—in addition to that, organizing, following up, monitoring, evaluating, and developing everything related to integrated waste management activities, attracting and encouraging investments in the field of these activities to ensure sustainable development, and following up the implementation of the necessary plans to organize waste management in cooperation with state institutions, local administrations, the private sector, civil society organizations, and international organizations. The agency aims to support the Egyptian state's relations with other countries and global and regional organizations in the field of waste management. In addition to that, organizing, following up, monitoring, evaluating, and developing everything related to integrated waste management activities, attracting and encouraging investments in the field of these activities to ensure sustainable development, and following up the implementation of the necessary plans to organize waste management in cooperation with state institutions, local administrations, the private sector, civil society organizations, and international organizations. The agency aims to support the Egyptian state's relations with other countries and global and regional organizations in waste management.

As for the disposal and treatment of sewage water, it is done through Decree 44/2000 regarding quality standards for discharge into public sewage networks, as well as Law No. 93 of 1962 and its executive regulations, Decree 649/1962 regarding wastewater disposal, which prohibits the disposal of liquid industrial waste into public sewers without a permit. Also, Law No. 48 of 1982 and its executive regulations outlined in Decree 8/1983 (amended by Decree 9/1989) controls drainage in the Nile, canals, drains, and groundwater through licensing. Licenses are granted by the Ministry of Water Resources and Irrigation, which also has administrative, and police mean to enforce them. The Egyptian legal framework for energy efficiency needs to be more extensive. Law 87/2015, the Electricity Law, in addition to the energy efficiency, includes stipulations that companies with a capacity of 500 kW or more are required to maintain an energy efficiency register and assign an energy efficiency manager and that the government will implement energy efficiency improvement projects for industrial buildings. In addition, the executive regulations of the Electricity Law detail the qualification requirements for the administrative role and the requirements for recording and monitoring energy use. It is worth noting that several government agencies in Egypt support the green transformation in the Egyptian industry (Figure 9) and often supervise various aspects of mechanisms for implementing cleaner production.

Figure 9. *The Egyptian government agencies concerned with the green transformation in the industry.*

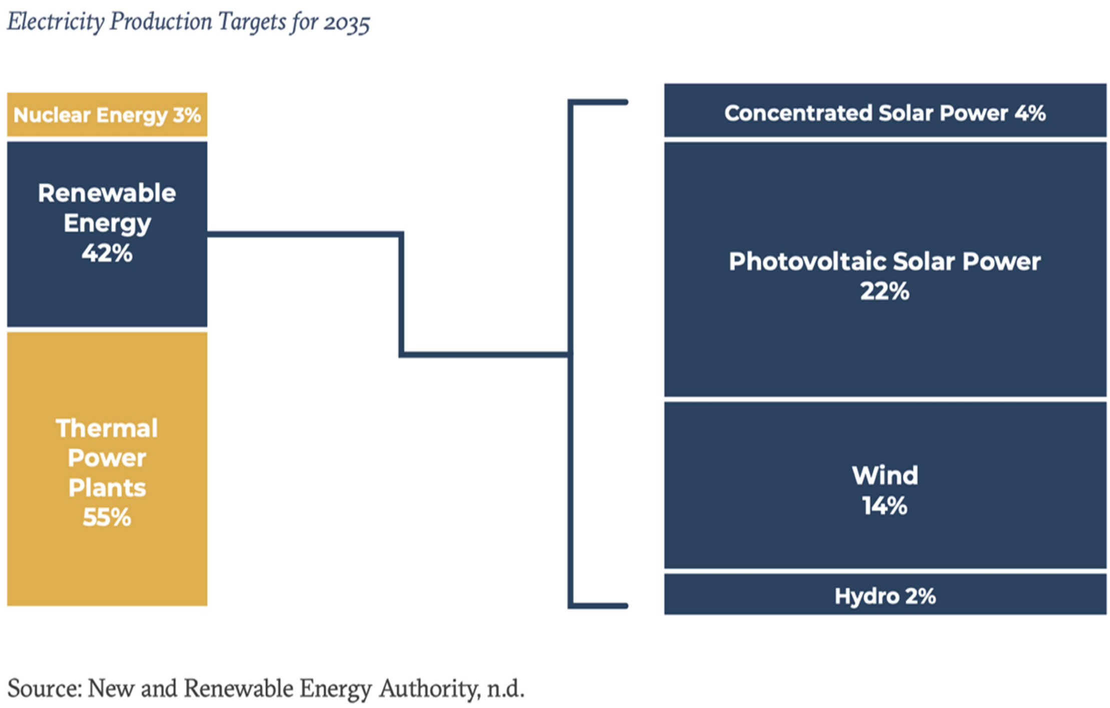
7.2. Opportunities of the Circular Economy in Egypt

Reforms in the new waste management law included better opportunities for waste management, incorporating the ban on open burning of waste, restrictions on the manufacture and distribution of single-use plastics, the establishment of a sanitation fund in each governorate to collect municipal waste, the introduction of “Green Label” certification to encourage the use of recyclable materials and reduce waste. It also required those involved in industrial activity to keep a record of industrial waste that is updated periodically. To encourage investment in waste collection, treatment, and disposal, the law also expands eligibility for tax exemptions and incentives under Investment Law 72/2017 to any company whose primary activity is waste management. The law also stipulates developing a system of economic incentives, including tax and customs exemptions, to promote producing and importing environmentally friendly alternatives to single-use plastic bags [60]. The WMRA[6], supported by the National Solid Waste Management Program (NSWMP), plays a significant role in the opportunities for industrial waste to be reused and converted into energy. Officials from the Ministry of Energy and Water revealed that the government plans to generate 300

6 which was initially established in 2012 under the Ministry of Foreign Affairs

megawatts of electricity from waste by 2025, using 4.2 million tons of solid waste. However, the maximum capacity is currently 13 megawatts [61].

Moreover, the Prime Minister issued Decree No. 41/2019 approving the feed-in tariff for electricity generated from waste-to-energy stations using local solid waste and biogas extracted from landfills at a value of 140 piasters per kilowatt. The responsibility for the feed-in tariff is related to WMRA and the Egyptian Electric Utility & Consumer Protection Regulatory Agency (EgyptERA). According to the Minister of Environment, 93 companies submitted the tender, and eight companies were selected to develop waste-to-energy plants in eight governorates with investments of 385 million US dollars [62]. Opportunities for the circular economy appear in wastewater treatment, especially after the Parliament approved the new draft water resources law in May 2021. The draft law prioritizes the efficiency and quality of water resources and includes provisions defining the roles of all relevant entities in updating water standards; and introducing mechanisms for private sector participation in managing the exchange system [56]. Egypt has invested in building the capacity to treat wastewater through the largest wastewater treatment plant in the world in Bahr El Baqar. Currently, 52 wastewater treatment plants are being developed in Upper Egypt, with a 418 million cubic meters capacity annually [63]. In addition, the Integrated Sustainable Energy Strategy (ISES 2035) and the National Energy Efficiency Action Plans 2018-2022 (NEEAP II) offer multiple opportunities for circular economy applications in the energy field. ISES 2035 was announced in 2016 and included four main pillars: Securing Energy Supply, ensuring the sustainability of the energy sector, developing corporate and corporate governance, and promoting and regulating competitive energy markets. The strategy aims to reduce total energy demand by 18% by 2035 by improving energy efficiency, particularly in buildings, transportation, and industry, with an expected total saving of 20 million metric tons [64]. The strategy also clarifies the Egyptian state's commitment to producing 20% of Egypt's energy from renewable energy sources by 2022 and 42% by 2035, as shown in Figure 10.



[IRENA], 2018

Figure 10. *Targets for electricity production in Egypt by 2035.*

The NEEAP II, approved in 2018, aims to improve the institutional framework and financial support for energy efficiency. It covers many sectors and outlines proposed energy efficiency measures in industry, including using low-carbon technologies, solar energy for heating processes, and highly efficient electric drives. Egypt is moving steadily towards diversifying energy sources with considerable investments in new and renewable energy sources. This is in line with the government reducing natural gas supplies to energy-intensive sectors, including the cement sector (by 50%), and applying procedures to eliminate energy subsidies [49]. It also established the Benban Solar Park, a complex with 41 solar power plants and is the world's fourth-largest solar power plant [65]. In 2022, the Sovereign Fund of Egypt signed a joint development agreement for a project to establish and operate a green hydrogen production facility with a capacity of 100 megawatts in the Ain Sukhna industrial zone of the Suez Canal economic zone. As well as the signing of the primary condition agreement for the hydrogen purchase contract for the project with company

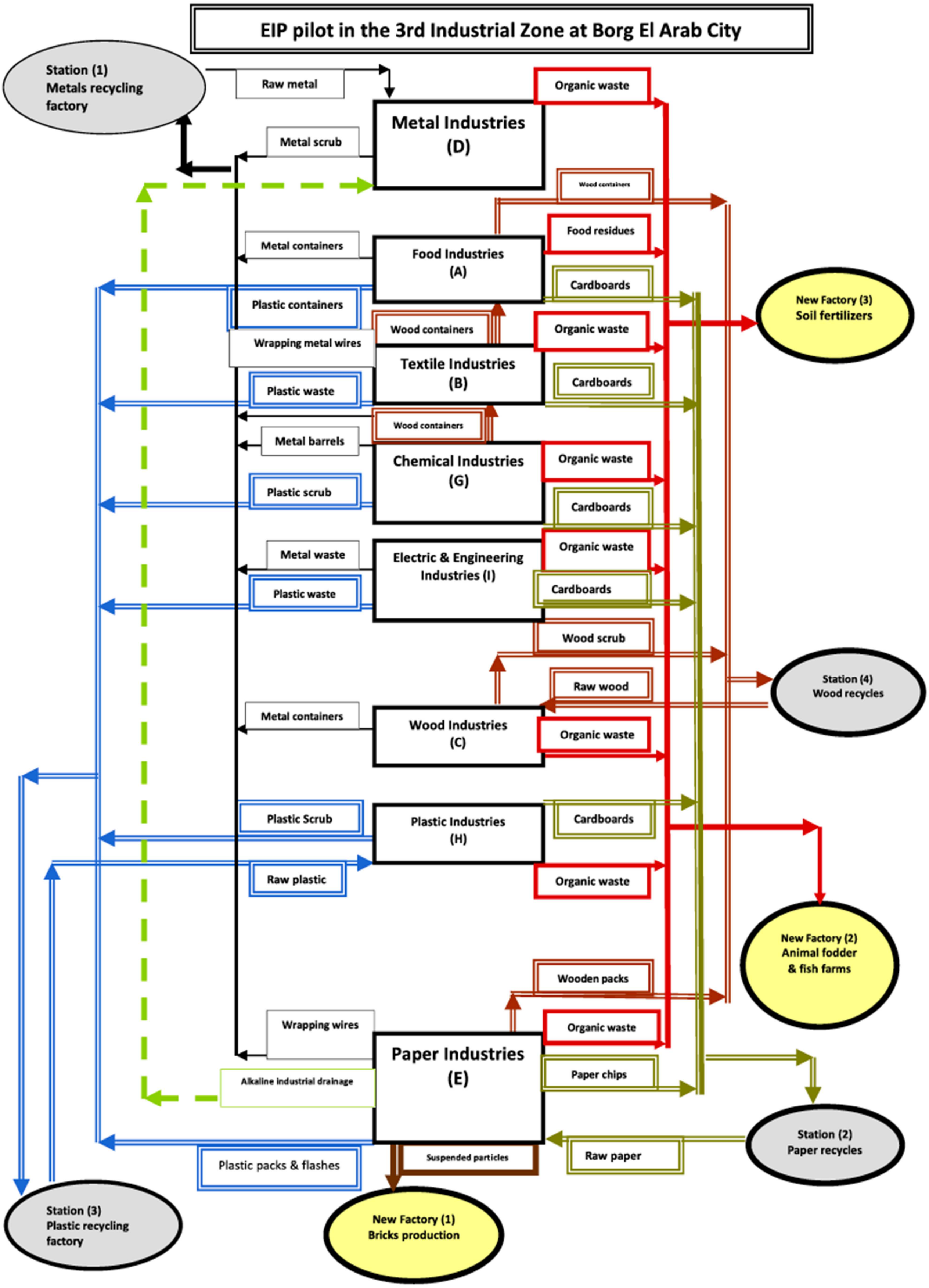
Scatec – the Norwegian renewable energy –, Orascom Construction, Fertiglobe company, and the Egyptian Fertilizer Company [63]. In addition to that, a memorandum of understanding was signed between the General Authority for the Economic Zone of the Suez Canal, the Sovereign Fund of Egypt, the Egyptian Electricity Transmission Company, the New and Renewable Energy Authority, and the Green Fuel Alliance consisting of "Zero West" and "EDF Renewables" companies. To establish a project within the economic zone of the Suez Canal in Ain Sukhna, according to which 350,000 tons of green fuel will be produced annually to supply ships. It should be noted that these projects are part of a series of projects implemented by the government to take advantage of the enormous potential of Egypt to produce green hydrogen, which can be used to support more sustainable production operations [66].

In addition to the above, the National Strategy for Cleaner Production presents opportunities for the Egyptian industry in the applications of the circular economy by offering several procedures to adopt the concept of cleaner production in the industrial framework, including preserving raw materials, conserving energy, and water, and reducing emissions for all environmental medias through applying modifications in the technology used in manufacturing to allow for benefiting from the techniques of Industry 4.0. Also, in an unprecedented development, as witnessed in 2021, the international non-governmental organization WasteAid and the international Dow Company entered into a partnership with the Egyptian government to promote the circular economy in the country by raising awareness regarding the circular economy and collecting and recycling used plastic waste in the production and packaging operations; mainly that the density of the volume of plastic waste that is disposed of in the largest river in Africa, and therefore, this project contributes to strengthening the work of WasteAid and Daw with local partners to transform the problem of pollution into an economic opportunity, and to promote re-entering the recycled plastics into the production cycle again. WasteAid organization identifies the most plastic waste-producing areas so that Daw can support local organizations and plastic recyclers to increase the efficiency of recycling operations and promote the adoption of the circular economy mechanisms. This partnership is part of Daw's African projects connected with the company's strategy to achieve global sustainability. The executive director of WasteAid noted: "The circular economy relies on all parts of the value chain working in unison, from manufacturers and brands to waste collectors and recyclers. The launch of this partnership with Daw unveils local solutions in Aswan for plastic recovery and recycling, with a particular focus on supporting waste collectors and those in charge of providing innovative recycling solutions since they have an essential role in re-entering the raw materials into the production cycle [66].

Considering the essential role of Industry 4.0 in facilitating and simplifying the transformation towards the circular economy, the challenges of Industry 4.0 in Egypt are nothing but other challenges facing the shift towards the circular economy in the state. Among the most prominent challenges is the lack of an integrated strategy for the fourth industrial revolution, which discourages the state's ability to benefit from the applications and technologies of this revolution, especially since its pillars, applications, and effects are connected to all economic sectors in Egypt. Furthermore, the absence of such an integrated strategy constitutes an obstacle to defining the ownership of goals, responsibility for decisions, and evaluation of performance, and thus disables the optimal interventions for development. In addition, the circular economy faces several legal and institutional challenges, the most prominent of which is the dispersal of the responsible authorities, as well as the multiplicity of laws and initiatives in this regard, without an integrated strategy for the circular economy linking and regulating the implementation mechanisms, as the current laws and initiatives are lacking in determining the alternative opportunity cost and the environmental and societal cost of the economic and consumer activities.

8. Conclusion and Policy Recommendations

Developing countries, including Egypt, represent global production centers and are a significant driver of global consumption, considering the steady increase in population. This paper reviews the ability of Industry 4.0 to provide techniques to adopt the circular economy's mechanisms efficiently and effectively. Investing in developing countries in the transformation towards the circular economy would enable them to reap many gains at the macro, micro and spatial levels, in addition to achieving their international commitment to sustainable development goals by 2030, especially the ninth, eleventh, and thirteenth goals. The increasing pressures on countries' economies imposed by the Covid-19 pandemic and the subsequent global economic changes have increased the interest of developing countries in transforming towards the circular economy compared to any previous time due to the economic and environmental gains it achieves in support of the green recovery. However, it should be noted that the burden of transforming toward a circular economy rests primarily with governments with a long-term vision for sustainable development. As for companies, their first and primary goal is to maximize profits, even if this has adverse effects on the environment. Therefore, governments should balance preserving the environment and achieving the desired economic growth rates.



Source: [53]

Figure 11. *Transforming Borg El Arab Industrial City into an Eco-industrial Park based on the circular economy.*

The technologies of the fourth industrial revolution facilitate the spatial localization of the circular economy in industrial clusters through big data applications, where it is possible, through cooperation between governmental agencies (ministries and agencies) and non-governmental (companies and civil society) in Egypt, to transform the industrial cities into environmental, industrial clusters that include circular economy applications. This is done by changing production structures from traditional linear methods based on using resources to manufacture products and then disposing of by-products as waste to circular ways through which by-products are exchanged, and waste is reduced in the first place [67]. It requires changes in industries, production methods, and the knowledge-based perspective of individuals while taking advantage of modern digital and technological applications. Figure 11 shows a model for transforming Borg El Arab Industrial City [7]into an Eco-industrial Park based on the circular economy mechanisms, by-product exchange, and reducing the volume of waste and emissions [53].

The study presents a set of policies that enable Egypt to benefit from the technological pillars of Industry 4.0 in the transformation towards the circular economy to achieve the SDGs:

1) Developing a comprehensive national strategy for the industrial revolution in Egypt. It works to define priorities and draw connections between all economic sectors and activities, secure financing sources, provide the necessary infrastructure for digital transformation, invest in honing the skills and capabilities of the human element, and ensure social adaptation to digital transformation. It should be noted that digitalization creates many new jobs. Still, it leads to the abandon the human element in many jobs, which requires qualifying the workforce to face these changes in the labor market.
2) Establishing a legislative and tax framework that supports the transformation towards the circular economy so that it establishes the legal reference for adopting the circular economy mechanisms, limiting the use of fossil fuels in manufacturing operations, as well as adopting the principle of “the polluter pays” about managing, separating, and treating waste and wastewater, as well as obligating carbon pricing, thus contributing to a low-carbon growth path.
3) Establishing the Egyptian Council for the Circular Economy. This Council undertakes the following tasks for example, but not limited to:
   a) Preparing a comprehensive national strategy for the circular economy that focuses mainly on addressing the previously presented challenges related to the application of the circular economy mechanisms while taking advantage of the available opportunities and following up the performance and evaluation of the application on the ground, and that is through the effective cooperation with all concerned parties locally and internationally in addition to developing a comprehensive framework for the sustainable management of natural resources and consolidating the principles of sustainable production and consumption by promoting innovative solutions on how to benefit from the technological pillars provided by Industry 4.0 towards a circular economy.
   b) Develop pilot projects for the circular economy based on modern digital technologies and in cooperation with governmental and non-governmental agencies such as the private sector, small projects, and financial technology services.
   c) Identify gaps and obstacles that prevent the application of the principle of circularity of materials, and work to bridge those gaps.
   d) Develop policies to regulate the separation and treatment of waste, predominantly liquid industrial waste, before disposal, with the help of smart waste management systems.
   e) Develop policies to regulate the separation and treatment of waste, predominantly liquid industrial waste, before being disposed of, with the help of smart waste management systems.
   f) Establish comprehensive databases for the inputs and outputs of industrial facilities, especially in industrial cities, to raise efficiency and improve the quality of decision-making and decision-making stages related to the circular economy applications.
4) Develop the traditional industrial cities to become Eco-industrial parks (Brownfield EIPs) based on the circular economy principles and adopt the circular economy methodology when establishing new industrial cities (Greenfield EIPs).
5) Raising public awareness regarding the importance of transforming towards the circular economy by relying on the various technological pillars of Industry 4.0. With the focus on clarifying the significance of the role of all members of society in the transformation process, relying heavily on soft powers to spread awareness in this regard, and providing training programs for decision-makers in the various sectors concerned, in addition to workers in those sectors that aim to integrate technology and the circular economy. In this context, commentary institutions must play a role in societal change and development by developing curricula and student activities to produce skilled graduates, linking scientific research outputs with industry, and developing new cultural values related to the circular economy.
6) Localizing the circular economy applications in the governorates, with the involvement of all central and local government agencies, the private sector, and civil society in the transformation towards a circular economy.

7 The third industrial complex in Borg El Arab, which produces the largest amount of solid waste compared to the rest of the industrial zone.

Key Messages of the Paper

1) Humans have released 2,500 billion tons of carbon dioxide into the atmosphere since 1850.
2) Industry in its current form poses a major threat to sustainability, as it generates 30% of greenhouse gas emissions that cause climate change.
3) Countries around the world are required to make a greater effort to shift towards green industry to reduce greenhouse gas emissions responsible for climate change.
4) Technologies of *Industry 4.0* support circular economy applications to move more efficiently and quickly towards the green industry to achieve the sustainable development goals.
5) Accelerating the development of a comprehensive national strategy for *Industry 4.0* in Egypt.
6) Formation of an Egyptian Council for the Circular Economy. It shall be the body responsible for setting laws, rules and regulations related to the circular economy, monitoring their implementation, and coordinating them with all parties.
7) Raising the level of societal awareness in Egypt of the importance and methods of transformation towards the circular economy.
8) Localizing the circular economy within the development policies at the level of governorates and environmental industrial clusters, while benefiting from digital transformation.
9) Developing a legislative and tax framework that supports the transformation towards a circular economy in Egypt.
10) Involvement of all governmental and non-governmental bodies in the transformation operations towards the circular economy in Egypt.
11) Establishing partnerships and providing sufficient funding to establish clean energy generation projects and benefit from the technologies of *Industry 4.0* on the path to the green industrialization.

References

[1] Atika, H., Ünlü, F., (2019). The Measurement of Industry 4.0 Performance through Industry 4.0 Index: An Empirical Investigation for Turkey and European Countries. Elsevier. Retrieved from: shorturl.at/xKOQ2

[2] Carbon Brief. (2021). Which countries are historically responsible for climate change? Accessed: 26-2-2022. Retrieved from: https://www.carbonbrief.org/analysis-which-countries-are-historically-responsible-for-climate-change

[3] United Nations Climate Action. (2021). Retrieved from: https://www.un.org/en/climatechange/paris-agreement

[4] United Nations. (2015). Paris agreement. Retrieved from the link: https://www.un.org/ar/climatechange/paris-agreement

[5] Circle Economy. (2021). The Circularity Gap Report 2021. Retrieved from: https://drive.google.com/file/d/1MP7EhRU-N8n1S3zpzqlshNWxqFR2hznd/edit

[6] Piscitelli et al. (2019). Circular Economy Models In The Industry 4.0 Era: A Review Of The Last Decade. Elsevier.

[7] Xu, M., et al. (2018). The Fourth Industrial Revolution: Opportunities and Challenges. International Journal of Financial Research.

[8] Bukht, R and Heeks, R. (2017). Defining, Conceptualizing and Measuring the Digital Economy. Development Informatics Working Paper no. 68, Available at SSRN: https://ssrn.com/abstract=3431732 or http://dx.doi.org/10.2139/ssrn.3431732

[9] World Economic Forum. (2018). Readiness for the Future of Production Report 2018. Retrieved from: https://www3.weforum.org/docs/FOP_Readiness_Report_2018.pdf

[10] Impactotic. (2020). The 5 leading countries in the Fourth Industrial Revolution and Colombia's position in the ranking. Available at: https://impactotic.co/en/the-5-leading-countries-in-the-fourth-industrial-revolution-Colombia/

[11] World Economic Forum. (2022). The Global Smart Industry Readiness Index Initiative: Manufacturing Transformation Insights Report 2022. Available at: https://www.weforum.org/whitepapers/the-global-smart-industry-readiness-index-initiative-manufacturing-transformation-insights-report-2022/

[12] World Bank. (2019). Doing Business 2019: Training for Reform. Retrieved from: https://www.doingbusiness.org/content/dam/doingBusiness/media/Annual-Reports/English/DB2019-report_web-version.pdf

[13] World Bank. (2020). About Doing Business. World Bank. Washington DC.

[14] Hidalgo, CA. & Hausmann, R. (2009). The building blocks of economic complexity. Proceedings of the National Academy Sciences. 106 (26): 10570–10575. https://doi.org/10.1073/pnas.0900943106

[15] Atlas of Economic complexity. (2021). Accessed 26-2-2022. Retrieved from: https://atlas.cid.harvard.edu/rankings

[16] The Growth Lab at Harvard University (2021). The Atlas of Economic Complexity. http://www.atlas.cid.harvard.edu.

[17] Visual capitalist. (2020). A Global Breakdown of Greenhouse Gas Emissions by Sector. Available at: https://www.visualcapitalist.com/cp/a-global-breakdown-of-greenhouse-gas-emissions-by-sector/

[18] Masterson and Shine. (2022). Available at: https://www.weforum.org/agenda/2022/06/what-is-the-circular-economy/

[19] Fura B, Stec M, and Miś T. (2020). Statistical Evaluation of the Level of Development of Circular Economy in European Union Member Countries. *Energies*, 13 (23): 6401. https://doi.org/10.3390/en13236401

[20] UNIDO. (2021). The Circular Economy: A driver of inclusive and sustainable industrial development. Retrieved from: https://iap.unido.org/articles/circular-economy-driver-inclusive-and-sustainable-industrial-development#fn-739-0

[21] Ellen MacArthur Foundation. (2019). Completing the picture: How the circular economy tackles climate change. Retrieved from: https://ellenmacarthurfoundation.org/completing-the-picture

[22] European Parliament. (2022). Circular economy: definition, importance and benefits. Retrieved from: https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits

[23] Kalundborg Symbiosis. (2022). Partners. Retrieved from: http://www.symbiosis.dk/en/partnerne-bag/

[24] European Circular Economy Platform. (2019). Kalundborg Symbiosis: six decades of a circular approach to production. Retrieved from: https://circulareconomy.europa.eu/platform/en/good-practices/kalundborg-symbiosis-six-decades-circular-approach-production

[25] Hamid Abdel Rahim. (2022). Obstacles and opportunities in the process of transforming to the circular economy.. and raising awareness of it in Egyptian universities. Contemporary economic prospects. The Information and Decision Support Center of the Egyptian Council of Ministers. Retrieved from the link: https://idsc.gov.eg/Upload/DocumentLibrary/Attachment_A/6798/%D8%AF.%20%D8%AD%D8%A7%D9%85%D8%AF%20%D8%B9%D8%A8%D8%AF%20%D8%A7%D9%84%D8%B1%D8%AD%D9%8A%D9%85%20%D8%B9%D9%8A%D8%AF.pdf

[26] Sustainable Development Report. (2021). Sustainable Development Report 2021. Retrieved from: https://www.sdgindex.org/reports/sustainable-development-report-2021/

[27] Cudečka-Puriņa N, Atstāja D, Koval V, Purviņš M, Nesenenko P, Tkach O. (2022). Achievement of Sustainable Development Goals through the Implementation of Circular Economy and Developing Regional Cooperation. *Energies*. 15 (11): 4072. https://doi.org/10.3390/en15114072

[28] Anupam Khajuria, Vella A. Atienza, Suchana Chavanich, Wilts Henning, Ishrat Islam, Ulrich Kral, Meng Liu, Xiao Liu, Indu K. Murthy, Temitope D. Timothy Oyedotun, Prabhat Verma, Guochang Xu, Xianlai Zeng, Jinhui Li. (2022). Accelerating circular economy solutions to achieve the 2030 agenda for sustainable development goals, Circular Economy, 1 (1). https://doi.org/10.1016/j.cec.2022.100001.

[29] Circularity Gap Reporting Initiative. (2021). The Circularity Gap Report Netherlands. Retrieved from: https://www.circularity-gap.world/netherlands

[30] UNEP. (2020). Switchmed and Circular Economy. Avaialble at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35954/SwitCE_Ar.pdf

[31] C40 Cities. (2018). Amsterdam's Circular Economy Roadmap: Lessons Learned and Tools for Upscaling. Retrieved from: https://www.c40.org/case-studies/amsterdam-s-circular-economy-roadmap-lessons-learned-and-tools-for-upscaling/

[32] PBL Netherlands Environmental Assessment Agency. (2019). Outline Of The Circular Economy. Retrieved from: https://circulareconomy.europa.eu/platform/sites/default/files/pbl-2019-outline-of-the-circular-economy-3633.pdf

[33] Lee, K., & Cha, J. (2021). Towards improved circular economy and resource security in South Korea. Sustainability, 13 (1), 17. Retrieved from: https://dx.doi.org/10.3390/su13010017

[34] Ellen MacArthur Foundation. (2020). Africa's first industrial symbiosis programme: Generating multiple benefits for the manufacturing industry. Retrieved from: https://cutt.ly/0b0GlbR

[35] http://library.fes.de/pdf-files/bueros/amman/18985.pdf

[36] https://pacecircular.org/circular-economy-indicators-coalition

[37] https://www.moenergy.gov.sa/ar/OurPrograms/Sustainability/CircularEconomy/Pages/default.aspx

[38] Aramco. (2022). carbon recycling economy. Retrieved from the link: https://www.aramco.com/ar/sustainability/climate-change/managing-our-footprint/circular-carbon-economy#

[39] KAPSARC. (2022). Circular Carbon Economy Index. Retrieved from: https://cceindex.kapsarc.org/cceindex/home

[40] Luomi, M. Yelmiz, F. and Alshahri, T. (2021). The circular carbon economy index results. KAPSARK. Doi: 10.30573/KS--2021-DP021

[41] ElMassah, S., Mohieldin, M., (2020). Digital Transformation and Localizing the Sustainable Development Goals (SDGs). Ecological Economics. Elsevier.

[42] Vrancken, K., (2019). Transitioning to Circular Economy through Industry 4.0. Retrieved from: https://www.uncrd.or.jp/content/documents/7500PS-6%20(A)-PPT-2.pdf

[43] Economic Research Institute for ASEAN and East Asia. (2020). Assessing the Readiness for Industry 4.0 and the Circular Economy. Retrieved from: https://www.eria.org/uploads/media/Books/2020-Assessing-the-Readiness-Industry-40-and-Circular-Economy/Full-Book.pdf

[44] World Economic Forum. (2018). Global Risks 2018: Fractures, Fears and Failures. Retrieved from: http://reports.weforum.org/global-risks-2018/global-risks-2018-fractures-fears-and-failures/

[45] Rajput, S., Prakash, S., (2019). Connecting circular economy and industry 4.0. International Journal of Information Management. Retrieved from: https://www.researchgate.net/publication/332071510

[46] Egypt presidency. (2020). Egypt's Vision 2030. Retrieved from the link: https://www.presidency.eg/ar/%D9%85%D8%B5%D8%B1/%D8%B1%D8%A4%D9%8A%D8%A9-%D9%85%D8%B5%D8%B1-2030/

[47] Abdallah, L., & El-Shennawy, T. (2020). Evaluation of CO2 emission from Egypt's future power plants. Euro-Mediterranean Journal for Environmental Integration 5, 49. Retrieved from: https://doi.org/10.1007/s41207-020-00184-w

[48] Kandil, A. (2021). Egypt's irrigation minister calls for rationing water amid GERD crisis. Ahram Online. Retrieved from: https://cutt.ly/anT2qAr

[49] Egypt Today. (2021a). Egypt's census to reach 119.8 million by 2030: CPAMAS. Retrieved from: https://cutt.ly/FmtywnO

[50] ElMassah, S., (2018). Achieving Sustainable Industrialization in Egypt: assessment of the potential for EIPs. Interdisciplinary Environmental Review. Vol. 19. No. 1.

[51] The Ministry of Environment. (2017). State of the Environment Report 2017. Retrieved from: The Ministry of Environment. (2017). State of the Environment Report 2017. Retrieved from: https://www.eeaa.gov.eg/portals/0/eeaaReports/SoE-2017/Egypt%20SOE%202017%20-%20Full%20Report%20Arabic.pdf

[52] Abdel Wahaab, R. (2014). Wastewater reuse code in Egypt. SWIM-Sustain Water MED 12–16 May 2014, Djerba Plaza, Tunisia. Retrieved from: https://goo.gl/nQpKra

[53] Enterprise. (2020). A look at Egypt's most polluting sectors. Retrieved from: https://cutt.ly/jb0GDoS

[54] SWEEP-NET. (2014). Country report on the solid waste management in Egypt. Deutsche Gesellschaft für Internationale Zusammenarbeit. Retrieved from: https://www.resource-recovery.net/sites/default/files/egypt_ra_ang_14_1.pdf

[55] Information and Decision Support Center. (2022). Circular economy. Contemporary economic prospects.

[56] Elshishini, S. (2015). Review of status and actual practices of industrial waste management in Egypt. Green Growth: Industrial Waste Management and SME Entrepreneurship Hub in Egypt. Retrieved from: https://cutt.ly/Hb0Gmg8

[57] Shalakany. (2020). New waste-management law brings Egypt closer to going green. Retrieved from: https://cutt.ly/cb2qYVy

[58] Salem, O. (2020). The government plans to generate 300 megawatts of electrical energy from waste. Retrieved from: https://cutt.ly/3b2qp3E

[59] Egypt Today. (2021b). 3 ministers review progress rate of Egypt's municipal solid waste system. Retrieved from: https://cutt.ly/Xb0FBAH

[60] Egypt Today. (2019). 52 sewage treatment plants are built in Upper Egypt: Housing min. Egypt Today. https://cutt.ly/wb0FLCk

[61] Egypt Today. (2020). Sisi: Egypt to inaugurate the world's largest wastewater treatment plant in 8 months. Retrieved from: https://cutt.ly/Gb0FXLJ

[62] Hasan, S., Al-Aqeel, T., & El Salmawy, H. (2020). Electricity sector liberalization in Egypt: Features, challenges and opportunities for market integration. King Abdullah Petroleum Studies and Research Center. Retrieved from: https://www.doi.org/10.30573/KS--2020-DP20

[63] World Bank. (2020). Implementation completion and results report. Available at: https://documents1.worldbank.org/curated/en/857651602606636925/text/Egypt-First-Second-and-Third-Fiscal-Consolidation-Sustainable-Energy-and-Competitiveness-Programmatic-Development-Policy-Financing.txt

[64] Ibrahim, M. (2022). Egypt signs two agreements for the production of green hydrogen in the "Suez Canal Economic". https://www.dostor.org/4044889

[65] State information services. (2022). Madbouly witnesses the signing of a memorandum to produce 350,000 tons of green fuel annually in Sokhna. Available at: https://www.sis.gov.eg/Story/233332/%D9%85%D8%AF%D8%A8%D9%88%D9%84%D9%8A-%D9%8A%D8%B4%D9%87%D8%AF-%D8%AA%D9%88%D9%82%D9%8A%D8%B9-%D9%85%D8%B0%D9%83%D8%B1%D8%A9-%D9%84%D8%A5%D9%86%D8%AA%D8%A7%D8%AC-350-%D8%A3%D9%84%D9%81-%D8%B7%D9%86-%D9%88%D9%82%D9%88%D8%AF-%D8%A3%D8%AE%D8%B6%D8%B1-%D8%B3%D9%86%D9%88%D9%8A%D8%A7%D9%8B-%D8%A8%D8%A7%D9%84%D8%B3%D8%AE%D9%86%D8%A9?lang=ar

[66] Lenkiewicz, Z., (2021). Dow and WasteAid launch new plastics partnership in Egypt. Retrieved from: https://wasteaid.org/dow-and-wasteaid-launch-new-plastics-partnership-in-egypt/

[67] Ellen Macarthur Foundation. (2023). What is the circular economy. Available at: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview