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Nexus of Circular Economy and Industry 4.0 to achieve the UN Sustainable Development Goals

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ABSTRACT
The sustainable development relies on the significant usage of natural resources and their efficiency. The concept of circular economy is implemented with the creation of new innovative technologies and paradigm shifts of the product and material reuse to extend their useful life. The use of circular economy strategies helps to close the material flows and extends the life cycle of the product with the involvement of the business realm. The new and innovative technologies include the principle of Industry 4.0 such as digitalization, prompt information, and optimize the supply chain of the resources by reducing resource utilization and environmental impacts. Digital technologies play an important role to enhance circular economy strategies and practices overcoming environmental issues. Both circular economy and Industry 4.0 concepts are interrelated. This article represents the nexus of circular economy and Industry 4.0 and demonstrates the importance of circular economy through Industry 4.0 and Artificial Intelligence to achieve the 2030 Agenda for Sustainable Development Goals.

Keywords: *Circular Economy; Industry 4.0; Artificial Intelligence; and Sustainable Development Goals*

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I. INTRODUCTION

With reference to the definition given by the Brundtland Report, 1987 "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The discourse around the subject of sustainability has been the pinnacle matter over the years around the world. The sustainable development includes three main pillars, economic growth, environmental protection, and social equity. From the environmental, economic and social dimensions, the circular economy opens the platform to discuss with an aim how to maintain, protect, restore, strengthen the natural resources with short-term and long-term perspective of regional, national and global level policies and regulation with the involvement of private sector. An expanding growth of population estimates at around 9.6 million in 2050 (UN, 2013) is putting huge pressure on the efficient use of natural resources. However, sustainability is declining at an unprecedented rate due to severe resource depletion and serious environmental degradation (Khajuria et al., 2008). Issues that are of a pressing matter are interrelated to environmental concerns such as air pollution, water pollution, loss of biodiversity, extreme land use and resource depletion are restoring the earth's 'life-support system' (Rockström et al 2009). To understand the safe operating space for humanity, the concept of Planetary Boundaries was first published (Rockström et al 2009) and updated with 'human development with changes in planetary boundaries' (Steffen et al. 2014). The planetary boundaries identify and estimate the quantification of essential environmental boundaries where society, environment, and economy have to be kept within limits and avoid a high possibility of leading in a different state of the earth system. The 3Rs (reduce-reuse-recycle) strategies help to improve and prevent negative environmental impact. 3Rs and resource efficiency policies and strategies provide opportunities to reduce vulnerability against the impact of waste (Khajuria, 2017). The potential benefits of 3Rs and resource efficiency policies and technologies help to mitigate numerous pressures on the planetary boundaries (Khajuria et al., 2020).

The 2030 Agenda for Sustainable Development Goals (SDGs) consisting of 17 goals and 169 targets include 231 indicators to balance the social, economic, and environmental sustainability to action to end poverty, protect the planet, enjoy peace and prosperity, shape the various targets to achieve sustainability. SDG 12 (Ensure sustainable consumption and production pattern) focuses on the efficient utilization of natural resources which shifts the transition of circular economy from the linear economy. The circular economy provides an opportunity to improve the use of material and environmental protection. A sustainable circular economy involves regenerating the environment in terms of natural reserves by minimizing the resource input and maximizing waste prevention and optimize environmental, social, economic, and material value. In addition, the circular economy offers a new perspective on restoring the value of natural resources. The use of natural

resources is very much linked to biodiversity loss whereas the innovative solutions for sustainable consumption and production lead to achieving various SDGs. The combination of resource efficiency, 3Rs related policies, and practices are feasible and possible to grow our economies and maintain our ecosystem within planetary boundaries. The integration of circular economy with the resource decoupling helps to make the product re-utilize and move towards energy-intensive with the involvement of development strategies of environmental issues (Khajuria, 2016a) and this integration helps to create a more sustainable system within planetary boundaries. The circular economy relies on recycling practices to closed-loop by redesigning and promoting the product via reused, repaired, and remanufactured. Furthermore, the recycling and re-utilization of products have to lead to a reduction in the use of virgin materials and energy, also indicate towards the reduction in carbon dioxide emission (Khajuria et al., 2016b).

The circular economy is a long-lasting process, including re-design, reuse, remanufacturing, refurbishing, and advanced recycling technology. The circular economy measures could be coherent with SDGs including goals of waste management and climate change. Through circular economy, the waste can be reduced, monetized, and circular across the supply chain and retain its value. The new digitalization world showing the ability the step ahead of transformation towards a circular economy. The technologies include Artificial Intelligence and robotics make a significant contribution to the effective consumption of the product and production of high-quality secondary raw materials (Wilts et al., 2021). The transition to a circular economy would enhance with the utilization of digital technologies. This article seeks to reconcile circular economy with SDGs and addresses the nexus between circular economy and Industry 4.0. Furthermore, this article shows the role of artificial intelligence in the circular economy.

II. RECONCILE CIRCULAR ECONOMY AND SUSTAINABLE DEVELOPMENT GOALS

The circular economy is an emerging economic model with the involvement of the private sector and the domain of environmental protection. The circular economy is designed to be a self-regenerating model where the reused material enters the production cycle and includes industrial symbiosis "someone's waste becomes a resource for someone's else" with the involvement of public-private-partnership. Industrial Symbiosis is the process in which by-products or waste from one industry works as an input for another industry (Desrochers and Leppala, 2010). The circular economy has a significant potential to achieve sustainable development through stopping the exhaustion of natural resources, lowering environmental damage from the withdrawal and undertaking of virgin materials, and reducing pollution from the procedure of process, use, and end-of-life of materials. The shift of circular economy refers to 'make-use-reuse-remake-recycle' from the linear economy 'take-make-dispose-pollute' as shown in **figure 1**.

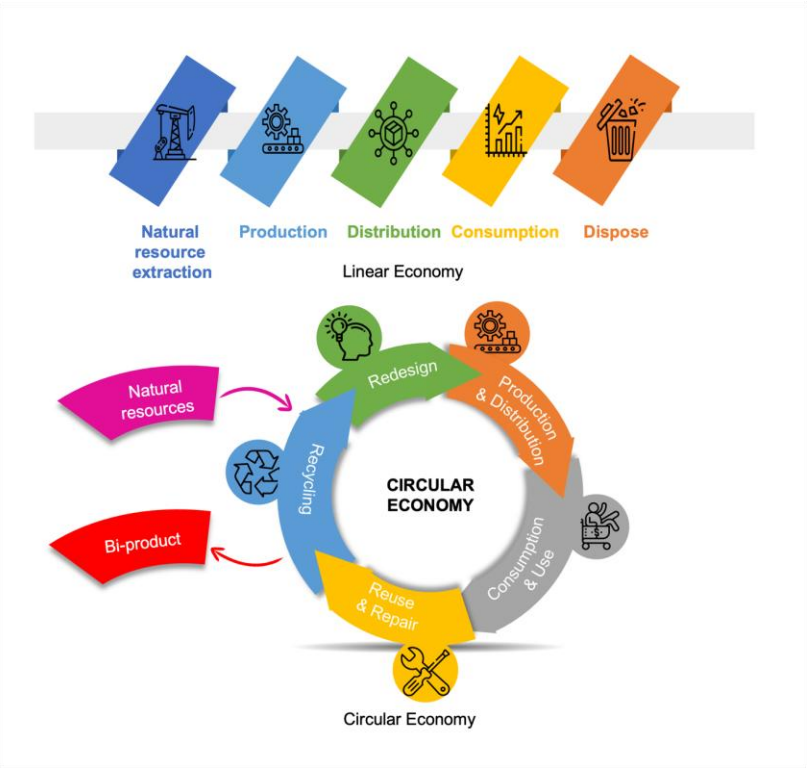

Figure 1: Linear Economy versus Circular Economy

The circular economy is examined under economic prosperity, along with environmental quality and its impact on social equity and upcoming future generations. Nonetheless, business models and consumers function patterns are outlined as enablers of the circular economy (Kirchherr et al., 2017). The circularity strategies start from 3Rs (Reduce-Reuse-Recycle) and extend to 4Rs (Reduce-Reuse-Recycle-Recover) and move to 9Rs (Refuse-Rethink-Reduce-Reuse-Repair-Refurbish-Remanufacture-Repurpose-Recycle-Recover) and furthermore 12Rs (Refuse, Rethink, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Research, Re-skill, Re-design, Re-vision and Recover) as shown in **figure 2.** In addition, the circular economy has evidently shown benefits in economic, environmental, and societal aspects, for instance reducing carbon emissions and generating jobs (Ellen MacArthur Foundation, McKinsey & Co and Goolge, 2019). The circular economy helps to endorse safe and clean waste (SDG 6), to facilitate renewable and clean energy (SDG 7), to create opportunities for a new business model (SDG 8), to develop and promote inclusive technologies (SDG 9), to reduce waste generation, pollution, and efficient use of raw materials (SDG 12), to reduce marine pollution (SDG 14), to restore ecological system (SDG 15). Schroeder et al., 2018 determined that the circular economy can potentially contribute directly to achieve a significant number of SDG targets.

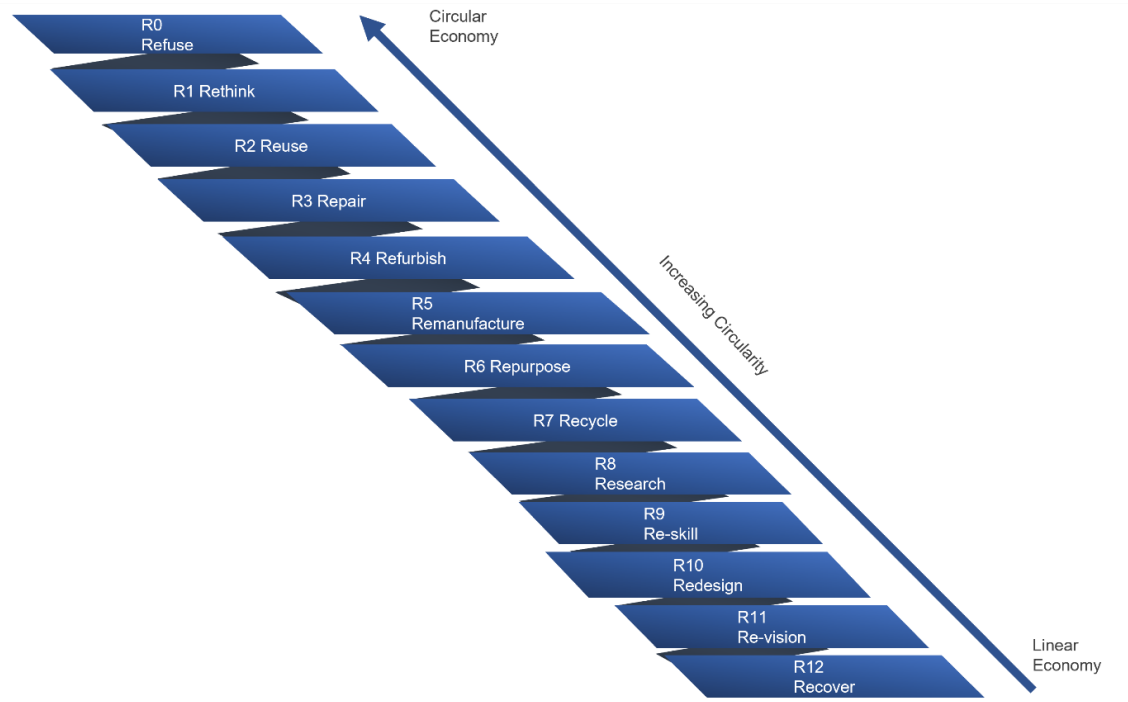

Figure 2: Strategies of 12Rs from Linear Economy to Circular Economy

III. NEXUS BETWEEN CIRCULAR ECONOMY AND INDUSTRY 4.0

The role of technologies in producer, consumers, and policy level involves closing and narrowing the loop of material flows in the circular economy. Industry 4.0 is the integration of machines and a combination of different technologies such as Advanced Robotics, Additive Manufacturing, Augmented Reality, Horizontal/Vertical Integration, Industrial Internet of Things, Cloud Computing, CyberSecurity, and Big Data and Analytics as shown in **figure 3**. The consolidation of electronic transmission helps to increase automation, improve communication and self-monitoring that can analyze and diagnose challenges and its issues (Awan et al., 2021). With the use of a high level of technologies, valuable products and materials can keep track very easily with the increasing of recovery opportunities. Furthermore, blockchain technology allows to development of a track record for the products and their parts. The coupling of blockchain information with the physical materials provides the information flow to support building a circular economy.

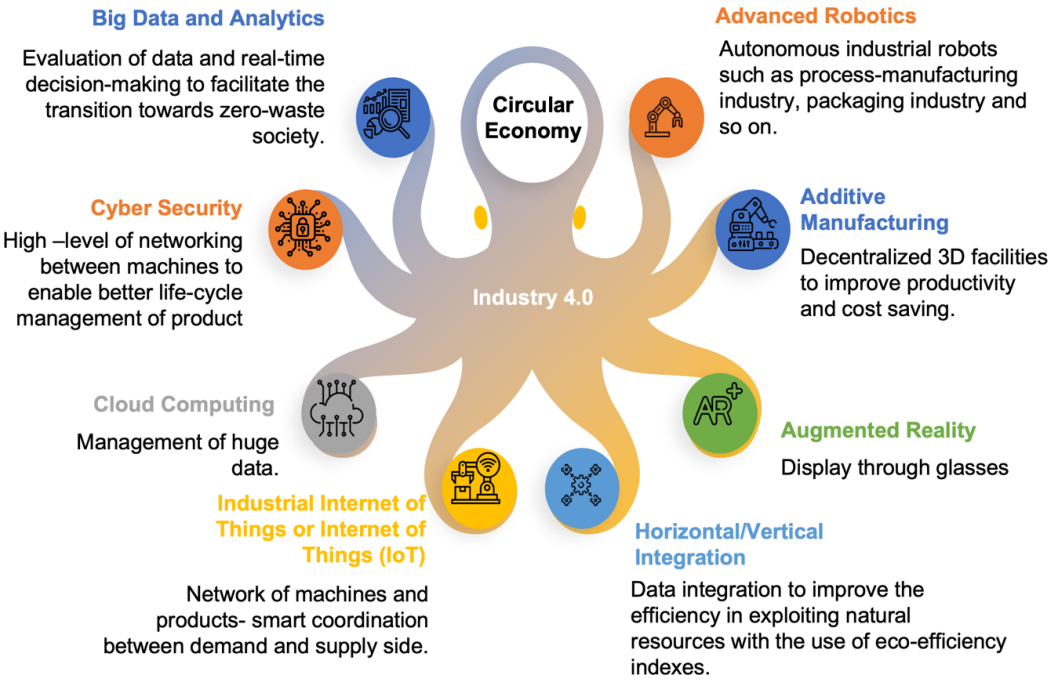

Figure 3: Applications of Industry 4.0

Industry 4.0 relies on digital technologies with traditional manufacturing/aspects. Rosa et al., 2020 considered that Industry 4.0 technologies can have a productive effect on the life cycle management of the product under the influence of the circular economy. Industry 4.0 could unlock new possibilities and leverage the circular economy to address several targets of SDGs. The nexus of circular economy and Industry 4.0 represents a new paradigm of natural resource strategies towards the success of SDGs. This nexus shifts to economic and industrial models with the use of smart technologies. The circular economy practices mainly focused on many Rs, it is the main core of the circular economy, including industrial symbiosis, waste-to-energy technology, and many more green technologies. The use of Industry 4.0 technologies in the circular economy approach can strongly benefit SDGs (Dantas et al., 2021). Industry 4.0 supports extensive opportunities to enable the circular economy. The circular economy leads to resource effectiveness and ensures more sustainable consumption and production with the use of digitalization and Industry 4.0.

IV. ROLE OF ARTIFICIAL INTELLIGENCE (AI) IN CIRCULAR ECONOMY

The artificial intelligence provides a wider impact on various sectors in the achievement of the SDGs. Vinuesa et al., 2020 discussed the positive impact (79 percent) as an enabler and the negative impact (35 percent) as an inhibitor on each goal and target of the SDGs. AI could enable decision-makers on how to design the product and consider various approached including its capabilities, reuse, repair, and durability (Ellen MacArthur Foundation, McKinsey & Co and Goolge, 2019). AI offers multiple benefits to enhance productivity through optimization and automation (a) by increasing the quality of products with the use of sensors, (b) by monitoring and detecting the error in real-time production, (c) by increasing the speed of big data simulation, and (d) by increasing the flexibility. AI also enhances more occupational safety, better working conditions increases training and collaboration, and provides a better and clean environment. AI helps to create a smart industry and maximizes the outcomes.

AI plays an important role in an effective waste management system, an automatic method for sorting waste aims helps to reduce waste and pollution. The advanced technologies such as Radio Frequency Identification (RFID), Internet of Things (IoT), and Sensor Network (SN) have been used to provide a new way to optimize waste management systems in various countries. Wilts et al., 2021 show the use of an AI-based robotic sorting system to assess the sorting process and to evaluate the performance quality with the use of the big database. AI assists to improve design, operating business models, and infrastructure, which is substantial for the circular economy. For example in plastic waste, high-definition optical sensors can be used for data collection, the laser techniques can be used to differentiate different types of plastics. The blockchain and multisensor-powered artificial intelligence interfaces could be used for efficiency and accuracy in plastic waste recycling. The potential value of waste that could be unlocked by AI in a circular economy is estimated to be

around 127 billion a year in 2030 (Akinode and Oloruntoba, 2020). Rajak et al., 2021 also showcased the mathematical model to maximize the net profit by incorporating remanufacturing to achieve SDGs.

V. FUTURE PERSPECTIVE

The circular economy helps to utilize natural resource efficiency while reducing waste generation and preventing pollution. The circular economy is an important approach for an effective production and consumption pattern to attain a sustainable society. AI helps to create efficiency and reduce manual labor, to minimize uncertainties, and enable efficient and intelligent segregation in the waste management systems. The circular business model promotes reuse and recycles with innovative technologies. Digitialization is one of the decisive approaches to protect the environment, contribute to socio-economic development, and act as an essential tool to ensure and attain sustainability. The SDGs and their core targets would benefit from using AI technologies. Both circular economy and Industry 4.0 are interlinked with each other, their nexus is very important to attain sustainable development.

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