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Reconsidering a Sustainable Future through Artificial Intelligence of Things in the Context of Circular Economy

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Abstract

To assure a sustainable future for current and future generations, the achievement of the 17 Sustainable Development Goals (SDGs) which was set by the United Nations is imperative. Hence, a fundamental social and cultural shift toward resource efficiency and more sustainable lifestyles is required. In this context, the need for a circular economy is becoming more evident. New technologies can assist in meeting SDGs and achieving an effective circular economy. Particularly, Artificial Intelligence (AI) and Internet of Things (IoT) are critical technologies for fulfilling these goals. The combination of AI with IoT leads to the Artificial Intelligence of Things (AIoT) which has the potential to further facilitate the transition toward and amplify the benefits for a sustainable future. This chapter aims to examine how AI can support the achievement of SDGs and realization of a circular economy. Additionally, the 4R sustainability framework (Reduce, Reuse, Recycle, and Rethink) is presented as a proposed extension of the 3R principles. To assess its suitability, a Sociocultural, Technical, Economic, Environmental, Political, Legal, Ethical, and Demographic (STEEPLED) analysis is conducted. The need to educate the younger generations and re-educate adults to achieve changes in attitudes and mindsets toward sustainability was highlighted as a vital process. The need to further improve adaptability and reusability of resources emerged as a requirement to effectively maximize the 4Rs. AI emerged as a determining factor in achieving SDGs and creating a circular economy.

Keywords: Sustainability, Sustainable development goals, Circular economy, Artificial intelligence, Artificial intelligence of things, Sustainable development

1. Introduction

All Member States of the United Nations endorsed the 2030 Agenda for Sustainable Development which contains a shared mission regarding peace and prosperity for the human kind and the environment (United Nations, 2015). Based on the definition provided by the World Commission on Environment and Development (1987), sustainable development is characterized as *“the development that meets the needs of the present without compromising the ability of future generations to meet their own needs”*. In total, 17 Sustainable Development Goals (SDGs) were developed to be met through a global partnership among all countries. The 17 SDGs focus on goals related to the environment, to wellbeing, economic growth, work, social justice, health, as well as politics. It is recognized that *“ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests”* and *“are determined to take the bold and transformative steps which are urgently needed to shift the world onto a sustainable and resilient path”* (United Nations, 2015).

The 17 SDGs and 169 targets set show the ambition and large scale of the universal 2030 agenda for Sustainable Development (Visvizi, 2022). The SDGs are integrated and indivisible and they both directly and indirectly impact on the social, environmental, as well as economic dimensions of sustainability and sustainable development, which imply an endeavor to satisfy the existing needs without risking future generations’ needs. Based on the 169 targets, it can be inferred that growth alone is not a straightforward goal, but a goal that is sustainable, equitable, and beneficial to everybody regardless of class, race, gender etc.

The SDG Report, which offers a global overview about the latest available data of the progress regarding the adoption and application of the 2030 Agenda for SDG, states in its foreword that *“As the world faces cascading and interlinked global crises and conflicts, the aspirations set out in the 2030 Agenda for Sustainable Development are in jeopardy”* (United Nations, 2022a). Based on current data, the report offers proof of the damaging influence of simultaneous crises, such as COVID-19, climate change, conflicts, and wars which are dangerously affecting all the SDGs including impacts on food and nutrition, health, education, the environment, as well as peace and security.

Furthermore, to maintain our current way of life, the natural resources which are used surpass the limits of what the Earth can produce. More sustainable solutions need to be discovered and implemented regarding how humans use natural materials, energy, as well as resources. This, however, requires a sociocultural transition, as highlighted in the 2030 Agenda for SDG. Achieving a circular economy may help meet the 17 SDGs as the circular economy aims at addressing global issues

and challenges related to nature (e.g., climate change, waste, pollution, and biodiversity loss, etc.) in a systematic manner. The circular economy aims at implementing a design-based approach regarding optimal use of natural resources, effectively circulating materials and products, regenerating and rejuvenating nature, as well as minimizing and eliminating waste and pollution. The circular economy concept comes from a structured and systematic thinking approach which aims at imitating natural systems that are characterized by adaptivity, complexity, openness, optimization, and resilience (Fehrer and Wieland, 2020; Siakas et al., 2023a). Due to its potentials, the circular economy has been increasingly promoted in various sectors to achieve environmental sustainability and minimize pollution and waste (De Angelis, 2020). In the context of the circular economy, products, services, resources, and materials remain in circulation for as long as possible. The circular economy is a viable approach for overcoming environmental challenges (e.g., Anthropocene epoch) and constitutes a key aspect in achieving SDGs.

To ensure a sustainable future, effective waste management is imperative. Until the late 20th century, the main waste measures in Europe, Japan, as well as the United States were the so called “*Back-Yard-Dumping*” and “*End-of-Pipe Approach*” (Sakai, 2020). Uncontrolled landfill and incineration together with illegally dumped and abandoned piles of waste all over the world were noticed in 1970-1980s needing enormous costs for remediation. It was gradually understood that regional and global sustainability would not be achieved within the framework of the traditional waste treatment. As a result, the concept of waste prevention and recycling appeared.

The main process in the circular economy is the hierarchical waste management process which contains three key actions commonly referred to as 3R Principles, that is, Reduce, Reuse, and Recycle (United Nations, 2022b). In the G8 summit which took place in Tokyo in 2005 the 3R initiative was launched as an attempt to transition toward creating a sound material-cycle society. An important issue in the waste management process is to maintain an adequate balance among consumption, reuse, and recycling. If consumption is reduced, the rate of reuse and recycling will also be reduced. In addition to reduction of product consumption, a reduction of energy and water is also needed to cater for future generations. The primary purpose of reusing old things either by modifications, donations or second-hand offerings and use, is to minimize the amount of waste. Recycling is a process in which the discarded items are transformed into new ones. Each measure of 3Rs enables waste reduction and energy conservation (Sakai, 2020). Waste treatment plants and social resources (social connections and interaction between social structure and individuals) pave the way for meeting the aims of the circular economy and a sustainable future.

In this context, Artificial Intelligence (AI), Internet of Things (IoT), as well as Artificial Intelligence of Things (AIoT) can help meet the goals of the circular economy and of the SDGs. Particularly, AI refers to the development of systems endowed with intellectual processes that can mimic human behaviors and way of thinking and autonomously perform actions and tasks related to intelligent beings (Lampropoulos, 2022; Russell, 2010). AI systems are characterized by their reasoning and learning capabilities as well as their rationality and adaptability (Lampropoulos et al., 2022; Zhang & Lu, 2021). Hence, AI can contribute toward the

realization of sustainable development (Goralski & Tan, 2020; Lampropoulos, 2023; Vinuesa et al., 2020). IoT is a global and dynamic network of interconnected devices, services, objects, and systems (Atzori et al., 2010; Lampropoulos et al., 2018; Li et al., 2015). These “things” can autonomously and securely sense, communicate, and interact with one another as well as with their environment (Lampropoulos et al., 2019; Lampropoulos & Siakas, 2022; Xu et al., 2014). Thus, IoT constitutes a vital component in achieving SDGs (Lopez-Vargas et al., 2020; Villiers et al., 2021). When embedding IoT in intelligent processes, AIoT can be realized. The adoption of these technologies in the context of the circular economy can enrich and accelerate the transition toward a more sustainable and greener future (McKinsey, 2019). Thus, the potential of AI is too immense to be neglected (Sætra, 2022).

Consequently, this chapter aims to explore how AI can support the achievement of SDGs and the realization of a circular economy and propose the 4R sustainability framework. Hence, in Section 2, the concept of the CE, the 3R principles and the proposed 4R sustainability framework are presented. In Section 3, a Sociocultural, Technical, Economic, Environmental, Political, Legal, Ethical, and Demographic (STEEPLED) analysis of the 4R sustainability framework is showcased. In Section 4, the key AI aspects in achieving SDGs and the goals of circular economy are presented. Finally, in Section 5, conclusive remarks and suggestions for future lines of research are provided.

2 Circular Economy and the 4R sustainability framework

In this section the concepts of the circular economy and the 3R principles are presented. Additionally, it goes over the proposed 4R sustainability framework. Their interrelation with and role in achieving SDGs are also discussed.

2.1 The Circular Economy

In recent years, the interest in the circular economy and the shift from a linear to a cyclic system for reusing, remanufacturing, and recycling materials has gained ground. By using the circular economy as a means to achieve climate goals, circular economy also contributes to the SDGs, particularly regarding SDGs related to energy, production, consumption, and waste.

Schroeder et al. (2018) examined the relevancy of the circular economy practices in the implementation and achievement of the SDGs. Their results confirmed that the circular economy practices contribute to achieving a significant number of SDGs. The strongest relationships were found to exist between the circular economy practices and the targets of Clean Water and Sanitation (SDG 6), Affordable

and Clean Energy (SDG 7), Decent Work and Economic Growth (SDG 8), Responsible Consumption and Production (SDG 12), as well as Life on Land (SDG 15). In addition, Industry, Innovation and Infrastructure (SDG 9) is of particular importance, since any success in achieving this goal will have important ripple effects for the other goals (Truby, 2020).

Dufourmont et al. (2020) argued that the circular economy supported by resilience thinking is a means to achieving an ecologically safe and socially just result. They identified the circular economy elements that are essential within the context of education, culture, legal systems, values, quality of life, behavioral norms and political and governance considerations. Taking this into account was a main factor for considering that the 3Rs need to be extended with a fourth R, namely RETHINKing. The process of RETHINKing is the starting point for any development. In the case of the SDGs, everyone needs to RETHINK how we consume resources, materials, and energy nowadays. A social and cultural shift contributed by every single person is imperative so that society can actively contribute to the transformation to a more sustainable future.

2.2 The 3R Principles

Based on the nature of human life, waste resulting in pollution is constantly produced (Samiha, 2013). When it comes to sustainable development, the 3R principle seeks to maintain the natural resources for future generations by reducing their use, reusing and recycling as much as possible. Waste reduction decreases pollution and prevents the environment contamination. The 3R principles are considered as the most proper way of waste disposal (Daniel, 2003). A policy is referred to as “*zero waste*” when it adopts and integrated all of the 3R principles to achieve zero warming and zero disposals from waste (Baba et al., 2020). It is a holistic concept of waste management recognizing waste as resources which were produced during the interim resource consumption process phase. By decreasing global resource requirements, we need to re-consider today’s resource and product management. Achieving zero waste requires a complex infrastructure, a change in mindsets, and innovative solutions.

2.3 The 4R Sustainability framework Depicted

In this chapter, a fourth R, RETHINK, is presented as an extension to the existing 3R principles (Reduce, Reuse and Recycle) (United Nations, 2022b), related to the circular economy and the SDGs interrelated to the environment.

In Figure 1, the suggested 4R sustainability framework is presented. The proposed framework has the existing 3R principles (Reduce, Reuse and Recycle) at its core

and extends the principles by including a fourth R, RETHINK, and highlighting the need for changing mindsets. It is proposed that no matter the aim, RETHINKing involves evaluating and quantifying the results. Additionally, this study argues that the RETHINK can be considered and deployed by using a STEEPLED analysis.

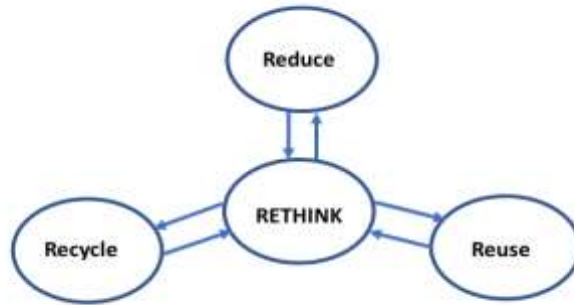


Figure 1: The 4R sustainability framework

There are numerous routes to be followed to achieve the 4R Sustainability framework. The position of RETHINK denotes the need and intention to always reconsider and repeat steps as necessary. RETHINKing includes a STEEPLED Analysis (Georgiadou et al., 2021a) to extend the 3R sustainability model. A STEEPLED analysis urges decision-makers to consider how each factor will impact society and how the results of Reduce, Reuse, and Recycle will fit into future circular economy scenarios. The influence, either negative or positive, of each macro-environmental factor can be determined and understood and thus, formulated strategies and respective remedial actions should be taken in terms of the 3Rs. The centrality of RETHINKing highlights the need to constantly review, analyze, measure, learn, and improve (Siakas et al., 2023a).

It is assumed that sustainability is paramount for progressing toward the circular economy. The shift toward circularity involves numerous benefits, including the creation of new value propositions. Optimizing how resources could be best used enables enterprises to innovate by creating new value propositions to appeal to increasingly aware consumers who seek for cleaner, healthier, greener, and more humane and equitable lifestyles. As argued above, reusing, recycling, and reducing materials, resources, and knowhow are desirable, and that their impact can be both specified and quantified. Georgiadou et al. (2021a) used a STEEPLED analysis for reviewing and extending the Software process Improvement (SPI) Manifesto while Siakas et al. (2023b) focused on analyzing system failures through a STEEPLED analysis. These eight dimensions help tackle perplex challenges, systems, and process which can further improve services, outputs, products, and outcomes. In the following sectors, the STEEPLED dimensions with regard to the 4R Sustainability framework are being analyzed.

3. Sociocultural, Technical, Economic, Environmental, Political, Legal, Ethical, and Demographic (STEEPLED) analysis

This section presents a STEELED analysis of the proposed 4R sustainability framework. Particularly, it examines it from eight different dimensions.

3.1 The sociocultural dimension

The Sociocultural dimension is particularly important in the current globalized and multicultural workforce which collaborate and communicate with colleagues from the same or other organizations in the same or in different countries in a distributed mode. Therefore, this dimension involves the influences, effects, and inspirations that derive from different cultures. Resistance to change and to knowledge sharing are cultural characteristics that affect the quality of decisions, actions, and outcomes (Georgiadou et al., 2011).

In modern society, emergent properties and behaviors of individuals and organizations are challenging sociocultural factors exerting significant impact on decisions, actions, and outcomes.

The acquisition and use of new technologies and methods of working present challenges in dealing with the uneven distribution of wealth and opportunities. Enormous differences in education levels and cultural norms present barriers toward changing mindsets and behaviors. On the one hand, there is excessive waste (no or low levels of Reducing (R1), Reusing (R2), or Recycling (R3)) in what have come to be known advanced economies. On the other hand, in the developing economies, there is no or low opportunity to acquire knowledge, material goods, and technologies. In advanced economies, direct and fast communication with text, voice, and image is enjoyed through the internet and social media. A UNESCO report (Markelova, 2005) revealed that *“more than 750 million adults around the world were illiterate – and two-thirds of them women. Another 250 million children of primary school age do not have a grasp of basic literacy skills”*.

In recent years, there is a lot of discussion and research into information and digital literacy (Georgiadou et al, 2021b; 2016; 2015). Inevitably in the CE, new technologies demand competencies in the use of the technologies and the ability to discern the correctness of information and the safe navigation through misinformation, disinformation, and mal-information.

3.2 The technical (or technological) dimension

The Technical dimension involves the analysis of variables concerned with the development and availability of relevant technologies. Over the course of time, factors relevant to the practical metrication and maintainable implementations of processes or products are also included and analyzed within the technical dimension. (Berki et al., 2018). In the light of the 4R Sustainability framework, innovative technologies for recycling, reducing and reusing are increasingly used. Hojnik et al. (2023), for example, argued that digitization improves the control over eco-innovation and enhances manageability and transparency. They asserted that digitization has enabled businesses to develop new services and products with less harmful effects on the environment and to optimize existing products and services in more sustainable ways.

Furthermore, Industry 4.0 seeks to transform traditional industries, manufacturing, and infrastructure into intelligent ones by integrating and combining novel smart technologies, such as AI, IoT, AIoT, cloud computing, blockchain, Cyber-Physical Systems (CPS), etc. (Awan et al., 2021; Reshad et al., 2023). These technologies can also facilitate the transition toward a circular economy and further enhance its benefits (Siakas et al., 2023a). On the other hand, Industry 5.0 capitalizes on humans and machinery to improve human-machine interaction and enables monitoring in real time. Industry 5.0 also aims to create more personalized to customer preferences and needs products and services and increase their quality by assigning tasks that require critical thinking to humans and tasks that are characterized by monotony and repetitiveness to machines (Reddy et al., 2021).

3.3 The economic dimension

The economy is constantly changing. Its growth or decline is influenced by several factors, such as gross domestic product (GDP), inflation, distribution channels, tax policies, unemployment, local and global economy, trends, growth and recession, interest and exchange rates, as well as supply and demand. To ensure the survival and success of a business, it is important for external economic developments to be matched in product launch strategies and in capital investment and specific refinements should take place.

Learning and using new tools, processes, and approaches often requires a steep and long learning curve for an individual to specialize in using them. Hence, it is important to focus on leadership aspects, effective training, and distributing tasks. In this context, the economic dimension involves the level at which an organization expands by training and hiring new staff, joining ventures with other organizations, or outsourcing (Georgiadou et al, 2020).

An economic view of society takes value creation activities and value-based decisions. In the context of software engineering, game theory can define

socioeconomic situations following mathematical models and can be adopted to examine, identify, and analyze potential concerns, issues, and challenges by developing different mechanisms (Yilmaz et al., 2010).

3.4 The environmental dimension

The transition toward circularity includes a multitude of environmental benefits, such as reducing the environmental footprint. By designing products and by considering reusability, recyclability, and industrial symbiosis, businesses will effectively reduce their environmental footprint and eliminate pollution and waste. Goal 13 of the 17 SDGs is directly related to the environmental dimension. It involves the urgent actions required to address and overcome environmental problems (e.g., climate change) and the evaluation of their potential impact.

Raja et al. (2018) emphasized that within the concept of sustainability, people, the planet, and general profits are key aspects. Additionally, they argued that *“climate change requires conceptualizations of the interactions between human actions and social structure on the one hand and ecosystem dynamics on the other”*.

The SDGs 2022 report (United Nations, 2022a) states that *“decades of misuse, poor management, over extraction of groundwater and contamination of freshwater supplies have exacerbated water stress. In addition, countries are facing growing challenges linked to degraded water-related ecosystems, water scarcity caused by climate change, underinvestment in water and sanitation and insufficient cooperation on transboundary waters”*. SDG 6 is directly connected with the environmental dimension due to its goal of ensuring access to sanitation and water for everyone.

3.5 The political dimension

The political dimension concerns aspects that are required to ensure and promote peace, justice, and inclusion in society. The related SDGs are monitored by the United Nations High-Level Political Forum on Sustainable Development (HLPF). HLPF is an annual forum which is organized by the United Nations Economic and Social Council (ECOSOC). Sustainability can be viewed from political, socioeconomic, sociocultural and sociopolitical dimensions. Niskanen et al. (2021) provided a broader analysis of the ideologies, interests, and institutions involved regarding future expectations and opportunities for repair and circularity. One of the SDGs mainly related to the political dimension is SDG 16.

3.6 The legal dimension

A legal guide to the SDGs was embarked on in 2015 by Advocates for the International Development (A4ID) (United Nations, 2016). A4ID is a global charity that works in partnership with leading worldwide law firms. A4ID aims at creating a guide which outlines key components and elements that connect SDGs and current legal concepts and framework within a broad global sense. Moreover, the guide points out the vital role of the law in ensuring the achievement of SDGs and focuses on policy makers. The A4ID arranges trainings and events and delivers pro bono legal services related to the SDGs.

3.7 The ethical dimension

According to Rahanu et al. (2021), RETHINK includes an End User License Agreement (EULA) to extend the 3R sustainability model shown. A set of logically related steps for carrying out an ethical/legal analysis was presented in a framework by Kallman and Grillo (1996). The related steps are summarized and presented below:

Step 1: “List the effects/challenges/impact of the issues under consideration”.

Step 2: “Identify the stakeholders (those affected by the issues raised in Step 1)”. Persons, such as customers, employees and citizens, who have responsibilities toward an organization and/or society and an interest in its success can be regarded as stakeholders.

Step 3: “Identify stakeholder obligation/duty to do or not to do something”. Stakeholders have different obligations/duties depending on their position in the organization/society. However, all persons can contribute to a better world with sustainable living and consumption.

Step 4: “Apply normative ethical/legal principles for the purposes of substantiation”. Ethical/legal principles need to be communicated and transmitted to all members of a society. Society as a whole has the responsibility to create common ethical values for its members.

In conducting EULA, stakeholders should be consciously aware of the context of the sustainability framework of the moral and legal duties and obligations they have, as well as of the rights of others. Thus, ethical themes such risk and reliability, privacy, rights, equity, life quality, access, and use of power permeate the decisions made concerning Reduce, Reuse, and Recycle.

3.8 The demographic dimension

Hojnik et al. (2023) suggested that businesses in order to stay ahead of competition, they adjust and modify their services and products based on the demographic trends to meet the new requirements. They argued that demographic changes bring about changes in the way society perceives the circular economy and eco-innovations. Soukopova et al. (2017) found that demographic characteristics are predictive of the amount of waste residents generate. For example, older generations create more household waste. Similarly, Smol et al. (2018) identified that younger generations are more accustomed to circular economy and environmentally friendly behaviors and actions.

Mukucha et al. (2023) carried out a recent study on the tendency to reuse plastic bags instead of cotton and paper found no difference in terms of demographics (age, gender, country of residence). This is encouraging as it reveals that change of mindsets and behaviors is possible.

4 Using AI to support the achievement of SDGs

This chapter explores how AI can be used to help achieve different SDGs. More specifically, it examines the role of AI in Zero hunger (SDG 2), Quality education (SDG 4), Affordable and clean energy (SDG 7), and Sustainable cities and communities (SDG 11).

4.1 AI and zero hunger (SDG 2)

Based on the expectations of the United Nations, the global population is to reach 9.7 billion by the year 2050. It warns that sustainable ways must be found to both produce and distribute food, otherwise the risk of widespread hunger and food insecurity is imminent (United Nations, 2023).

Kugler (2022) reported on how intelligent systems that use AI, machine learning (ML), and deep learning (DL), are exploiting large volumes of data datasets and robust computer science methods to increase boost farm productivity and yields, improve food supply chains, and prevent diseases from destroying crops. Vågsholm et al. (2020) reported on numerous novel technologies and AI solutions that can be used to address issues of food security, safety, and sustainability. Table 1 presents some examples of information technology (IT) and AI solutions that are being used to address these issues.

Table 1: Examples of IT and AI solutions that are being used to address issues regarding food security, safety, and sustainability

Issue	IT/AI solution
Reduction of Food Loss and Waste to improve food security (Vågsholm et al., 2020)	<p>Poyatos-Racinerro, et al. (2018) identified specific sensor categories that address issues related with product freshness, time-temperature indicators (TTI), food package integrity, and identification tags. Through the use of these sensors, intelligent packaging can be developed to reduce food waste.</p> <p>Zhang and Issar (2020) proposed e-commerce platforms that capitalize on big data infrastructure. These platforms would enable food supply chain efficiencies and customer behavioral insights to be realized by gathering, examining, and drawing meaningful insights from diverse data sources and analyzing them in real time.</p>
Increasing Crop yields	<p>Javaid et al. (2023) identified numerous AI applications in the agriculture sector including increasing crop yields. By using technologies (e.g., IoT, data analytics, etc.) and sensors, a number of AI applications can assist in, amongst other things, predicting weather and plant diseases, monitoring crop and soil, identifying wasteful resource consumption patterns, guiding on water management, and detecting anomalies and impurities. Resulting, thus, in improving agricultural efficiency.</p> <p>Quantilus (2022) reported on scientists who use AI to create new crop variations which are more resilient to diseases and pests, can be farmed even in extreme weather conditions, and demand fewer fertilizers and smaller water quantities.</p>
Distributing food more efficiently	<p>Alabi and Ngwenyama (2023) advocated the use of smarter, digital food supply chains to improve food security and negate disruptions. The authors identified the following technologies to achieve this:</p> <ol style="list-style-type: none"> 1) New supply chain technologies deployment (e.g., blockchain, AI, ML, DL, data analytics, etc.). 2) The use of Cloud based technologies can support full food supply chain visibility and asset movement (Terblanche, 2021). 3) Application of Industry 4.0 model, where digitalization and interconnectedness are achieved through the use of technologies, such as cognitive computing, IoT, CPS, and cloud computing.

The solutions identified in Table 1 address the ethical themes of Quality of Life (QoL), Risks and Reliability, and Equity and Access, which should permeate the decisions made concerning Reduce, Reuse, and Recycle in using AI to support the achievement of zero hunger sustainable development goal.

4.2 AI and quality education (SDG 4)

In an attempt to reveal how AI can support the SDGs and benefit the society as a whole, Luckin et al. (2016) presented lucid arguments for the use of AI in Education (AIEd). In another study, Zawacki-Richter et al. (2019) showcased an extensive research overview regarding the adoption and use of AI applications in higher education. Four key areas of AIEd emerged from their study. These areas involve the use of AI in institutional, academic, and administrative support services. Particularly, these areas are: 1) intelligent tutoring systems (ITTs), 2) assessment and evaluation, 3) adaptive systems and personalization, as well as 4) profiling and prediction.

Chaudhry and Kazim (2022) presented the findings of an overview regarding the use of AI in Education based on perspectives from both academia and industry. The authors highlighted the research emphasis on reducing the workload of teachers, contextualizing learning for students, improving evaluations, and developing ITTs. Similarly, Chassignol, et al. (2018) argued that AI will change and reshape the education landscape via four broad categories: 1) technology enhanced assessment, 2) communication between students and educators, 3) innovative teaching methods, and 4) customized educational content.

When applying AI solutions in the education domain, attention should be given to the ethical theme of Equity and Access, which should permeate the decisions made concerning Reduce, Reuse, and Recycle in the use of AI to support education quality (SDG 4). UNESCO (2023) promotes digital learning and the transformation of education via the deployment and exploitation of AI. But it alerts developers and policy makers to the multiple risks and challenges that AI brings, including the technology role in overcoming existing inequalities concerning access to *“knowledge, research and the diversity of cultural expressions and to ensure AI does not widen the technological divides within and between countries”*. UNESCO advocates the promise of *“AI for all”* in this AI technological revolution in education.

4.3 AI and affordable and clean energy (SDG 7)

It was highlighted in a recent report by the United Nations (2021) that in 2021 one fifth of the global population did not have access to electricity. The United Nations argued that due to the drastic increase in energy consumption and demand, the use of renewable energy sources must be increased. Salim et al. (2018) stated that the concept of sustainable production and consumption of energy needs to balance the negative externalities (reducing resource utilization, energy usage, waste, and pollution), on one hand, with maintaining economic prosperity and social well-being on the other. Ediger (2019) argued that to overcome the difficulties and challenges caused by the conventional energy plants (e.g., fossil fuels) it is important to transition toward renewable energy resources.

Hannan et al. (2021) stated that AI plays an essential role in increasing “*RE utilization and contribution to the energy mix, as well as the potential to revolutionize the RE sector*”. Table 2 presents examples of AI applications and approaches that are being used to optimize RE resources production, consumption, and distribution.

Table 2: Examples of AI solutions that are being used to develop renewable energies

Reported In	AI Applications and Approaches
(Zahraee et al., 2016)	By integrating AI solutions and applications in the renewable resource domain, the overall energy efficiency, safety, and reliability can be improved. Additionally, the impact on the environment and the overall costs can be reduced. The integration and digitalization of smart grids and microgrids that more effectively produce, manage, and distribute energy resources can be enhanced.
Chatterjee & Dethlefs (2022)	The use of AI-based solutions to monitor and analyze issues in solar panels and turbine blades, via the use of computer vision techniques and data analytics. To develop more effective AI models to achieve corrective and predictive maintenance, data from historical failures caused by sensors in solar panels or wind turbines can be used.

When applying AI solutions in the RE domain particular attention should be placed to the ethical themes of Risks and Reliability and Equity and Access, which should permeate the decisions made concerning Reduce, Reuse, and Recycle in using AI to assist in meeting the goal of Affordable and Clean Energy (SDG 7). Jones (2018) reported on the need to use large computing centers to further advance AI technology and research as well as AI-based products, which, in turn, can have a very high energy consumption rate and carbon footprint. The author estimated that the total electricity demand for ICT infrastructure could require up to 20% of the total world electricity demand by 2030. Hence, the transition toward greener energy resources and ICT infrastructure is ethically essential (Karnama, et al., 2019).

4.4 AI and sustainable cities and communities (SDG 11)

According to the United Nations Development Programme (UNDP), over half of the world population currently live in cities and it is estimated that by 2050 that number will increase to two-thirds of all humanity (United Nations Development Programme, 2023). Therefore, the UNDP argued that it would be impossible to achieve sustainable development without changed the way cities are designed, build, and managed.

Allam and Dhunny (2019) reported on how urban centers are increasingly using new technologies to overcome issues related to “*society, ecology, morphology, and many others*”. Among other technologies, smart cities incorporate sensors and big data through the IoT. The AI-based analysis of data deriving from such sources brings new opportunities in the city organization and management, contributing to the concepts of urban fabric, sustainability, and livability, along with opportunities for economic growth.

Singh et al. (2020) stated that smart cities can contribute toward the development of a more intelligent society by deploying and exploiting new technologies. They advocated that the adoption and integration of blockchain technology has contributed toward “*a paradigm shift to a new digital smart city ecosystem*”. The convergence of AI and blockchain technology is revolutionizing the smart city network architecture to build sustainable ecosystems. Bokhari and Myeong (2022) highlighted that using AI-based solution to analyze big data deriving from smart cities could enhance autonomous decision-making systems. Gupta and Degbelo (2022) identified examples of how the integration of AI to monitor and manage resources and systems in smart cities has contributed toward the achievement of sustainable cities.

The AI solutions in the realm of sustainable cities address the ethical themes of Quality of Life, Risks, Privacy and Reliability, and Equity and Access, which should permeate the decisions made concerning Reduce, Reuse, and Recycle in using AI to assist in developing sustainable cities and communities (SDG 11). Pastor-Escuredo, et al. (2022) stated that the ethical danger of digital technologies deployed in smart cities is that they have an impact at both a societal and individual level, “*posing several risks including a more homogeneous and predictable humankind*”.

5. Discussion and conclusions

The aim of this study was to reveal how AI can support the creation of a circular economy and help achieve SDGs to benefit society. The proposed 4R sustainability framework, which was based on the 3R principles, concluded in the RETHINKing of values and actions to transition to a circular economy. The circular economy focuses on using natural resources more efficiently; hence, it coincides with several of the SDGs. A change in mindsets is necessary to develop a viable re-modelling approach of deep-rooted practices; thus, the transition should be associated with appropriate sociocultural frameworks and policy debates. Understanding consumers’ cultural behaviors is essential for this transformational change. Additionally, changes must be made on an individual and local level to address the global challenges. Hence, the wider sociocultural transition should be met with appropriate individual actions and initiatives. This transformational change can result in better performance, improved engagement, and higher levels of innovation and creativity. AI and AIoT are significant components in creating a circular economy and achieving SDGs which, in turn, will result in a sociocultural transition.

Rethinking requires changes of mindsets and attitudes starting from raising awareness through educating the younger generations and re-educating adults who may be more set in their ways of thinking and often not open to new ideas. Additionally, to maximize any of the 3Rs (Reduce, Reuse, Recycle), it is necessary to increase reusability and adaptability of products, organize resources and knowhow into small and independent packages so that changes are controllable without generating a ripple effect of uncertainty.

It is simplistic to look for technological solutions without understanding the human centered environment. It is only through combining the “*human-centered and collectiveness-oriented digital development*” which can result in the development of new ethical social models (Pastor-Escuredo et al., 2022). Thus, it is necessary to combine ethical principles with the digital innovation undergoing in all the dimensions of sustainability. Vinuesa et al. (2022) proposed that to achieve sustainable development, the deployment of AI needs to be further promoted and supported by regulatory insight and oversight. They concluded that failure to do so could result in gaps in “*transparency, safety, and ethical standards*”.

Future work will concentrate on the required changes to attain a sociocultural transition toward achieving a circular economy and SDGs. Other actions will focus on validating the suggested 4R sustainability framework by conducting case studies within enterprises and industries in cross-country and cross-cultural settings.

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