THE IMPACT OF INDUSTRY 4.0 ON SUSTAINABLE DEVELOPMENT GOALS: SUSTAINABILITY, SOLAR ENERGY AND IOT ON CLEAN WATER FOR MARGINALISED COMMUNITIES

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Abstract: *The 17 Sustainable Development Goals, formulated in 2015 by the United Nations General Assembly, have been established in order to end poverty, improve health and promote prosperity and well-being through environmental sustainability. Sustainable development is defined as a balance between sustainable economic growth and ecological regeneration, requiring the fulfilment of environmentally friendly technologies that are efficient and adaptable to local conditions through the integration of ecological and engineering postulates. Significant technological evolutions have been listed during the last decades, in particular the so-called 4th Industrial Revolution, which refers to a technological, social, economic, political and cultural phenomenon that brings about a greater adaptability to the needs of production and an improvement in resource efficiency. The objective of this work is to propose how through the use of 4.0 technologies it is possible to respond to several of the SDGs, such as sustainable communities, social welfare and good health, water purification and sanitation, solar energy, and zero poverty. We present a case study featuring a portable, cost-effective solar-powered device for water purification, which exemplifies the potential of the Internet of Things (IoT) connectivity. This device incorporates a water quality monitoring system with satellite connectivity to facilitate timely notifications to technicians regarding repairs or replacements, thereby enabling marginalised populations to access clean water.*

Key words: SDG, Industry 4.0, solar energy, water purification, digitalisation

1. INTRODUCTION

The Sustainable Development Goals (SDGs), or Global Goals, are 17 goals that have been established in order to end poverty, improve health and education, and promote prosperity and well-being through environmental sustainability. They were formulated in 2015 by the United Nations General Assembly (UN-GA) with the proposal to achieve them by 2030. The philosophy of the 2030 Agenda is that "no one is left behind" and requires global alliances and participation in the integration of environmental dimensions, social, economic and governance in the development process. Sustainable development goals were established to end poverty, improve health and education, and promote prosperity and well-being through environmental sustainability (Berawi, 2019).

The concept of sustainable development is conceived as a balance of sustainable economic growth and ecological regeneration. Sustainable development requires the implementation of appropriate environmentally friendly technologies that are both efficient and adaptable to local conditions (Berawi, 2019). In this situation, ecotechnology can facilitate the conservation and restoration of the environment through the integration of ecological and engineering principles.

In relation to Engineering, important technological evolutions have been registered during the last decades. The advent of the global data communications network (Internet), Artificial Intelligence (AI) and cyber-physical systems (CPS) no longer produce an evolution but a technological revolution with high social impact (Salimbeni, 2019). All these technologies aim to improve the connectivity between the components within the industry, and to build an inclusive and sustainable industrial development (Hidayatno, Destyanto and Hulu, 2019).

Towards the end of the 18th century, the beginning of the 1st Industrial Revolution was determined, primarily, by the invention of the steam engine, but the entire process originated in England brought with it profound economic, social, scientific and technological transformations that established the development achieved as a consequence. In addition, the exodus of the population residing in rural areas towards industrial areas allowed the growth of cities by modifying their structure and size, such as the

construction of factories. Thus, the 1st Industrial Revolution ended in the 1840s and during the 19th century, with the industrial use of electricity, the 2nd Industrial Revolution began, which implied the expansion of development by countries in Europe, Asia and North America. Not only were there the technological advances acquired in the 1st Revolution, but also access to natural resources that were not previously available or were considered of little use, such as the use of metals like steel, aluminium or copper, among others, and chemical products. The world of transportation had new technologies, allowing the connection and expansion of markets that were previously unconnected and the transportation of people and merchandise by rail or other transportation that implemented the use of fossil fuels such as oil. The so-called 3rd Industrial Revolution, in the middle of the 20th century, began with the invention of semiconductor and digital techniques. The concept of "Information Society" was formulated based on the confluence of new communication technologies between markets. Thus, the 3rd Revolution introduced information technologies, communication, process automation and the development of renewable and sustainable energy. Finally, the 4th Industrial Revolution, a concept introduced in 2011, refers to a technological, social, economic, political and cultural phenomenon that has been developing since the 1st Revolution originated in Europe in the 18th century, and which gave rise to to an urbanised and industrialised society and to smart factories (4.0 factories), which included greater adaptability to production needs and improved resource efficiency. The 4th Revolution is based on AI, the use of CPS, the Internet of Things, mobile communications and interoperability between the "real" and the "virtual" world, connecting the first 3 Industrial Revolutions in terms of organisation and automation of production and marketing processes and means. In line with these objectives, the 4th Industrial Revolution is believed to have significant relation with sustainable energy (Hidayatno, Destyanto and Hulu, 2019). Data collected in 2020 during the testing of the tool for 28 EU countries indicate that, initially, strengthening social aspects should become a priority. This means that social smartness is a basis for smart and sustainable EU 4.0. However, the main long-term objective should be a high balance of technological and social indicators. Consequently, the organisation's knowledge of the factors to develop in the first place and the factors that can be achieved at a high level in the long run is important (Adamik and Sikora, 2021).
This article presents the design of a device that works as a solution to deliver drinking water to marginalised communities, in emergency situations and/or without the possibility of accessing urban centres or their basic services due to distance, weather conditions, difficulty or inability to move, among others. The solution is not only proposed to generate an immediate impact, but also as a resource for the introduction of a notable improvement in the quality of life of people and their conditions of access to drinking water. Using solar energy collected by solar panels strategically located in areas where a response to the problem is imperative, a portable device capable of purifying water from rivers, wells, streams or other sources of nearby fresh water was designed, with the capacity of performing process monitoring using IoT sensors. These sensors will collect relevant information such as temperature, humidity, pressure, presence of minerals and chemical contaminants (such as arsenic) in the water, among other variables, and the data will be sent to the cloud via satellite communication to be processed. In addition to allowing monitoring and control of the process, this data flow will enable preventive, corrective, prescriptive and predictive maintenance. This development makes use of some of the most important enabling technologies of Industry 4.4 (I4.0), such as satellite communication, Cloud Computing, Big Data & Analytics, AI, among others.
In this way, the objective of this work is to propose a solution to this problem through the use of 4.0 technologies, responding to several of the Sustainable Development Goals (SDGs), such as sustainable communities, social well-being and good health, purification and sanitization of water, solar energy and zero poverty (Mabkhot et al., 2021).

2. I4.0 & ENERGY EFFICIENCY

2.1 Industrial and Sustainable Development

Industrial development refers to the practice and study of how industry responds to current sustainability challenges and eventually becomes part of a larger, fully sustainable system. For its part, sustainable development can be understood as development that raises the standard of living of current generations in such a way that the same aspirations can be fulfilled by future generations. This addresses not only environmental responsibility, but also economic and resource efficiency, and social equity (for example, advanced technologies linked to social sustainability, as they can improve ergonomics, worker safety, and facilitate risk assessment, etc.) (Adamik and Sikora, 2021).

One of the sources of sustainable development are intelligent organisations. They have the ability to dynamically adapt by creating, obtaining, organising and sharing knowledge that can then be used to create and exploit new opportunities to increase operational effectiveness, sustainable development and competitiveness in the global marketplace. In other words, when something is “smart”, its innovations are implemented proactively with an aspirational and goal-oriented purpose, thus leading to the achievement of a desired future (Adamik and Sikora, 2021).
Furthermore, energy efficiency is linked to the digital transformation that may change the processes in the industry, which are highly influenced by technological innovations. While the number of industries using I4.0 technology increases, industrial productivity will also experience the same growth (Hidayatno, Destyanto and Hulu, 2019).
Sustainable I4.0 should include many elements, such as: energy management, reduction of greenhouse gas emissions, reduction of negative environmental impact, reduction of raw materials consumption, water management, social and economic sustainability, and even life cycle assessments (LCA) (Gajdzik et al., 2020).

2.2 Circular Economy, I4.0 and Sustainability

Like sustainable development, I4.0 emphasises efficiency, productivity, continuous improvement, and a better customer experience, contributing to sustainable manufacturing. These initiatives can provide manufacturers with many advantages such as cost savings due to material, energy and resource efficiency, brand reputation, public trust and competitiveness (Ching et al., 2022).
Likewise, we are currently facing the challenge of producing more and more products to satisfy growing consumption, from increasingly scarce resources and trying to reduce pollution and damage. Therefore, I4.0 offers a way to face these challenges, since they are aimed at achieving sustainable development in the economic, social and environmental dimensions (Gajdzik et al., 2020).
The Circular Economy is a systematic change towards a viable but regenerative economic model, based on the reinsertion of used resources through material cycles (technological and biological). In addition, the Circular Economy model promotes the minimization of resource consumption, waste generation and emissions while ensuring socioeconomic development (Dantas et al., 2021). However, the transition from a Linear Economy to a Circular Economy requires investment and technological development. That is why the Circular Economy is closely related to the revolution brought about by I4.0 (Sulich and Rutkowska, 2021).
Nevertheless, despite the relationship between both models, Circular Economy and I4.0 were considered for many years as two individual processes or flows (Reddy, Reddy and Prakash, 2020). Their convergence and combination is called the CE-I4.0 nexus and is a promising research topic linking innovative technologies with system-wide changes in our economic and industrial models (Dantas et al., 2020).
The I4.0 revolution promises significant changes in technology and part of them can be dedicated to supporting the transition to CE or protecting the environment (Sulich and Rutkowska, 2021). The Circular Economy proposes an innovative path towards sustainable development introducing a different way of perceiving value in the management of natural resources (Dantas et al., 2020).
The Circular Economy is a useful tool to achieve the 2030 agenda of the SDGs. The transition to a Circular Economy can keep the value of resources and products at a high level and minimise waste production (Khajuria et al., 2022). This has significant potential to achieve sustainable development by halting the depletion of natural resources, reducing environmental damage from the extraction and processing of virgin materials, and reducing pollution from processing, use, and end-of-life procedures (Khajuria, 2021).

2.3 Technological Pillars in I4.0

The I4.0 allows the complete digitization of value chains, from suppliers to end customers, through the integration of data processing technologies, intelligent software and sensors, in order to be able to monitor, predict, control, plan and intelligently produce what generates the greatest value for the entire chain. The IoT, AI and CPS are pillars of the I4.0 (The Industrial Internet of Things Volume G1: Reference Architecture, 2019).
The I4.0 concept is based on key pillars which result from continuous advances in new technologies, such as the Internet of Things, cloud computing, Big Data, modelling and simulation, autonomous systems AS), augmented reality (AR), additive manufacture (AM) and cybersecurity (Gajdzik et al., 2020).
The implementation of technology advances in I4.0 can result in cutting-edge solutions based on data collection and intelligent manufacturing processes. These technologies are not only beneficial due to their

manufacturing advantages, but also because they can be used to reduce waste generation, minimise environmental impacts, and help push industrial development to cleaner production processes. However, investing in technology is not enough to achieve the SDGs because a single focus on technology development may lead to industrial growth, but at the same time, it can increase greenhouse gas emissions and further diminish the availability of natural resources.

2.4 AI in achieving the Sustainable Development Goals

The application of Artificial Intelligence (AI) has the potential to play a crucial role in the achievement of the Sustainable Development Goals by facilitating the delivery of essential services such as food, health, clean water, and sustainable energy to communities worldwide (Vinuesa et al., 2020). It can also contribute to the development of low-carbon systems by enabling the creation of Circular Economies and smart cities that optimise resource utilisation (Chui, Lytras and Visvizi, 2018).

One of the significant advantages of AI lies in its ability to analyse vast interconnected databases to develop joint actions aimed at preserving the environment and promoting sustainable practices. Reported potential impacts of AI indicate both positive and negative impacts on sustainable development. The integration of AI into various sectors holds promise. For example, in agriculture AI-powered systems can enhance crop yields by optimising irrigation, fertilisation, and pest control, leading to increased food production and reduced food waste (Dharmaraj and Vijayanand, 2018).

Another promising field is healthcare, where AI algorithms can assist in early disease detection and personalised treatment plans, improving health services and patients' lives (McKinney et al., 2020). Furthermore, AI can contribute to the development of clean and renewable energy sources through the optimisation of energy production, distribution, and consumption.

On the other hand, it is important to acknowledge that the development of AI also presents challenges and potential risks to sustainable development. The large-scale collection and analysis of data required for AI systems involves large amounts of energy to power and cool the facilities where the programs are being run. In addition, the production of the hardware necessary for AI to function also entails a significant energy consumption. Moreover, it also raises concerns regarding privacy, data security, and ethical considerations. Therefore, it is essential to ensure responsible and inclusive AI deployment, considering its potential impacts on social, economic, and environmental dimensions and sustainable development.

In summary, AI has the capacity to act as an enabler for achieving the SDGs by supporting the provision of vital services. However, careful consideration must be given to the ethical, social, and economic implications of its implementation. By addressing these challenges and harnessing the potential of AI in a responsible and inclusive manner, we can accelerate progress towards a more sustainable and equitable future.

2.5 IoT in Sustainable Analytical Chemistry

The Internet of Things (IoT) plays a significant role in enabling real-time data acquisition and analysis, not only for industrial processes but also for monitoring various environmental conditions and human health. By leveraging IoT technology, it becomes possible to remotely access and examine analytical information, providing valuable insights and facilitating informed decision-making. In the context of sustainability, the development of analytical methods is crucial, and it necessitates the consideration of several key factors (Cadeado et al., 2022).

Firstly, these methods should have minimal environmental impact, ensuring that they do not contribute to pollution or resource depletion. By adopting sustainable practices in analytical processes, such as reducing chemical waste and energy consumption, it becomes possible to minimise the environmental footprint associated with analytical testing.

Secondly, sustainable analytical methods should also bring economic benefits to society. This can be achieved by optimising resource utilisation, reducing costs, and improving efficiency. By implementing cost-effective and resource-efficient analytical techniques, the financial burden associated with testing and monitoring can be reduced, making these methods more accessible and affordable for various stakeholders.

For instance, one innovative example of a sustainable analytical device is the use of fibre optics to transport light directly to a detector, such as a Raspberry Pi Camera. This device employs absorption and fluorescence measurements to detect contaminants like E. coli and total coliform in water. Using fibre optics, this method minimises the use of chemical reagents and reduces waste generation, making it environmentally friendly, and its portability facilitates *in situ* analysis. Additionally, the Raspberry Pi Camera provides a cost-effective and accessible platform for data collection and analysis.

3. CASE STUDY & DISCUSSION

3.1 Real Life Case Study: I4.0 Enabling Technologies

The integration of I4.0 (I4.0) enabling technologies presents real-life case studies that demonstrate their potential in addressing sustainable development challenges. One such example is a portable water purification equipment, prominently featured in the photo. This innovative solution operates on battery power and is further supplemented by solar panels, highlighting its self-sufficiency and renewable energy reliance. The equipment, manufactured by a Brazilian company called PWtech, is specifically designed to provide drinking water to marginalised communities.

Figure 1: Portable water purification equipment. Source: PWTech photo.

By leveraging IoT connectivity, cloud computing, and big data analytics it becomes possible to remotely monitor and assess water quality, enhancing efficiency and effectiveness. This integrated approach allows for real-time testing and analysis of water samples, enabling proactive interventions and preventive measures to maintain water quality standards.
Furthermore, the autonomous operation of the water purification equipment is facilitated by solar energy. This ensures continuous and sustainable operation, even in areas with limited or no access to traditional power sources. The use of solar power aligns with the goal of promoting renewable energy solutions and reducing carbon emissions.
Additionally, the implementation of advanced analytics and predictive maintenance techniques for the equipment ensures optimal performance and longevity. By analysing data collected from the equipment's sensors, it becomes possible to detect potential issues or malfunctions in advance, enabling timely maintenance or repairs. This proactive approach minimises downtime, increases equipment lifespan, and reduces operational costs.
By combining IoT connectivity, cloud computing, big data analytics, and solar energy, this case study showcases the practical application of I4.0 technologies in promoting sustainable development and improving the well-being of marginalised communities through the provision of clean drinking water. It serves as a testament to the positive impact that technology can have on achieving the United Nations' Sustainable Development Goals (SDGs) and fostering a more sustainable and equitable future.

3.2 Discussion

Urbanisation prompts a larger migration of rural population to an urban area, leading to an increase in energy usage and consumption (Zakari et al., 2021). The need for Solar Water Heater (SWH) is increasing daily due to some factors such as electric power deficiency, high fuel price, rapid urbanisation, low cost of installations, government intervention and environment-friendly applications, which acts as a direct replacement to fossil fuels. Considering the epileptic nature of electric power outages in developing countries, the reliance on solar applications for water heating will lead to better reliability of service for hot water needs and will have minimal negative impact on environment pollution (Bori et al., 2022). Not only are marginalised communities unable to provide themselves with hot water for bathing, for example, but also clean water for consumption. The consumption of non-potable water in developing countries generates thousands of deaths per year. In both developed and developing countries, current infrastructure for wastewater treatment and the safe production of water that is readily available is struggling to stay up with more and more severe regulations and the growing need for superior purity water. The rapid growth of population expansion in emerging regions will proceed to increase hygienic water needs from a residential, agricultural, industrial, and energy viewpoint in the coming decades. By 2025, it's expected that half of the globe's population would live in water-stressed areas (WHO, 2014) (Singh, Singh and Rai, 2021).
Water is the most valued and important resource in the world and the lack of it has become a serious problem. Industrialization, urbanisation, and climate change have created an urgent demand for the clean water that is so essential to human health. Lack of water can cause diseases such as typhoid fever, dysentery, cholera, and diarrhoea, resulting in many deaths worldwide. There are traditional methods that include processes such as filtration, sedimentation, distillation, and chlorination, but these have limitations and can be resistant to, for example, antibiotics. Water purification involves removing undesirable chemicals, biological contaminants, or even suspended solids from water systems to produce clean, safe water for human consumption and other purposes (Spoiala et al., 2021).

4. CONCLUSIONS

Different research projects are promoted to encourage smart and sustainable growth through innovation and to create an ecosystem favourable to the development of companies. A case has been presented where the new applied technologies are applied for the good of the most vulnerable communities. The 4th Industrial Revolution is currently in a new phase where the effects caused to the ecosystem and society are fundamentally considered. More attention is being paid to ecology, to the reuse and/or recycling of products once their useful life is over. Organisations make use of the new T4.0 in order to consider sustainability, sustainability and the Circular Economy as an additional factor of utmost importance and with the Sustainable Development Goals (SDGs).

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