Chapter

Industry 4.0 Technologies: What Is Your Potential for Environmental Management?

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Abstract

The Industry 4.0 is a new industrial model characterized by excellent productive, procedural, and environmental performance. This new industry is perceived as a truly sustainable manufacturing model. And one of the aspects that most contributes to this insight is the extensive set of largely innovative technologies in the industry 4.0. Largely because such technologies are not necessarily unheard of, what changes is the integration between them in the context of industry 4.0. From this explanatory context, the purpose of this chapter is to present the full potential of industry's 4.0 leading technologies for their highly effective Environmental Management. Thus, it is possible to understand how integrated technologies cooperate together for an environmentally sound and sustainable positioning of industry 4.0 in all its areas. The industry 4.0 has a more conscious use of natural resources, less waste, processes are leaner and the life cycles of its machines and equipment are longer. All these factors together with the technologies, contribute for the Environmental Management 4.0 to be disruptive in relation to the still industries 3.0. The chapter also presents the main challenges for the industry's 4.0 environmentally sound and sustainable performance through its technologies.

Keywords: Industry 4.0, sustainable manufacturing, advanced manufacturing, Environmental management 4.0, Technologies 4.0

1. Introduction

The Industry 4.0 or Fourth Industrial Revolution is a new and imminent industrial model characterized as advanced manufacturing. What most differentiates this new industry model from the three previous industrial revolutions is the integration of its components. These are represented by people and their human work, machines and equipment, and technologies. Industry 4.0's internal environment is more integrated, agile, accurate, synchronized, and encourages external stimuli to arrive and be received in the same way.

This new industrial model is also known for its high technological, virtual and digital positioning. Existing technologies in industry 4.0 are not necessarily new, what changes is the integration between them, allowing the industry to behave dynamically and quickly respond to internal and external needs. In the context of production, these technologies enable production processes to be more efficient, lean and faster.

In industry 4.0 as well as in today's industries, care for the environment, proper and conscious use of natural resources, optimization of physical resources used, waste generation and reuse, and the search for no waste must also be strictly observed. Industry 4.0 Environmental Management is as relevant an area as all of its innovative potential, as it must set guidelines, supervise actions and monitor processes so that they are consistent with an environmentally sound and truly sustainable industrial profile.

The aforementioned industry 4.0 technologies are strong supports for Environmental Management 4.0. The technological potential of the new industrial model is one of the key aspects that allow industry 4.0 to be known as a truly sustainable manufacturing model. Its technologies working in an integrated way, allows not only the environmental management process to be more solid, but the industrial activity itself in all its processes. These become more virtualized, lean, accurate and made on demand.

From this explanatory context, the purpose of this chapter is to present the potential of the industry's 4.0 leading technologies for their respective Environmental Management. For this, five next sections are distributed in such a way that the first one refers to the presentation of industry 4.0, the second one refers to the presentation of their respective technologies, while the third one refers to environmental management in industry 4.0, the fourth refers to the potential of technologies for environmental management 4.0, and lastly, the fifth refers to the main challenges for environmental and sustainable beneficiation through the use of technologies 4.0.

2. Industry 4.0

The term Industry 4.0 was first mentioned in the German language during the "Hannover Fair" event in 2011 in Germany, and came up as a proposal for the development of a new concept of German economic policy that is based on high technology strategies, which symbolize the beginning of the so-called Fourth Industrial Revolution [1, 2]. Thus, as of 2011, scientific publications on industry 4.0 began to emerge, increasing exponentially around 2013. And many scholars, researchers and business professionals have paid attention to the new industrial model and its potential technologies.

The industry 4.0 is an imminent advanced manufacturing model characterized by a comprehensive set of technologies that streamline industrial performance, making it more integrated, virtual, digital, with excellent response time to internal and external stimuli, and especially with exemplary environmental and sustainable behavior. The industry 4.0 itself includes a set of six design principles that intrinsically include technologies. Such principles are named Decentralization, Virtualization, Interoperability, Modularity, Real-Time Capability and Service Orientation.

One of the peculiarities of the industry 4.0 is its integration capability. The author [3] presents the fundamental and interdependent presence of two value chains, horizontal and vertical. **Figure 1** presents the first value chain, the horizontal, together with their respective elements.

The digitization process is on its way to both horizontal and vertical value chains. The horizontal value chain digitization works to integrate and optimize the flow of information and goods from the customer through their own company to the supplier, and so the information comes back again. This process involves the

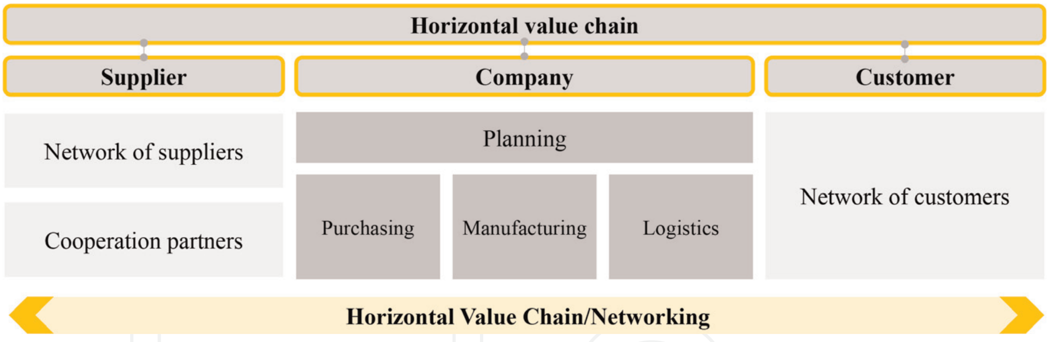

Figure 1.
Horizontal value chain in Industry 4.0. Source: adapted from [3].

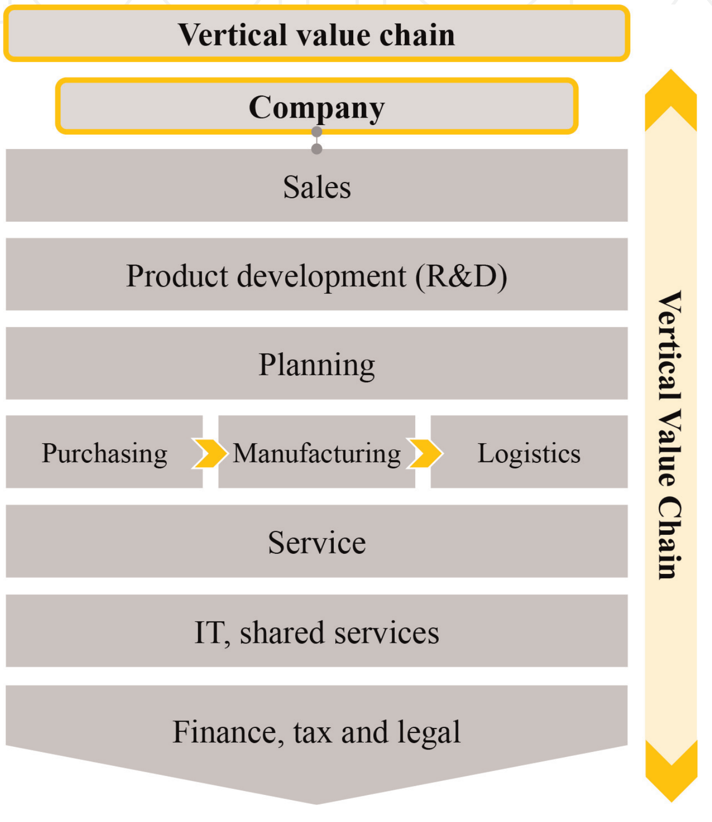

Figure 2.
Vertical value chain in Industry 4.0. Source: adapted from [3].

integration and proactive control of all internal areas of the company, such as planning, purchasing, production and logistics. The process also includes all external value chain partners who are key participants in meeting customer demand requirements and fulfilling the requested services [3]. **Figure 2** shows the vertical value chain with its respective members.

The digitizing the vertical value chain, on the other hand, is associated with ensuring a flow of sales data and information through product development for manufacturing and logistics. The quality and flexibility can be increased and costs reduced through the precise and optimal connection of manufacturing systems and their respective failure prevention, thus cooperating with better analytical skills [3].

3. Industry 4.0 technologies

The industry 4.0 itself encompasses an extensive set of technologies with broad innovative potential due to their integration. Such technologies are perceived by some industry scholars or professionals as tools or pillars, or industry 4.0 principles. This is because there is a need for more publications to be done in order to properly name each of the industry 4.0 components. In this section, key industry 4.0 technologies are presented in subsections.

3.1 Cyber-physical systems

One of the most significant advances in the development of information and communication technologies is represented by Cyber-Physical Systems (CPS). These are computational collaboration systems that are in strong connection with the surrounding physical world and its respective active processes while providing and utilizing data access services as well as data processing available on the Internet [4]. The CPS integrate the relationship with people, data and information, machines and equipment, in order to streamline the process of receiving and sharing data and information, analysis and interpretation, and decision making.

3.2 Cloud manufacturing

Cloud manufacturing (CMfg) is a research field that integrates cloud computing (CC) and traditional product design and manufacturing. CMfg is a service-oriented product development model in which consumers are able to design and make products through the use of information technology and online manufacturing resources [5]. In this way, CMfg cooperates with the customization of products made on demand directly deliberated by the customer.

3.3 Big Data analytics

Some scholars use the term Big Data analytics (BDA) to emphasize the process and tools used to extract insights from Big Data. In essence, BDA includes not only the organization on which data analysis is performed, but also the elements that make up the tools, the infrastructure and the means to visualize and present insights [6]. Thus BDA presents a stronger structure for receiving, archiving, analyzing and sharing data and information, enabling more concrete decision making based on real information and properly organized and treated.

3.4 Augmented reality

The augmented reality (AR) is defined as a computer graphics technique that transforms the real environment into a digital environment also using virtual objects in the real world [7]. The AR has several possibilities of use in different areas, either in the transmission of knowledge, in the performance of work activities, in the elaboration of products, in the deliberation of logistic routes, among many other applications.

3.5 Smart sensors

The Smart Sensors (SS) are one of the key elements of the future smart grid, as it enables remote monitoring at each specific point on a network to assess real-time system performance and to find likely errors [8, 9]. This technology enables the industry to better respond to internal and external needs for adaptation or change at a given point in the network.

3.6 Location detection

The location detection systems are designed to make it easier to identify the respective location of a user or a particular object in a physical space. However, the systems come in different varieties, some requiring users to have tags with identification that is viewed through fixed and calibrated fixed sensors. There are systems that provide object tracking anonymously, while some adopt fixed infrastructure (WiFi or Bluetooth). Location detection systems differ in aspects such as extent, area coverage, accuracy and cost [10]. While these systems differ at these points, regardless of the breadth of their potential, they enable the industry to have greater control over its resources and processes so that they are always optimized and directed to the right location.

3.7 Industrial Internet of Things

The industrial Internet of Things (IIoT) is a system that involves intelligent networking, cyber-physical systems, cloud computing platform that allows access, collection and evaluation of communications, and also enables the industry to exchange data, such as processes, products and services, in real-time, thus generating the optimization of production value [11]. Thus, IIoT is also one of the key technologies responsible for ensuring the integration of data and communications across the industry and beyond, in constant exchange of information with the stakeholders involved.

3.8 Additive manufacturing

The additive manufacturing (AM) is a technique that aims to bring together a wide variety of complex geometries and structures from three-dimensional (3D) model data. The process consists of printing successive layers of materials that are formed on top of each other. The AM involves various methods, materials and equipment, and has evolved over the decades and has the ability to transform manufacturing and logistics processes. The AM has been widely applied in a variety of industries including biomechanics, prototyping and construction [12]. This technology uses different materials for different purposes, for which aspects such as capacity, durability, consistency, limitations, and contact with other possible types of materials must be observed.

4. Environmental Management in Industry 4.0

The pace of technological progress opens space for reflection on its impacts not only on the economy, but also on society and the environment. Beginning with the Stockholm Conference in 1972, several meetings are held around the world to discuss environmental issues. Over the years there is a clash between the perspectives of industrial production, economic expansion and sustainable development. In addition to the use of water and energy, extraction of raw materials and exploitation of soil, there is a huge amount of waste generated [13].

The Environmental Management of traditional industries or industries 3.0 is very effective in its guidelines, supervisions and actions. However, traditional industry models do not allow complete and satisfactory environmentally sound and sustainable industry performance. These still have their processes that use many natural resources, which are sometimes over-harvested, the level of waste can still be considered high, the reuse of production resources does not occur effectively, as well as the reverse logistics process, among many other points that do not allow the industry to have a sustainable behavior.

The organizations seeking to perform well in sustainability actions must be ready to present the results of their practices to society and the market. To this end, the main mechanism used by corporations is the annual sustainability report. Through indicators, sustainability reports present the results of companies in the environmental, social and economic dimensions in a given year. This type of document contributes to broadening communication and relationships about these dimensions among key participants in the business environment in which the company is a part [14]. **Table 1** presents the aspects of environmental performance in the sustainability indicator proposed by [15].

In addition to the environmental performance aspects of the author's sustainability indicator [15], those proposed by [16] in **Table 2** are presented.

It is necessary to reflect on past actions and consequences and establish new relationships with the environment [10]. One of the goals set in 2015 by the United Nations (UN) in the 2030 Agenda for Sustainable Development is to promote modernization, including in industries with the aim of making them inclusive and sustainable with an increasingly efficient use of resources and implementation of technologies in industrial processes so that they become cleaner [17].

In this positive context, Environmental Management in industry 4.0 can count on its excellent ability to establish plans, deliberate on projects, grant or withdraw permits, verify processes and to monitor results, it can still use a wide range of integrated technologies that cooperate together for exemplary environmental and sustainable performance, which still has lower costs and expenses and increased industrial profitability.

Aspects of environmental performance	
Water utilization	Decrease in total water consumption
	Increase in percentage of recycled water utilization
Material utilization	Decrease of material intensity
	Decrease in raw material utilization percentage
	Increased use of recycled/remanufactured/reused material
	Decrease in percentage use of hazardous materials
Energy utilization	Decrease in total energy consumption
	Increase in percentage of renewable energy utilization
	Increased percentage of energy saved
Waste	Decrease in total waste generated
	Increased level of recyclable/remanufactured/reusable waste
	Decrease in percentage of waste brought to landfills
	Decrease in hazardous material waste percentage
	Decrease in water waste percentage
Emission	CO_2 emission reduction
	Decrease in greenhouse gas emissions

Source: adapted from [15].

Table 1.
Aspects of environmental performance.

Aspects of the environmental dimension	
Natural resources	Water use (m^3/year)
	Recycled water rate (%)
	Land use (m^2)
Environmental legislation and compliance	Environmental accidents (No./year)
	Cost for environmental, health and safety compliance ($/year)
Energy	Energy utilization (kWh)
	Idle energy loss rate (%)
	Renewable energy fraction (%)
Material	Material used per production unit (kg/piece or m^3/piece)
	Scrap rate (%)
	Process scrap rate (%)
	Quantity of material reused or recycled (%)
	Use of packaging material (kg/year or m^3/year)
	Use of additive processes (kg/year or m^3/year)
	Quantity of recycled process additives (%)
Waste and emissions	Waste (kg)
	Hazardous waste (kg)
	Emission of ozone-depleting substances (kg)
	Emission of greenhouse gases (kg)
	Emission of other environmental gases (kg)

Source: adapted from [16].

Table 2.
Aspects of the environmental dimension (continuation).

Since industry 4.0 has a strengthened environmental and sustainable awareness, along with the use of its potential technologies, the acquisition of natural resources and all energy efficiency is done according to need and demand, without exaggeration. Thus, spending on the acquisition of productive inputs tends to decrease or, at least, to control, since the right and necessary volume of a certain resource to be used in production is being acquired. As well as the operating costs of generators, central computers, virtual and digital devices, machines, equipment, they are also reduced as they are activated at the right time and as there is a need to remain active. The minimal waste generated can also cease to be a cost to industry if it is reused as a new material to be integrated into other products, or even as a raw material for the construction of tools that assist in the production, or being the fuel for it, for some specific types of industry.

In addition to reducing costs and expenses, the environmental and sustainable behavior of industry 4.0 can increase its profitability. Industries in the same segmentation can create a network of partnerships in which the acquired resources that will no longer be used in production are passed on to other industries that need them, rather than rendering them useless or lost in industrial storage, leading to expenses and losses. Similarly, the use of machines and equipment can be shared across industries 4.0. This consists in sharing the operating capacity of industries and is a way of providing services to each other so that the supplying industry has the benefit of keeping its machinery running and generating volatile revenue when it is not operating in the industry from which it operates. At the same time, the industry using the machinery maintains its productive activity without interruption or loss of demand.

The interconnection of value generation networks in industry 4.0 provides new opportunities for the consolidation of closed-loop product lifecycles and industrial symbiosis. The network interconnection enables efficient coordination of water, energy, material and product flows throughout product life cycles, as well as between different factories. The closed-loop product lifecycles help keep products in life cycles with various phases of use, with remanufacturing or reuse between them. The industrial symbiosis describes the cooperation between different factories to gain a competitive advantage by trading and exchanging water, energy, materials and products [18] as well as smart data at the local level [19].

The approach to sustainable product design in industry 4.0 focuses on designing closed product lifecycles, enabling specific product reuse and remanufacturing or applying cradle-to-cradle principles. Different design approaches also focus on seeking consumer well-being. These concepts can be supported by applying identification systems, such as to recover cores for remanufacturing, or by applying new services that are additional to the product to achieve a higher level of customer well-being [20].

The transformations presented by industry 4.0 revolutionize the forms of commercialization and promote behavioral changes in the consumption and production spheres, and mainly, can cooperate for the structuring and formation of more sustainable business models [19]. Constantly these new technologies impact sectors such as health, energy and construction, and are configured in a junction of intelligent processes that originate products and services whose goal is to provide comfort and quality of life associated with the management of existing resources [21].

5. Technology potential for Environmental Management 4.0

The industry 4.0 just like every business organization, and every individual themselves, needs to have a strong environmental awareness. The difference with this new industrial model is that it can utilize an available set of technologies that enable it to have more environmentally consistent, clean and efficient industrial performance. **Figure 3** presents industry 4.0 technologies, demonstrated by using

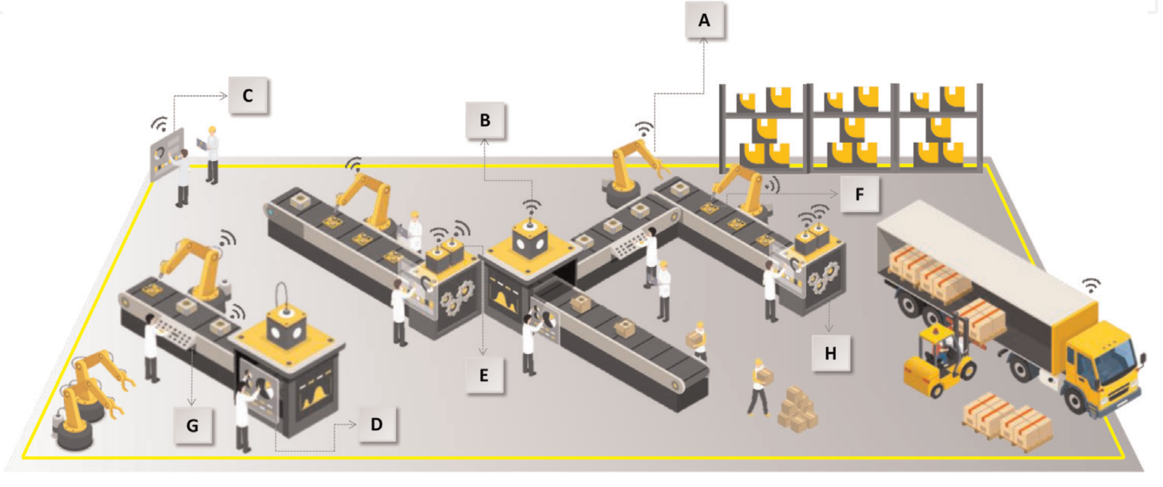

Figure 3.
Potential Technologies for Environmental Management in Industry 4.0. Source: Elaborated by the authors.

points, which have high potential favorable to Environmental Management 4.0. Each of the points is described subsequently.

5.1 Cyber-physical systems

The cyber-physical systems (CPS) are relevant agents for Environmental Management because they can receive production planning, stipulate production steps, provide data on resource utilization and production inputs, and manage them throughout the manufacturing process. The CPS can meet production schedules by receiving and providing real-time data and information, and can change any production step as needed.

Thus, the use of resources, mainly natural, is made more consciously and only in accordance with the need for integration in the production of the product. Similarly, less waste can be generated because the right materials are being used to the right extent and as needed. Because they are connected to the internet, and are the industry's leading interconnectors making it a network system, any changes that need to be made, the CPS can communicate it through notices to computer systems and mobile devices and perform autonomous (when programmed) or allowed (when coordinated by people), the necessary changes in the production process.

5.2 Cloud manufacturing

The cloud manufacturing (CMfg) is another potential agent for the consolidation of strong Environmental Management 4.0. This technology is responsible for receiving, storing, processing, presenting and sharing production data and information. Through this technology, not only the stimuli of the internal environment are treated, but also the external ones. Due to its service orientation feature, any minor change or need to adjust customer orders, notifications are sent and presented in systems to those responsible for a given production step.

The industry 4.0 has a high ability to offer customization to its customers' orders. By making it possible for customers to follow up the production steps of a product, they may or may not suggest modifications. This, in a traditional industry, could result in a vast amount of waste of resources, materials, energy efficiency, leading to waste and waste. However, with CMfg, it is possible to have the product planning to be executed, and thus acquire the necessary inputs. If any product change is requested by the customer, after systemic analysis, production can be changed without significant waste of resources, materials and efficiency, and other materials that can be used can be integrated into the production process, resulting in optimization of resources.

5.3 Big Data analytics

The Big Data analytics (BDA) stores and analyzes all industry data. Its potential for Environmental Management 4.0 is to group, analyze and provide relevant data and information on existing resources, resources used, machine functionality, energy efficiency, waste generation, waste utilization and pollution levels emitted. The BDA can provide historical information on a possible resource already used in the production of the same good, which may be reused. It can also notify, by systems, the lack of a certain resource for production, or even the breakdown of some machine, causing the production process to be interrupted.

With access to CMfg information, the BDA can suggest changes in the specificities of the production process. With these and other possibilities, the BDA serves as a warning of opportunities and correction needs, as well as its high capacity for storing data and information. Thus, any opportunity to improve production capacity by using fewer resources or taking advantage of fewer machines functionality, or by alerting to the misuse of a resource or material aimed at producing a good, or even the activity of a broken machine, can be notified by BDA, making it an environmentally active contributor.

5.4 Augmented reality

The augmented reality (AR) cooperates effectively with Environmental Management 4.0 because it can advise on planning before it comes to fruition, simulations of what is to be implemented, and the need for corrections even at a distance, or from different locations. It also contributes to the training and capacity building processes, imparting knowledge and teachings to employees about environmentally sound and sustainable actions through the visualization of real projections. It helps in the loading and unloading routes, so that truckers are better advised as to where they need to arrive, so that they are directed to the right location, without errors or deviations in the route and possible increase of pollutant emissions by their vehicles. The AR also cooperates with the monitoring of production operations, allowing to check failures, breaks, interruptions or errors in the production lines, among many other relevant functions.

With AR, plans can be prepared and viewed virtually before they are even directed, so any planning errors can be fixed before resources are acquired or triggered unnecessarily. The simulations that AR makes possible allow engineers, technicians, operators and designers to be able to check product-wide compliance and modification needs before they are produced. The AR still allows points that are distinct or distant from the industry site to be viewed virtually, so that the reality of a given point can be known even in real-time, thus streamlining the decision making process to perform actions or repairs.

5.5 Smart sensors

The smart sensors (SS) are a type of technology that informs systems for employee viewing of possible errors or non-conformities whether in materials, products, machines, steps or production lines, and can measure levels of waste or pollution generated.

The SS is a technology that can send these notifications to employees through systems on machines, central computers, or mobile devices and can take no further action, or can act, when so programmed, autonomously. The SS may receive an initial configuration of acceptable indices distributed at different scales, and when nonconformity that exceeds such ranges occurs, the SS may notify employees or take action that the production process is not erroneous at any stage, resulting in negative results for the environment.

5.6 Location detection

The location detection is a technology commonly used with the tag system. When you know the right location of machines and equipment, products in the production stage, finished products, a lot of time, accuracy, reduced waste generation and pollutants are gained throughout the industry.

The location detection helps resources that should be on the production line be easily located without wasting a lot of time and energy efficiency on running machines. Just as production-stage batches stored in temporary inventories do not need to be redone because they are not found, as well as completed batches need not be stopped in inventories generating industry costs and customer dissatisfaction, or even risk being confused with lots that have failed.

With location detection the industry becomes more agile and accurate, reducing waste generation due to local verification errors. Also logistics can prevent wrong deliveries and cargoes by mistake in defining the correct location to arrive.

5.7 Industrial Internet of Things

The industrial Internet of Things (IIoT) connects data and information from all areas of the industry and beyond with the stakeholders involved. The IIoT allows us to identify reversible or non-reversible machine and equipment failures, sensor and system problems, production disruption, changing customer demand requirements, stakeholder service opportunities, and many other possibilities.

Thus, the IIoT is a valuable technology for Environmental Management 4.0 because it can prevent the loss of a production machine or equipment because the hazardous situation has not been verified before, thus generating waste to the environment. Likewise, it can quickly verify that sensors and systems are not working properly and cannot perceive the improper use of a specific feature in a product, which could lead to loss of feature and product, leading to lost feature extraction and residue to the environment by the nonconforming product.

The IIoT also cooperates by informing customers of changing orders, so that the necessary resources and adjustments are handled carefully to avoid waste. Through IIoT, a network of industries can remain interconnected, so that with active communication, opportunities for offering and acquiring service claims can be observed and embraced, making it possible for an industry to need machinery that you do not own but can make available is to avoid buying machinery so that they will not be spare in this industry.

5.8 Additive manufacturing

The additive manufacturing (AM) is a technology that has a high degree of innovation in the use of resources in production. The AM's main contribution to Environmental Management 4.0 is that it can use other types of materials that are not necessarily taken from nature for the manufacture of various types of products.

With AM, some industry segments can switch production of their products using materials that do not come directly from nature, or that are biodegradable, or even edible, for some very specific types of industry. In this way the industry can achieve a more environmentally correct behavior regarding the acquisition of productive inputs.

In terms of waste generation, the AM can use materials that have been nonconforming or spare in the industry and make them viable to produce new products that integrate them rather than selecting materials to be extracted or prefabricated, eliminating irregular ones causing negative environmental results.

6. Challenges for environmental and sustainable beneficiation through technologies 4.0

The industry 4.0 technologies are very relevant to the environmental and sustainable commitment of industries. However, they do require a lot of observation and care in their correct implementation planning, operation, maintenance and discard. If all of these are not well analyzed prior to their realization, they can have an effect contrary to the environmentally correct and sustainable industrial positioning.

The Industry should be aware that technologies require continuous monitoring in order to ensure their full and effective use and no harm to the environment. **Table 3** presents the key challenges for the environmental and sustainable beneficiation of each of the industry's 4.0 technologies.

The industry 4.0 technologies are relevant contributors to environmental management, if properly and jointly used. One action of a given technology needs the cooperation of the other in order for efforts to complement and consolidate effectively.

Technologies 4.0	Main challenges
Cyber-physical systems	Cost considered still high for acquisition
	Installation in suitable places considering space and distance
	Need to connect to all machines throughout the production area
	Need to connect to all systems and sensors in the production area.
	Be connected in real-time to the whole productive area
	Pass by constant and periodic maintenance
Cloud manufacturing	Have ample data and information storage capacity
	Receive, archive and share data and information in real-time
	Be connected in real-time to industry computers, systems and machines
	Be connected in real-time with stakeholder demands
Big Data analytics	Have ample data and information storage capacity
	Receive, combine, analyze, archive and share data and information in real-time
	Be connected in real-time to industry computers, systems and machines
	Have historical information and records of changes made
	Be connected in real-time with the needs and changing demands of stakeholders
Augmented reality	Have interconnected auxiliary devices of adequate amplitude
	Have discipline in strictly necessary uses
	Be connected with systems and sensors for assisted production operations
	Have internet connectivity for use in different parts of the industry or in another location.
	Have internet connectivity for use in different parts of the industry or in another location that require direct interaction through communication
Smart sensors	Have space and distance required for correct performance
	Be connected to internet in real-time
	Be connected to systems in real-time
	Be connected to each other and machines in real-time
	Have the machines integrated performance capability
Location detection	Be properly and accurately installed in machinery and equipment
	Be connected to internet in real-time
	Be connected to systems in real-time
	Act together with smart sensors

Technologies 4.0	Main challenges
Industrial Internet of Things	Capacity installation on all machines, sensors and systems
	Be included on all central computers and mobile devices
	Receive, combine, share and notify industry internal and external stimuli
	Be included in partnering and service network systems from other industries
Additive manufacturing	Consider the best materials use option in the manufacture of a product
	Consider the need for resistance of the material to be used in the manufacture of the product
	Consider the use of waste generated as material for manufacturing
	Deliberate the ideal ways of disposing of the product when no longer used
	Control manufacturing according to need and demand, always considering the impacts on the environment

Source: Elaborated by the authors.

Table 3.
Main challenges for environmental and sustainable beneficiation through Technologies 4.0 (continuation).

7. Conclusion

In this chapter we have presented the industry 4.0 and its main technologies, so that its integrated structure and all the technological possibilities that the new industrial model includes are described. The context of Environmental Management in industry 4.0 was also presented, denoting the cooperation of the set of technologies 4.0 for environmentally sound and sustainable performance. Then, the potentials of each technology for Environmental Management 4.0 were presented, and finally, their respective challenges for environmental and sustainable beneficiation.

It can be noted that industry 4.0 is a model that uses the foundations of other industrial revolutions that occurred previously, but with greater innovation and integration. The Environmental Management 4.0 is disruptive because it can fully integrate the capabilities of the extensive set of technologies available to achieve systemic behavior that is more directed toward effective practices of consciously sourcing inputs, correct and accurate use as needed and demanded, less waste generation and reuse, quick perception of failures and corrections, real-time contact with stakeholders, among many other possibilities. However, as in traditional industries, excellent environmental and sustainable behavior requires awareness and collective action, and in the case of technologies 4.0, understanding and systemic actions.

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