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The Impact of Industry 4.0 on the Future of Green Supply Chain

Tamás Bányai and Mohammad Zaher Akkad

Abstract

The fourth industrial revolution offers new technologies to transform conventional supply chain solutions into cyber-physical supply chain ones. This transformation makes it possible to increase the efficiency, availability, quality, and cost-efficiency of the value-making chain, while the energy consumption and the GHG emission can be decreased. Within the frame of this chapter, the authors introduce the most important Industry 4.0 technologies and Internet of Things tools and demonstrate their potentials to update supply chain operations. This update of conventional operations can lead to greener and more sustainable purchasing, production, and distribution processes. The successful future of the green supply chain is based on a wide range of factors, like production management, logistics management, societal and regulatory environment. However, the Industry 4.0 technologies are expected to strongly influence the whole supply chain performance positively. This chapter aims to explore the potentials of Industry 4.0 technologies and the transformation of conventional supply chain solutions into cyber-physical systems, especially from a municipal waste collection point of view. The research findings can provide useful insights for supply chain experts, manufacturing, and service companies.

Keywords: cyber-physical system, green supply chain, Industry 4.0, Internet of Things, logistics, sustainability

1. Introduction

Green supply chain refers to convert the traditional supply chain process into a sustainable environment-friendly one. Sustainability covers a wide comprehensive that includes the concept of “green in” systems, which means reducing energy and resource consumption and wastage in processes, next to the context of “green by” systems, which covers human and economic improvements. Sustainability can be considered within five dimensions mainly are human, social, technical, environmental, and economic [1]. These dimensions are interconnected with each other directly or indirectly, therefore, one dimension of sustainability cannot be reinforced without considering others. In addition, other concepts connect sustainability and the supply chain. For instance, Circular Economy (CE) and reverse logistics (RL). Circular systems aim to eliminate waste and to have continuous use of resources by applying reuse, share, repair, refurbishment, and recycle approaches to create a closed-loop system, which minimizes the use of resource inputs and reduces waste scraps, pollution, and carbon emissions. Reverse logistics was defined [2] as “the process of planning, application, control of the operation, cost and flow of raw materials, the inventory process, finished products, the information related,

from the point of consumption to the point of origin, in order to recover or create value or proper disposal”. RL is considered as product return management, real-time inventory and workflow, tracking warranties, ordering and exchange parts, the flow of materials and information, data analysis, execution of repairs, customer notification, and all the logistics return flow.

Within the frame of our research work, we have used the systematic literature review methodology to identify the most important research topics regarding industry 4.0 in green supply chain solutions and to find potential research gaps. Within the frame of our systematic literature review, we have formulated research questions, selected sources from Web of Science and Scopus, and analyzed them. We have used the following keywords to search in the mentioned database: TOPIC: (“industry 4.0” and “green supply chain” or “green logistics”). Initially, 48 articles were identified. This list was reduced to 40 articles selecting journal articles in English only. Our search was conducted in January 2021; therefore, new articles may have been published since then.

Figure 1 shows some approaches focusing on the impact of Industry 4.0 on green supply chain solutions, including the following aspects: environmental consideration [3], IoT technologies and green supply chain [4], business logistics and circular economy [5], drivers of Industry 4.0 and circular economy [6], diffusion of green products [7], sustainable business models [8], pilots and applications [9, 10], lean paradigm in green supply chain [11, 12] and supply chain performance [13].

We can analyze the available sources from multidisciplinary point of view. The green supply chain problems include a wide range of scientific problems, including innovation management [14], price balancing [15], fuzzy optimization [14, 16–18], impact of manufacturing on environment [19], collection channel

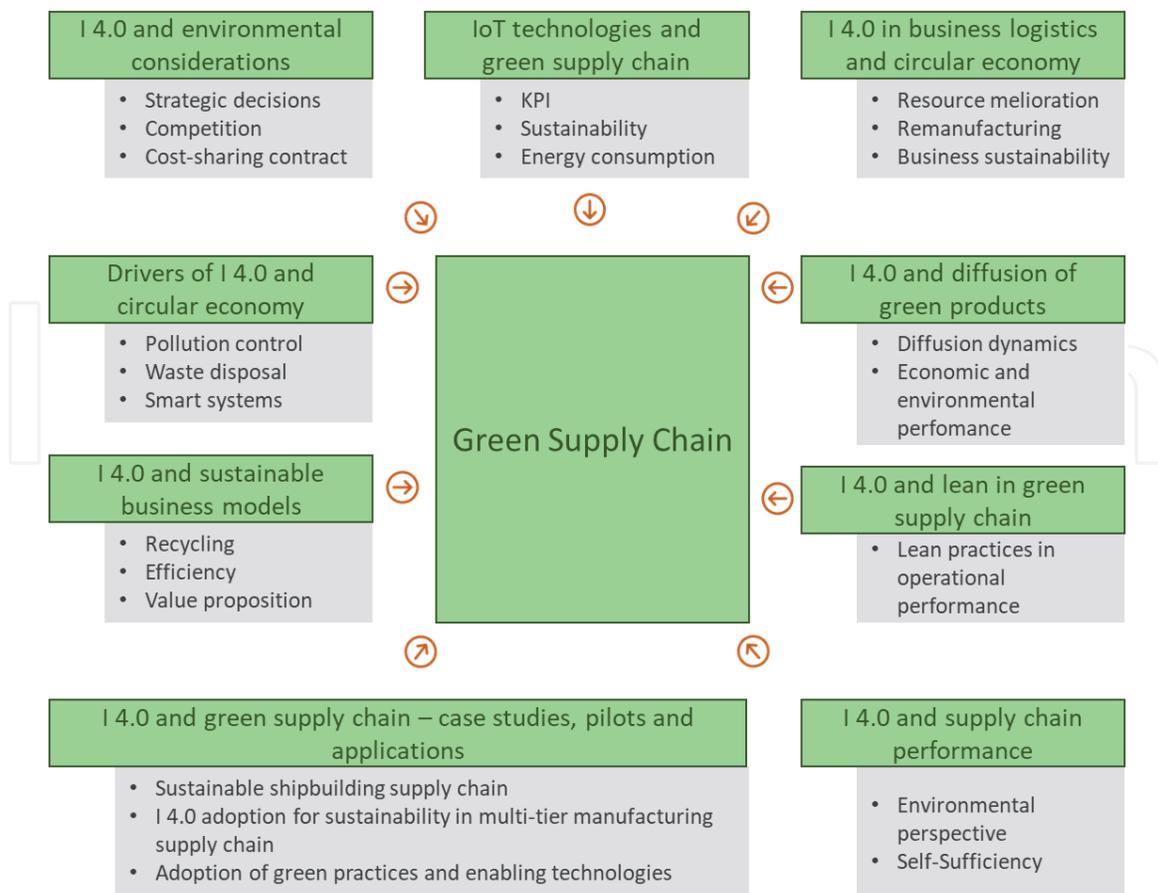


Figure 1. Relationships between Industry 4.0 technologies and green supply chain from the literature review point of view.

design [20], cross-shareholding problems [21], big data and artificial intelligence applications [22], dual channel supply chain design [23, 24], integrated optimization of green supply chain operations including routing and scheduling [25], social impact of greening [26], and green water transfer design [27]. These aspects are analyzed in different case studies [28–30].

On the other hand, the term industrial revolution represents a quantum leap in the industry, which means raising the quantity, quality, or both in the industry and adopting innovative industrial methods through new technologies. Modern digital technologies, such as cyber-physical systems (CPS), the internet of things (IoT), and the internet of services (IoS) represent new models that are fast gaining ground in industrial transformation in the last few years [31]. So far, there have been three industrial revolutions. We are now in the midst of the Fourth Industrial Revolution, or briefly called “Industry 4.0”, which is now being developed and dominated by the different industrial sectors comprehensively. The most prominent feature of Industry 4.0 is the adoption of intelligent technologies that rely on the Internet of Things and remove the lines that separate the physical, digital, and biological areas [32]. Industry 4.0 applications include the most recent technologies, especially in telecommunications, the internet, and nanotechnology, which allowed us to use small devices with great efficiency [33]. This combination of advanced technologies supported obtaining various applications that have revolutionized the world of industry and changed the traditional concept of communication between machine and human into having the concept of communication between machine and machine [34, 35]. It is possible to argue that Industry 4.0 technologies can pave the way for green supply chain management, for example by tracking products post-consumption to recover components. Nevertheless, due to the very recent development of these ideas, the relationship between the green supply chain and Industry 4.0 technologies has not been widely evaluated in the literature or practice, even though the two topics have been analyzed separately. As the main finding, Industry 4.0 has wide influence and effects because of its numerous modern applications that come from the recent technological revolution. These technologies are being developed based on interconnecting different areas, linking the fields of artificial intelligence, information technology, logistics and supply chain systems, and environmental engineering to each other. On the other side, sustainability is an inclusive term that includes many dimensions with an increasing interest in using it to reach a better world. The green supply chain is expected to be significantly affected by Industry 4.0 in an accelerated way especially with the increased interest for using those new technologies to support sustainability by increasing the efficiency, reliability, and flexibility all along with saving energy and time with protecting the environment. To clarify the possibilities in this manner, we will describe a few of the Industry 4.0 technologies that support developing the green supply chain and adopting cyber-physical systems that raise sustainability. In addition, a few examples of green supply chain applications within the industry 4.0 environment are also to be discussed.

2. Industry 4.0 technologies

Industry 4.0 applications include the most recent technologies, especially in telecommunications, internet, and nanotechnology areas, which allowed us to use small devices with great efficiency. This combination of advanced technologies supports obtaining various applications that have revolutionized the world of industry and changed the traditional concept of communication between human and machine into having the concept of communication between machine and machine. It is easy to observe the rapid pace of development of the industry, which makes it imperative to follow up on the new applications of Industry 4.0 eagerly for keeping

abreast of this development and benefit from it. We can consider the following technologies as the tools that may move the green supply chain to the next level.

2.1 Internet of things

Internet of Things or IoT is an emerging term that we can describe as the new generation of the internet network that is linking directly the interconnected devices. These devices include instruments, sensors, artificial intelligence tools, or other smart devices. This definition goes beyond the traditional concept of connecting people with smart devices over a single network to reach having all devices that can work on the internet and that can collect, send, and process the data that they capture from their surrounding environment using built-in sensors and processors in addition to communication media. They are often called connected or smart devices because they can communicate with other devices connected to them in a process known as machine-to-machine communication. Once several devices can work together, and even with devices from different manufacturers, we will be able to complete many of the daily tasks. IoT is also distinguished by allowing people to be free from the specified place. Therefore, the person can control the tools without being in a particular location, taking into consideration that the harmony between the devices is direct and that the person is one of the nodes of communication like other terminals. The connected things here mean any device or peripheral that can be identified on the internet by an IP address such as a car, television, or any household appliances such as refrigerator, washing machine, alarms, doorways, and air conditioners. It also extends to animals' hoops in breeding farms, nature reserves, seas, and forest elements [36]. The rule in defining internet objects is everything that the internet can recognize through known internet protocols. In this case, the human is the beneficiary of all these harmony and objective communications. A person is also considered something as well if he/she has a specific internet address attached to him/her, such as a watch, glass, bracelet, electronic clothing, or medical equipment on or in the body.

IoT enables humans to control effectively objects near or far. Here are some selected examples of things that communicate online without direct human intervention. For example, a user can operate his car engine and control it from his smartwatch, or he can control the washing duties of his washing machine. In addition, he can identify the contents of the refrigerator remotely. Yet these are examples of the primitive form of IoT. The mature form goes to the direct communication between machine and machine directly. A few examples about that, the refrigerator can communicate with the shopping center to purchase and order supplies without human intervention. A specialist software in a car maintenance workshop can communicate remotely with a car to detect a defect within it without the need of visiting the workshop. A car can detect the edges, sidewalks, and signals in order to make decisions while driving or for lining up without driver intervention. A water evaporator can be released depending on a moisture and heat sensor at the atmospheric monitoring station. Our imagination could build many examples of IoT that could become a reality in our daily lives.

2.2 Gentelligent products

Product life cycle information is often required for product development and manufacturing in the supply chain. Thus, the application of lifecycle data retention for smart products provides new opportunities for information transfer to a new product generation and this technology is called gentelligent. Intelligent products are developed usually in research centers using gentelligent technology, which collects and stores information from products through their life cycle. Gentelligent technology starts

recording data during the manufacturing process. It sends the data online directly to storage units at the company server at specified intervals or retained on the device until the waste collection to be separated and then sent to the research center that is responsible for it. The method of sending information depends on the device type and the internet availability within it. This technology is a promising one for cyber-physical systems that contain analyzing side for enhancing the supply chain possesses.

Several requirements are to be considered for structuring the intelligent components' system. Generally, the requirements are manufacturing, flexibility, environment, the best fit for technical inheritance information use, and the development description. The classification key of collected data is divided into two parts mainly [37]. The first part is common for all components of the current generation and the second part considers the individual information. From the first part, the single key digits are arranged and sorted so, that they consider the information from manufacturing and development phases and do not need to be changed during the time and proceeding life cycle. The second key part includes the usage phase, which can change during time and information related to the environment.

2.3 Radio frequency identification technology

Radio Frequency Identification (RFID) is continuously increasing its market share, taking the place of the traditional barcode technology, which supports the development of new applications, especially with using it as a powerful innovative gadget adopted in the development of IoT. This technology works on automatic identification by using specialized devices in the process of capturing signals emitted by RFID Tags, which is a very small piece that can take multiple forms. Two types of RFID technology are used, passive and active RFID systems. Passive RFID waits for a signal from an RFID reader. The reader sends energy, which converts that energy into an RF wave. Active RFID systems use battery-powered RFID tags that continuously transmit their own signal. RFID technology as an application in IoT has engaged in different manufacturing industry sections. Employing RFID systems as an IoT application has great importance in supply chain management as a valuable part of modern manufacturing and industrial automation. With the aid of using an RFID system, managers are able to track, monitor, and control their products in real-time from the status of being as raw material to the rotation as final products in shelves and warehouses. They have all the required data related to shipments, location, temperature, pressure, and time depending on the used sensors [36]. Moreover, in intelligent shopping by using RFID technology as an application of the IoT, the consumers can manage their time in daily life more efficiently, and they can save money. A real-time grocery list can be generated automatically for consumers and list the items that will be consumed or expired soon. Therefore, it prevents people to buy items that are not necessary and it will reduce waste. In addition, utilizing RFID as an IoT application by retailers will enable them to collect real-time data from their inventory, resources, and products next to have a better overview of their chain of customers and employees.

2.4 Cloud computing, fog computing, edge computing

Cloud computing term refers to the available on-demand computing resources and systems that provide several integrated computer services without local resources to facilitate user access. These services include data storage, backup and self-synchronization, software processing capabilities, task scheduling, e-mail payment, and remote printing. When the user is online, he/she can control these resources through a program interface that facilitates and ignores many internal

details and processes. Fog computing (or it is called fogging) is the structure that uses one or more clients or devices close to the user to complete a large amount of storage and communications next to management, configuration, measurement, and control instead of being stored as primary storage in the cloud data centers and internet. Both fog computing and cloud computing provide applications, storage, and data to end-users. Nevertheless, fog computing is close to end-users and more geographical distribution. On the other hand, edge computing (or it is called edge) has processes closer to the data source and does not need to be sent to a remote cloud or other centralized processing systems. By eliminating the distance and time that is used to send data to central sources, it improves the speed and performance of data transfer, in addition to devices and applications on the edge. For devices that are connected to the internet, the edge is where the device or the local network that contains the device is connected to the internet. For example, a user's computer or processor that is located within an IoT camera is considered the edge of the network, but the router of the user, internet service provider, or local edge server is also considered the edge. The important advantage is the network edge geographically close to the device, unlike cloud servers, which can be very far from the devices that are connected to.

Even with the differences in the three previous terms, they meet on replacing local resources with other internet-based participatory devices to save resources and energy. These applications are used at a corporate level locally or internationally, on a private server or within a wider scope within the internet, and individually or collectively.

2.5 Digital twinning

Digital Twins is the outcome of integrating IoT, software analysis, machine learning, and artificial intelligence with spatial network diagrams to create live digital simulation models that are changed and updated as their physical counterparts change. Digital twin continuously learns and updates by itself using several sources to keep real-time status. This learning system uses sensor data that transfers different aspects of the operating state. The cloned twin that is on a virtual platform is a digital form of the physical object. The essential utilize is to enhance business performance, by data analyzing and systems controlling to stop the possible problems and avoid stop working. Connectivity is one of the key characteristics of digital twinning technology. The recent development of IoT contributes to a few new upgrades into digital twinning technology. This technology authorizes the connection between the real component and its digital match; the basis of digital twins is defined on that. Without it, there will be no digital twin technology. This connection is created by sensors on the actual product that gets and integrates this data through various integration techniques. In addition to this, digital twin technology increases the connectivity between customers, products, and organizations.

The digital twin concept helps to reduce the production costs, since the products will be correct from the first run, and there are no demands for expensive physical tests or product/procedures updates. The digital twin technology is often predicting various outcomes supported by the information flow. With further programming and data analysis, digital twins can regularly control the IoT deployment to fulfill the highest level of efficiency. It also helps to understand how things would work before actually applying them.

3. Green supply chain applications within the industry 4.0 environment

Using industry 4.0 technologies supports reaching various applications within the green supply area that achieve sustainable results regarding saving time,

material, and energy. In the following, we will discuss five of the possible applications [1] that support building environment-friendly supply chains and would be adopted in cyber-physical systems.

3.1 Collection and transfer trucks

The trucks that collect garbage or transfer goods can be upgraded depending on the required tasks. Those trucks are defined either by size or by the type of transferred waste. The size can be important when the truck collects the waste from narrow alleys. Active RFID systems are useful to use on trucks to track their locations and active movements. Defining the truck's route by optimization algorithms is used. In the case of collecting garbage, the algorithms that create the routes of the collection trucks target the containers that give notification that the container is almost full until it is enough to fill the truck capacity. If there is still space, the containers that give less full notification are added to the route. If there is a container with a full notification, it means there is an urgent condition to empty it, within a short time. That reflects the flexibility of the system by creating the routes depending on the actual waste amount. There is no need to have the same routes every day in order, which means the ability to choose the shortest way for the truck next to not having full containers with garbage for a long time. This supports the protection of possible biological environment pollution. In addition, linking the work of the traffic lights and the trucks is possible to make the traffic lights changed into green light when the trucks are near. This connection would reflect positively on reducing GHG emissions by decreasing the truck waiting time at the traffic lights.

By taking into consideration the energy efficiency, developed optimization models using e-cars and e-bikes [38] are considered for city logistics supply chain operations. The research showed promising results for decreasing GHG emissions and consumed energy. Other researches also focused on garbage trucks [39] for validating the efficient model and evaluating its performance to increase the cost-efficiency and warrant environmental awareness of the waste collection process.

3.2 Smart containers

Many Industry 4.0 technologies could be applied to the containers both for garbage or goods containers. It is possible to install sensors that define the amount of waste/goods inside the container. The sensors would define more than one notification depending on the inner amount; for instance, when it is 50% full, 75% full, or 90% full. It is possible to install light alert, sound alert, or both to work with those notifications. Radio Frequency Identification (RFID) technology is a powerful innovative gadget, which would be used. By using active RFID systems, the containers send live data directly to the information collection system. On the other hand, active RFID systems are much more expensive than passive ones. It should be considered that there are different types of containers as well. In the case of the waste containers, they are defined depending on the waste types as organic and inorganic or as more specific targets, for instance, paper, glass, metal, or plastic. However, it is possible to use a smart container that can separate the inorganic waste by itself. This separation mechanism uses the relative relationship between the size and weight of the received waste since for each material; there is a specific density, next to the sound that appears when the waste is received. The sensors define the data (sound, size, and weight) of this received waste. Other mechanisms might be used as well, such as using IR (Infrared Radiation) or X-rays.

The collection containers are usually the first step of the collecting chain, which are in contact with the users. It is important to keep in mind that any change of the

collection procedures that should be done by the users should be essential, really needed, and would not be changed or at least, for a long time relatively. Because making different changes might confuse the users, and it costs a lot to make it clear and spread the right instruction about any the procedures to the users. Research studies [5] are working on using Industry 4.0 technologies to develop efficient waste containers within cyber-physical waste collection systems. Further development was researched [40] on a standard commercial waste bin. This dustbin was able to detect its current load, open-close the cover automatically, and remote access the load level using an online interface.

3.3 Data management

All the parts of cyber-physical systems should connect directly to data management using the internet. This management stores data and deals directly with all the system parts. Data about transportation, delivery time, collection trucks, and quantities in each part of the system, as well as the records of surveillance cameras (if they are used), are saved within this management. The used algorithms for creating routes of collection and transfer trucks are processed within this management as well. IoT enables the connectivity between the interconnected devices to make all the parts defined within the system to the management. The data management would use cloud-computing technology that refers to the computer resources available on-demand, which provides several integrated computer services without being restricted to local resources. In cases that require more privacy, private servers are used to store the received and processed data. If there is not enough more space in the servers, the new data will overwrite the oldest one.

On the other hand, data management provides creative solutions for raising sustainability and saving materials by counting on the connected users. Considering the users' kinds as individuals, workshops, factories, or companies, their Tender and taking possibilities are defined. For instance, a user (textile factory) has excessed textile materials. This user enters all the needed information on the platform (amount, type, and color). Any other interested user who finds the available materials can contact the offering user directly to get them. This proposed platform provides the possibility to use the excessed materials directly between the producers and reproducers. Moreover, it gives a space for creativity by finding out the available materials for upcycling and recycling that support sustainability without the need for extra transporting and treating steps.

3.4 Local composting

Composting is an effective way of the organic waste upcycling into compost to fertilize the plants. Local composting units are an effective environmental application that is possible to use. By disrupting them in appropriate locations that should be easy to access by local people, those units provide the possibility to the local people to directly fertilize their own organic waste like fruits, vegetables, dairy products, cereals, bread, coffee filters, eggshells, or meat. Generally, if the waste grew in a field or garden, it is relatively easy to compost it. Items such as red flesh, bones, and small amounts of paper are acceptable but take longer to degrade. Local composting would be connected to the data management so it would show the available space for waste until it is full and the needed time until completing the transformation into compost. When the compost is ready, it is used for the farms. However, there is a possibility to give back part or all of the resulted compost to the local community if they wanted. The participant users in filling the units should use ID cards to open the units and add their waste. Data management gives the

possibility to the users to register and make accounts for saving their waste sharing data and the required compost they want. The data management would inform the participant users about the compost collection amount and time details. The user should confirm his wanted share of the compost and he/she can use their ID card to collect the compost from the unit. The data management would arrange each person's share depending on the provided waste amount, the number of participants, and the actual need of the farms to receive the compost. By using local composting units, many advantages would be achieved.

3.5 Ecological footprint

The ecological footprint measures the amount necessary by nature to support humans or the economy. The calculations compare the required region for a biologically productive human consumption with a biologically productive region in the world. It is a measure of the human impact on the ecosystem of the planet, and it reveals the dependence of the human economy on natural capital. Therefore, it acts as a warning call for people and countries to monitor and regulate the activities that put the environment at risk, and if everyone notices their environmental footprint, there will be fewer environmental problems today, as problems such as carbon emissions, lack of clean air, increased desertification and global warming, and reduced environmental pollution. The available stored data within the data management allows making a direct application for the users reflects their attitude and lifestyle consequences. This could reflect on the whole supply chain positively on the environment by minimizing the direct demand of the last part of the chain. The users can select the used data types to measure their footprint depending on their preferences. The data comes from different resources directly such as the user's waste type and amount, the spent resources such as water and electricity, the daily purchased items, and the used transportation type. Data management analyzes and processes the collected numbers to reach suggestions and advice for the users to improve their selected options to raise sustainability and minimize the negative impact on the environment.

4. Results

4.1 Managerial and practical implication

The described research within this chapter aims to identify, clarify, and examine the possibilities and potentials of Industry 4.0 technologies on the green supply chain to enrich this area that is experiencing an increasing interest in both academic and industrial sectors.

The framework of this research can present a good answer for the reasonable possible questions of managers, coordinators, or stakeholders of the supply chain area such as:

- Should I consider upgrading my supply chain network using the new technologies?
- What are the possible upgrades that I can use?
- Is Industry 4.0 helping the supply chain to be greener and more sustainable?

Of course, those possible applications are to be tested and validated to ensure the anticipated results. However, those applications may have partly studied or

implemented, next to taking into consideration the flexibility and interchanging ability of the technologies depending on the desired results.

In practice, chapter 3 gives suggestions and recommendations for using the new technologies to raise the efficiency and productivity of the supply chain and waste management sectors considering the environmental and sustainable sides. Those suggested solutions should be considered fully or partly applied by the Research and development (R&D) departments depending on the business itself or to use them as bases for other suitable solutions that might support the positive impact on the environment by raising productivity or reducing the GHG emissions. The spread and development of Industry 4.0 are fast, and it should be considered to keep following those advancements to suit the target beachhead market.

4.2 Novelty

As it was researched within the systemic literature review, researching the Industry 4.0 topic has increased gradually in the last few years. The increasing number of the state of art Industry 4.0 applications in the different fields supports researching their effects and results. However, in the manner of green supply chain and applying Industry 4.0 technologies in the logistics and supply chain areas are yet to require more and more research as this research topic is still new and under development.

This chapter shows those applications simply and directly without addressing the complex technical details, which allows for non-IT specialists especially in the supply chains and sustainability sectors to consider those applications applied in reality. This work takes its importance from the diversity, variety, and richness of the application contents it has.

4.3 Future of digitalization of the green supply chain

It should be considered that digitalization in the green supply chain is inevitable, as so far, the newly developed technologies provide effective and direct environment-friendly solutions. Also, we cannot ignore the COVID-19 pandemic effect in accelerating the growth of supply chains that use the internet and cyber technologies. Considering that internet and online technologies that allow and facilitate remote control and orientation are the ground of Industry 4.0 tools, the digitalization of the green supply chain is going to grow fast in the short and medium terms for the next few years at least.

5. Conclusion

Industry 4.0 technologies provide interconnected applications that contribute directly to developing the green supply chain into cyber-physical systems that provide efficient performance in reducing GHG emissions, rising sustainability by increasing reliability, efficiency, and flexibility all along with saving energy and time next to protecting the environment. The transformation of conventional supply chain solutions into a cyber-physical green supply chain can be based on the above-described Internet of Things technologies and this transformation can lead to an improved, sustainable production, packaging, product sales, marketing, logistics, and product end-of-life management [41]. The authors presented the work of a few technologies within Industry 4.0 and discussed examples of the green supply chain within the industry 4.0 environment that support adopting the cyber-physical systems. Also, the anticipated results were presented as the managerial and practical implication and the future of digitalization of the green supply chain.

Conflict of interest

The authors declare no conflict of interest.

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