SPS2022
A.H.C. Ng et al. (Eds.)

doi:10.3233/ATDE220194

Emerging Technologies: Facilitating Resilient and Sustainable Manufacturing

Kerstin Johansen[a, 1], Serdar Akay[a]

[a]School of Engineering, Jönköping University, Sweden

Abstract. In the global manufacturing business, more sustainable solutions are needed, and in parallel manufacturing companies also need a capability to react quickly to unpredictable changes in a highly competitive marketplace. This has become more visible at the start of the Covid-19 pandemic when many companies experienced manufacturing constraints such as a shortage of raw materials as well as a need for transformation of manufacturing facilities to produce vital items. In parallel, many manufacturing companies also are in the transition towards more digitalization as well as automation in their facilities, which can contribute to the capability to manage unpredictable changes, but it might also contribute to challenges. Therefore, the digital transformation of production processes with innovative and emerging technologies, and the contribution and challenges of these technologies are of importance to understand. Specifically, in which way these emerging technologies contribute to a resilient and sustainable production process from a technological perspective, and how these production processes might contribute to achieving sustainability goals. Based on findings from literature an analysis is performed aiming to explore the emerging technologies perspective in relation to capabilities as well as challenges regarding implementing solutions that contributes to a resilient and sustainable production process. The overall findings indicated the importance of having flexible production facilities to be able to respond to customer expectations. However, the digital transformation of production facilities demonstrated other challenges such as energy consumption, lack of skilled personal, low level of standardization, financial sources, and security problems. To conclude, the relationship between the content of resilient and sustainable production systems that are influenced by emerging technologies are suggested, with the ambition to contribute to a more competitive manufacturing company that increase its capability to manage customer expectations.

Keywords: Resilient Production, Sustainable Production, Flexibility, Innovative Production Systems, Digitalization, Industry 4.0

1. Introduction

In the global manufacturing industry, companies need capabilities to respond to unexpected and quick changes as well as new customer expectations on a competitive market. At the same time, these manufacturing companies have societal demands to become more sustainable and contribute to the Sustainable Development Goals (SDGs). In the early 2000s, sustainability was described as an emerging milestone for production-like quality and IT [1]. Therefore, sustainable production provides optimised production processes to minimise waste and adds value to eliminate unexpected challenges [1-2].

[1] Corresponding author, kerstin.johansen@ju.se

Resilient production refers to how a company will respond and adapt to unexpected disruptive obstacles throughout the supply chain [3]. To be able to support resilience in production process, it is crucial to consider various types of flexibility, such as: changes in material, product portfolio, and market [3]. Emerging technologies [4] in the context of manufacturing companies and the prodution processes, combined with greater digitalization, present IT infrastructure obstacles, where the selection and design of innovations, interfaces, and operations will be critical in upcoming Industry 4.0-inspired production technologies [5]. Furthermore, emerging technologies are possible and essential components that must be handled in terms of: efficiency, productivity, and agility [6].

Technological improvements have become more crucial for manufacturing companies, especially related to the increased societal demands on sustainable manufacturing [7] and managing uncertainty such as disruption in material supply or new customer requirement or segments [8], which indicates a need to be resilient [9]. These needs are to be managed as a manufacturing company inthe ongoing fourth industrial revolution, also known as Industry 4.0, which is defined as a new degree of organization and control over the whole value chain of a product's life cycle, focused on increasing personalized customer requirements [10]. Therefore, Industry 4.0 with its portfolio of emerging technologies, digitalisation, artificial intelligens (AI), Cyber-Physical Systems (CPS), Cloud Computing (CC), Additive Manufacturing (AM), Autonomous Technologies (AT), and Big Data Analytics (BDA) [11-14], might contribute to increasing capabilities for competitiveness in a manufacturing company. There are many opportunities that can be considered beneficial for sustainability within a company [12]. For instance, one of the benefits of Internet of Things (IoT) [15-16], which can be seen as a tool supporting digitalisation, is that it enables monitoring all the production data at the same time, supporting optimisation of the system and contributing to i.e. possibilities to save energy and reduce waste in production [15-16]. Moreover, AM has a crucial role in the new industry era characterised by Industry 4.0. It enables manufacturing of acomponent using the information generated from a Computer-Aided-Design (CAD) file to a layer-by-layer manufacturing [17], which can contribute to a more efficient use of material and in the long term perspective a more sustainable use of raw material. In addition, CPS enables the control of huge data sets in production [18], which can support the possibilities to optimise the processes [15-16]. Autonomous technologies, such as self-driving vehicles, sensors, and robots can contribute to more flexible solutions and help to accelerate production capacity [8], [19].

However, all these possibilites with emering technologies that can contribute to increased competitiveness for a manufacturing company also indicates a need for understanding how to implement these. Especially, in a global market place that is uncertain and where disruptive issues can change both the material supply as well as customer needs. Therefore, the aim of this paper is to explore the use of emerging technologies in production systems that facilitates the need for resilience and sustainable solutions related to production processes. These emerging technologies will be reflected from different perspectives, such as the drivers for a resilient and sustainable production system and which challenges that might occur implementing emerging technologies in relation to a digital transformation of a production system. And finally, reflect if these emerging technologies can contribute to a production system, that contributes to the competitiveness for a manufacturing company.

2. Research method

In order to be able to explore the relation between resilient and sustainable production process and emerging technologies, a a search in Scopus, inspired by the process of performing a systematic literature review [20], as well as the motivation for illustrating the discource in a certain field or combination of areas [21], was done during the autumn 2021. For mapping the area related to the aim for the paper the following keywords were used as inspiration to defining the search strings: resilient, sustainability, green, innovative production methods, production technology, digitalization, automation, smart manufaturing, and Industry 4.0 technologies.

The final keywords and their synonyms used in Scopus for this study are presented in Table 1. The following search strings were used related to Resilient and Sustainable Production, Smart Manufacturing, Industry 4.0, and Emerging technolgies:

- (sustain* OR resili*) AND (digitalization OR Industry 4.0) AND (production OR manufacturing)
- (sustainable OR green) AND (resilient OR flexible produc* OR agile) AND (smart OR innovat* OR emerg*)
- (resilient produc* OR flexible produc*) AND (digitalization OR emerging technologies) AND (smart production OR innovation) AND (automation OR robotic technologies)

Table 1. The Keywords and Synonyms

N	Keywords	Synonyms
1	Sustainable Production	Green Production
2	Resilient Production	Flexible, Agile
3	Industry 4.0	Innovative, Smart
4	Emerging Technologies	Innovative, Intelligent
5	Automation	Robotic Technologies

The literature review process, presented in Figure 1, shows the beginning of the process, after deciding upon relevant keywords for the study (See Table 1). In the initial part, 743 articles were found in Scopus and as a complement to Scopus, a parallel search was done in Google Scholar as a reference to the field engineering and business. The result of this showed that most of the findings from Google Scholar overlapped with Scopus, but supported the snowballing method in the final step. The snowballing method improved the final selection of the reviewed articles. The review of the final 77 papers were guided by three questions that was defined with the intention to contribute to fulfilling the aim for the paper. The three guiding questions were:

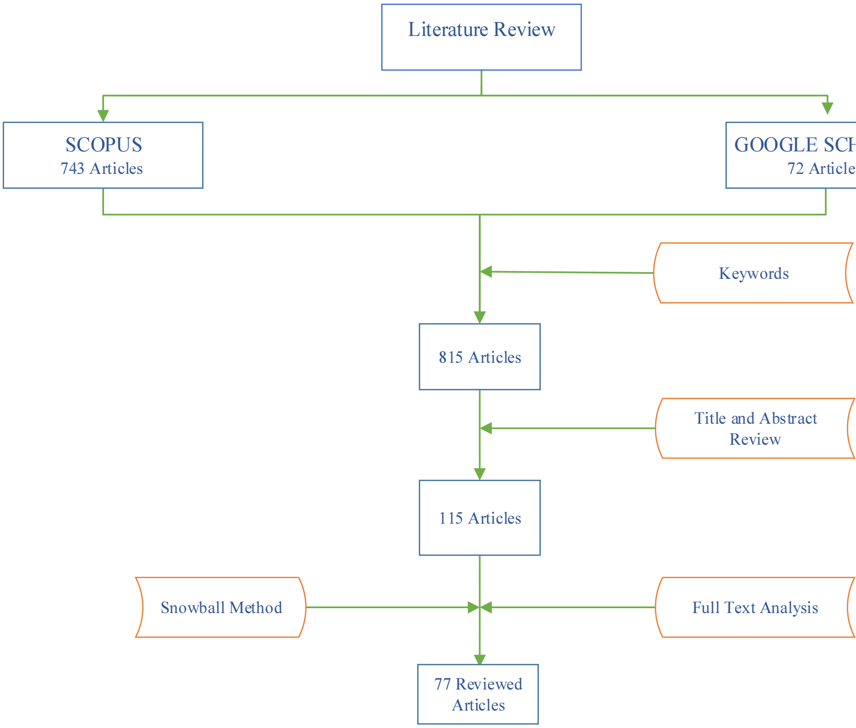

Figure 1. The Map of the scientific literature research process

1. What is the drivers for a resilient and sustainable production system?
2. What types of challenges are related to emerging technologiesin digital transformation of production systems?
3. Can emerging technologies contribute to a resilient and sustainable production system?

In Figure 2, the distribution between continents performing research in this area is presented, showing that the majority of the 77 reviewed papers are developed within Europe (38%), thereafter North America (26%). Asia, in third place, has 17% of the identified papers with an increasing trend. A keyword analysis show that a majority of the 77 reviewed papers focused on Industry 4.0 and related technologies (Figure 3). The trend is that research in this field generally is increasing, which is shown in Figure 4.

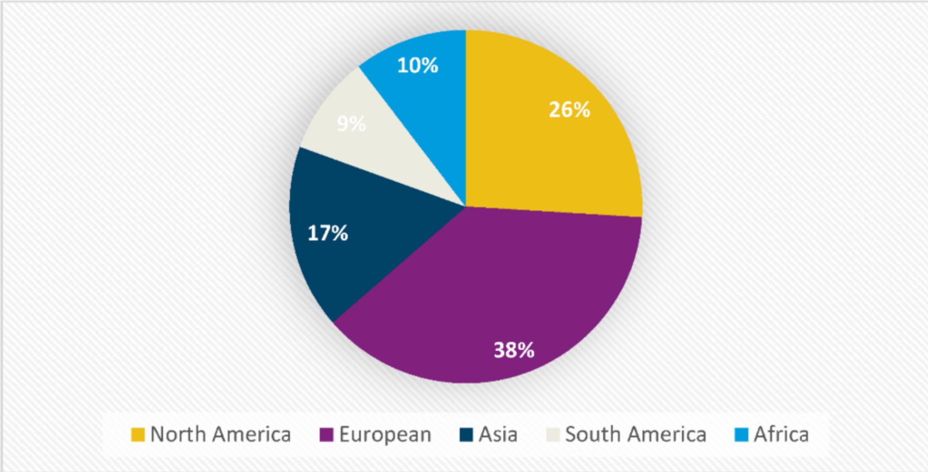

Figure 2. Distribution of the articles based on continents

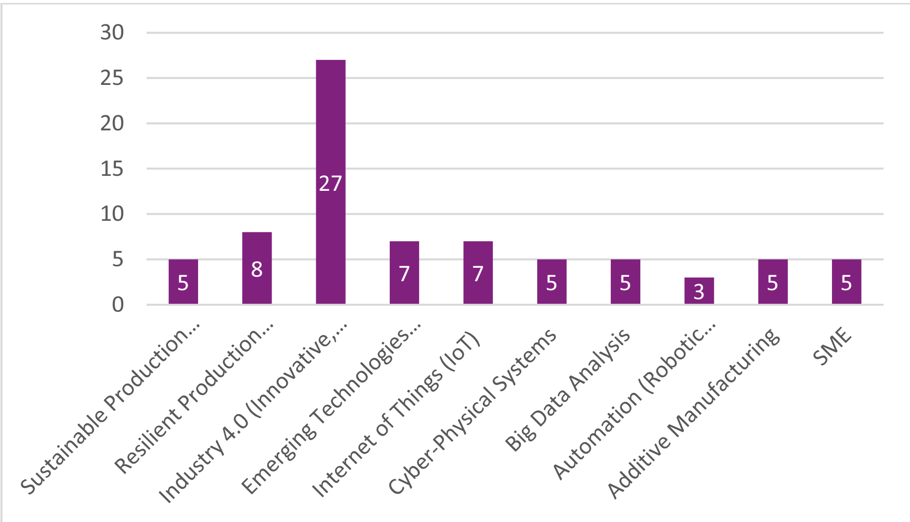

Figure 3. Number of articles based on keyword selection

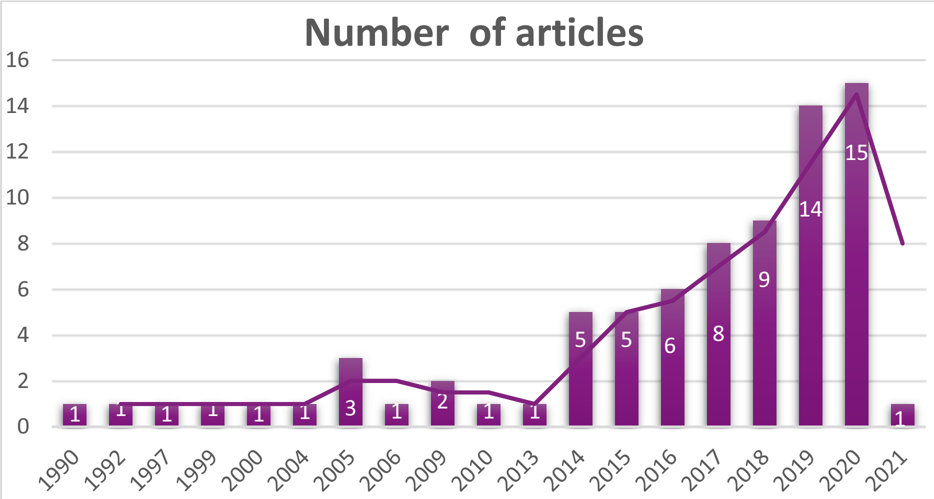

Figure 4. Number of articles based on yearly distribution

3. Findings from the literature review

The findings are presented related to production systems and its identified need for flexibility for contributing to a resilient and sustainable manufacturing company. The possibilities to gain competitiveness and inproved productivity through utilization of the Industry 4.0 concept, including aspects related to implementing emerging technologies is explored, as well as drivers or enablers related to emerging technologies for contributions to a resilient and sustainable production system.

3.1. Production systems

Production systems are continously improved, starting already at the first industrial revolution more than 225 years ago [22]. Production systems can be categorised as craft production, mass customisation, lean production, and global manufacturing [23], and designed as a pull or push system. Another classification of production systems are related to processes, such as casting, machining, joining, sheet metal, polymer process, and also the quality process [24]. Smart production systems, however, are characterised as an analysis of their condition and planning of appropriate continuous improvement projects independently [25], which supports the intention to improve productivity. Therefore, the manufacturing industry started to invest in smart production systems [25], which allows simultaneously operation and optimisation of multiple production lines with different machines in parallel, comparable to the emerging technologies related to Industry 4.0 [11-14]. To be able to operate smart production systems, information flow must involve all levels in the organisation – from the company manager to employees within the production system, such as operators and engineers [25].

3.2. Flexibility in production

In the manufacturing industry, flexibility has become a more competitive aspect for companies due to the need for responding to customer expectations in the market [26]. Flexibility in production gives companies the capability to modify production processes faster, produce new products, and quickly react to competitive challenges in the market [8], [26]. Flexible production systems have also been built to meet the needs of mid-volume and mid-variety in production [27], so-called HighVolume-LowMix [28]. To achieve an economical perspective, similarities amongst parts in the design process and manufacturing process have been used. In flexible production, varieties between products from input to output are more resilient, but a high capital investment is needed [27]. Therefore, flexibility in production has been categorised in different ways in the literature. Some of those flexibility variations are summarised as [3], [29]:

- *Product Flexibility*: the ability to enable production system to produce more product types utilising similar machines and supporting the products to become more agile.
- *Capacity Flexibility*: the ability to produce different types of products to applicate the changes in the volume.
- *Operation Flexibility*: ability to produce different types of products with more machines, goods, and production processes.
- *Control Program Flexibility*: in terms of running the production system virtually, ability to implement smart machines and software to production.

These different variations supports understanding in how flexibility can be managed while optimising and improving production processes [3], [29].

3.3. Sustainable production

Sustainable production as a concept emerged at the United Nation Conference on Environment and Development (UNCED) in 1992 [30], and was from the beginning interlinked with sustainable development. This conference concluded that the biggest reason for this sustainable approach was the threat towards the environment, the consumption of energy, specifically in the countries which haddeveloped industry facilities [30]. Therefore, the Agenda 21 Action Plan emphasised to governments, industries, and businesses to implement sustainable measures to become more sustainable in production. Due to the high reputation of sustainability, managers in industries and have noticed the strategic oppourtunities of being sustainable and producing the products in a more sustainable way [31-32]. Although some businesses have not been able to cover the benefits of sustainability, the majority of the small-medium enterprises and global companies have been implementing sustainability in their production process [33], but it is still challenging and new opportunities are rising with emering technologies to influence the future of sustainable production [7]. Sustainable production mainly emphasises that continuously improving environmental aspects and adding value to products to become more sustainable will minimise the environmental risks [34]. This is supported by the conclusion that the product design and development process determines about 80% of the sustainablility performance for a product during its complete life-cycle [35]. The overall expectation of sustainable production is traditionally focusing on reusing, recycling, and remanufacturing (3R) of products [36], but this has been further explored during the last decade and now research indicates a need for managing up to 11Rs [9], adding refuse, rethink, reduce, repair, refurbish, repurpose, recover and resilience to the first 3Rs. Therefore, the emerging technologies, such as automation in combination with different digital tools [9] and IoT can support businesses to see the data of energy and materials consumptions and thereafter give them control over the flow in production [15-16]. The possibilities that emerging technologies and Industry 4.0 can contribute with in the production process can be used with the intention to become more sustainable, but it is a need for understanding how to organize and combine the different technologies to reach the potential.

3.4. Industry 4.0

The Fourth Industrial Revolution, also called Industry 4.0, was introduced by German Scientists and the German Government regarding improving the production process after the 2011 Hannover Fair [37]. The Industry 4.0 concept, which mainly focus on considerations related to manufacturing, contains on five aspects [22]: (1) digitalisation of manufacturing, (2) decentralisation of manufacturing, (3) vertical and horizontal integration of the value chain, (4) increased productivity, and (5) flexibility. Industrial systems have been affected by the development of emerging technologies related to Industry 4.0 i.e. Internet of Things (IoT), Cyber-Physical Systems (CPS), big data analysis during the las decade [22], [38]. However, these emerging technologies can made a significant contribution to the growth of production and service operations through solutions that interact, coordinate, link, and promote information transparency at various stages of business ideas [39]. The possibilities to monitor and control machines and equipment in real-time, utilise machine-data to anticipate when maintenance should be conducted, to introduce intelligent production processes, improve supply chain processes by implementing product traceability, logistics management, and inventory management are possibilities that can be enabled through implementation of Industry 4.0 technologies [40]. But, even with all these possibilities research indicates that there is a significant need to develop knowledge about how manufacutring SMEs can utilize and participate in the transition and implementation of these new emerging technologies in the production process, such as the interaction between machines, computers, and people by IoT, and autonomous CPS connecting virtual data and information [39].

3.5. Emerging technologies within Industry 4.0

Industrial companies benefit from digitalisation in terms of productivity, effectiveness, profit growth, employment, and investment since it allows production processes to be completely integrated, automated, and enhanced [10]. Digitalisation of manufacturing is one of the main aspects in the concept of Industry 4.0 [22], which consists of components, such as Cyber-Physical-Systems (CPS), Internet of Things (IoT), and Technological innovations; but also so-called emerging technologies such as Cloud technology including big data, Artificial Intelligence (AI), robots, Additive Manufacturing (AM), some of these included in the technological innovations [22]. A combination of digitalisation and automation of manufacturing are promoted to be implemented in industry, for increasing productivity, sustainability and competitiveness due to reduced cost per produced component and/or product [22], but still Industry 4.0 is mostly recognized to be defined scientifically and less based on industrial implementation experience. Based on this, an overview of the findings about the key emerging technologies related to digitalisation and automation is explored.

3.5.1. Artificial intelligence

The Artificial Intelligence (AI) concept was introduced to show how to create algorithms based on orders and reactions related to humans [40]. The key element was to examine some key roles and make accurate reactions based on formats pre-defined by humans [40]. AI tools and techniques are a critical step towards data exploitation and the development of applications that should result in optimal use of manufacturing unit and resources during dramatic changes in plans and in reaction to simultaneous problems [2]. In industry, AI is frequently utilized to develop automated solutions to manage problems thatdemand human interaction [41]. AI is described as “a system's” ability to correctly comprehend external data, learn from that data, and to utilise learning from this data and achieve flexible adaptation of the task [41]. Some typical tasks where AI applications can support a manufacturing process are for predictive maintenance, self-learning machines, and detection systems in machinery and infrastructures [42].

3.5.2. Internet of Things (IoT)

IoT was defined as items with characteristics and personalities that connect and communicate in social, environmental, and user contexts that utilise intelligent interfaces [43]. In terms of ontology, the IoT is stated as “a globally accessible network of interconnected things based on common communication systems [44]. To conduct effective industrial supply chain operations, the use of this new emerging technology has become crucial to promote tracking and tracing, automating of the production process, controlling materials consumption, energy management, and ergonomic tolerance [2], [39]. Through implementation of IoT, it can be possible to contribute to sustainability for a company by designing a smart factory, smart production line, smart wearable systems supporting operators, for instance, clothes, smartwatch, or digital sensors [39].

3.5.3. Cyber physical systems

Cyber-Physical Systems (CPS) are described as intelligent and autonomous, whereby these two aspects are influencing each other through their working environment and conditions, as well as the ability to integrate IoT to secure and optimize the production processes [45], [46]. According to [47], CPS are defined as ‘a*n innovative system that converts data from linked systems into predictive activities in order to achieve resilient performance'*. Therefore, CPS seems to be a vital component that enables production processes to become more resilient and provide fast response to disruptive changes in customer expectations.

3.5.4. Big data analysis

Business and production processes become more complex due to high production volume, high speed, and quick changes in the market that require data management [48], which also can be related to the need for managing low volumes in high mix [28] with many changes in the production process, where set-up times between orders are crucial. According to [49], '*big data analytics enable to production operations to lower service cost, improve trust between customer and companies, maintain customer privacy, data security, and control over the customer data*'. Here, implementation of digitalisation that supports big data analysis that utilize existing information can support efficiency and improve productivity [22].

3.5.5. Autonomous technologies

Autonomous technologies are a collection of different technologies that is utilise in a production system to decrease cost, improve production performance, secure safety, and accelerate production processes [50]. However, implementing these technologies enables the integration of computer-based technologies with physical processes, and might contribute to innovative solutions [50]. Face sensors, AI, IoT, cloud robots, and cyber-physical robots are some examples of robot advancements are such innovative solutions based on computer-based technologies [50]. Autonomous technology ensures real-time information and data transfer between physical and virtual elements, allowing for a high level of coordination, management, accessibility, and efficiency amongst supply chain members, resulting in increased productivity and performance [39]. This technology is used in the supply chain such as being used in: assembly, manufacturing, and more in logistics operations [39]. Therefore, conventional production processes are supported by technological developments in all levels of businesses.

3.5.6. Additive manufacturing

Even though there are different types of material production processes existing, including: drilling, heat treatment, cutting etc., there is a new method that has been implemented, the so called Additive Manufacturing (AM), using 3D Computer-Aided Design (CAD) for guiding material layer-by-layer for manufacturing the component [39]. AM as a method provides manufacturing of more customer-oriented products such as complex design and geometries, which are not easy to produce by traditional production methods [51]. Furthermore, AM enabling companies to produce new prototypes with high production flexibility, short lead-time, reducing inventory, and increase product varieties, which in a way contribute to sustainable use of resources [39]. However, AM has one disadvantage from a sustainable perspective, which is the energy consumption [52], where manufacturing industries in general are more sustainable with less energy consumption, reduced carbon footprint and the control of material usage [53].

3.6. Implementation aspects for emerging technologies

Smart and sustainable technologies have a crucial impact on the production systems due to the control of production operations [15-16], [25]. For instance, according to [54], having control over production processes determines or anticipates varieties and expected adjustments, and the balance between stability and robustness in the production processes allow for a resilient production process [54]. In addition, the functional map of production control method introduced by [54] extracted from a case study within steel industry, show that the company faced rework problems in the production processes. By identifying the main reasons for the problems, having transparency and reducing complexity in the production decreased the number of faults [54]. Having a synchronous flow throughout the production processes, is one important aim within Industry 4.0, and to achieve this, enterprises must be able to optimize their production to be more flexible to respond to quick changes in the market [55]. By implementing Internet of Things (IoT) it is possible to enable companies to collect the data within production processes such as energy consumption [15]. Internet of Things (IoT), according to [56], is an emerging technology that enables the transfer of products and services in global supply chain operations. It has, however, an impact on the security and privacy of the shareholders. According to [57], a Cloud Computing based system supports collaboration between enterprises, which enables them to react quickly when unexpected changes occur.

Additive manufacturing (AM), has shown to be a flexible technology during the Covid-19 crisis, with its capability to producemedical goods in an emergency situation with a short set-up time [58]. Other possibilities with emerging technologies can be related to the collection and tracking of data, where big data analysis enables manufacturing companies to evaluate and monitor ongoing production processes which provides the opportunity to enhance production quality and flexibility to adapt for disruptive needs, such as Covid-19 demands that occurred in the public-health system [59]. Furthermore, robotic autonomous technologies has an impact on productivity and provides stabilized quality in production, which enables higher resource efficiency, as well as less waste [60].

From a technological perspective, it can be summaries that companies find it difficult to implement smart and innovative system to their operations. Even though having a sustainable production provides a high amount of positive effects in production processes, there are some researchers that argue that these emerging technologies also consume more energy and materials, additionally encountering more waste during the production process [14], [61-62]. In addition, some challenges have been faced by SMEs in the integrating Industry 4.0 innovative technologies. According to [63-64] having limited financial resources, limited knowledge of resources, and limited technology awareness have been reported in their findings. Table 2 below illustrates some challenges that companies have faced during operating smart production systems in their production processes.

Table 2. Challenges related to implementation of emerging technologies

N	Challenges	Source
1	Low level of standardization, Poor knowledge regarding integrating systems architecture	[61]
2	Lack of skilled person in the field of AI, Autonomous, and IoT fields Emerging Technologies	[63]
3	Security problem regarding data and information flow in the production processes	[56]
4	Energy and Material Consumption	[14] [61] [62]
5	Limited Financial Sources	[63]

4. Discussion

Based on the literature review several aspects have been noticed to be important to manage from the perspective of implementing and utilizing emerging technologies in a production system that facilitates the need for resilience and sustainable solutions. First of all, drivers have been identified that contribute to developing a resilient and sustainable production system, thereafter we discuss the challenges related to the emerging technologies and finally, a discussion about possible impacts from emerging technologies on a production system are presented.

4.1. The drivers for a resilient and sustainable production system

Unexpected disruptive challenges in the world has forced companies to become more flexible in their production facilities. For instance, the current ongoing Covid-19 pandemic situation demonstrated the importance of flexibility [8]. Being resilient in the production systems means, enables companies to answer unexpected challenges that might occur in all the steps of the supply chain [3]. Having resilience, enabling companies to be more product and production oriented in their business, if they have flexibility capabilities [3], [20]. As an example, if companies can optimize their production systems for different types of products and also become more sustainable in the production processes, these companies will be able to manage quick changes in the market and create value for customers [3]. Moreover, as observed, the current climate changing discussion in the world creates awareness amongst customers to consider buying sustainable products. Therefore, managing the three pillars of sustainability: social, economic, and environmental aspects contributes to the creation of value in businesses [28]. Based on this, drivers for resilience in a production system are identified to be related to encounter customer expectations, having a flexible and sustainable production system, and build capabilities for managing disruptive changes in market as well as problems in material supply chains.

The trend of sustainability has influenced society and businesses to become sustainable and environmental friendly in every field of the product lifecycle. After Sustainable Development Goals have been introduced [23], educational developments have involved all parts of the society from schools to media and therefore, building a new sustainable world has become crucial for the society, where manufacturing industry are one important player. As a result, sustainable production processes have begun to be implemented in the manufacturing industry. For instance, we can clearly say that energy consumption, materials, and fossil fuels systems have become the main concerns for the manufacturing industry [10]. Hence, to be able to minimise energy consumption, reuse, remanufacture, or recycling of materials, and fossil-fuel-free in production processes, companies have started to invest in sustainable and smart production systems by implementing emerging technologies such as IoT, AI, AM, and autonomous technologies to increase product quality and the flexibility in production systems. As emphasised by [58], [59] converting all the production facilities are still challenging for many companies, especially for SMEs due to the high cost of investment. However, the companies which could invest in these technological improvements in their production processes, have noticed economical and social benefits as a result of this [58]. Even though initial investment cost is high [58], there are a considerable number of global companies and SME`s that have started to invest in sustainable production systems to stay competitive in the market. In conclusion, drivers for investing in emerging technologies that supports the transition towards a more sustainable production system is related to better process control, the possibilities to optimize the processes i.e. reducing material and energy use, decrease the set-up times by using digitalized information from the product models into the programming of machines in combination with the business systems, with the purpose to satisfy customer expectaions.

4.2. Challenges related to implementing emerging technologies

From the literature review some challenges related to transforming the production systems into a more digitalized environment have been identified. If a company would like to utilize technological developments, such as emerging technologies, there is usually a need for more investment, both in machines and infrastructural solutions, i.e. IoT and automation, as well as in personal skills. However, global large companies as well as manufacturing SMEs are challenged by the lack of economical sources for technology investments that are required [58], [59]. This is a challenge that must be managed in order to be able to utilize the expected benefits from the emerging technologies.

Another important challenge is the lack of skilled people in these emerging technological fields [58]. For instance, companies are now more automated and computer-oriented, which change the recruitment profile for employees that needs knowledge and skills in new domains to support the business. The trend of life-long learning is cruical here, and companies are challenge to manage a continuation in training for their employees in a creative way. A lot of possibilities for online training are promoted in industry-university or industry-technical schools collaborations to train future managers, engineers, and technicians. However, it is important that the training has a purpose and contribute to a competence valuable for the company.

Cyber-Security is another crucial challenge for companies [60]. Due to competition amongst companies, non-legal network security attacks can be observed. The integration of the vertical and horizontal value chain [22], utilizing emerging technologies, indicates a need for skills that manage software security in the IoT infrastructure.

Flexibility provides more customer-oriented products [21]. However, this need for flexibility can challenge some businesses because of standardisation [61]. However, standardisation can also contribute to managing large variation of products in order to develop flexible production systems that manage high mix in low volumes [28] or that the products are designed for recycling, reuse or remanufacutring [36]. Furthermore, the emering technology AM can contribute to a high flexibility for production [58], as well as reducing the material waste, but the challenge is related to the product design and how it is linked to the AM process. In general, the challenges to implement and utilize emerging technologies are mainly related to how mature the company is in its digitalisation transition in the production system, the knowledge about how to utilize which technology for what purposes, the skills in the organisation and the infrastructures for IoT.

4.3. Impacts from emerging technologies on a production system

The findings related to production systems showed that customer-oriented requirements forced companies to have high-tech production lines that were optimised with robots, sensors, and autonomous technologies [11-14]. As an example, robotic technologies [39], can support more flexible layouts in the production flow, which contribute to possibilities to design a production layout that utilize collboration between humans and robots by installing i.e. safety sensors. Furthermore, Internet of Things (IoT) support more information control and can contribute to trace energy consumption and material usage [31]. Additive Manufacturing (AM) enables the production of more customer-oriented products and with less material usage, however, there are some concerns regarding energy consumption for some type of AM processes [48]. Big data analytics support collection of data in the production flow and therefore enable companies to optimise production systems [38]. To summarise, the overall impact emerging technologies can contribute with in a production system is the possibilities to trace information, optimise processes, manage flexibility that is related to customer demands. However, even though these impacts also contributes to the possibilites to develop resilience through knowledge databases and sustainability through the possibilities to optimize consumptions in the production system, it is still challenging to invest in the infratructures and perform the digital transition for fully utilization of the possibilities.

5. Concluding remarks

From a methodology perspective, this systematic literature review (SLR) focused on a resilient and sustainable production process related to emerging technologies. An increased number of articles were found in the literature on resilience and sustainable production, smart production, and Industry 4.0 across multiple search strings and research issues in which these regarded: drivers, challenges, and contributions have been investigated in the SLR. The literature review has some limitations due to that mainly one database was used, Scopus, for identifying reviewed papers, as well as that only papers in English were possible to read for the authors.

One notable observation from the review of the literature is that there still is an important gap for empirical research and case studies for resilient and sustainable production phenomena, which also is motivated as a need for develop more knowledge about the relation between sustainability and emerging technologies within Industry 4.0 [65]. This in combination with the possibilities that has been identified related to emerging technologies, where drivers for resilience and sustainability could be managed by the transition towards a more digitalised production system is an area to further research. However, the transition towards utilization of emerging technologies demands infrastructural changes as well as organisational support for new ways of working.

Acknowledgements

The authors acknowledge the Strategic Innovation Programme Produktion2030, and Vinnova, Swedish Governmental Agency for Innovation Systems, who jointly enabled this research as well as the KK foundation supporting the research and education environment on Knowledge Intensive Product Realization SPARK at Jönköping University, Sweden.

References

[1] Peter, O., Mbohwa, C. New Future for Sustainability and Industrial Development: Success in Blockchain, Internet of Production, and Cloud Computing Technology. 9th International Conference on Operations and Supply Chain Management, Vietnam, 2019.
[2] Peter, O., Mbohwa C. Cloud Computing and IOT applications: Current statuses and prospect for industrial development. Agricultural Waste Diversity and Sustainability Issues. 2019:1-14.
[3] Sethi, A.K, Sethi, S.P. Flexibility in manufacturing: a survey. International journal of flexible manufacturing systems. 1990;2(4):289-328.
[4] Rotolo, D., Hicks, D., Martin, B.R. What is an emerging technology?. Research Policy. 2015;44:1827-1843.
[5] Ande, R., Adebisi, B., Hammoudeh, M., Saleem, J. Internet of Things: Evolution and technologies from a security perspective. Sustainable Cities and Society. 2020;54:101728.
[6] Oztemel E, Gursev S. Literature review of Industry 4.0 and related technologies. Journal of Intelligent Manufacturing. 2020;31(1):127-182.
[7] Matta, A., Axinte, D., Walker, I. Automation Technologies for Sustainable Production [TC Spotlight]. IEEE Robotics & Automation Magazine. 2019;26(1):98-102.
[8] Johansen, K. Challenges for Manufacturers when Customers are Locked Down: Is it Possible to be Prepared?. The Journal of Applied Economics and Business Research (JAEBR). 2020;10(2):54-58.
[9] Johansen, K., Öhrwall Rönnbäck, A. Small Automation Technology Solution Providers: Facilitators for Sustainable Manufacturing, Procedia CIRP. 2021;104(1):677-682.
[10] Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., Harnisch, M. Industry 4.0: The future of productivity and growth in manufacturing industries. Boston Consulting Group. 2015;9(1):54-89.
[11] Nascimento, D.L.M., Alencastro, V., Quelhas, O.L.G., Caiado, R.G.G., Garza-Reyes, J.A., Rocha-Lona, L., Tortorella, G. Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. Journal of Manufacturing Technology Management. 2019;30(3):607-627.
[12] de Sousa Jabbour, A.B.L., Jabbour, C.J.C., Foropon, C., Godinho, F. M. When titans meet–Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. Technological Forecasting and Social Change. 2018;132:18-25.
[13] Carvalho, S., Cosgrove, J., Rezende, J., Doyle, F. Machine level energy data analysis—Development and validation of a machine learning based tool. ECEEE Ind Summer Study Proc. 2018:477-86.
[14] Oláh, J., Aburumman, N., Popp, J., Khan, M.A., Haddad, H., Kitukutha, N. Impact of Industry 4.0 on environmental sustainability. Sustainability. 2020;12(11):4674.
[15] Ang, J.H., Goh, C., Saldivar, A.A.F., Li, Y. Energy-Efficient Through-Life Smart Design, Manufacturing and Operation of Ships in an Industry 4.0 Environment. Energies. 2017;10:610.
[16] Lins, T., Rabelo Oliveira R.A. Energy efficiency in industry 4.0 using SDN. 2017 IEEE 15th International Conference on Industrial Informatics (INDIN); 2017:609-614.
[17] Haleem, A., Javaid, M. Additive manufacturing applications in industry 4.0: a review. Journal of Industrial Integration and Management. 2019;4(4):1930001.
[18] Chen, Y., Chen, H., Gorkhali, A., Lu, Y., Ma, Y., Li, L. Big data analytics and big data science: a survey. Journal of Management Analytics. 2016;3(1):1-42.

[19] Sell, R., Rassõlkin, A., Wang, R., Otto, T. Integration of autonomous vehicles and Industry 4.0. Proceedings of the Estonian Academy of Sciences. 2019;68(4).
[20] Tranfield, D., Denyer, D., Smart, P. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. British Journal of Management, 2003;14(3):207–222. https://doi.org/10.1111/1467-8551.00375.
[21] Mies, A., Gold, S. Mapping the social dimension of the circular economy. Journal of Cleaner Production. 2021;321:128960.
[22] Speringer, M., Schnelzer, J. Differentiation of Industry 4.0 Models – The 4th Industrial Revolution from different Regional Perspectives in the Global North and Global South, In: Regional Academy on the United Nations (RAUN) (Eds.) 2019. "Innovations for Development: Towards Sustainable, Inclusive, and Peaceful Societies." Vienna. Accessible at: http://www.ra-un.org/publications; 2019.
[23] Mourtzis, D., Doukas, M. Design and planning of manufacturing networks for mass customisation and personalisation: Challenges and outlook. Procedia CIRP. 2014;19:1-13.
[24] Kalpakjian, S., Schmid, S.R. Manufacturing Engineering: Pearson Prentice Hall: Upper Saddle River, NJ, USA; 2009.
[25] Alavian, P., Eun, Y., Meerkov, S.M., Zhang, L. Smart production systems: automating decision-making in manufacturing environment. International Journal of Production Research. 2020;58(3):828-845.
[26] Oke, A. A framework for analysing manufacturing flexibility. International Journal of Operations & Production Management. 2005;25(10):973-996.
[27] ElMaraghy, H.A. Flexible and reconfigurable manufacturing systems paradigms. International Journal of Flexible Manufacturing Systems. 2005;17(4):261-76.
[28] Gördi, I., Kardos, C., Pfeiffer, A., Váncza, J. Data analytics-based decision support workflow for high-mix low-volume production systems. CIRP Annals – Manufacturing Technology 2019;69:471-474. https://doi.org/10.1016/j.cirp.2019.04.001.
[29] Chryssolouris, G., Manufacturing systems: theory and practice: Springer Science & Business Media; 2013.
[30] Weiss, E.B. United Nations conference on environment and development. International Legal Materials. 1992;31(4):814-817.
[31] Farrow, P.H., Johnson, R.R., Larson, A.L. Entrepreneurship, innovation, and sustainability strategies at Walden Paddlers, Inc. INFORMS Journal on Applied Analytics. 2000;30(3):215-225.
[32] Veleva, V., Hart, M., Greiner, T., Crumbley, C. Indicators of sustainable production. Journal of Cleaner Production. 2021;9(5):447-452.
[33] Fiksel, J. Designing resilient, sustainable systems. Environmental Science & Technology. 2003;37(23):5330-9.
[34] Van Berkel, R., Willems, E., Lafleur, M. The relationship between cleaner production and industrial ecology. Journal of Industrial Ecology. 1997;1(1):51-66.
[35] Nasr, N., Russell, J., Bringezu, S., Hellweg, S., Hilton, B., Kreiss, C., von Gries, N. UNEP International Resource Panel, Re-Defining Value: The Manufacturing Revolution-Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy. IRP Reports. Available online: https://www.resourcepanel. org/reports/re-defining-value-manufacturing-revolution, 2018. (Accessed: 2022-01-30).
[36] Nasr, N., Thurston, M. Remanufacturing: A key enabler to sustainable product systems. Rochester Institute of Technology. 2006;23:14-17.
[37] Gilchrist, A. Industry 4.0: the industrial internet of things: Springer; 2016.
[38] Wollschlaeger, M., Sauter, T., Jasperneite, J. The future of industrial communication: Automation networks in the era of the internet of things and industry 4.0. IEEE industrial electronics magazine. 2017;11(1):17-27.
[39] Onu, P., Mbohwa, C. Industry 4.0 opportunities in manufacturing SMEs: Sustainability outlook. Materials Today: Proceedings. 2021;44:1925-30.
[40] Avishay, D., Pavlov, V., Pavlova, G., Petrov, B., Dimitrov, N. Industry 4.0 – Robots with Distributed Mobility and Elements of Artifical Intelligence. Global Journal of Computer Science and Technology. 2019;19(1).
[41] Kaplan, A., Haenlein, M. Siri, Siri, in my hand: Who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence. Business Horizons. 2019;62(1):15–25.
[42] Krauß, J., Frye, M., Döhler Beck, G.T., Schmitt, R.H. Selection and Application of Machine Learning-Algorithms in Production Quality. In Machine learning for cyber physical systems. Springer Vieweg, Berlin, Heidelberg. 2019:46-57.
[43] Ashton, K. That 'internet of things' thing. RFID Journal, 2009;22(7):97-114.
[44] Tabaa, M., Monteiro, F., Bensag, H., Dandache, A. Green Industrial Internet of Things from a smart industry perspectives. Energy Reports. 2020;6:430-46.

[45] Monostori, L., Kádár, B., Bauernhansl, T., Kondoh, S., Kumara, S., Reinhart, G., Sauer, O., Schuh, G., Sihn, W., Ueda, K. Cyber-physical systems in manufacturing. CIRP Annals. 2016;65(2):621-41.
[46] Wang, L., Törngren, M., Onori, M. Current status and advancement of cyber-physical systems in manufacturing. Journal of Manufacturing Systems. 2015;37:517-27.
[47] Lee, J., Bagheri, B., Jin, C. Introduction to cyber manufacturing. Manufacturing Letters. 2016;8:11-5.
[48] Bibri, S.E. The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability. Sustainable Cities and Society. 2018;38:230-53.
[49] Rehman, M.H., Chang, V., Batool, A., Wah, T.Y. Big data reduction framework for value creation in sustainable enterprises. International Journal of Information Management. 2016;36(6):917-28.
[50] Tošić, A., Vičič, J., Mrissa, M., editors. A Blockchain-based Decentralized Self-balancing Architecture for the Web of Things. European Conference on Advances in Databases and Information Systems; 2019: Springer.
[51] Frazier, W.E. Metal additive manufacturing: A review. Journal of Materials Engineering and Performance. 2014;23(6):1917-1928.
[52] Heinicke, M. Implementation of resilient production systems by production control. Procedia CIRP. 2014;19:105-10.
[53] Ford, S., Despeisse, M. Additive manufacturing and sustainability: an exploratory study of the advantages and challenges. Journal of Cleaner Production. 2016;137:1573-87.
[54] Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., Barbaray, R. The industrial management of SMEs in the era of Industry 4.0. International Journal of Production Research. 2018;56(3):1118-36.
[55] Weber, R.H. Internet of Things–New security and privacy challenges. Computer Law & Security Review. 2010;26(1):23-30.
[56] Ren, L., Zhang, L., Tao, F., Zhao, C., Chai, X., Zhao, X. Cloud manufacturing: from concept to practice. Enterprise Information Systems. 2015;9(2):186-209.
[57] Larrañeta, E., Dominguez-Robles, J., Lamprou, D.A. Additive manufacturing can assist in the fight against Covid-19 and other pandemics and impact on the global supply chain. 3D Printing and Additive Manufacturing. 2020;7(3):100-3.
[58] Javaid, M., Haleem, A., Vaishya, R., Bahl, S., Suman, R., Vaish, A. Industry 4.0 technologies and their applications in fighting Covid-19 pandemic. Diabetes & Metabolic Syndrome: Clinical Research & Reviews. 2020;14(4):419-22.
[59] Ghobakhloo, M. Industry 4.0, digitization, and opportunities for sustainability. Journal of Cleaner Production. 2020;252:119869.
[60] Berkhout, F., Hertin, J. De-materialising and Re-materialising: Digital Technologies and the Environment. Futures. 2004;36(8):903-920.
[61] Chiarini, A., Belvedere, V., Grando, A. Industry 4.0 Strategies and Technological Developments: An Exploratory Research from Italian Manufacturing Companies. Production Planning & Control. 2020;31(16):1385-1398.
[62] Orzes, G., Rauch, E., Bednar, S., Poklemba, R. Industry 4.0 implementation barriers in small and medium sized enterprises: a focus group study. 2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM); 2018:1348-1352.
[63] Mittal, S., Romero, D., Wuest, T. Towards a smart manufacturing toolkit for SMEs. In: IFIP International Conference on Product Lifecycle Management. Springer, Cham. 2018:476-487.
[64] Chhetri, S.R., Rashid, N., Faezi, S., Al Faruque, M.A. Security trends and advances in manufacturing systems in the era of industry 4.0. 2017 IEEE/ACM International Conference on Computer-Aided Design (ICCAD). 2017:1039-1046.
[65] Bai, C., Dallassega, P., Orzes, G., Sarkis, J., Industry 4.0 technologies assessment: A sustainability perspective. International Journal of Production Economics. 2020;229:107776.