The role of People and Digitalization as an Enabler of Resource Efficiency in Manufacturing

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Abstract

Global sustainability challenges have been escalating in recent times, resulting in climate change, pollution, and resource scarcity. Reducing the amount of resources being used can help to mitigate these challenges by lowering our carbon footprint, reducing waste and improving our economic resilience. To achieve these benefits, researchers and industries have begun looking into Industry 4.0 technologies as a tool to drive resource efficiency gains. In this paper, the research question explores the challenges that hinder companies from adopting digital technologies. Other topics discussed include how digital technologies can support resource efficiency, and how people can support resource efficiency.

Data for this study was collected from a face-to-face workshop event which included expert participants from industry, academia, and the UK Government. This workshop aimed to gain insights into the adoption barriers and opportunities for digital technology to target environmental performance.

The main adoption barrier identified was lack of knowledge. Other barriers include lack of trust, lack of finance and lack of expertise. Environmental performance is usually not targeted because it is not a priority for many organizations. Nevertheless, external stakeholders are putting pressure on companies to incentivize sustainable change.

This paper identifies the challenges that hinder companies from adopting digital technologies and gives insights into how digital technologies can support people for resource efficiency.

Keywords

Industry 4.0, digitalization, digital technologies, people, resource efficiency, sustainability, manufacturing, Industry 5.0.

1. Introduction

Sustainability can be defined as the ability to meet current needs without compromising the future generation [1]. According to the United Nations environment program, "*the unsustainable use of resources has triggered critical scarcities and caused climate change and widespread environmental degradation*" [2]. This stresses the urgency and need to reduce the amount of resources being used. Resource efficiency has become vital for the above reason, as extracting more value from resources inherently reduces the amount of resources needed. The benefits of resource efficiency directly impact the economic and environmental dimensions of sustainability [1], [3]–[5]. From an economic perspective, less resources needed lowers the operating expenditures of factories and makes them more

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resilient in times of resource scarcity [6]. From an environmental perspective, less resources needed reduces the carbon footprint and waste generated [6].

In factories, people can use resources a lot more efficiently than they currently do, and digital technologies are often argued to serve as an enabler to help attain this goal [7]. Sensors and data analytics tools can provide awareness as well as performance tracking. Artificial intelligence and blockchain technology introduce novel ways to improve traceability and transparency throughout a product's lifetime [7]. This supports workers with the visibility and information to make better decisions for resource efficiency benefits.

Yet, in order to gain the aforementioned value, there are still many challenges to be solved and gaps hindering the sustainable adoption of digital technologies. Hence, the following Research Question (RQ) was formulated:

RQ: What are the challenges that hinder companies from adopting digital technologies for resource efficiency benefits?

In addition to the research question, insights into the following topics were discussed:
1. How can digital technologies support resource efficiency?
2. How can people support resource efficiency?

To answer the research question and discuss the above topics, the researcher completed a literature review and organized a face-to-face workshop. The workshop included expert participants from industry, academia, and the UK Government.

2. Literature review

The database used for this literature review was Scopus. Three sets of keywords were chosen: digital (set A), resource efficiency (set B) and manufacturing (set C). All the sets included related terms with singular and plural forms, as shown in table 1.

Table 1
List of keywords in the Scopus search box

Search box: **Set A** *AND* **Set B** *AND* **Set C**		
Set A	**Set B**	**Set C**
Digital* *OR* "Industr* 4.0"	{resource efficiency}	Production OR Manufacturing OR Factory OR Factories

The search taxonomy retrieved articles that had a combination of words from Set A, Set B and Set C within the article title, abstract, or keywords. Through a thorough filtering process by abstract evaluation relative to the research questions, 85 non-relevant articles were eliminated, leaving 52 articles.

The literature extracted from these articles can be categorized into Industry 4.0 and resource efficiency. After exploring these two components independently, this review aims to combine them together and identify the role of Industry 4.0 and people for resource efficiency benefits. Any potential gaps identified would be mentioned in section 2.3.2.

2.1. Industry 4.0

Based on the literature, Industry 4.0 is also referred to as industrial digitalization technologies, digitalization technologies, and digital technologies. In the context of this paper, they all share the same meaning. However, Industry 4.0 was used more often than other phrases. Hence, Industry 4.0 has been selected as the phrase for this literature review.

Industry 4.0 can be defined as an intelligent horizonal and vertical networking of people, machines, and information systems with the aim of dynamically controlling more complex industrial systems [10]. These systems need to be integrated for horizontal and vertical networking to occur. Horizontal integration can be described as "the linkage of value creation modules throughout the value chain of a product life cycle and between value chains of adjoining product lifecycles" [11]. This enables traceability, which can be referred to as the ability to track materials, products, and processes, thereby generating real-time information on the supply of materials, production of goods, and post-consumption of resources [9]. Integrating through value networks enables collaboration between suppliers, customers, and other external stakeholders [12], [13]. Vertical integration on the other hand, describes system integration at different hierarchical levels [14]. For example, sensors on the shop floor level, Manufacturing Execution Systems (MES) on the production management level, and Enterprise Resource Planning (ERP) systems on the corporate planning level [14]. Vertical integration enables flexible, reconfigurable manufacturing systems [15], which allows for a higher level of organization and control over the whole value chain [11].

The United Nations Industrial Development Organization (UNIDO) points to the following six attributes of Industry 4.0 [16]–[18]. These include virtualization, interoperability, modularity, service orientation, real-time capability, and decentralization [14], [16]. Virtualization enables the creation of virtual versions of physical systems, facilitating simulation processes [17]. Interoperability allows systems, products, or applications to connect and communicate in a coordinated way without much effort from the end user [17]. Modularity supports coupling or decoupling system modules; this grants flexibility and allows for the rearrangement of production lines [19], [20]. Service orientation entails services as an integral part of the production processes [21]. Real-time capability enables the instant collection of information [17]. Decentralization can be described as distributed control; in the form of independent, self-organized, and self-deciding entities [17], [22]

To attain the above attributes, the following technologies can be adopted by manufacturing industries: additive manufacturing (3D-printing), artificial intelligence (machine learning), augmented reality, autonomous robots, big data analytics, blockchain, cloud computing, digital twin (simulation), Industrial Internet of Things (IIOT), sensors, and virtual reality [23].

There are several benefits and opportunities granted by Industry 4.0. These include; improved product customization using additive manufacturing, increased operational productivity, accuracy, and efficiency using autonomous robots, enhanced data visualization through augmented and virtual reality, and improved data security using blockchain technology [14], [16], [24].

Despite these advantages, multiple barriers hinder the adoption of Industry 4.0. The main obstacles are the cost of implementation, lack of expertise, and employees' attitudes [16]. Other obstacles include security issues, lack of trust, lack of management support, lack of policies, and lack of government support [25].

Nevertheless, several authors believe that Industry 4.0 has significantly more benefits than the challenges incurred [16], [23], [26].

2.2. Resource efficiency

Resource efficiency can be defined as extracting more value from resources [27]. This allows companies to do more with less resources (material and energy), providing several benefits such as; waste reduction, cost savings, and lower carbon footprint [27].

According to Duflou et al., resource efficiency approaches should address multiple levels [28], ranging from technological improvements on a machine level through to the restructuring of manufacturing sequences, factory layouts, and entire value creation networks [28], [29].

In many industries, resource efficiency efforts are hindered by a lack of awareness about resource consumption trends [27]. For instance, food factories may have generic data showing the amount of resources consumed via utility bills [30]. However, these factories are often unaware of the resource use and waste generated at a production-line level or even down to a machine level [30].

2.3. The role of Industry 4.0 and people for resource efficiency

Industry 4.0 is not just about technology, it is a socio-technical system in which technological, social, and organizational aspects interact [14]. Hence, this section presents literature on how Industry 4.0 can support people for resource efficiency benefits.

2.3.1. Current state of research

The current state of research can be categorized into health and safety, decision making, and production on demand.

For improved health and safety, robots can replace humans in tasks that are considered dangerous [13], [31], which leads to a reduction in work accidents and injuries [17], [32]. Robots can also work alongside humans in physically demanding workstations, to help alleviate stress and preserve the employees' health and productivity [10]. Autonomous systems can handle repetitive and monotonous tasks, this frees up time for people to undertake more mentally stimulating tasks and think about avenues for resource efficiency improvements [31], [33], [34].

Decision making processes can be supported using information from Industry 4.0 technologies. Industry 4.0 enables the collection and analysis of resource data down to the machine level [27]. This provides the management team with information about the resource consumption of machines and production lines [27]. Identifying the most inefficient parts of a system is key to making better decisions for resource efficiency improvements. According to Muller et al., (2018), decision making processes could fall to autonomous systems in a decentralized manner [10] . Klimant et al. (2021) adds to this point by stating that "the human is still an important guarantor for the production of the future"; as an intelligent problem solver, observer, and final decision maker [35].

Production on demand is another feature enabled by Industry 4.0. The higher the Industry 4.0 maturity level of a company, the greater its ability to match supply with demand [36]. Siltori et al. (2021) supports this claim and elaborates on the subject by stating that Industry 4.0 enables a better understanding of customers' needs and consumption trends, making it possible to produce small batches of highly customized products to meet demand [17]. This inherently reduces resource use since items that are not demanded would not be produced [17], [18], [34].

In contrast to the expectations from academics and practitioners [36], Beier et al. (2022) argues that "Industry 4.0 will not automatically lead to environmental improvements", the digital transformation needs to be accompanied by supporting measures such as regulation and incentivization [36].

2.3.2. Gaps in current research

There is an extensive amount of literature on Industry 4.0, but very few articles explore and establish a connection between Industry 4.0 and resource efficiency. Resource efficiency is often treated as a co-benefit rather than an integral part of Industry 4.0. Consequently, the resource efficiency dimension is not researched comprehensively, and possible potentials are yet to be identified. In addition to this knowledge gap, the researcher did not find articles specifically targeting "the role of people and Industry 4.0 for resource efficiency benefits". Hence, this qualitative study was created to fill the gap in the literature. The researcher also investigates several challenges that hinder the sustainable adoption of Industry 4.0.

3. Methodology

This section explains how the researcher gathered and analyzed data for this research.

3.1. Data collection

The data for this study was collected from a face-to-face workshop event titled "*Strengthening sustainability through Digitalization*". This workshop was conducted on the 31st of March 2022 at the University of Cambridge, Institute for Manufacturing. There were 18 participants involved in the workshop, from which three groups were formed. Out of these participants, eight were from industry, six were from academia, and four were from the UK Government (civil servant on industrial policy). To ensure diversity in ideas, each group included people who did not know each other and were from a different background (academia, industry, and the UK government).

The workshop aimed to discuss and answer the following questions: "*1. What is hindering you from using digital technologies to improve environmental performance? 2. What is encouraging you to use digital technologies to improve environmental performance?*" We began the workshop by asking the participants to try answering the above questions on post-it notes, one post-it note per idea, and no discussions between members. After 15 minutes of silence, we asked the participants to share their post-it notes with other members of the same group and discuss their ideas. They were encouraged to note down any new ideas inspired by their conversations on the post-it notes. After 15 minutes of knowledge sharing, the groups were asked to take their post-it notes and place them on an A0 paper. The A0 paper contained the following headings: Design, Production, and Distribution on the X-axis, Brakes and Accelerators on the Y-axis. After 30 minutes of organizing the post-it notes and discussing, the three groups were asked to move around and see the A0-paper of the other groups while having discussions and taking notes of any new inspirational ideas. After 30 minutes of knowledge sharing, the three groups were asked to present their ideas, findings, and insights to everyone else. Once the presentations were done, all the groups merged to discuss further for 90 minutes. The researcher took notes of the great ideas shared during this meeting. Overall, the experts developed 229 post-it notes from the 3 A0-papers and 35 post-it notes from the discussions afterward.

3.2. Data analysis

Data was transferred from the workshop post-it notes into an excel spreadsheet and analyzed by the researcher. During the data analysis process, the researcher aimed to find relevant information on either of the following topics: 1 The challenges that hinder companies from adopting digital technologies for resource efficiency benefits. 2 How digital technology can support resource efficiency. 3 How people can support resource efficiency. The researcher categorized relevant information based on the level of priority shown by the participants. For example, data that was emphasized by the participants had a higher level of priority over data that had no emphasis; data that was presented multiple times in a group had a higher level of priority over data that was presented once; overlapping data from multiple workshop groups had a higher level of priority over data that was presented by a single workshop group. The researcher connected data with the highest level of priority to other relevant pieces of data. This provided great insights into the most valuable information from the workshop and its connection to the rest of the datasets.

4. Results

This section presents the analyses of all the information derived from the workshop data. Based on the workshop participants, the phrase "digital technologies" was used in the place of "Industry 4.0". Hence, the result and discussion sections would continue with this phrase.

4.1. Challenges that hinder companies from adopting digital technologies

The main challenges in adopting digital technologies were identified as lack of knowledge, lack of incentive, lack of skills, lack of finance, lack of data sharing and lack of data integration.

The core of these challenges was found to spiral from a fundamental lack of knowledge about digital technologies. According to the participants, many companies are unaware of how to implement digital technology in a useful way to extract valuable information, they are also unaware of the benefits that these technologies provide. Participants believe that there is a mindset in the industry which perceives the implementation of digital technologies as too difficult and too expensive. This presumption adds another barrier.

Organizations were considered to lack incentive to act first and take the risk. The identified risks include 1 Losing a business advantage due to short-term product disruption and/or change in processes required. 2 Risk of investing in technology that is soon outdated. 3 Risk of investing in a digital solution that is unreliable and difficult to maintain. 4 Risk of workers not being able to adapt promptly.

All the workshop groups independently concluded that there is a skill gap in the industry as some workers are unaware of how to operate digital technologies. This was believed to cause concerns in the top-level management team regarding the in-house expertise required to administer, operate, and manage these digital tools. Workers were described to have a busy schedule, making it difficult to find time and learn a new skill, especially in small companies with less bandwidth.

Lack of finance was identified as another barrier. Participants claim that smaller companies may not have the financial headroom to invest in digital technologies. They also pointed out that it is very expensive to implement digital technology on a large scale to a high level of maturity.

4.2. How digital technologies can support resource efficiency

This sub-section is categorized into the design, manufacturing, and distribution stages of a product.

In the design stage, participants suggested modeling of products using software such as computer aided design, product lifecycle management, and other simulation tools. They claim that these tools provide early visualization and insights into how the product looks and operates, allowing for design alterations to be made before investing in resources for manufacture. Without this technology, participants were confident that a lot of resources would have been wasted in the trial-and-error phase before finally creating the desired product. Data from these technologies was identified to enable more informed decision-making, which could significantly impact resource use.

In the production stage, all participants supported the notion that digital technologies can improve awareness of the waste generated by processes within a factory. Among all the benefits of digital technologies, participants were most enthusiastic about traceability. They claim that traceability has a high impact on resource efficiency as it allows factories to track materials and potentially retrieve them for re-use and refurbishment.

In the distribution stage, participants stated that digital technologies could link consumers data directly to the manufacturer, for the analysis and prediction of future consumption trends. They claim that this information enables the manufacturer to supply just enough to meet the demand. In the case of perishable goods like food, it was identified that this technology could have large resource saving impacts as there would be less waste generated downstream.

4.3. How people can support resource efficiency

Based on responses from the participants, people within the leadership team, workers, and external stakeholders can all be supported by digital technologies. These people can have an immense impact on resource efficiency, but they need to educate themselves first and make it a priority.

The most important stakeholder to drive change in a company is the leadership team. It is presumed that data from these technologies can help the leaders to make better and more informed decisions. One of the workshop groups added to this point by stating that real-time data of workers can provide the management team with insights into the sectors that require a larger allocation of human resources and vice versa. All the workshop groups independently mentioned that there is a shortage of skilled workers that are digitally knowledgeable in the manufacturing industry, so training new workers is of great importance. One of the industrial participants stated that “it is easier to take people from manufacturing and give them the digital skills rather than the other way around, this is because manufacturing is more complex”. It was noted that training should ideally be handled by skilled workers, but these workers require the time to do so. Automation technology was recognized as a solution to this problem, as the machines can handle repetitive laborious tasks, thereby freeing up the workers time and allowing them to train others. It was identified that this training process can be supported using visualization technologies like virtual reality, which can significantly speed up the training process while increasing the workers’ confidence and reducing any potential risks, especially for workers in hazardous roles.

From a compliance perspective, all participants agreed that digital technology could provide reliable information to support Environmental Social Governance (ESG) auditors during the auditing process. Many of the industrial participants added to this point by stating that “digital technology can help to counter-act greenwashing as we can accurately legitimize claims made by factories and suppliers”.

From a policy perspective, the government and policymakers were recommended to focus more on resource efficiency rather than labor productivity. Participants from the UK government and industry stated that “policies, regulations, and carbon taxation need to be put in place to incentivize factories to comply with environmental sustainability goals”.

From a community perspective, digital technology was perceived to provide new avenues for companies to engage with customers and suppliers. Investors and customers were recommended to support resource efficiency by only investing in and buying from companies that are actively trying to be more sustainable. This external pressure is said to incentivize companies to make resource efficiency a priority.

5. Conclusions and discussion

In factories, people and digital technologies can improve resource efficiency, but our data shows that it all begins with the leadership team. They need to have a vision and culture that supports the incorporation of resource efficiency goals, this way, people can be encouraged to actively try and find ways to improve. External stakeholders like the government, customers, and investors can help to accelerate this process through policies, purchasing decisions and investment decisions. Once the right culture is in place and there is a plan, technology can help with its execution. Digital technology can provide awareness, enable performance tracking, and support traceability [7]. This equips people with visibility and information to make better decisions. The above findings support Beier et al. (2022), who argues against most of the literature by stating that “Industry 4.0 will not automatically lead to environmental improvements, instead this transformation towards a more sustainable economy needs to be accompanied by supporting measures” [36]. The researcher firmly agrees with Beier et al. (2022) and recommends supporting measures such as, incentives, regulation, and education.

Most participants in the study believe that in the future, all systems within the factory and supply chains would be connected to create an end-to-end holistic view. This view is expected to enable the identification and investigation of resource efficiency hotspots [11], [37]. Bai et al. (2020) adds to this point by stating that “It is necessary to address sustainability concerns from a holistic perspective” [23]. The participants recognized traceability as another major benefit of the end-to-end holistic view. Traceability allows resources to be tracked and potentially retrieved for re-use and refurbishment [9]. According to the researcher, both benefits combined could compound to a high magnitude of resource efficiency. Nevertheless, members of the supply chain need to be willing to share their data between one another [24], [38]. Companies also need to share best practices to accelerate resource efficiency.

The main adoption barrier for digital technology was clearly identified by the experts to be lack of knowledge. Companies were felt to be unaware of how to implement digital technology in a useful way, they were also felt to be unaware of the benefits that these technologies provide.

The second adoption barrier is lack of finances. Factories that are interested in adopting digital technologies may not be able to afford the cost of implementation and maintenance [39].

The third adoption barrier is lack of trust. In factories that have implemented digital technologies, there is still a lack of data sharing and integration due to trust issues. Companies are afraid of accidentally revealing intellectual property and losing their competitive advantage [24]. Companies are also afraid of security breaches that could happen when using digital technologies and sharing data [24].

The final adoption barrier is lack of standardization. For factories that are willing to share their data, this data cannot easily be integrated due to different data formats and platforms [10], [14], [16].

Through this research, we have gained a better understanding of the connection between digital technologies and people for resource efficiency benefits. We have learnt more about the adoption barriers and the significant benefits of digital technologies when organizations target resource efficiency rather than their historical use towards labor efficiency.

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