Increasing Resource Efficiency Through Digitalization – Chances and Challenges for Manufacturing Industries

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Abstract. Companies are increasingly focusing on the sustainability of their products and processes. Especially the manufacturing companies attempt to increase material and energy efficiency, as those costs already account for a major part of their total costs. The digitization of the production process, as a first step in the implementation of Industry 4.0, can be a great opportunity for realizing resource efficiency potentials thereby reduce costs in companies. However, the manufacturing companies are faced with the challenge, on one hand, to implement a successful design of digital transformation in the development and production of goods and services. On the other hand, it is about maintaining the competitiveness of companies, which requires a decoupling of economic growth from the consumption of resources - and thus a more efficient use of resources. Although company examples show a positive connection between digitalization and resource efficiency, it is often unaware of companies or not investigated and quantified. Firstly, companies have a problem identifying whether they are ready to implement digitization in their processes. Secondly, they are facing challenges on how to find adequate measures in order to increase resource savings achieved through digitization. This article explores the interactions of these challenges and highlights ways to improve the resource efficiency offered by Industry 4.0 approaches. Furthermore, it proposes a framework for increasing resource efficiency through digitalization in a company.

Keywords: Resource efficiency · Digitalisation · Industry 4.0 · Framework

1 Introduction

In recent decades, manufacturing companies have increasingly focused on considering and integrating aspects of sustainable development into their products and processes. There are many reasons for this, ranging from securing a competitive advantage over competitors, to creating a better image and marketing, to developing new innovative solutions (including technical, organizational or financial), or to make an important contribution to sustainability. Furthermore, the operating environment of companies has changed. For instance, the challenges at the company level are growing due to rising energy and raw material prices, the generally increasing public concern about

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social issues, cost savings (e.g. through waste reduction and effective resource management) and health and safety. The main challenge here is effectively to design the market success factors such as cost, quality, time and adaptability for a long-term successful production. Whereas previously manufacturing costs and quality were decisive factors, speed and flexibility are now gaining in importance [1]. A key lever for achieving these goals is increasing the efficiency of all production factors [2]. Industry 4.0 opens up new possibilities to manage and increase efficiency [3, 4]. In particular, resource efficiency can experience a sustainable increase through digital transformation and at the same time make a positive contribution to reducing negative environmental impacts and reduce costs.

The digital transformation means however significant change for the manufacturing companies [5]. It offers opportunities for qualitative growth and can be seen as a future perspective for a changed sustainability paradigm [1]. However, it presents also a challenge for them and opens several questions: How to implement the digitalization in the development and production of goods and services? What significance does digitalization have for increasing sustainability in companies? Which core elements of the digital transformation are relevant for increasing resource efficiency? Are they ready for the implementation of digitalization? What are the adequate measures to increase resource savings achieved through digitization? This article aims to provide some answers and to explain the challenges and potentials for increasing resource efficiency through digitalization. I addition, a framework for increasing resource efficiency through digitalization in a company is presented.

2 Digital Transformation: Opportunities for New Growth

In the context of industry 4.0 and digital transformation, the physical and digital worlds are becoming increasingly interlinked. Equipping machines, plants, work pieces or products with sensors and actuators and connecting them with information and communication technologies (ICT) and the Internet opens up countless new possibilities for designing production and value-added chains. This is accompanied by the digitalization of all business areas, as well as horizontal and vertical integration of corporate levels [6, 7].

Industry 4.0 enables a form of industrial value creation in which all production factors are real-time capable, intelligent and digitally networked to the extent that they affect the processes, products and business models of industrial enterprises [8, 9]. It comprises the networking of all human and machine actors along the entire value chain as well as the digitization and real-time evaluation of all relevant information with the aim of making value creation processes more transparent and efficient in order to optimize customer benefits with intelligent products and services [10].

The Internet of Things (IoT) [11] and Cyber-physical Systems (CPS) [3] are the central concepts of industry 4.0. They are accompanied by the automation and digitization of companies and the training of so-called intelligent production technology on the basis of modern ICT and the associated IT. Digitalization represents the consistent and comprehensive use of digital technologies to increase effectiveness and efficiency through automation, facilitated human-machine collaboration and the creation of new products and business models, taking into account the social aspects structure [12]. The Internet of Things (IoT) refers to the linking of clearly identifiable physical objects with a virtual representation within an Internet structure. In an industrial context, this enables horizontal and vertical networking along the value-added chain and the continuous organization, planning, control and monitoring of industrial combination processes from the normative-strategic to the operative level. CPS are systems in which information and software components are connected with mechanical or electronic components. This is accomplished with Smart devices and sensors, which can convert information into digital form, process it and transmit it, enable a holistic recording and control of all processes and procedures of a company [7].

The industry 4.0 therefore enables:

- continuous evaluation of process and machine states.
- the ability to take action or take countermeasures at the right time in order to keep.
- the process constantly at its optimum.
- aggregation and filtering of the data to be able to make the decision on a data basis.
- that does not contain any unwanted outliers or falsifications.
- Prediction and simulation of process impacts.
- creation of smart factories.

For all the applications and concepts of the industry 4.0 mentioned above the huge amount of data will be generated, stored, sent, managed and evaluated. Data management concepts such as Big Data and Data Mining have established themselves in order to be able to deal with these data volumes [13]. They also enable further increases in the efficiency of existing processes and the generation of new products and services [14].

3 Increasing Resource Efficiency Through Digital Transformation

Digital transformation offers numerous possibilities for increasing resource efficiency. The digitization of production is in many places in the development and implementation phase and should be seen as an ongoing process rather than a result [15, 16]. This enables companies to actively shape this process. It offers possibilities to partially decouple growth from resource consumption, which can only be achieved through the increasingly efficient use of natural resources in companies.

An essential feature of industry 4.0 is the digital consistency in the vertical integration of different levels within companies, as well as the horizontal integration between different actors in a value chain [1, 7]. The potential opens up at the level of individual processes within a company (e.g. field level, control level, process management level, operational management level corporate level), right up to system solutions for the supply chain and at the level of product life cycles. The goal is the dynamic management of these complex systems, in particular, the optimization of production processes, products, and services. In this context, the implementation of digital solutions should be oriented towards the management system and resources of the company. The decisive factors for the impact of digitization measures on resource efficiency are the system framework considered and the level in the value chain. The manufacturing companies organised by this way are defined as smart or intelligent factories. The Smart Factory provides a production environment that ideally organizes itself without human intervention. This includes production facilities and logistics systems. Core components are cyber-physical systems and intelligent networking [6].

3.1 Industry 4.0 Solutions for Resource Efficiency at Different Levels

In practice, a number of solutions have already been implemented for saving operational material resources through digitalization, such as energy and material, but also “intangible” resources, e.g. capital. The applications can be found not only on the process and company level, but also on the level of supply chain an product life cycle [17].

Individual digital solutions to increase resource efficiency are implemented, for example, to optimize the material or energy consumption of certain processes. In addition, energy consumption and material losses can be reduced at the process level by changing the machine utilization to an intensive optimum of machines. This also offers great potential in data and information transparency, which makes energy and material consumption transparent and reveals potential savings. The results of resource-efficient digitization at the process level are [18]:

- information on material and energy consumption can be provided in a standardized way,
- measurement data can be processed via uniform interfaces in information models and
- real-time key performance indicators can be provided.

An example of the individual solutions at the process level is for instance “digitization in industrial forging”. The use of digital solutions in a forging process made compressed air consumption transparent and subsequently enabled compressed air to be generated in line with demand and energy savings of up to 10%; the use of electronic ballasts led on average to 5% less energy consumption. The further example shows implementation in the process industry [17]. In the process industry, with relatively high use of raw materials and supplies, the use of certain auxiliary materials can be reduced with the assistance of dynamic process controls in order to improve the supply of operating materials. In the steel industry, secondary metallurgical treatment can minimize the burn-up of chromium and other metals during decarburization of high-chromium steels, for example, by optimizing the oxygen supply [1, 17].

There are numerous ways to make production processes more effective and efficient. This can be achieved by the implementation of digital solutions on operation/company level. The applications range from business information systems in combination with measurement sensors, to smart production services, to solutions from information, communication and automation technology, such as simulation and forecasting models, self-learning assistance systems and diagnostic tools, or lab-on-chip systems for real-time analysis of very small quantities of substances [1, 17]. This changes the manufacturing processes in companies since adapted manufacturing processes are used. For example, production processes can be made more flexible and individual by using networked machines and components that communicate with each other via the Internet and form cyber-physical systems (smart factory) [17]. In addition to increasing resource efficiency, a reduction in inventories and processing times is mostly achieved. A further example of the increase in resource efficiency is the usage of new additive manufacturing processes such as 3D printing technologies, which make it possible to individualize the production of components. Generative production systems have the potential to enable time savings and improved resource and energy efficiency. Thanks to optimized component structures, they lead to weight savings, waste reduction and thus improved life cycle costs. Another application is in maintenance and quality management. Machines equipped or retrofitted with sensors and mechanical systems (retrofitting) enable Big Data Analytics to implement anticipating maintenance concepts (predictive maintenance) and forecast models for quality assurance. In quality management, the permanent collection and evaluation of data offer optimization potential through improved possibilities for the realization of Jidoka (automatic production stop in the event of errors or defects) [12]. The increase in resource efficiency can be especially achieved by introducing lean management methods within the manufacturing processes. Lean Management is an approach of continuous process optimization and encompasses the efficient design of the entire value chain. The main objective of lean management is to coordinate all processes and activities in such a way that any kind of waste along the value chain is avoided. After all, such philosophy ultimately leads to an economic design of uneconomical areas: Resources are better used, new potential can be discovered. The methods can be applied to all levels of a company, in production, marketing or sales [19, 20].

The digitization of production systems enables far-reaching changes in industrial value-added processes. Intelligent value chains are a compelling and complementary complement to digitization as they control the ecosystem of suppliers, production, logistics and sales [1]. This creates opportunities for the development and implementation of new innovative business models. Business models that integrate products and complementary services allow for cross-lifecycle concepts. The examples of the business models for the equipment manufacture are for instance [17]:

- pay-per-hour - The equipment manufacturer takes responsibility for the availability and reliability of his equipment during the operating phase by defining the environmental and general conditions. The plant manufacturer sells available, ready-to-use plants in the form of a pay-per-hour settlement using service level agreements.
- pay-per-piece - In this model, the plant manufacturer sells the manufactured product or service and thus also accepts responsibility for production. Examples are the production of compressed air (compressors) or conveyed piece goods (conveying and storage equipment). In this business model of pay-per-piece invoicing, the turnover is generated for each part produced by the plant.
- pay-per-value - In Application Lifecycle Management, the development and production of the product (service) also guarantees its further development (e.g. software). The business model implies pay-per-value accounting, whereby the customer's own product must exert a significant influence on the customer's end product.

3.2 Measures for the Digital Transformation

The digitization of production as the first step towards industry 4.0 can be an opportunity for companies to increase their own resource efficiency and thus reduce costs. Although examples show this positive correlation between digitization and resource efficiency, companies are often unaware of it or are not examined and quantified in more detail.

A study by VDI examined the implementation of digital transformation measures to increase resource efficiency. Using descriptions of best-practice cases from Germany, eleven concrete measures for digital transformation in practice and the necessary components were developed. These are measures from small and medium-sized as well as large companies from different industries. By combining these measures, companies can implement individual practical applications (see Table 1). The measures can be used in isolation or in combination to drive digital transformation in the enterprise while saving resources [17].

Table 1. Identification of eleven measures of digital transformation

ID	Measure	Description
1	Cross-linking of sensors and actuators	A basic prerequisite for digital value creation is the digital connection of sensors and actuators. This allows data from different sensors and actuators to be monitored and recorded over a longer period of time and also to be viewed in combination in an integrated process
2	Use of digital object memories	Physical objects (products, machines) are equipped with digital memory. Relevant data is stored in the memory and is directly accessible at the machine or product
3	Decentralized control	The intelligent workpiece becomes an important component in the decentralized production and value-added network. It has knowledge of its properties and provides information on how it can be manufactured. Thus it can control its own production process
4	Measures for worker support and assistance	Assistance systems can support workers in a wide range of manufacturing and assembly tasks with the help of mobile terminals
5	Dynamically cooperating systems and modularization	Modular encapsulated functionality makes it easy to add new or modified plant components to production plants, create, modify or dissolve interoperation between two or more parties with minimal effort
6	Introduction and use of positioning and localization systems	Tracking and locating systems make it easier to find machines and plant components in a production facility, as well as the finished products
7	Condition monitoring	Various operating states of plants and processes are continuously analyzed on the basis of recorded data and with the aid of suitable software solutions, and deviations are marked and reported

(*continued*)

Table 1. (*continued*)

ID	Measure	Description
8	Predictive maintenance	Predictive maintenance systems should detect machine faults (e.g. machine failures or malfunctions) before they even occur. Maintenance or early repairs should prevent errors
9	Consistent data integration	Consistent data integration and uniform access to data structures enable the integrated consideration of production and order planning. To implement agile production processes, vertical integration of Enterprise Resource Planning (ERP) systems is essential
10	Virtual product development	In virtual product development, a digital 3D model of a product is created on the computer. The virtual model can be modified, tested and optimized by simulations or produced using 3D printing
11	Cloud Computing	Individual workspaces (e.g. programs, storage space, computing capacity) are no longer provided on the hard disk, but via the Internet or the cloud

The case studies make it clear that identified process inefficiencies can often be reduced by digitization measures. These results should help companies to select appropriate measures. They form the basis for practical applications of digital transformation, the targeted use of which can lead to resource savings.

3.3 Framework for Increasing Resource Efficiency Through Digitalization

For many companies is the possible link between resource efficiency and digitization often not perceived. In many cases, digital solutions are used to optimize processes, but there is no systematic monitoring of the success or quantification of resource savings. Companies therefore often lack the basic information on their operational consumption of resources, which they could use to derive targeted measures. The implementation of industry 4.0 or elements of industry 4.0 must be considered from several points of view. The dimensions, which need to be considered, are the competitors of the same industry, the requirements of the customer and the company's own goals and needs [21]. Therefore, the process of digitization in companies must be holistic, transparent and more planned, and used as a strategic goal. A digitization strategy must be developed and implemented in the form of a roadmap (see Fig. 1). Figure two shows a framework and implementation steps designed in accordance with the PDCA circuit. The prerequisite for the implementation of digital solutions for increasing resource efficiency is a clear, strong and strategic involving of management within all projects.

The first step is the preparation phase, which includes two different detailed analyses. At the start, it is necessary to analyze in detail the existing business of the company and its relations with stakeholders. The current state analysis includes a detailed environmental analysis that should show which strengths and weaknesses exist in the company, in which direction should go development, identify the opportunities and risks offered by the market, and at the end define the development strategy.

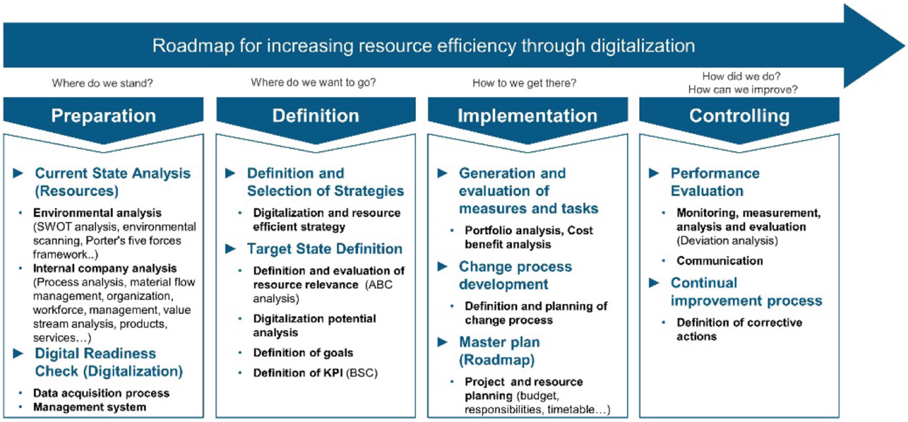

Fig. 1. Roadmap for increasing resource efficiency through digitalization

A second important part of the current situation analysis is the internal analysis of the company. The main goal of this analysis is to identify all processes and products. This is achieved with process analysis (identification of the system boundaries, identification of the material and energy flow and the identification of the process steps), and the visualization of the resources flow. At this point, it is also necessary to list all resources that are consumed or disposed by the company and identify the current measures to improve resource efficiency. After conducting a detailed analysis of the current state, it is necessary to analyze the readiness of the company for the implementation of digitization. This analysis is determined by using the Digital Readiness Check. Digital Readiness Check shows the digital potential of the company in the form of a maturity model [22]. The maturity level to which a company's digital transformation has progressed can be determined online by the digital maturity check. Haag et al. 2018 present another example of the maturity model, which classifies companies into six stages with the focus on data acquisition [23]. This model/framework is not only an evaluation tool but also in addition as a planning tool to support resource efficiency efforts in companies with a strategic approach.

After identification of the current state, occur the definition of where the company wants to go. A decrease in resource use can be achieved in principle with the strategies efficiency, sufficiency, and consistency. The second step, therefore, defines the digitalization and resource efficiency strategy. This is an analytical process of selection of the best suitable course of action to meet the organizational objectives and vision. Companies should develop a targeted strategy for resource efficiency measures as part of their digital transformation. The next step is a definition of the target state. The target state provides the details of a future state of a company that will be developed. In order to accomplish this, it is necessary to use the results of the current state (from step one) and where a company really wants to be within a reasonable timeframe (second step). Further, the definition of the relevance of resources for the company takes place, as well as the digitalization potential. The process begins by analyzing which value chains are most important for each company and where digitization can be critical to business outcomes and operational control. Not every company has to be completely "digitized". Rather, it is a matter of defining the sections of the operational processes in which digitization is either absolutely necessary or can be expected to bring considerable benefits. Once we know where the company is heading; now we are in a position to define specific goals that will enable a company to achieve that vision. These goals are the specific outcomes, which we are trying to achieve. The goals should be defined for every resource and organization/management function. At this point, it is necessary to define Key Performance Indicators (KPI) in order to evaluate the success at reaching targets.

With the definition of the goals and KPI the implementation process can be started (third phase). The implementation only gets a real foothold in day-to-day business when the adopted strategies, goals and packages of measures are translated into concrete operational measures. It is important to keep an eye on the relation between effort and benefit. In practice, the evaluation of measures in terms of their impact on the achievement of objectives has proved helpful. This allows implementation priorities to be defined, which form the basis for upcoming decisions or budgeting. Asides of measurement operationalization, a change process should be defended and planned. This stage of preparation focuses on the involvement of other parties involved in the digitization process, such as the company's own employees or external cooperation partners. There are not only communicative reasons for this, but such an approach can also contribute to distributing tasks and responsibilities within the company, integrating the expertise and experience of other participants, taking away the fear of change and ensuring the support of employees and customers for the transformation process. The result of this planning step is a concept for the change process. The last part of the implementation phase is development and definition final roadmap that contains a time plan as well as a description of fields of action, a budget and the projects that will be implemented.

Once all measurements are defined and planned in the form of a roadmap, a controlling phase takes place. This is done through continuous performance evaluation. The implementation of measures needs to be constantly monitored, controlled, analyzed and evaluated. The utilization of the framework is an iterative process. It is recommended to reevaluate the monitoring on a regular basis, and if required the correction measures should be defined and implemented.

4 Conclusions

The digitalization is associated with high expectations of reducing the consumption of natural resources in the manufacturing industry. It can help to raise the potential for increasing material and energy efficiency. The benefits are multiple; the competitive advantage over competitors is maintained, the resource efficiency gained enables new innovative solutions (including technical, organizational, financial and more) and business models to be developed and makes an important contribution to sustainability by reducing environmental impacts. The possible link between resource efficiency and digitization is often not perceived. From a business perspective, digital transformation offers great potential, but for most companies, it means a transformation process lasting several years and a challenge. A company's digital transformation aims to use digital technologies and business models to adapt to a changing market and further improve its performance. It is important to understand that the foundation for success is the corporate culture and the involvement of employees. Lean management is, therefore, the basis and prerequisite for Industry 4.0 and targeted digitization. The aim of this paper was to give a brief outline of the possibilities of digitalization for increasing resource efficiency at different levels and propose a framework for increasing resource efficiency through digitalization in a company. Nevertheless, for many companies the possibilities are not present; therefore further projects, subsidies, and initiatives are needed to show the potentials and to take measures.

References

1. Tschiggerl, K., Topic, M.: Potenziale durch Industrie 4.0 zur Steigerung der Ressourceneffizienz. WINGbusiness, Nr. 1/2018, pp. 25–28 (2018)
2. Anderl, R., Abele, E., Metternich, J., Arndt, A., Wank, A.: Industrie 4.0 – Potentiale, Nutzen und Good Practice-Beispiele für die hessische Industrie. Studie: Zwischenbericht zum Projekt Effiziente Fabrik 4.0. Meisenbach GmbH Verlag, Bamberg (2015)
3. Lee, J., Bagheri, B., Kao, H.A.: A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. Manuf. Lett. **3**, 18–23 (2015)
4. Stock, T., Seliger, G.: Opportunities of sustainable manufacturing in Industry 4.0. Procedia CIRP **40**, 536–541 (2016)
5. Zhu, K., Dong, S., Xu, S.X., Kraemer, K.L.: Innovation diffusion in global contexts: determinants of post-adoption digital transformation of European companies. Eur. J. Inf. Syst. **15**(6), 601–616 (2006)
6. Wang, S., Wan, J., Li, D., Zhang, C.: Implementing smart factory of Industrie 4.0: an outlook. Int. J. Distrib. Sens. Netw. **2016** (2016)
7. Kagermann, H., Wahlster, W., Helbig, J.: Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0. Acatech – National Academy of Science and Engineering, Frankfurt am Main (2013)
8. Siepmann, T.: Industrie 4.0 – Grundlagen und Gesamtzusammenhang. Einführung und Umsetzung von Industrie 40. Springer, Heidelberg (2016)
9. Frank, A.G., Dalenogare, L.S., Ayala, N.F.: Industry 4.0 technologies: implementation patterns in manufacturing companies. Int. J. Prod. Econ. **210**, 15–26 (2019)
10. Roth, A: Industrie 4.0 – hype oder revolution? In: Roth, A. (Hrsg.) Einführung und Umsetzung von Industrie 4.0. Springer, Heidelberg (2016)
11. Atzoria, L., Iera, A., Morabito, G.: The Internet of Things: a survey. Comput. Netw. **54**(15), 2787–2805 (2010)
12. Schaefer, S, Pinnow, C.: Industrie 4.0: Grundlagen und Anwendungen. In: 6. Fachtagung: "Berliner Industrie 4.0 - Grundlagen und Anwendungen". Beuth Verlag, Berlin (2015)
13. Wu, X., Zhu, X., Wu, G.Q., Ding, W.: Data mining with big data. IEEE Trans. Knowl. Data Eng. **26**(1), 97–107 (2014)

14. Bernerstätter, R.: Daten als Ressource in Industrie 4.0: Kosten und Nutzen von Datenqualität. WINGbusiness, Nr. 1/2018, pp. 36–40 (2018)
15. Biedermann, H., Tschiggerl, K., Topic, M.: Nachhaltige Entwicklung vor dem Hintergrund der digitalen Transformation - Herausforderungen und Potenziale für Ressourcen- und Energieeffizienz mit Industrie 4.0. In: Sustainability Management for Industries 7: Transformationen - neue Wege zu industrieller Nachhaltigkeit. Hampp Verlag, München (2017)
16. Bienhaus, F., Haddud, A.: Procurement 4.0: factors influencing the digitisation of procurement and supply chains. Bus. Process Manag. J. **24**(4), 965–984 (2018)
17. Schebek, L., Abele, E., Anderl, R., Sauer, A., Zühlke, D.: Ressourceneffizienz durch Industrie 4.0 – Potenziale für KMU des verarbeitenden Gewerbes. VDI Zentrum Ressourceneffizienz, Berlin (2017)
18. ZVEI: Energieeffizienz durch Digitalisierung – Handlungsempfehlungen und Anwendungsbeispiele. Position paper, ZVEI - Zentralverband Elektrotechnik- und Elektronikindustrie e. V., Frankfurt am Main (2018)
19. Arnheiter, E.D., Maleyeff, J.: The integration of lean management and Six Sigma. TQM Mag. **17**(1), 5–18 (2005)
20. Rothenberg, S., Pil, F.K., Maxwell, J.: Lean, green, and the quest for superior environmental performance. Prod. Oper. Manag. **10**(3), 228–243 (2001)
21. Merz, S.L., Siepmann, D.: Industrie 4.0 – Vorgehensmodell für die Einführung. In: Roth, A. (Hrsg.) Einführung und Umsetzung von Industrie 4.0. Springer, Heidelberg (2016)
22. ISPO Academy. https://webtool.innolytics.de/ispo-survey.php?p=YWZlZTMzMGItMDFmMiMjNDU&action=set_language&language=2. Accessed 11 June 2019
23. Haag, S., Bauerdick, C., Campitelli, A., Anderl, R., Abelle, E., Schebek, L.: A framework for self-evaluation and increase of resource-efficient production through digitalization. Procidia CIRP **72**, 850–855 (2018). 51st CIRP Conference on Manufacturing Systems