Sustainable Introduction of Industry 4.0: A Systematic Literature Review

Erwin Rauch
Industrial Engineering and Automation (IEA)
Faculty of Science and Technology
Free University of Bolzano-Bozen
Bolzano, Italy
erwin.rauch@unibz.it

David S. Cochran
Center of Excellence in Systems Engineering
Purdue University Fort Wayne
Fort Wayne, IN, 46805, USA
cochrand@pfw.edu

Abstract

The introduction of Industry 4.0 and the associated digital transformation present great challenges for many companies. Such a project poses a danger to companies insofar as the technologies themselves are very often available and applicable, but their successful introduction requires great skill in change management. At the same time, companies and their manufacturing systems should be designed in such a way that they are successful in the marketplace for the long term. At present, there are already efforts in the direction of methods, roadmaps and strategies for the introduction of Industry 4.0. However, only a few of these methods explicitly deal with the long-term sustainable implementation of Industry 4.0.. Therefore, the aim of this work is an analysis of current methods for the introduction of Industry 4.0, which focuses on long-term sustainability in the redesign of systems. A systematic literature review provides a methodology for identifying relevant work in the scientific literature. Subsequently, the methods found are compared with each other and limits and gaps in the literature are discussed.

Keywords
Industry 4.0, Sustainability, Industry 4.0 Roadmap, Systematic Literature Review

1. Introduction

In recent years, the industrial environment has been changing radically due to the introduction of concepts and technologies based on the Fourth Industrial Revolution (Sendler, 2013) or better known as “Industry 4.0” or I4.0. The focus of Industry 4.0 is to combine production, information technology and the internet. Thus, with Industry 4.0, innovative advanced manufacturing technologies are combined with information and communication technologies to increase the level of digitalization of operational and business processes. Regardless of the size of a company, an appropriate digital transformation strategy offers future opportunities for growth and sustainable competitiveness on a global market. Today many companies still struggle in implementing new technologies related to Industry 4.0, Internet of Things and Smart Manufacturing. Furthermore, a challenge for many companies is to introduce these new technologies in a thoughtful way in order to not risk the long-term sustainability. Therefore, there is a need for strategies and methods to support firms in introducing Industry 4.0 while keeping in mind long-term sustainability of the company.
In this article, we want to analyze the suitability of already existing methods in scientific literature regarding the long-term sustainability for introducing Industry 4.0. After defining the research question, we propose a systematic literature review as a research methodology. Subsequently we show the procedure we conducted to analyze scientific

works from the Scopus database in order to identify 13 works pertinent with the aim of this study. In a next step, the suitability of these methods is discussed before highlighting that there is still a need for further research.

2. Research Question and Methodology

2.1 Research Question

The aim of this paper is to review the current literature in order to find existing papers dealing with long-term sustainable introduction of Industry 4.0. Once this work has been identified, it will be examined for methods and procedures to achieve a sustainable implementation of Industry 4.0.

> RQ: What kind of methodologies are proposed in scientific literature for a sustainable introduction of Industry 4.0?

2.2. Systematic Literature Review (SLR) as Research Methodology

In this research, we apply Systematic Literature Review (SLR) as a research methodology as it is based on a systematic, method-driven and replicable approach (Booth et al., 2016). Compared to traditional approaches of unstructured literature review, the SLR approach aims to search, appraise, synthetize and analyze all the studies relevant for a specific field of research (Palmarini et al., 2018). According to Tranfield et al. (2003), SLR is characterized by a scientific and transparent process that aims to minimize bias through exhaustive literature searches and by providing an audit trail of the reviewer's procedures and thus making it replicable also for other researchers. Compared to other instruments, like also co-citation analysis, SLR takes into account every source beyond the number of citations, which naturally are relatively low for recently published works and emerging topics. As research on the introduction and implementation of Industry 4.0 is a relatively new and an emerging field, this fact played an important role in the selection of the research methodology for conducting the literature review.
In literature there are several studies on how to conduct a SLR (e.g. Palmarini et al., 2018; Petticrew and Roberts, 2008; Denyer and Tranfield, 2009 and Durach et al., 2017. In our research, we applied the SLR approach as suggested by Denyer and Tranfield (2009). Based on this reference, we defined the following four consecutive steps for our search and screening procedure:

- Step 1: Establishing the research objectives
- Step 2: Defining the conceptual boundaries of the research
- Step 3: Setting out the data collection by defining the inclusion/exclusion criteria
- Step 4: Reporting the validation procedure and efforts.

3. Systematic Literature Review

3.1 Search and Screening Procedure

According to the research methodology selected and described in paragraph 2.2 we first established our research objectives. Thus, we deduced the objectives of this research from the research question described in paragraph 2.1. The main objective is to identify not only existing works dealing with long-term sustainability in the introduction of Industry 4.0, but also to identify used methods or strategies. This research aims to analyze the long-term sustainable introduction and implementation of Industry 4.0 (I4.0). Thus, the setting of the conceptual boundaries was based on the terms 'sustainable' and 'sustainability' combined with 'introduction' and 'implementation and, of course, considering the term 'Industry 4.0'.
In addition to the conceptual boundaries, several search as well as inclusion/exclusion criteria, in terms of database, search terms and publication period need to be defined. We used Scopus as the electronic database for the keyword search, which we identified as being the most relevant for publications in the engineering and manufacturing area. A previous check of other sources such as ISI Web of Knowledge, Science Direct and Emerald did not show any major changes in relation to adding to the sources. Therefore, we decided to conduct the SLR with the Scopus database as it represents the most relevant source for our purpose.

Table 1 shows the applied search approach and the inclusion and exclusion criteria in relation to the search query. In different steps, we identified relevant and pertinent papers for our study. In a first step we identified the related literature using the following search string for searching in title, abstract and keywords: (TITLE-ABS-KEY ("sustainability" OR "sustainable") AND TITLE-ABS-KEY ("industry 4.0") AND TITLE-ABS-KEY ("introduction" OR "implementation")) AND (LIMIT-TO (LANGUAGE , "English")). In this step all kinds of subject areas and documents were included and only works in the English language were selected. As we conducted the search on January 2, 2020, we limited the period of research to works published by 2019. As a result, we obtained 121 papers.
In a second step, we conducted a screening of the identified literature. We applied a coding scheme which evaluated the appropriateness and pertinence of a search result using a score of 0 and 1 (where 1 denotes high appropriateness and 0 denotes no or low appropriateness). The screening was carried out in two phases. In the first phase, (1° round of screening) only the title and abstract were read. In the second phase (2° round of screening), the whole paper was examined. In the first round of screening, by reading the paper title and abstract, the number of papers reduced from 121 files to 23 as the focus of most of the works was not on a sustainable introduction of Industry 4.0. In most of the cases the papers were dealing with Industry 4.0 technologies and how they affect ecological sustainability of enterprises. In the second round of screening, by reading the whole paper, the number of papers reduced from 23 to 13 papers files. The remaining 10 papers have been excluded in this second round of screening, because they do not provide any or sufficient information about methodologies.

Table 1. Inclusion and exclusion criteria

Limitation	**Criteria**	**Count**
Source	Scopus	—
Search in	Article title, Abstract, Keywords	—
Search terms and connections	("sustainability" OR "sustainable") AND "industry 4.0" AND ("introduction" OR "implementation")	132
Time	earliest (2014) - 2019	124
Source type	All types (conference proceedings, journal contribution, book chapters, books, editorials, short surveys, trade journals,…)	124
Language	English	121
Screening	First phase of coding: examination of title and abstract	23
	Second phase of coding: examination of the whole paper	13

3.2 Search and Screening Results

Table 2 gives an overview of the final round of the identified and pertinent scientific works using the SLR process, including authors, title, year and the source of the paper.

Table 2. Search and screening results

No.	**Author(s)**	**Title**	**Year**	**Source**
1	Habib M.K., Chimsom C.	Industry 4.0: Sustainability and design principles	2019	Proceedings of the 2019 20th International Conference on Research and Education in Mechatronics, REM 2019
2	Birkel H.S., Veile J.W., Müller J.M., Hartmann E., Voigt K.-I.	Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers	2019	Sustainability (Switzerland)
3	Halse L.L., Jæger B.	Operationalizing Industry 4.0: Understanding Barriers of Industry 4.0 and Circular Economy	2019	IFIP Advances in Information and Communication Technology

4	Rajput S., Singh S.P.	Industry 4.0 − challenges to implement circular economy	2019	Benchmarking
5	Sony M., Naik S.	Critical factors for the successful implementation of Industry 4.0: a review and future research direction	2019	Production Planning and Control
6	Mora Sanchez D.O.	Corporate social responsibility challenges and risks of industry 4.0 technologies: A review	2019	Smart SysTech 2019 - European Conference on Smart Objects, Systems and Technologies
7	Ghobakhloo M., Fathi M.	Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing	2019	Journal of Manufacturing Technology Management
8	Rosin F., Forget P., Lamouri S., Pellerin R.	Impacts of Industry 4.0 technologies on Lean principles	2019	International Journal of Production Research
9	Khakifirooz M., Cayard D., Chien C.F., Fathi M.	A System Dynamic Model for Implementation of Industry 4.0	2018	2018 International Conference on System Science and Engineering, ICSSE 2018
10	Moica S., Ganzarain J., Ibarra D., Ferencz P.	Change made in shop floor management to transform a conventional production system into an 'Industry 4.0': Case studies in SME automotive production manufacturing	2018	2018 7th International Conference on Industrial Technology and Management, ICITM 2018
11	Müller J.M., Kiel D., Voigt K.-I.	What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability	2018	Sustainability (Switzerland)
12	Dombrowski U., Richter T., Krenkel P.	Interdependencies of Industrie 4.0 & Lean Production Systems: A Use Cases Analysis	2017	Procedia Manufacturing
13	De Carolis A., Macchi M., Negri E., Terzi S.	A maturity model for assessing the digital readiness of manufacturing companies	2017	IFIP Advances in Information and Communication Technology

3.3 Descriptive Sample Overview

The descriptive sample overview shows some quantitative data of the identified works in the SLR search and screening approach. Figure 1 shows the development of works over time. While the search process before the screening process included also works starting in 2014 the selected works for this study are concentrated in the years from 2017 to 2019 rising from two to eight works. This shows that a sustainable introduction and implementation of Industry 4.0 is of increasing interest. This might be because many companies are starting now to introduce Industry 4.0 technologies and concepts developed in research over the last decade.

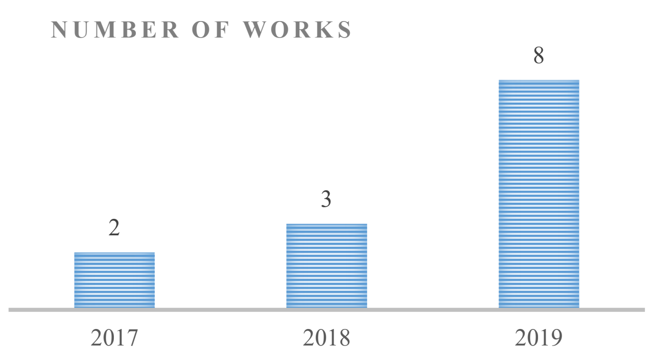

Figure 1. Number of identified works over time.

In addition to the analysis of the evolution of the number of papers, we also categorized the papers by source type (e.g. conference contributions or journal articles). Figure 2 shows the results of this analysis. The nearly equal distribution between conference papers and articles in journals shows that the topic is no longer an emergent issue in research but is already documented in peer-reviewed journal articles.

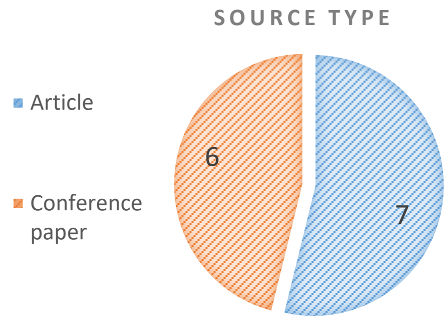

Figure 2. Categorization of source types.

4. Content Analysis

4.1 Maturity-Based Assessment and Readiness Models

The first category of methods found in the scientific literature to ensure the sustainable implementation of Industry 4.0 are maturity-based assessment and readiness-based models. In the readiness model of De Carolis et al. (2017) the five maturity models are: 1) initial, 2) managed, 3) defined, 4) integrated and interoperable and 5) digital oriented. The readiness model contributes to the long-term sustainable introduction of Industry 4.0 as it supports the analysis of the current status of digitalization and readiness for Industry 4.0 in manufacturing companies. Based on this analysis, it is much easier for company managers to define the priorities of Industry 4.0 technologies to be introduced and to estimate the effort based on the current level of implementation.

4.2 Lean-Based Methods

The second category of methods for a sustainable implementation of Industry 4.0 are so-called "lean-based" methods. In this category "Lean" is seen as one of the fundamental enablers of Industry 4.0. According to this concept, Lean is a basis for Industry 4.0 and helps to increase enterprise efficiency. Dombrowski et al. (2017) show a framework to facilitate an individual enterprise selection process for the implementation of Industry 4.0. The framework is organized into three levels. The first level describes process-related characteristics of Industry 4.0 like vertical integration, real-time data, traceability, visualization of data, self-optimization and others. The second level describes "Systems of Industry 4.0", by categorizing them into (i) Smart Data Analytics, (ii) Intelligent objects, (iii) Internet of Things, (iv) Cyber-Physical Systems and (v) Machine-to-machine communication. The third level of the framework of Dombrowski et al. (2017) shows the main Industry 4.0 technologies: big data, RFID, cloud computing, augmented and virtual reality, sensors-actuators, real-time data or automated guided vehicles. The article by Rosin et al. (2019) states the link between the principles and tools proposed by Industry 4.0 and those proposed by the Lean approach. Rosin et al. assert that Industry 4.0's technologies are improving the implementation of Lean principles, depending on the technologies' capability levels. A better connectivity of machines and products with the production environment as well as customers and suppliers facilitates the reduction of lead-time and empowers mass customization. In addition, the use of collaborative robots may help to reduce non value adding processes as they can be assigned to cobots. The results obtained show strong support of Industry 4.0 technologies for Just-in-time and Jidoka, but little or no support for waste reduction, teamwork and people. Also, according to Ghobakhloo and Fathi (2019), lean-digitized manufacturing systems offer sustained competitiveness in the Industry 4.0 era. Their research findings show that an Industry 4.0 transition based on lean-digitized manufacturing systems is a viable business strategy for corporate survivability. Overall, the lean-based models provide a classification into technologies, systems and process-related characteristics to achieve Lean principles that helps companies to derive a comprehensive strategy for introducing Industry 4.0 based on the precepts of the Lean Production System.

4.3 Methods Describing Enabler and Barriers of Industry 4.0

The third category of identified methods is based on analyzed enablers/opportunities as well as challenges/barriers of Industry 4.0. In Müller et al. (2018) the authors define some hypotheses about the challenges and opportunities of Industry 4.0 and assert proof based on quantitative data. The authors develop a model with the following main elements to create opportunities based on Industry 4.0: strategy, operations, environment and people. In addition, the main elements regarding challenges in introducing Industry 4.0 are: competitiveness and market viability, organizational and production efficiency. Sony and Naik (2019) are describing ten critical factors for a successful implementation of Industry 4.0 in companies: 1) align the Industry 4.0 initiatives with organizational strategy, 2) commitment of the top management, 3) employees as key factor, 4) make products or services smart, 5) digitalization of the supply chain, 6) digitalization of the organization, 7) change management during the introduction, 8) efficient project management, 9) managing cyber security and 10) emphasize sustainability when introducing Industry 4.0. In contrast to this approach, Rajput and Singh (2019) analyzed the most important barriers for introducing Industry 4.0 by identifying 20 barriers:

- Need for sensor technology
- Process digitization
- Data analysis
- Fog computing
- Infrastructure standardization
- Semantic interoperability
- Smart devices
- Cyber-physical systems modeling
- Cyber-physical systems standards and specifications
- Automation system virtualization
- Collaboration and coordination
- Business model design
- Interfacing and network
- Compatibility
- Investment cost
- Smart services
- Product technology improvement
- Eco-efficiency of production processes
- Global standards and data sharing protocols
- Cyber-security.

Notice that many of these barriers seem to be more like enablers or physical solutions of Industry 4.0 when these technologies become available. While the above-listed barriers are valid for the general implementation of Industry 4.0, Halse and Jæger (2019) defined specific barriers for the introduction of Industry 4.0 combined with circular economy and its ecologic aspects. Circular Economy (CE) is based on the concept of changing the take-make-use-dispose pattern into closed-loops of material flows through processes such as maintenance, repair, reusing, refurbishing, remanufacturing and recycling. They identified six barriers for CE are: 1) difficult disassembly of products, 2) supply chain complexity and recyclability (e.g. high amount of components of different nature), 3) coordination problem among different companies involved in the assembly/disassembly, 4) lack of circular economy thinking in product design and production, 5) quality issues and 6) high costs for changing to circular economy.

Habib and Chimsom (2019) developed a model consisting of sustainable I4.0 design principles. Such design principles can also be seen as enablers of introducing Industry 4.0 in manufacturing companies. For example, the model of Habin and Chimson is based on the following design principles, which are very similar to other enablers seen before in the work of other authors in this category: interoperability, modularity, eco-design, virtualization, decentralization, real-time capability and service orientation.

The models and methods in this category of methods based on enablers and barriers of Industry 4.0 are assumed to contribute the long-term sustainable introduction of Industry 4.0 by asserting that it is necessary to identify the enabling as well as the limiting/challenging elements of the implementation process. In so doing, these approaches allows company leaders to focus on the right enablers and to be prepared regarding challenging situations.

4.4 Roadmap models for Industry 4.0

The fourth category of identified methods, Roadmap Models, shows possible roadmaps for introducing Industry 4.0 in companies. Roadmaps are characterized in giving companies an overview of suitable process steps during the implementation process. Moica et al. (2018) show a three-stage roadmap model for Industry 4.0 with the following main three stages: 1) Vision 4.0 (develop a vision and strategy for Industry 4.0), 2) Enable 4.0 (in this stage the company defines the technology portfolio needed and elaborates a strategic roadmap for introduction), 3) Enact 4.0 (the output of this three-stage model is a timely ordered perspective of actions to be implemented for achieving the goals of the Industry 4.0 vision and strategy). Khakifirooz et al. (2018) describe the proposed roadmap for introducing Industry 4.0 as a systems engineering V-model type diagram. The process is presented with two sides that form a "V". The first side presents the project definition while the right side gives an overview of the test and integration phase. It starts with the requirements analysis that is necessary to implement "Industry 4.0" and specifications depending on the types of manufacturing. The next steps are the digitalization of value chains (e.g. seamless horizontal data integration through Big Data and Internet of Things) and the digitalization of products (e.g. identification and traceability of products using Radio Frequency Identification, called also RFID). At the beginning of the introduction of Industry 4.0 technologies first pilot activities need to test and verify the actions taken. Once these technologies are implemented, maintenance is always required to keep the implemented Industry 4.0 technologies working.
Such Industry 4.0 roadmaps are crucial for the sustainable introduction of Industry 4.0 in companies as they help practitioners to derive the right steps for implementation and to bring these steps into a meaningful order for setting up a successful Industry 4.0 implementation project.

4.5 Risk Frameworks

The fifth category of identified methods deals with the management of possible risks when adopting and introducing Industry 4.0 technologies and concepts. The work of Mora Sanchez (2019) gives a detailed overview of environmental, social and economic challenges as well as risks for: 1) Internet of Things, 2) robotics and artificial intelligence, 3) cloud computing, 4) cybersecurity, 5) big data, 6) unmanned systems, 7) blockchain, 8) 5G, 9) autonomous vehicles, 10) additive manufacturing, 11) virtual reality and 12) augmented reality. To reach a sustainable introduction of Industry 4.0 the author strongly suggests companies to consider all the identified corporate social responsibility challenges and risks of the 12 Industry 4.0 technologies. Birkel et al. (2019) develop a risk framework for Industry 4.0 in the context of sustainability grouping the risks into five categories: 1) technical and IT risks, 2) economic risks, 3) social risks, 4) legal/political risks and 5) ecological risks. Figure 3 shows the Industry 4.0 sustainable risk framework with all the sub-items developed by them.

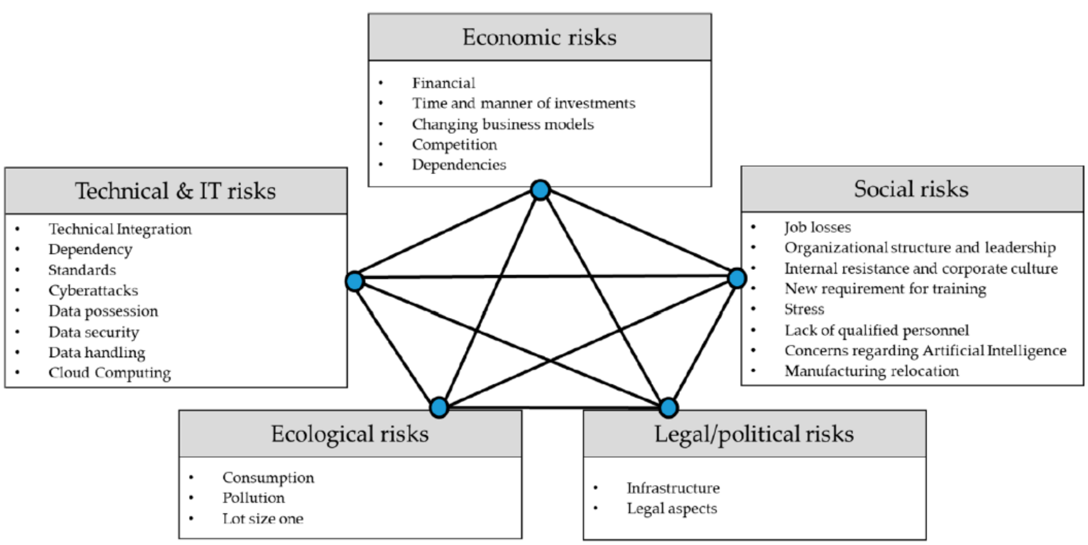

Figure 3. Industry 4.0 sustainable risk framework according to Birkel et al. (2019)

5. Discussion

5.1 Suitability of Identified Methods for Long-Term Sustainability

Based on the outcome of the content analysis described in paragraph 4, we want to discuss now the suitability of the single identified methodologies for a long-term sustainable introduction of Industry 4.0 in our companies. In Table 3, we see an evaluation of the suitability of the individual methods for a long-term sustainable introduction of Industry 4.0. Each of the 13 methods identified in the SLR has been categorized with a low, medium or high suitability. We define suitability as the ability of a method to make a positive contribution to the sustainable introduction of Industry 4.0 in companies. This includes the effectiveness of the introduction, in that the methods help to select the right Industry 4.0 technologies for the single company. Further, it includes the efficiency in the introduction, in that the methods accelerate the process of introduction. Next, it means also the quality of the introduction, in that the methods increase the success rate of the implementation process. Lastly, we mean also the capability of a method to contribute positively to a long-term maintenance and further development of the implemented Industry 4.0 technologies. The evaluation of suitability is based on the findings of content analysis and the experience of the authors of this paper. A low suitability means that the method contributes only partly and with a low positive impact to a sustainable introduction of Industry 4.0. A high suitability is characterized by a high positive impact on effectiveness, efficiency, quality and sustainability of the implementation process for Industry 4.0. A medium suitability can be placed between these two extremes.

Table 3. Suitability of identified methods for long-term sustainable introduction of Industry 4.0 (low-medium-high)

Author	Type	Method	Suitability	Notes
De Carolis et al. (2017)	Maturity-Based Assessment and Readiness Models	Readiness model with 5 maturity levels	medium	Assessment or readiness models for Industry 4.0 have a certain impact on the long-term sustainable introduction of Industry 4.0 and prioritize the I4.0 concepts to be implemented in a first step.
Dombrowski et al. (2017)	Lean-Based Methods	Framework to facilitate an enterprise selection process of Industry 4.0	low	The framework provides a general overview of Industry 4.0.
Rosin et al. (2019)		Industry 4.0 technologies improving Lean principles	high	Lean is asserted to be a set of principles for guiding manufacturing systems and many companies have adopted lean production techniques. Industry 4.0 technologies improve information readiness that contributes to long-term sustainability
Ghobakhloo and Fathi (2019)		Industry 4.0 transition based on lean-digitized manufacturing	high	Idem to previous point.
Müller et al. (2018)	Enabler and Barriers of Industry 4.0	Challenges and opportunities of Industry 4.0	low	A better overview of the main challenges and opportunities is helpful in a limited way for sustainable implementation.

Sony and Naik (2019)		Ten critical factors for successful implementation of Industry 4.0	high	The analysis of critical success factors is of crucial importance for long-term sustainability.
Rajput and Singh (2019)		20 most important barriers in introducing Industry 4.0	medium	Practitioners learn how to be better prepared and gain the knowledge of the main barriers in implementing Industry 4.0.
Halse and Jæger (2019)		Specific barriers for the introduction of Industry combined with circular economy	medium	Idem to previous point
Habib and Chimsom (2019)		Sustainable Industry 4.0 design principles	low	The design principles formulated are very general.
Moica et al. (2018)	Roadmap models	Three stage roadmap model	medium	The roadmap model is helpful for a general orientation on how to structure an Industry 4.0 implementation project.
Khakifirooz et al. (2018)		V-model diagram	medium	The V-model represents a structured approach for requirements analysis, implementation and validation of results when introducing Industry 4.0.
Mora Sanchez (2019)	Risk frameworks	Economic, ecological and social risks of Industry 4.0 technologies	medium	Awareness of potential risks increases the probability of success for the introduction of industry 4.0.
Birkel et al. (2019)		Risk framework for Industry 4.0	medium	Idem to previous point

Some of the mentioned models are very general and do not contribute to a sustainable implementation of Industry 4.0. Other works are of a medium suitability for a sustainable introduction of Industry 4.0, mainly to prepare practitioners before they start with the introduction process. Only three methods have been categorized with a high suitability. One summarizes ten critical success factors to be considered when starting an Industry 4.0 project, thus having a high impact on effectiveness, efficiency, quality and sustainability of the implementation process. In addition, the other two Lean-based methods have a high impact on this criteria. Effectiveness can be increased as those Industry 4.0 technologies can be selected that have a positive impact on already implemented Lean principles. The efficiency and success rate of the implementation of Industry 4.0 can be increased as the benefits will be immediately noticeable if based on previously implemented Lean principles. The sustainability of the implementation process will also be higher as continuous improvement is an important element of Lean.

5.2 Need for Further Research

Based on the results in Table 3 there is a need to synthesize the positive attributes of the above-describe methods, to develop new methodologies and to conduct further research in the long-term introduction of Industry 4.0 to create enterprises that are sustainable. Such an approach should first start with the analysis of the needs of those people that have to implement and to maintain Industry 4.0 in a company followed by defining the requirements for long-term sustainability of SMEs and investigating how Industry 4.0 might act as descriptor of the means to create enterprises

that are sustainable.. In the authors opinion, only such a procedure can lead finally to design solutions that aim not only to digitalize production, but also to make enterprises more sustainable and resilient.
We are starting a research initiative titled "Sustainable Small-Medium Enterprises (SMEs) 4.0 – Development of a Methodology for the Long-Term Introduction of Industry 4.0 to Sustain SMEs" where we give a certain focus to small and medium sized enterprises (SMEs) as they often struggle in the implementation of Industry 4.0.

6. Conclusions

In this contribution, we analyzed the scientific literature regarding the methods and tools for a long-term sustainable introduction of Industry 4.0. According to the research question, we looked into scientific works, in our case Scopus database, to find methods that already deal with the introduction of Industry 4.0 to sustain SMEs. At this moment, we have to clarify that, the study is not about investigating how to implement sustainability in Industry 4.0, but much more how to implement Industry 4.0 in companies so that companies are more sustainable!. Based on the advantages of SLR for this study we selected SLR as the research methodology. By using the SLR approach, we identified 13 works that propose methods and frameworks to improve the way of introducing Industry 4.0 in manufacturing. The content analysis and results of this investigation showed us, that there are several concepts and methods that, each by itself, is helping a system designer to improve the manufacturing system, but there is missing a comprehensive approach for designing and implementing small and medium manufacturing enterprises that are sustainable for the long-term. In the future, this lack in scientific literature should be closed by developing a methodology within the below acknowledged research project.

Acknowledgements

This research is part of the project "Sustainable SMEs 4.0 – Development of a Methodology for the Long-Term Introduction of Industry 4.0 to Sustain SMEs" and has received funding from the Autonomous Province of Bolzano (grant number TN2279).

References

Birkel, H. S., Veile, J. W., Müller, J. M., Hartmann, E., and Voigt, K. I., Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers. *Sustainability*, vol. 11, no. 2, pp. 384, 2019.

Booth, A., Sutton, A., and Papaioannou, D., *Systematic approaches to a successful literature review*. Sage, Newcastle upon Tyne, 2016.

De Carolis, A., Macchi, M., Negri, E., and Terzi, S., A maturity model for assessing the digital readiness of manufacturing companies. *Proceedings of IFIP International Conference on Advances in Production Management Systems,* 3-7 September 2017, Hamburg, Germany, pp. 13-20, Springer, Cham, 2017.

Denyer, D., and Tranfield, D., Producing a systematic review, in Buchanan, D.A. and Bryman A. (eds.) *The Sage handbook of organizational research methods*, Sage, Newcastle upon Tyne, pp. 671-689, 2009.

Dombrowski, U., Richter, T., and Krenkel, P., Interdependencies of Industrie 4.0 & Lean production systems: A use cases analysis. *Procedia Manufacturing*, vol. 11, pp. 1061-1068, 2017.

Durach, C. F., Kembro, J., and Wieland, A., A new paradigm for systematic literature reviews in supply chain management. *Journal of Supply Chain Management*, vol. 53, no. 4, pp. 67-85, 2017.

Ghobakhloo, M., and Fathi, M., Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing. *Journal of Manufacturing Technology Management*, Vol. 31 No. 1, pp. 1-30, 2019, https://doi.org/10.1108/JMTM-11-2018-0417.

Habib, M. K., and Chimsom, C., Industry 4.0: Sustainability and Design Principles. *Proceedings of the 20th International Conference on Research and Education in Mechatronics (REM)*, 23. - 24. May 2019, Wels, Austria, pp. 1-8, IEEE, 2019.

Halse, L. L., and Jæger, B., Operationalizing Industry 4.0: Understanding Barriers of Industry 4.0 and Circular Economy. *Proceedings of the IFIP International Conference on Advances in Production Management Systems,* 1-5 September, Austin, TX, USA, pp. 135-142, Springer, Cham, 2019.

Khakifirooz, M., Cayard, D., Chien, C. F., and Fathi, M., A system dynamic model for implementation of industry 4.0. *Proceedings of 2018 International Conference on System Science and Engineering (ICSSE)*, 28th to 30th June 2018, Taipei, Taiwan, pp. 1-6, 2018, IEEE.

Masi, D., Day, S. and Godsell, J., Supply chain configurations in the circular economy: A systematic literature review. Sustainability, vol. 9, no. 9, 1602, 2017.

Moica, S., Ganzarain, J., Ibarra, D., and Ferencz, P., Change made in shop floor management to transform a conventional production system into an" Industry 4.0": Case studies in SME automotive production manufacturing. *Proceedings of 7th International Conference on Industrial Technology and Management (ICITM)*, 7th to 9th March 2018, Oxford, United Kingdom, pp. 51-56, 2018, IEEE.

Müller, J. M., Kiel, D., and Voigt, K. I., What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*, vol. 10, no. 1, pp. 247, 2018.

Palmarini, R., Erkoyuncu, J. A., Roy, R., and Torabmostaedi, H., A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing*, vol. 49, pp. 215-228, 2018.

Petticrew, M. and Roberts, H., *Systematic reviews in the social sciences: A practical guide*. John Wiley & Sons, Hoboken, NJ, 2008.

Rajput, S., and Singh, S. P., Industry 4.0− challenges to implement circular economy. *Benchmarking: An International Journal*, Vol. ahead-of-print No. ahead-of-print, 2019, https://doi.org/10.1108/BIJ-12-2018-0430.

Rosin, F., Forget, P., Lamouri, S., and Pellerin, R., Impacts of Industry 4.0 technologies on Lean principles. *International Journal of Production Research*, pp. 1-18, 2019.

Sanchez, D. O. M., Corporate Social Responsibility Challenges and Risks of Industry 4.0 technologies: A review. *Proceedings of the Smart SysTech 2019; European Conference on Smart Objects, Systems and Technologies*, June 04- 05, 2019, Magdeburg, Germany, pp. 1-8, 2019, VDE.

Sendler, U. *Industrie 4.0: Beherrschung der industriellen Komplexität mit SysLM*. Springer Vieweg, Berlin Heidelberg, 2013.

Sony, M., and Naik, S., Critical factors for the successful implementation of Industry 4.0: a review and future research direction. *Production Planning & Control*, 2019, pp.1-17.

Tranfield, D., Denyer, D., and Smart, P., Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, vol. 14, no. 3, pp. 207-222, 2003.

Biographies

Erwin Rauch is an Assistant Professor in Manufacturing Technology and Systems at Free University of Bolzano, Italy. He received his BSc in Logistics and Production Engineering from the Free University in Bolzano (Italy). He also holds an MSc in Mechanical Engineering from the Technical University Munich (TUM) and a Master in Business Administration from the TUM Business School. Since 2007, he worked in a Management Consultancy as a Consultant for Lean management. Later he obtained his PhD in Mechanical Engineering at the University of Stuttgart in Germany. Since 2014, he is Assistant Professor at the Free University of Bolzano and Visiting Researcher at Worcester Polytechnic Institute (USA) and at Chiang Mai University (Thailand). Further, he is Head of the Smart Mini Factory laboratory for Industry 4.0 application at the Free University of Bolzano. His research interests include industry 4.0, axiomatic design, agile and reconfigurable manufacturing systems as well as optimization in SMEs.

David S. Cochran is a Professor of Systems Engineering and is the Director of the Indiana University Purdue University (IPFW) Center of Excellence in Systems Engineering in Fort Wayne, IN. He serves on the Board of Directors of the IIE Lean Division, the Orthoworx Advanced Manufacturing Council and is a member of the St. Francis Hospital Innovation Center. He earned a Ph.D. in Industrial and Systems Engineering from Auburn University and Masters of Industrial Engineering from the Pennsylvania State University. Prior to joining IPFW, Prof. Cochran established System Design, LLC and served as Adjunct Professor to Meijo University in the School of Business, Nagoya, Japan and the Southern Methodist University Systems Engineering program. He Developed the Production System Design Laboratory in the Department of Mechanical Engineering at the Massachusetts Institute of Technology and created an industry-based research program for Masters' and PhD students to do enterprise and manufacturing system design research and implementation with industrial sponsors. He is the two-time recipient of the Shingo Prize for Manufacturing Excellence for his research to advance enterprise design as an engineering discipline and was awarded the Norman Dudley Prize for Best Paper by the International Journal of Production Research in 2000.