Industry 4.0: why a definition is not needed (just yet)

Giovanna Culot (culot.giovanna@spes.uniud.it)
Polytechnic Department of Engineering and Architecture, University of Udine, Italy

Guido Nassimbeni
Polytechnic Department of Engineering and Architecture, University of Udine, Italy

Guido Orzes
Faculty of Science and Technology, Free University of Bozen, Italy

Marco Sartor
Polytechnic Department of Engineering and Architecture, University of Udine, Italy

Abstract

Industry 4.0 is currently a hot topic for practitioners and academia. However, as the concept originates in manifestos by government-sponsored initiatives or companies, a widely-accepted academic definition is still lacking with significant uncertainties and ambiguities concerning country-, industry- and size-specific factors. In this paper – through a systematic literature review – we categorize current definitions and provide the scientific and managerial communities with an analytical perspective to navigate the current ambiguity. We conclude by proposing some directions for research to shedding light on the phenomenon, although a rigorous definition of Industry 4.0 is neither possible nor needed at this point in time.

Keywords: Fourth Industrial Revolution, Conceptual framework, Systematic literature review

Introduction

The last few years have witnessed a mounting interest in the topic of the next industrial revolution, usually labeled as Industry 4.0. Policy makers, management consultants and private companies have all been intensifying their efforts in this direction. For its part, academia has not been immune to this fascination (Liao *et al.*, 2017).

A clear-cut identity and delimited scope of the phenomenon might be thus expected after such an extensive and qualified discussion. The opposite is true in the case of Industry 4.0, as scholars are still questioning the key points differentiating this from previous industrial revolutions (Khan and Turowski, 2014; Torn *et al.*, 2018), its distinctive characteristics (Kirazli and Hormann, 2015; Qin *et al.*, 2016; Hermann *et al.*, 2016), non-technological definitional elements (Schuh *et al.*, 2016; Torn *et al.*, 2018) and its expected outcomes (Roblek *et al.*, 2016; Schwab, 2016; OECD, 2017).

Some of these questions will be inevitably answered as research progresses counting on a growing number of empirical evidences, which have been limited so far. Industry 4.0 is, in fact, an industrial revolution announced *a priori* on the basis of the fact that a set of promising technological innovations was reaching maturity (Drath and Horch, 2014). This idea was first expounded outside a typical academic context in 2011, as a working group supported by the German Government presented the strategic initiative Industrie 4.0 (Kagermann *et al.*, 2013), using this term as the label of both a vision of the future and the action program to achieve it. Similar ideas have been brought up with different names in the private sector, such as General Electric's Industrial Internet (Evans and Annunziata, 2012) or Cisco's Internet of Everything (Bradley et al., 2013), as well as in academia with Smart, Cyber, Cloud manufacturing and the like (among others, Mittal *et al.*, 2016; Lee *et al.* 2016; Tao *et al.*, 2011).

Among the various terms, Industry 4.0 has eventually spread to the point of becoming also known to the public. In this process, however, many research groups, companies, think tanks and government advisors have often complemented the German vision with their peculiar point of view. As a result, different or even contradictory perspectives can now be subsumed under this label.

Against this backdrop, scholars have already expressed concerns and engaged in discussions about the "right" definition of the phenomenon or even proposed a new one (among others, Pereira and Romero, 2017; Hermann *et al.*, 2016; Torn *et al.*, 2018).

The aim of this paper is thus not to add yet another definition. The ambition is, on the contrary, to categorize current definitions and provide the scientific and managerial communities with an analytical perspective to navigate the current ambiguity. Our work is in fact based on the assumption that definitions are ultimately neither right or wrong at this point in time, but simply present different points of view on a phenomenon that not only is in the making (Lasi *et al.*, 2014; Drath and Horch, 2014), but is also meant to accommodate context-specific factors, such as country, size or industry (Zhou *et al.*, 2015; Wan *et al.*, 2015; Moeuf *et al.*, 2017; Radziwon *et al.*, 2014; McKinsey Digital, 2015).

Methodology

We developed a systematic literature review on contributions providing a definition of Industry 4.0 and related terms. We followed the approach proposed by Rousseau *et al.* (2008) and Tranfield *et al.* (2003), considering not only academic papers, but also a selection of non-academic publications to account for the relative novelty of the topic and the influence of industry, policy-makers and other players in shaping the concept.

With respect to the academic literature, we performed a search on title, abstract and keywords on Elsevier's Scopus. Two different sets of keywords have been utilized in a combined search. The first set comprised a total of 18 keywords including Industry 4.0 and the most common expressions used as synonyms or overlapping concepts. The second set comprised 13 further keywords, related to the semantic fields of "definition" and "classification". Overall, 2,766 publications were identified. Explicit exclusion criteria previously defined by the team have been deployed and 101 papers preselected. Thereafter the full-text of the pre-selected articles has been examined. Altogether, 64 academic publication were included in the analysis.

With respect to the non-academic literature, we looked online for publications of a set of different stakeholders: *governmental sources*, *international sources* in the form of both intergovernmental organizations and international think tanks, *consulting* firms, *standard-setting* bodies and *multinational companies* which have been cited by the academic papers we selected. As a result, we collected a total of 19 non-academic publications.

Thereupon, we proceeded with the coding analysis. Two researchers have been involved in the process and any inconsistency between their independent evaluations has been discussed within the team until agreement was reached. Each contribution has been broken down by means of six coding categories, which have been hypothesized *a priori* based on our experience and later on adjusted These categories are: *i) label of the phenomenon*; *ii) key enabling technologies*; *iii) other enablers* – that is what else it is required either prior to the adoption of new technological solutions or to fully unfold their potential; *iv) application scenarios* – whether the phenomenon is limited to the manufacturing sector or spaces in other fields; *v) distinctive characteristics* – peculiar and distinguishing properties ; *vi) possible outcomes*.

Finally, the results of the coding activity have been analyzed through two lenses. On the one hand, we looked for commonalities in order to understand the most agreed upon features of the phenomenon. On the other hand, we analyzed the differences, clustering the definitions according to the kind of publication, expressions used to label the phenomenon and year of publication. Main findings are summarized in Appendix.

Thematic findings

In this section commonalities and differences among the various definitions of Industry 4.0 and related terms are presented.

Label of the phenomenon

A variety of different terms emerges to mark the phenomenon in the examined contributions. However, Industry 4.0 has attracted the most attention so far, becoming *de facto* the label of the Fourth industrial revolution.

Other labels used in academia often appear in conjunction, or even as synonyms, with Industry 4.0 or Fourth industrial revolution, stressing nevertheless specific focal points. First, some labels – “Smart”, “Intelligent” or “Cyber Manufacturing” – draw attention to enhanced connectivity and computational capabilities (Radziwon *et al.*, 2014; Lee *et al.*, 2016). Second, “Social” and “Wisdom manufacturing” build on the opportunity for manufacturing to get closer to the final consumer / user (Xiong *et al.*, 2018; Yao *et al.*, 2017). Third, “Cloud manufacturing” promotes the idea of manufacturing servitization (among others, Fisher *et al.*, 2018). Fourth, the “Smart city” concept has also been related to advances in manufacturing (Kumar *et al.*, 2016). Finally, “Manufacturing-for-design” focuses on innovation is as new production methods might ease the constraints on designers (Chu *et al.*, 2016).

Non-academic sources show proportionally a greater variety of labels, in particular in the case of governmental sources, which often brand for their strategic initiatives for publicity reasons, and multinational companies.

Key enabling technologies

Technology is the fundamental definitional dimension for Industry 4.0 and related labels. However, there are significant differences in terms of technologies listed, terminology and level of detail.

Building on previous studies (Mittal *et al.*, 2016; Cristians and Methven, 2017; Kusiak, 2018; OECD, 2017), we identified 13 sub-categories of key enabling technologies. We also added a residual one, *Technological generics*.

We developed a framework mapping the key emerging technologies according to two dimensions (see Figure 1). The x-axis defines the nature of their respective components along a hardware/software continuum. The y-axis, instead, considers the kind of connectivity structurally implied by the technology, ranging from limited (Firm or department) to extended (Supply chain). The purpose of this analysis goes beyond a precise setting of the effective coordinates of each technology, which might be refined, and our goal is to provide a tool to orient in a complex and evolving technological landscape.

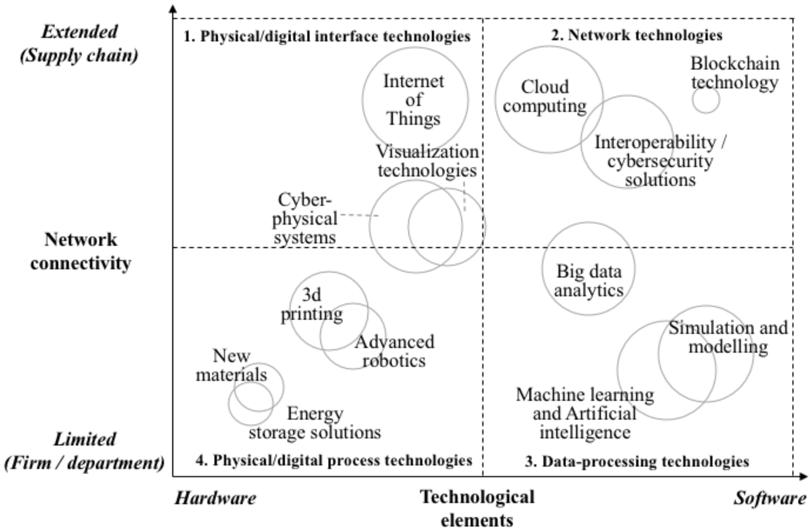

Figure 1 – Key enabling technologies clustered by the nature of their technological elements and kind of network connectivity - Bubble size proportional to occurrences in literature

Four different clusters can be identified. First, *Physical/digital interface technologies* (significant presence of hardware elements / extended network connectivity), which provide a bridge between the reality of machines and people at work and the cyber-space. This bridge can be two-way, as for *Cyber-physical systems* and the similar concept of the *Internet of Things* (Atzori *et al.*, 2017), or one-way machines to humans as in the case of *Visualization technologies* (Chryssolouris *et al.*, 2009).

Second, *Network technologies* (high share of software elements / extended connectivity) have mainly the role to support the functionalities of the other technologies. *Cloud computing* is, in this sense, an economically-effective way to increase on-site computational capabilities and storage capacity (Armbrust *et al.*, 2010). *Interoperability and cybersecurity solutions* provide secure seamless digital data flow across different hierarchical levels and production systems (Anderln, 2015; Kagermann, 2015). The *Blockchain technology*, which is still in its infancy, has the potential to support machines in conducting decentralized transactions (Ahram *et al.*, 2017).

Third, *Data-processing technologies* are mainly software-based and present a lower structural level of connectivity whenever they do not operate on cloud platforms. They include *Simulation and Modelling*, *Machine learning and Artificial intelligence* and *Big data analytics*, where the analysis can be real-time or off-line according to timeliness requirements (Chen *et al.*, 2014).

Finally, the fourth cluster is about *Physical/digital process technologies* with a high share of hardware components and limited connectivity. These are, in turn, technologies usually not thought of as digital, as *New materials* or *Energy storage solutions* (OECD, 2017), and devices typically used in production, like *3d printing*, or additive manufacturing, and *Advanced robotics.*

Some technologies, which have been the most mentioned in both academic and non-academic literature, show the strongest mutual interdependencies in their evolutionary path and actual application. *Physical/digital interface technologies*, in fact, imply not only connectivity of real objects, but a set of analytical and computational capabilities to be carried out in the cyber space (Lee and Lee, 2015; Lee *et al.*, 2015; Atzori *et al.*, 2017). These capabilities are typically provided by *Data processing technologies*, often as service applications delivered through *Cloud Computing*. The more the system encompasses units beyond corporate boundaries, the more *Interoperability and cybersecurity solutions* must be in place (Kagermann *et al.*, 2013; Anderln, 2015; Li *et al.*, 2017).

With respect to the technologies that have been less frequently mentioned, some patterns can be traced. First, academic publications generally present a narrower scope than non-academic ones, typically neglecting *Physical/digital process technologies*. Second, the background of the authors might play a role too in favoring technologies developed in computer science and related fields. Third, the label adopted, especially for academic definitions, accounts for some differences. At one extreme, Fourth / next industrial revolution and Smart manufacturing typically include most of the technologies. At the other extreme, Cloud manufacturing selects only the technologies supporting the development of a cloud platform. Fourth, the year of publication affects the selection of most recent advances, as in the case of *Blockchain technology*.

Other enablers

Non-technological enablers, i.e. *organizational enablers* and *new business models*, have also been reported in the examined literature, albeit with significantly lower frequency and level of detail. As for *organizational enablers*, the underlying assumption is that technology does not normally offer ready-to-use solutions and, unless changes in business processes and work practices are also implemented, no major productivity gain can be expected (Schuh *et al.*, 2014). Authors have discussed the topic on three levels: organizational design principles based on new collaboration tools (Lee *et al.*, 2016; Lu, 2017; Schuh *et al.*, 2014), flat organizational structures (Hofmann and Rüsch, 2017; Roblek *et al.*, 2016), skills and capabilities (among others, Hermann *et al.*, 2016; Hofmann and Rüsch, 2017; Schwab, 2016).

Regarding *business model innovation*, there are two different drivers calling for a change. On the one hand, companies will increasingly develop data driven services (among others, McKinsey Digital, 2015; Rußman *et al.*, 2015; Saldivar *et al.*, 2015). On the other hand, digital integration will facilitate communication along the value chain, but revenues and cost models will need to be revised (Pereira and Romero, 2017; Kagermann, 2015). This point has been especially raised by Cloud manufacturing.

Application Scenarios

Most of the emerging technologies have applications that are not confined to the manufacturing industry (Kagermann, 2015; Evans and Annunziata, 2012). Many economic sectors or branches, especially retail, financial services and transportation, are expected to evolve in parallel with manufacturing (Lasi *et al.*, 2014, Barreto *et al.*, 2017). Some definitions use different terms to define the scope of the discussion. For example, Industrie 4.0 has been defined as “the Internet of Things and Services in the manufacturing environment” (Kagermann, 2015), or Smart factory as “Industry 4.0 production system” (Roiko, 2017).

Technological advances might also blur the lines between industry and the final consumer / user. A higher consumer involvement has been especially advocated by promoters of Social manufacturing (Xiong *et al.*, 2018).

Distinctive characteristics

Some definitions have also discussed the typical properties of an Industry 4.0 manufacturing system beyond technological solutions that might change and evolve over time. The answer to this question is in what we call here *distinctive characteristics*. Some of them strongly echo the properties of the abovementioned key enabling technologies. *Virtual representation of the real world* and *Real-time information transparency* are in this sense typical functionalities of Physical-digital interface technologies (Lee *et al.*, 2015). Similarly, *Predictability* is enabled by the availability of real-time data handled through data processing technologies. *Modularity and reconfigurability* are possible thanks to programmable machines with mobile agents and robots (Roiko, 2017).

Organizational enablers need also to be brought into play in the case of *Autonomy*. This applies in fact to machines enhanced with Artificial Intelligence and Machine learning, but also to people at work (Hermann *et al.,* 2016; Evans and Annunziata, 2012).

For other distinctive characteristics business model innovation is also called into question. This is the case of *Process integration* (Kagermann *et al.*, 2013) and *Servitization of manufacturing capabilities* (Yadekar *et al.*, 2016).

Possible outcomes

Literature typically tackles the topic from two angles: firm- or supply-chain-level and country-level. The latter has been more addressed by non-academic papers. In the case of *firm-/supply-chain level outcomes*, potentially all the classic performance dimensions of operations management can be affected (McKinsey Digital, 2016. The real question here is not what technology can enable, but which priorities companies will set against a market scenario characterized, on the one hand, by increasingly fragmented and volatile demand, shorter innovation cycles, growing environmental concerns and a general trend toward the so-called experience economy (Tien, 2012; Lasi *et al.*, 2014), and, on the other, by decreasing labor cost differential between low- and high-income countries, aging workforce in the economic West and vulnerability of global supply chains (Ben-Daya *et al.*, 2017). Consistently with this scenario, the most common expectations are *Productivity*, *Flexibility* and *Mass customization / personalization*. Still extensively mentioned, albeit to a lesser extent, *Time- and cost-to-market* and *Environmental sustainability*. Vice versa, *New revenue streams*, *Quality* and *Lead-time* have not attracted significant attention.

A few contributions, mainly non-academic ones, have tackled *country-level potential outcomes*. It has been argued that the result of the process will be *economic growth*, in terms of GDP (Evans and Annunziata, 2012; Qin *et al.*, 2016). Possible effects on *employment* have also been discussed, typically with a positive outlook.

Discussion

This review of the literature underlines how current definitions of Industry 4.0 are overall generic, often contradictory and somehow overlapping with other terms, or labels of the phenomenon, whose definitions are in turn vague and ambiguous. Building on the findings of our analysis, we developed a set of statements and open questions.

Statement 1 – ***There is general agreement on the potentially disruptive impact of "Industry 4.0", however perspectives differ in terms of content and scope***

Definitions of Industry 4.0 diverge essentially in terms of *Key technologies.* Some sources present a comprehensive review of most technological innovations reaching maturity in these years. This is often the case of authors utilizing the label Fourth / next industrial revolution and Smart manufacturing. Other sources focus more strictly on the *Internet of Things*, or *Cyber-physical systems* and their mutually independent technologies, mostly regarded as the cornerstone of Industry 4.0.

Another significant difference is with respect of the *Servitization of manufacturing capabilities*, which has been mainly reported by the advocates of Cloud manufacturing do far

Finally, the scope of the phenomenon in terms of *Application scenario* is also mostly controversial. The trend toward digital connectivity is now massive in consumer products and is developing in many economic sectors (Lasi *et al.*, 2014). Many authors have selected specific labels to isolate industrial applications (Kagermann, 2015). These borders are however blurring as there is a strong interplay between innovation in manufacturing and, on the one hand, in complementary fields such as logistics, finance, retail, on the other, in consumer applications.

As for the other two coding categories, i.e. *Other enablers* and *Possible outcomes*, notwithstanding a broad agreement on their relevance, they have been just vaguely discussed in the definitions. Therefore,

Open Question 1 – ***In which directions should research focus to provide the most valuable insights to define Industry 4.0?***

Most of the research efforts have been focusing on the technological dimension so far. The time has come to consider other dimensions. There is, in fact, limited evidence in terms of *Possible outcomes*, especially at country-level. Against an overall general optimism, it needs to be acknowledged that effects on employment may be profound due to increasing automation and shift in the capabilities required (OECD, 2017; Schwab, 2016). This issue is also related to *Organizational enablers* and *Business model innovation*, which need to be revised to fully reap the benefits of technological application (Schuh *et al.*, 2014; Torn *et al.*, 2018).

It has been claimed indeed that an understatement of the role of *Other enablers* versus technology has been one of the main causes preventing manufacturing to move in the past toward increasing flexibility and product customization (Zhang *et al.*, 2014; Ren *et al.*, 2017; Brödner, In press). Many times, over the past 30 years, technology has raised hopes for a dramatic transformation of manufacturing and, overall,

Statement 2 – ***Many defining elements of Industry 4.0 are not a novelty.***

All the *Dinstinctive characteristics* now mentioned for Industry 4.0 have been already brought up and repeatedly: *Autonomy* and *Real-time information transparency* at least since 1980s (Brödner, In press), *Virtual representations of the real world* (Onosato and Iwata, 1993; Kusiak, 1992) and the *Servitization of manufacturing capabilities* since 1990s (Goldhar and Jelinek, 1990); *Process integration* (Yusufa *et al.*, 1999; Montreuil *et al.*, 2000), *Predictability* and *Modularity and reconfigurability* since early 2000s (Koren *et al.*, 1999, ElMaranghy, 2006).

In terms of *Key enabling technologies*, most of the tech ingredients now coming into play have been available for a while (Drath and Horch, 2014; Monostori, 2014; Li *et al.*, 2017). Now, however, many believe technologies to have reached maturity while a lower cost than the past sustains a wider adoption. Therefore,

Open question 2 – ***Are we facing a new paradigm at all? And if so, what is the difference versus the past?***

Several manufacturing paradigms, some more theoretical, others more applicative, have been conceived in the past leveraging technology to exceed the limits of mass production. It is particularly complex to mark the line between these paradigms and Industry 4.0 as there is no single breakthrough innovation, but rather a set of technologies evolving by convergence and combination, whose combined effect might be perceived as a revolution (Drath and Horch, 2014; Kagermann, 2015; Kirazli and Hormann, 2015; Kang *et al.*, 2016; OECD, 2017).

However, part of the issue is that there is no general agreement on what constitutes an "Industrial revolution" (Maynard, 2014). Looking back, even the number of revolutions occurred as of today is not agreed upon, with some seeing this as the third (Tien, 2012; Evans and Annunziata, 2012), the fourth (among others, Kagermann, 2015; Hermann *et al.*, 2016; Pereira and Romero, 2017; Liao *et al.*, 2017) or rather the fifth one (Ezell, 2016). With the spreading of the concept of Industry 4.0, the view of the German working group has eventually prevailed, in fact

Statement 3 – ***Current understanding of Industry 4.0 is strongly influenced by its initial conceptualization under the German "Industrie 4.0" initiative.***

Prior to Industrie 4.0 many other governmental or inter-governmental initiatives have supported technology-driven innovation in manufacturing, however not selecting any particular technology. The German working group, vice versa, decided to highlight just a few of them as the most impactful (Kagermann *et al.*, 2013). These technologies are, to date, the most mentioned by other definitions as the final report of the German working group has been often cited in academia (Liao *et al.*, 2017) and considered by other countries as a benchmark.

The recommendations of the Industrie 4.0 initiatives are however underpinned by an assessment of the economic and societal landscape of the country. The goal of productivity is typical of an advanced economy with highly qualified but aging labor force, flexibility of industries requiring a high degree or product variance, such as the German-dominated automotive sector. Against this background, we wonder

Open question 3 – ***The German prototype is generalizable, or a context-specific speciation will occur?***

The German context presents some specific characteristics in terms of main industrial sectors (automotive, automation, electrical equipment), company dimensions and ownership structure (with several medium size companies), and role of applied research (the Fraunhofer-Gesellshaft is a key example in this sense).

Some differences in how (and when) Industry 4.0 will manifest in practice emerge in the literature. First, the difference between advanced economies and emerging markets, as countries with high-cost skill labor should capitalize on productivity, whereas in other parts of the world new models might be adopted (McKinsey Digital, 2015; Rußman *et al.*, 2015; Zhou *et al.*, 2015; UNIDO, 2017). Second, the difference among industrial sectors, in terms of batch size, product variety and quality standards (Rußman *et al.*, 2015; Mittal *et al.*, 2016). Third, the difference of SMEs versus large corporation. The smaller the company size, the highest usually the requirements for flexibility and reactivity with, however, higher organizational and financial constraints (Moeuf *et al.*, 2017).

Overall, as Industry 4.0 penetrates different contexts, it might be expected that different elements will gain more relevance, or that even completely new technological and non-technological solutions will emerge. Moreover, research is rapidly moving also in other fields, such are quantum computing, that are supposed to have significant impact on the manufacturing sector and beyond (Kusiak, 2018). In fact,

Statement 4 – *Uncertainties and ambiguities about Industry 4.0 are due to a scenario that is rapidly evolving.*

This industrial revolution has been announced *a priori* (Lasi *et al.*, 2014). Following the German example, many other stakeholders have put forward their visions, each according to their own perspective. These visions need to be complemented or revised as technologies evolve and first evidences of actual application are available.

Therefore,

Open question 4 – *Is a definition of Industry 4.0 possible, or even needed, at this point in time?*

At present, the lack of historical perspective impedes the generalization of a precise and strict definition. Definitional efforts are nonetheless important for the different stakeholders currently involved in the debate to meet on a common ground. This process is, however, ultimately open-ended. Without pre-defined boundaries, research is better positioned to seize the enormous opportunities to investigate what is really happening and analyze the interplay among its various components.

Conclusions

In this paper we discussed the results of a systematic literature review focusing on the definition of Industry 4.0. We developed a set of four statements and open questions to and highlighted the areas were further investigation is needed. In conclusion, we claimed that a strict and precise definition might not be possible nor necessary at this point in time.

There are at least three major contributions of this paper to the scientific debate. First, we provide a ready-to-use compass for researchers to orient in the ambiguity of definitions. Second, we put forward some areas for future research. Third, we advocate a more dynamic understanding of Industry 4.0. As for the industry, our article overturns the view that the industry 4.0 has already happened and companies need to rush to embrace the new approach. Finally, with respect to policy making, the value of this paper lies again in the opportunity to get a comprehensive outlook of the different perspectives on Industry 4.0 and the role of country-specific factors.

Some limitations need to be acknowledged. First, our study is conceptual and empirical evidence will provide the basis for further considerations. Second, we included a limited number of non-academic publications compared to what is available online. Finally, the subjective perspective and disciplinary background of the authors might have played a role.

Appendix

Source	Label	Key enabling technologies															Other enablers		Application scenarios		Distinctive characteristics							Possible outcome									
			Cluster 1			Cluster 2			Cluster 3			Custer 4																Firm / Supply chain								Country	
		Number of occurrences / label	Internet of Things	Cyber-physical systems	Visualization technologies	Cloud computing	Interoperability / cybersecurity	Blockchain technology	Machine learning and Artificial Intelligence	Simulation and modelling	Big data analytics	3d printing	Advanced robotics	New materials	Energy storage solutions	Technological generics	Organizational enablers	Business model innovation	Engaging the final consumer / user	Beyond manufacturing	Process integration	Real-time information	Virtual representation of the real world	Autonomy	Predictability	Servitization of manufacturing	Modularity and reconfigurability	Productivity	Flexibility	Mass customization / personalization	Time- and cost-to-market	Environmental sustainability	New revenue streams	Quality	Lead-time	Economic growth	Edmployment
	Industry 4.0	29	25	29	11	24	16	1	20	14	19	7	6	-	-	13	13	9	7	9	24	26	24	24	12	5	12	22	22	24	15	9	12	10	6	3	2
	Cloud man.	13	13	2	2	13	10	-	8	12	4	2	-	-	-	1	2	11	6	-	12	8	12	4	2	13	1	11	10	8	8	5	2	3	5	-	-
	Smart man.	7	6	5	5	5	5	-	5	5	5	5	3	3	1	3	-	-	-	1	5	5	4	6	5	4	1	5	5	5	2	5	-	3	3	1	-
	Cyber man.	2	2	2	1	2	1	-	2	2	2	1	-	-	-	-	1	-	1	-	1	1	1	2	2	1	-	2	1	-	1	1	-	1	2	-	-
	Smart city	2	1	1	1	1	1	-	1	2	1	1	-	-	-	1	1	1	2	1	1	1	1	2	-	1	2	1	2	1	1	1	1	-	1	-	-
	4th ind. rev	2	1	-	-	2	1	-	2	1	1	2	2	2	1	1	-	-	-	2	1	1	1	-	-	-	1	1	1	1	-	1	1	-	-	2	1
	Intelligent enterprise	2	1	2	1	1	-	-	2	2	1	1	1	-	-	-	1	-	-	-	2	2	2	2	-	1	-	2	2	2	-	1	-	1	-	-	-
	Social	2	2	1	1	2	1	-	2	1	1	2	-	-	-	1	1	1	2	-	1	1	-	-	-	-	-	1	2	2	1	-	-	-	-	-	-
	Others	5	3	3	1	4	2	-	3	2	3	3	1	-	-	3	1	1	1	2	4	3	3	3	3	3	1	4	5	4	1	4	3	2	1	-	-
Total academic		**64**	**54**	**45**	**23**	**54**	**37**	**1**	**45**	**41**	**37**	**24**	**13**	**5**	**2**	**23**	**20**	**23**	**19**	**15**	**51**	**48**	**48**	**43**	**24**	**28**	**18**	**49**	**50**	**47**	**29**	**27**	**19**	**20**	**18**	**6**	**3**
Germany	Industrie 4.0	1	1	1	-	1	1	-	-	1	1	-	-	-	-	1	1	1	-	-	1	1	1	1	1	-	1	1	1	1	-	1	1	-	-	1	1
	Industry 4.0	2	1	-	2	1	1	-	1	2	1	2	2	1	-	2	1	-	1	-	1	1	1	1	1	-	1	2	2	-	2	1	2	2	1	-	-
	Others	6	5	4	6	5	5	2	3	6	5	5	5	5	4	2	5	4	1	4	6	5	1	3	2	2	2	6	3	6	5	5	5	4	3	6	3
	Industry 4.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-
	Others	3	3	-	2	3	3	1	3	2	3	3	3	3	3	1	3	3	3	2	2	2	2	2	2	1	1	3	3	2	3	3	3	3	3	3	2
Standard-setting	Others	1	1	1	1	1	1	-	1	1	1	1	1	-	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	-
Consulting	Industrie 4.0	2	2	1	2	2	2	-	2	2	2	2	2	-	1	-	2	2	-	-	2	2	2	2	2	1	2	2	2	2	1	2	2	2	2	1	1
Companies	Others	2	-	-	-	2	2	-	2	-	2	-	-	-	-	2	2	1	-	2	1	2	-	1	1	-	-	2	1	1	1	2	-	1	-	1	1
Total non.academic		**18**	**14**	**8**	**14**	**16**	**16**	**4**	**13**	**15**	**16**	**14**	**14**	**10**	**10**	**10**	**16**	**13**	**6**	**9**	**15**	**15**	**9**	**12**	**11**	**6**	**9**	**18**	**14**	**14**	**14**	**16**	**15**	**14**	**11**	**13**	**8**
Total		**82**	*68*	*53*	*37*	*70*	*53*	*5*	*58*	*56*	*53*	*38*	*27*	*15*	*12*	*33*	*36*	*36*	*25*	*24*	*66*	*63*	*57*	*55*	*35*	*34*	*27*	*67*	*64*	*61*	*43*	*43*	*34*	*34*	*29*	*19*	*11*