Technology in Society 70 (2022) 102028

Contents lists available at ScienceDirect

Technology in Society

journal homepage: www.elsevier.com/locate/techsoc

Implications of Industry 4.0 on industrial employment: A comparative survey from Brazilian, Chinese, and German practitioners

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ARTICLE INFO

Keywords:
Employment
Industry 4.0
Digitalisation
Staffing
Qualifications
Company size
Sector
Domain

ABSTRACT

Industry 4.0 is fundamentally changing industrial employment around the globe. Yet, the burgeoning scientific and societal discourses both highlight the need for more empirical evidence of how Industry 4.0 affects industrial employment by taking into consideration varying circumstances and preconditions. Given the heterogeneity of industrial development and technology proliferation between countries, it is crucial to understand and compare future outlooks of industrial practitioners from different regions. This study analyses how Industry 4.0 will affect industrial employment comparing practitioners' perceptions from Brazil, China, and Germany. Moreover, in our analysis we provide insights for different industrial sectors and company sizes. The study provides evidence that the effects of Industry 4.0 on staffing requirements differ between domains. Domains generally associated with larger shares of relatively low-skilled labour are expected to experience declines in staffing requirements, suggesting an increase in the polarisation between high- and low-skilled labour in terms of job opportunities. This effect is observable especially in larger companies. Moreover, an increase in the required employee qualifications is expected in all domains. Unlike in the other two countries, the inter-sectoral variability of perceptions is very small in China. There the company size seems to have the reverse effect on required qualifications compared to Brazilian and German companies, where less respondents expect higher qualifications for SMEs. Although we find sectoral differences both within and between countries, there is no clearly discernible trend allowing for generalizable sectoral conclusions, highlighting that impacts of Industry 4.0 on qualification should be further investigated under consideration of underlying contextual factors.

1. Introduction

A decade ago, the concept Industry 4.0 was introduced. Despite varying understandings of what exactly Industry 4.0 means, a high degree of automation, digital interconnectedness through information and communication technology (ICT) and a high degree of flexibility, which allows for an autonomous self-reconfiguration of all involved systems, can be regarded as the main characteristics of the concept [1–4].

The fundamental disruption of integrating digital technologies at the core of business operations according to the Industry 4.0 concept has affected the industrial production sector in many different ways. Among the most prominently discussed aspects are the effects on industrial employment, as these are of great importance for the socio-economic development of societies. Early studies have linked Industry 4.0 to the substitution of workers and rising unemployment [5–8], while later some scholars have argued that the extent to which Industry 4.0 will decrease employment is often overestimated [9,10] or might even lead to more industrial employment [11,12]. Thus, there is inconclusiveness regarding the employment-related effects of Industry 4.0. However, most publications have discussed anticipated theoretical assumptions, while empirical evidence looking at the actual changes is scarce [13].

We identify the dearth of empirical evidence on the impacts of

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https://doi.org/10.1016/j.techsoc.2022.102028
Received 7 January 2022; Received in revised form 12 April 2022; Accepted 10 June 2022
Available online 15 June 2022
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Industry 4.0 on industrial employment that compares different country perspectives [14,15] as a major research gap and hence aim to provide insights from practitioners' perspectives that are relevant both for advancing the scientific debate as well as for other societal actors and decision makers. For that purpose, we employ a survey-based approach, investigating developments at company level in three different regions of the world: Brazil, China and Germany. More specifically we present and compare the results of three national questionnaire-based surveys of company representatives which have been conducted in 2020 to find out how Industry 4.0 will be affecting staffing requirements, employee qualifications and in how far these employees will be assisted through intelligent assistance systems in Industry 4.0 contexts. Additionally, we analyse a variety of industrial sectors and compare findings with regards to differences in the size of companies. In doing so, we address prior calls that have emphasised the importance to account for the heterogeneity between and within countries concerning industrial development as well as proliferation of Industry 4.0 technologies when investigating the impacts of Industry 4.0 on employment [14,15]. In this regard, analysing practitioners' expectations from different countries has been stated to be a fruitful approach to also investigate future outlooks [14,15]. As companies and political decision makers equally strive to gain a better understanding of the short- and long-term effects of the proliferation of Industry 4.0, we aim to provide further insights on how practitioners' expectations on employment-related effects have developed ten years into the concept.

2. Theoretical background

2.1. Industry 4.0 & industrial employment

Industry 4.0 is likely to make certain manual tasks obsolete. Some early studies suggested that large shares of industrial jobs will be vulnerable to automation [5,8]. However, empirical evidence that this will lead to mass technological unemployment is scarce [16–18]. Additionally, scholars have also argued that such approaches are not suitable to assess the effects of automation as they are prone to technological determinism and therefore do not provide a realistic picture of the actual change processes occurring inside workplaces [14]. Such estimations should also take into account that jobs comprise multiple elements, not all of those can be automated [19].

With regard to empirical investigations, Focacci [20] compared the effects of increasing robot installations in China and Korea and found that robots did not always increase unemployment growth. In a study from Mexico, labor demand was increasing despite growing automation in jobs with a low and very low risk of automation [21]. In another study, technological progress boosted the labor market, while the substitution effect of employment was greater than the creation effect [22].

Due to the complex nature of the socio-technical interdependencies that occur when studying the effects of Industry 4.0 on employment, or the 'social shaping of technology' as Neufeind et al. [23] frame it, many scholars have demanded to investigate a broad variety of potentially influencing factors and have therefore also chosen different research methods. Some researchers emphasize that workers can resist changes [13], adapt to new challenges [6], and actively shape the way in which new hardware or processes are integrated into their business routines [24–26]. Demographic factors also seem to play a role, as the direction of labor demand was found to be inverse to the characteristics of gender, age, and education in one Mexican study [21]. The impact of Industry 4.0 on industrial employment also strongly depends on a number of contextual factors such as a countries' social protection mechanisms, education policies, the structure of the workforce [6,27–31], and factors on the company-level such as workplace organization or management strategies [32]. Fleming [33] has suggested the concept of 'bounded automation' which suggests that the pace of automation and digitalisation are limited by the costs of labour, power relations within the organisation and the characteristics of the job profile.

Other barriers to an increasing automation of labour are low wages and permissive employment regulation [34]. On a similar notion, sticking to labour-intensive processes might in some cases simply be less cost-intensive and high investments into automation technology might also contradict with shareholder desires for short-term profits, while high wages can work as an incentive to automate [35,36]. Especially in highly industrialized countries, the limited availability of qualified workforce as well as the reduced potential for further productivity improvements might limit the potential returns for additional capital investment [36].

Additional studies have focused on the societal advantages and disadvantages of digitally-enabled automation. On the side of the positive aspects, it is argued that automation may reduce repetitive tasks, reduce working hours and therefore enable workers to share productivity gains [14,37]. Spencer [38] questions whether work will actually be reduced by technological progress and argues that the threat workers associated with technological progress mainly comes from the erosion in the quality of work rather than from the loss of work. This notion is underlined by a study from Bulgaria, that identified the attitudes towards the dehumanizing effects of automation, peer-pressure, and the individual self-perception of workers as being the main drivers of the fear of automation [39]. Similar concerns are raised by Fleming [33] and Gallie [40]; who suggest that the broad application of digital technologies might eventually lead to intensified work and managerial control or even surveillance in highly automated companies.

Consequently, rather than considering it as an automatic job destroyer, Industry 4.0 should be seen as an industrial transformation process which involves a complex interplay of different social-economic and technological aspects [41].

2.2. Required qualifications

As physical operations on the shop floor are becoming more and more computerised and automated, greater importance shall be placed on soft, generic and transferable skills, with increasing emphasis on computer skills [42]. In order to keep up with the evolving technology, more creative, social and technical skills are expected to strengthen the position of workers in a changing work environment [42,43]. Hammershøj [26] emphasizes, that it is vital to focus on the unique human capacities of such as sensing, understanding, and dealing with sudden change, as digital technologies are only capable of solving tasks according to predefined rules or patterns found in data sets.

Most researchers agree that lower-skilled and older workers are more vulnerable and likely to be displaced through the introduction of more complex Industry 4.0 processes [44,45]. Because of the rising complexity of job profiles [46], different types of skills and a higher level of education will be requested [47–49], which the aforementioned groups are least well-equipped to respond to [46,50]. Positions for new jobs due to Industry 4.0 are more likely to be filled with highly-skilled workers [51,52]. These developments bear the risk that Industry 4.0 could increasingly polarise industrial employment. However, there are also contradicting findings that have identified an increase in different standardised activities due to the integration of digital technologies in an Italian automotive company [53]. Similarly, Achtenhagen and Achtenhagen [54] have observed reduced task variety and periods of 'boredom' even though workers required new skills to operate modern equipment and to interpret the increased volume of data. Such data-oriented skills along with process knowledge and interdisciplinary thinking have also been regarded as central elements for Industry 4.0 upskilling by enterprises [55]. A study from the automotive industry in South Africa revealed that employees who were not electrically inclined were found to be self-encouraged to seek technical and electrical skills to secure their employment in the sector [56].

On a more general level, a review of policy-focused literature identified a dominant narrative that treats current digital innovations primarily as a prime cause of challenges for the labour market, while the

primary responsibility for being able to operate successfully in this market is put on individuals in the form of 'upskilling' [57]. This impression is partially contradicted by another study, which shows only small effects of technological change on changing skills use, while the changing working environment seems to have larger effects [58]. Following this line of argumentation, labour-use strategies were found to depend less on process technologies per se, but rather on the institutional framework and the role of the organization in introducing new processes and technologies [14].

2.3. Company size & industry 4.0 implementation

Shevyakova et al. [55] have found differing foci with regard to the benefits taken from the implementation of digital technologies: while SMEs pay particular attention to customer-oriented processes and competences related to infrastructure and organization, large companies focus their attention on the technology itself and data-oriented topics. Mittal et al. find that SMEs often lack a clear vision of how to incorporate digital technologies and approaches in their operations [59]. This might be one reason, why the divide between companies that are taking advantage of Industry 4.0 and others which have not yet begun to digitalise and connect their work processes and equipment is growing [60]. Generally, larger companies are more likely to work in a digitally interconnected way than small- and medium-sized enterprises (SMEs) [60]. Some studies find that SMEs face more obstacles than larger firms [61] e. g. due to higher financial constraints [62,63]. The progress of the Industry 4.0 implementation in SMEs is often hampered by a lack of expertise and human resources [61,64]. Additionally, adopting digital technologies in SMEs is also hindered by the fact that many technologies are developed by large companies and therefore often do not suit the specific needs and challenges of smaller firms [59,62].

3. Methods

The main objective of this survey was to analyse how Industry 4.0 will affect industrial employment. We have decided to use a jointly developed questionnaire as the method of choice for data acquisition to ensure companies in all three countries are facing the same questions and answer options.

3.1. Questionnaire design

Based on a questionnaire used for a previous study by two authors among Chinese and German companies, the questionnaire was iteratively developed in multiple video conferencing sessions in English. The questionnaire started with a brief explicatory text describing the main characteristics of Industry 4.0 concept to ensure a shared understanding among participants. In order to allow for an easier understanding, we used the term 'Digitalisation and Interconnectedness' instead of the term 'Industry 4.0', which is mainly established in Europe. Apart from that it contained the basic structural elements: personal characteristics, company characteristics, and labour conditions.

The indicators were selected based on their perceived relevance in the scientific literature on Industry 4.0 and their relevance for industrial employment (see section State of the art). Variables were mainly measured through a 5-point Likert-type scale, multiple nominal (verbally described) options or, in few instances, allowed for a free text response. Additionally, the first two variants of questions also provided the two answer options "Don't know" and "No Answer". An overview of relevant questions addressed in this paper is provided in Appendix I.

The preliminary questionnaire was discussed with potential interviewees in China and Germany, collecting their feedback and comments for revising the design of the questionnaire. This finalised version was translated into German, Chinese and Brazilian Portuguese by professional translators and subsequently retranslated into German or English by native speakers who were not involved in the study, to verify the translation.

3.2. Data acquisition and analysis

The developed questionnaire was distributed in the official language of the respective country by separate teams in Germany, Brazil and China to acquire data. As a result, we have collected data in three different Chinese provinces: Zhejiang, Jiangsu, and Liaoning. The key parameters of the data acquisition process are provided in Table 1.

Suitable industry representatives were mainly identified through online research and contacted directly. In Brazil and Germany, a number of industry associations also advertised for participation in the study in their newsletters. In China, a service agency was used to identify and contact industry representatives. The final questionnaire was distributed to people working in the industrial sector in Brazil and Germany via the online tool Limesurvey. In China the data acquisition was also realized through an online survey and in some cases the questionnaire was completed via personal interviews.

Most of the data analysis for the complete data set was carried out in Microsoft Excel, while only some additional statistical tests were performed with the statistics tool R. We used R Studio to perform Fisher's exact test on contingency tables of various indicator combinations. Given the large tables (up to six possible replies per question), the p-value is estimated (i. e. not exact) based on $1e^7$ simulations.

3.3. Data set

Some basic characteristics of our sample can be taken from the following tables.

3.3.1. Personal characteristics

Table 2 shows the personal characteristics of our sample. Regarding the respondents' age the difference between the youngest sample, Liaoning, and the oldest one, Germany, is 9 years according to the mean and 11 years when comparing the medians. With regards to the gender balance, Germany and Brazil have similarly male-dominated samples, while the Chinese samples are more balanced. When looking at the respondents' positions in the company, Germany's and Zhejiang's samples have a much higher proportion of managers included compared to Brazil, Liaoning, and Jiangsu.

3.3.2. Company characteristics

In terms of company size, Germany and the Chinese samples most prominently include companies which have less than 250 employees, which are also called small and medium-sized enterprises (SMEs). However, although the proportion for Germany and Zhejiang is the same, Liaoning and Jiangsu are far more concentrated towards this company size. At the same time, whereas companies which have more than 5000 employees make up more than a third of the Brazilian and German samples, the values are far lower for the Chinese samples. Overall, we see considerable variation between the samples with regards

Table 1
Key parameters of the data acquisition process.

	Format	Duration	Sample size
Germany	Limesurvey (online survey)	12/2019–05/2020	**105**
Brazil	Limesurvey (online survey)	03/2020–06/2020	**117**
China: Zhejiang	online survey and questionnaire	09/2019–06/2020	172
China: Jiangsu	online survey and questionnaire	09/2019–06/2020	125
China: Liaoning	online survey and questionnaire	09/2019–06/2020	148
China total			**445**

Table 2
Age, sex and position of company of respondent.

Country/Province	Age		Sex			Position in Company		
	Mean	Median	Female	Male	Other	Management	Operational	Other
Germany (n = 104)	45	46	15%	85%	0%	71%	23%	6%
Brazil (n = 83)	37	34	16%	84%	0%	45%	30%	25%
Liaoning (n = 145)	36	35	38%	62%	0%	39%	49%	13%
Jiangsu (n = 125)	41	42	42%	58%	0%	38%	51%	10%
Zhejiang (n = 171)	39	38	45%	55%	0%	78%	14%	8%

to this indicator in Table 3.

The samples diverge regarding companies' sector. Although in four of the five samples one third of the companies are in plant and mechanical engineering, the other sectors differ in weight across the samples. For instance, whereas ICT makes up around a third of the sample for Liaoning and Jiangsu, the proportion is less than 10% for Germany, Brazil, and Zhejiang (see Table 4).

4. Results

4.1. Staffing requirements

Question: How will 'Digitalisation and Interconnectedness' affect staffing requirements in your company (in the different phases of production)? The company will require: (1 – Far less workers .. 3 – No change expected .. 5 – Far more workers).

4.1.1. Overall

4.1.1.1. Development domain. With regard to the development domain, German participants have the highest shares when adding up the two answer options for a growing number of jobs ("more workers" and "far more workers"). More than half of all German participants[1] (52.4%; n = 105) expect this effect due to Industry 4.0 here compared to 48.8% in China (n = 441) and 42.6% in Brazil (n = 115). However, Brazilian companies are responsible for the by far highest share of answers in the "far more workers" category with 22.6% (see Fig. 1). On the other end of the scale, Chinese companies have the highest combined share for a decreasing number of jobs with a combined 28.6% of respondents expecting "less workers" or "far less workers" in the development domain due to Industry 4.0 (BRA: 12.2%; GER: 3.8%). It is also noticeable that 12.4% of German respondents were uncertain about these impacts.

4.1.1.2. Manufacturing domain. With regard to the manufacturing domain, Brazilian respondents provide the highest share when adding up the share for the two answer options "more workers" and "far more workers". 27.8% of Brazilian participants (n = 115) have selected one of these two options, while only 12.9% of Chinese (n = 441) and 6.7% of German (n = 104) respondents did so. From the German participants 44.2% expected no change in employment in the manufacturing domain due to Industry 4.0, while most of their Chinese counterparts (61.2%) expect a loss of jobs by selecting either "less workers" or "far less workers".

Table 3
Company size.

Company size	Germany	Brazil	Liaoning	Jiangsu	Zhejiang
<250	37%	20%	53%	69%	37%
250–1000	18%	19%	9%	24%	31%
1000–2500	8%	13%	4%	1%	13%
2500–5000	2%	12%	20%	3%	5%
>5000	35%	35%	14%	3%	14%

Table 4
Sector.

	Germany	Brazil	Liaoning	Jiangsu	Zhejiang
Automotive	18%	29%	20%	10%	12%
Plant and mechanical engineering	41%	13%	28%	36%	35%
ICT	8%	5%	28%	33%	9%
Electronics	8%	4%	7%	19%	11%
Other	26%	49%	16%	2%	33%

4.1.1.3. Assembly domain. The overall impression for the assembly domain is similar to the manufacturing domain. Brazilian respondents have by far the highest share for the two answer options signaling a growing number of jobs ("more workers" and "far more workers"). With 22.6% of Brazilian participants (n = 115) selecting one of these two options they account for a higher share than both Chinese (10.7%; n = 441) and German (4,.8%; n = 104) respondents combined. Here again, almost half of all German participants (48.1%) expect no change in employment in the assembly domain due to Industry 4.0. Their Chinese counterparts mainly expect job losses as 60.1% of them expect either "less workers" or "far less workers".

4.1.2. Company size

4.1.2.1. Development domain. Among the SMEs, Brazilian respondents account for the highest share of answers expecting far less workers for the development domain due to Industry 4.0 (8.7%), while the Chinese data is the most heterogenous with significant shares expecting either less or more workers (see Table 5). With regard to respondents from companies with more than 250 but less than 5000 employees, far more German respondents expect growing job numbers than their Brazilian and Chinese counterparts. The high share for option "no change" in Brazil (37.5%) is also noteworthy. The Chinese sample is heterogeneously split with 29.5% for combined less or far less workers. When looking at large companies with more than 5000 employees, not a single respondent expected far less workers in the Brazilian and Germany sample (CHI: 13.0%). It is noticeable that in Brazil a third of all participants from large companies expect far more workers in the development domain, more than double the values for this option of German (16.2%) or Chinese (13.0%) respondents.

There seems to be a tendency for expectations for the development domain to be leaning more towards growing number of jobs with increasing size of the companies. We performed Fisher's exact test to check for association between expected impact of Industry 4.0 on staffing requirements and company size in the development domain. No significant association was found in either Germany (p = 0.195), Brazil (p = 0.196) or China (p = 0.191).

4.1.2.2. Manufacturing domain. For the manufacturing domain,

[1] "n" represents the total number of respondents from a particular region that meet the criteria of the subject matter just described.

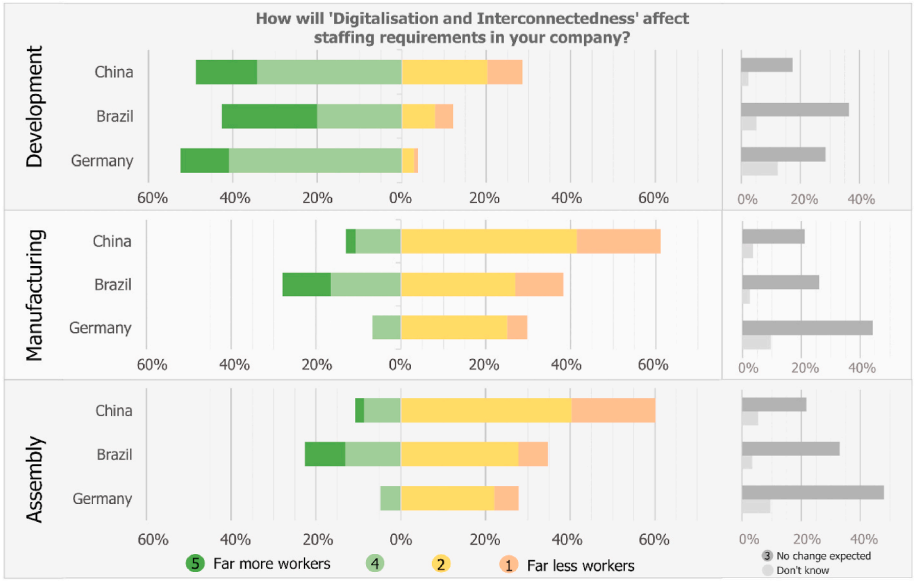

Fig. 1. Distribution of expectations for changing staffing requirements in the domains development, manufacturing and assembly.

Table 5
Share of respondents expecting more or far more workers in the development domain due to Industry 4.0 implementation per company size.

More or far more workers	GER (n = 105)	BRA (n = 115)	CHI (n = 441)
1 < employees <250	41.0%	39.1%	50.7%
250 < employees <5000	62.1%	37.5%	43.4%
5000 < employees	56.8%	52.8%	58.7%

German SMEs expect mainly moderate job losses due to Industry 4.0. Both options (less or far less workers) are chosen much less frequently compared to the overall values for Germany. In that category, German respondents have neither selected the answer option "far less workers" nor for the opposite option "far more workers", while the majority expects no change at all (51.3%). The Brazilian sample is almost evenly split, with 29.2% expecting more or far more workers and 33.3% expecting less or much less workers as a consequence of the Industry 4.0 implementation. In the next bigger category (250 - 5000 employees), the picture is very similar: no one selected the edge options and 44.8% expected no change from the German companies. The Brazilian sample contains the highest share (with 19.6%) of respondents expecting more or far more workers, while almost 60% of Chinese companies expect a loss in employment for the manufacturing domain due to Industry 4.0 (see Table 6). Expectations from big German and Chinese companies lean towards job losses, which is also underlined by the fact that not a single Chinese participant and only 5.6% of German participants selected one of the two options suggesting increasing number of jobs. Here again, the Brazilian sample draws a different picture, with 40.0% for the combined options suggesting increasing number of jobs.

With regard to the German and the Chinese sample, there seems to be a tendency for expectations for the manufacturing domain to lean more towards job losses with increasing size of the companies. We performed Fisher's exact test to check for association between expected impact of Industry 4.0 on staffing requirements and company size in the manufacturing domain. A significant association was found in Germany ($p = 0.0006847$), in Brazil ($p = 0.0127$) and also in China ($p = 0.02454$).

4.1.2.3. Assembly domain. Similar to the manufacturing domain, German SMEs expect mainly moderate job losses due to Industry 4.0 for the assembly domain: 59.0% do not expect any change and not a single participant opted for one of the two edge categories here. In the other two countries the picture tends more towards bigger job losses (see Table 7). In the next bigger category (250 - 5000 employees), very few respondents opted for the "far more workers" option (GER: 0.0%; BRA: 1.8%; CHI: 0.6%), while high shares of respondents, do not expect any change in that domain (GER: 48.3%; BRA: 41.1%; CHI: 19.9%). For the biggest companies (5000+ employees) the data is similar to the manufacturing domain: hardly any expectations for increasing job numbers in Germany (combined 2.8%) and China (combined 2.2%), but very high shares expecting less or far less workers. The Brazilian sample is evenly split with 37.1% each deciding for the two combined options for increase and decrease of jobs respectively.

With regard to the German and the Chinese sample, there is a clear tendency for expectations to lean towards job losses with increasing size of the companies for the assembly domain. Like for the manufacturing domain, the Brazilian sample seems to be an outlier in that regard. We performed Fisher's exact test to check for association between expected impact of Industry 4.0 on staffing requirements and company size in the assembly domain. A significant association was found in Germany ($p = 0.001479$), in Brazil ($p = 0.009868$), and also in China ($p = 0.01109$).

4.1.3. Sector

4.1.3.1. Development domain. The expectations regarding the effects of Industry 4.0 on employment in the development domain vary both between sectors and countries. To provide an impression of the

Table 6
Share of respondents expecting less or far less workers in the manufacturing domain due to Industry 4.0 implementation per company size.

Less or far less workers	GER (n = 104)	BRA (n = 115)	CHI (n = 441)
1 < employees <250	10.3%	33.3%	59.8%
250 < employees <5000	31.0%	42.9%	59.0%
5000 < employees	50.0%	34.3%	76.1%

Table 7
Share of respondents expecting less or far less workers in the assembly domain due to Industry 4.0 implementation per company size.

Less or far less workers	GER (n = 104)	BRA (n = 115)	CHI (n = 441)
1 < employees <250	5.1%	37.5%	55.9%
250 < employees <5000	31.0%	32.1%	63.3%
5000 < employees	50.0%	37.1%	69.6%

heterogeneity of these values between the three countries Fig. 2 shows the distribution of "average values" per sector for the development domain - even though this value is statistically not precise for Likert-like data. From the Chinese and German companies the two combined categories less or far less workers were selected most frequently from the automotive sector (CHI: 35.9%, n = 64; GER: 10.5%, n = 19). 30% of Brazilian companies are expecting less or far less workers in the development of the electronics sector making it the sector expecting the biggest job losses. 75% of German participants even expect far more workers due to Industry 4.0 technologies here, while in Brazil 83.3% expect either more or far more workers for the ICT development domain in the future. In China the plant and mechanical engineering sector is expecting the highest increase of jobs on average.

4.1.3.2. Manufacturing domain. In Germany not a single respondent from the ICT, plant and mechanical engineering or electronics sector expected staffing requirement to grow. The automotive sector (n = 18) has the highest share with a combined 38.9% expecting less or far less workers in manufacturing due to Industry 4.0. In Brazil (combined 37.9%; n = 29) and China (combined 57.8%; n = 64) this sector accounts for the second highest share for these two combined options. The highest value expecting less or far less workers in manufacturing due to Industry 4.0 is the plant and mechanical engineering sector in China (combined 62.5%; n = 144) and electronics in Brazil (combined 40.0%; n = 10).

4.1.3.3. Assembly domain. Expectations in the assembly domain are similar to those of the manufacturing domain. Electronics is the sector expecting the biggest job decrease in Germany (combined 62.5%; n = 8) and Brazil (combined 50.0%; n = 10) - even though the low number of respondents have to be taken into account here. While in China this is the case for plant and mechanical engineering (combined 61.1%; n = 144) and similarly the automotive sector (combined 60.9%; n = 64). It is also noteworthy that the average values for all Chinese sectors are extremely similar in the assembly domain.

4.2. Employee qualifications

Question: To what extent will 'Digitalisation and Interconnectedness' affect the qualifications that your company requires of its employees (in the different phases of product creation)? (1 – Much lower … 3 – No change expected … 5 – Much higher).

4.2.1. Overall

4.2.1.1. Development domain. All three countries have in common that far smaller shares of respondents expect Industry 4.0 to lead to lower required employee qualifications rather than higher qualifications in the development domain (see Fig. 3). Whereas 0% and 0.9% of German and Brazilian respondents opted for one of the combined answer options "lower" or "much lower" respectively, 12.9% of Chinese respondents expect a decline in the required employee qualifications due to Industry 4.0 in the development domain. In contrast, combining the answer options "higher" and "much higher", this accounts for 65.7% of German, 80.0% of Brazilian and 68.0% of Chinese surveyed firms.

4.2.1.2. Manufacturing domain. The results concerning the manufacturing domain show similarly unbalanced expectations, with shares of 7.8%, 5.2% and 16.6% of respondents in Germany, Brazil and China respectively expecting either lower or much lower required employee qualifications. This is contrasted by much greater shares of 55.3% (Germany), 62.1% (Brazil) and 62.1% (China) expecting higher or much higher required employee qualifications due to Industry 4.0. Moreover, a notable 25.9% of Brazilian firms expect no changes in required employee qualifications.

4.2.1.3. Assembly domain. Our results regarding required employee qualifications in the assembly domain portray a slightly different picture. Firstly, considerable shares of 28.9% of German firms, 36.2% of Brazilian firms and 23.1% of Chinese firms expect no changes. Secondly, although still much more prevalent than expectations of declining requirements of employee qualifications, shares of 39.4%, 50.9% and 51.9% in Germany, Brazil and China respectively expect either "higher" or "much higher" required qualifications in the assembly domain, which is less than in the domains of development and manufacturing for all countries.

4.2.2. Company size

4.2.2.1. Development domain. In all three countries, the majority of SMEs expects either higher or much higher required employee qualifications due to Industry 4.0 in the development domain (see Table 8). Similar to overall values, this share is considerably higher in smaller Brazilian firms (78.3%) than in smaller German firms (51.3%). Among companies with this firm size, a much greater share of German respondents (35.9%) expects no changes in required qualifications, as

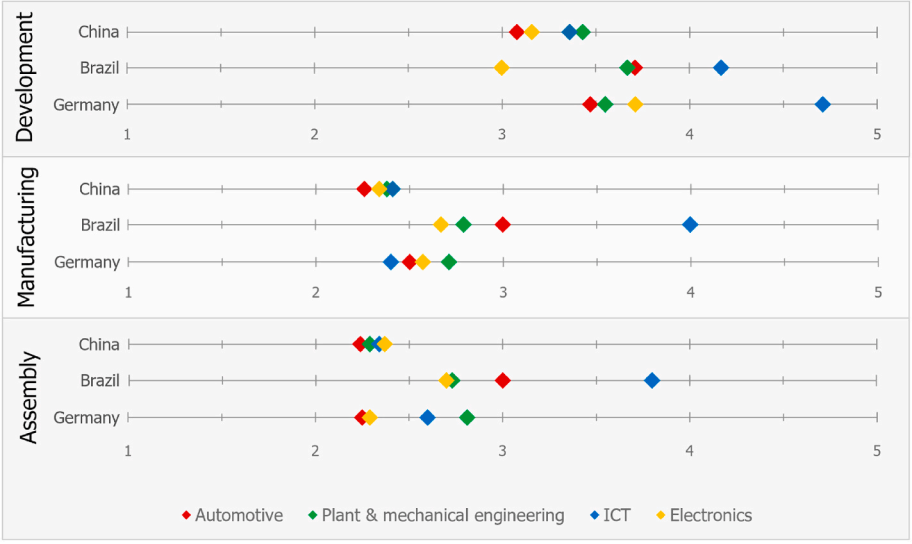

Fig. 2. Average values for expectations regarding changing staffing requirements in the domains development, manufacturing and assembly per sector.

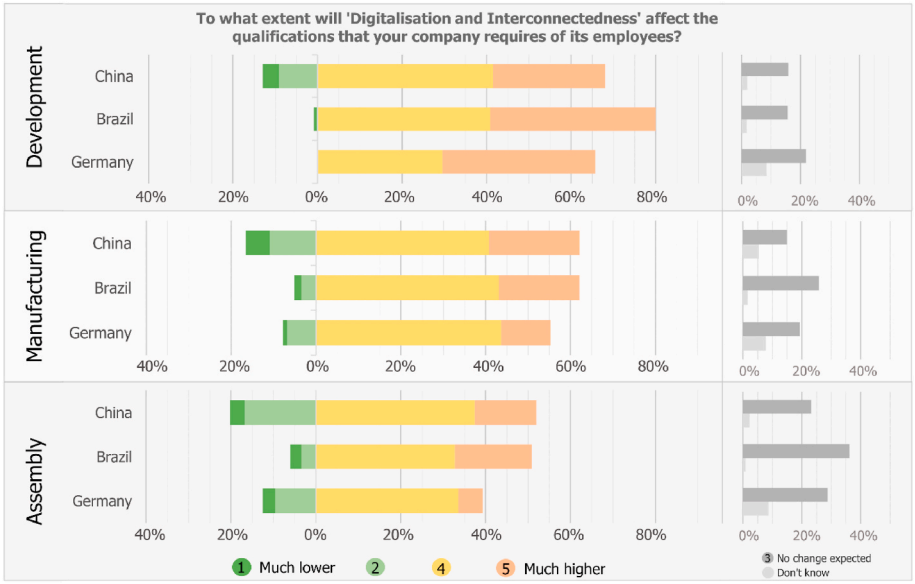

Fig. 3. Distribution of expectations for changing skill requirements in the domains development, manufacturing and assembly.

Table 8
Share of respondents expecting higher or much higher qualification requirements in the development domain due to Industry 4.0 implementation per company size.

Higher or much higher qualifications required	GER (n = 105)	BRA (n = 115)	CHI (n = 441)
1 < employees <250	51.3%	78.3%	69.4%
250 < employees <5000	72.4%	73.2%	69.3%
5000 < employees	75.7%	91.7%	56.5%

opposed to only 17.4% in Brazil and 14.4% in China. Remarkably, there are bigger shares of companies expecting higher qualification requirements in large firms with more than 5000 employees in both Germany (75.7%) and in Brazil (91.7%). However, the opposite is the case for large Chinese firms, where only 56.5% of respondents expect higher or much higher qualification requirements. It is also worth noting that among large Chinese firms, 19.6% expect lower or much lower requirements, whereas no single German or Brazilian firm with more than 5000 employees had similar expectations.

We performed Fisher's exact test to check for association between expected impact of Industry 4.0 on required qualifications and company size in the development domain. A significant association was found in Germany ($p = 0.0303$), but not in Brazil ($p = 0.3812$) or in China ($p = 0.07762$).

4.2.2.2. Manufacturing domain. Compared to the average overall values, smaller shares of surveyed SMEs in all countries expect higher or much higher qualification requirements due to Industry 4.0. For instance, in Germany, only 35.1% of respondents among SMEs (see Table 9) had such expectations, as opposed to an average of 55.3%. However, this discrepancy was much smaller in China with a difference of less than 2% compared to average values. Similar to the development domain, there are varying trends between countries when looking at responses for larger firms (>5000 employees). That is, in both Germany and Brazil, much larger shares among this group expect higher or much higher qualification requirements than their SME counterparts in the respective country. The opposite is the case for Chinese firms, although this reverse trend is less pronounced.

We performed Fisher's exact test to check for association between expected impact of Industry 4.0 on required qualifications and company size in the manufacturing domain. A significant association was found in Germany ($p = 0.01747$), but not in Brazil ($p = 0.09405$) or in China ($p = 0.4635$).

4.2.2.3. Assembly domain. In the assembly domain, fewer surveyed SMEs in Germany and Brazil expect lower or much lower qualification requirements compared to the respective country average (7.9% as opposed to 12.5% in Germany; 4.2% as opposed to 6.0% in Brazil). A similar trend was not found in Chinese firms. Among the group of firms with a size of 250–5000 employees, a significant share of Brazilian respondents expects no changes in required qualifications (41.1%), compared to only 27.6% in Germany and 20.5% in China. The expectations for higher or much higher required qualifications can be seen in Table 10.

We performed Fisher's exact test to check for association between expected impact of Industry 4.0 on required qualifications and company size in the assembly domain. A significant association was found in China ($p = 0.005869$), but not in Germany ($p = 0.3228$), nor in Brazil ($p = 0.09407$).

Table 9
Share of respondents expecting higher or much higher qualification requirements in the manufacturing domain due to Industry 4.0 implementation per company size.

Higher or much higher qualifications required	GER (n = 105)	BRA (n = 115)	CHI (n = 441)
1 < employees <250	35.1%	45.8%	60.3%
250 < employees <5000	62.1%	62.5%	66.9%
5000 < employees	70.3%	72.2%	54.4%

Table 10
Share of respondents expecting higher or much higher qualification requirements in the assembly domain due to Industry 4.0 implementation per company size.

Higher or much higher qualifications required	GER (n = 105)	BRA (n = 115)	CHI (n = 441)
1 < employees <250	26.3%	41.7%	48.0%
250 < employees <5000	44.8%	46.4%	57.8%
5000 < employees	48.7%	63.9%	50.0%

4.2.3. Sector

4.2.3.1. Development domain. Comparing expectations for combined "lower" or "much" lower required qualifications, there are only negligible deviations between sectors (see Fig. 4). Neither in Brazil nor in Germany did a single respondent from the automotive, plant and mechanical engineering, ICT, and from the electronics industry expect a decline in required qualifications. In China, this share was highest in the ICT industry (15.2%, n = 99). Regarding the opposite expectations of "higher" and "much higher" required qualifications, we find the greatest share among German surveyed firms in the automotive industry (79.0%, n = 19), similar to Brazilian firms (93.1%, n = 30) and also Chinese firms (73.4%, n = 64).

4.2.3.2. Manufacturing domain. In the manufacturing domain, perceivable differences from overall values regarding expectations of "lower" and "much lower" required qualifications can be found in Brazil. Particularly in the ICT industry (16.7%, n = 6) and the electronics industry (30%, n = 10) did greater than average shares (5.2%) expect a decline of required qualifications, even though the low number of respondents limits the validity of this result. In the plant and mechanical engineering sector, it is noteworthy that especially a large share of German firms (36.6%, n = 41) expects no changes. Moreover, "higher" or "much higher" required qualifications are expected most frequently in the automotive industry in Brazil (73.3%, n = 30) and the plant and mechanical engineering sector in China (70.8%, n = 144).

4.2.3.3. Assembly domain. Looking at expectations of (much) lower required qualifications, little differences can be found between the sectors within the respective country. Again, we find a relatively large share of German respondents from the plant and mechanical engineering sector expecting no changes (42.9%), compared to 37.5% in Brazil and 25.0% in China. Significant differences can be found regarding expectations of "much higher" required qualifications, which account for 37.5% (n = 8, limited validity due to low number of respondents) in Germany, but 0% in the German automotive industry (n = 19). In China, sector-specific differences are not as pronounced, ranging from 9.3% (n = 54) in the electronics industry to 17.2% in the ICT industry.

4.3. Intelligent assistance systems

Question: How often will your employees be supported in complex tasks by intelligent assistance systems in the next 5 years (e.g. by explanatory software on tablets or per head-mounted display)? (1 – Much less often … 3 – No change expected .. 5 – Much more often).

4.3.1. Overall

At least two thirds of respondents in all three countries expects workers to get supported with complex tasks by intelligent assistance systems in the next 5 years (see Table 11).

4.3.2. Company size

The values seem to change depending on the company size in the sense that smaller companies are expecting support through intelligent assistance systems less often than bigger companies (see Table 12).

We performed Fisher's exact test to check for association between expected impact of Industry 4.0 on support by intelligent assistance systems and company size. A significant association was found in Germany (p = 0.02021), but not in Brazil (p = 0.09407), nor in China (p = 0.07579).

5. Discussion

5.1. Staffing requirements

Our data regarding staffing requirements shows that the majority of participants expects employment to be likely to expand in the development domain, while in the manufacturing and assembly domains positions will likely be reduced. Even though the specific numbers vary between the three countries, the overall impression supports findings in the literature that expect positions of high-skilled workers to be less affected by Industry 4.0, which is also similar to the findings from a

Table 11
Share of respondents expecting employee support for complex tasks through intelligent assistance systems per country.

Intelligent assistance	Germany (n = 105)	Brazil (n = 116)	China (n = 441)
1 - Much less often	0,95%	0,86%	3,17%
2	0,00%	3,45%	10,43%
3 - No change expected	14,29%	4,31%	13,38%
4	40,00%	31,90%	47,17%
5 - Much more often	26,67%	50,86%	20,18%
Don't know	12,38%	4,31%	3,63%
N/A	5,71%	4,31%	2,04%

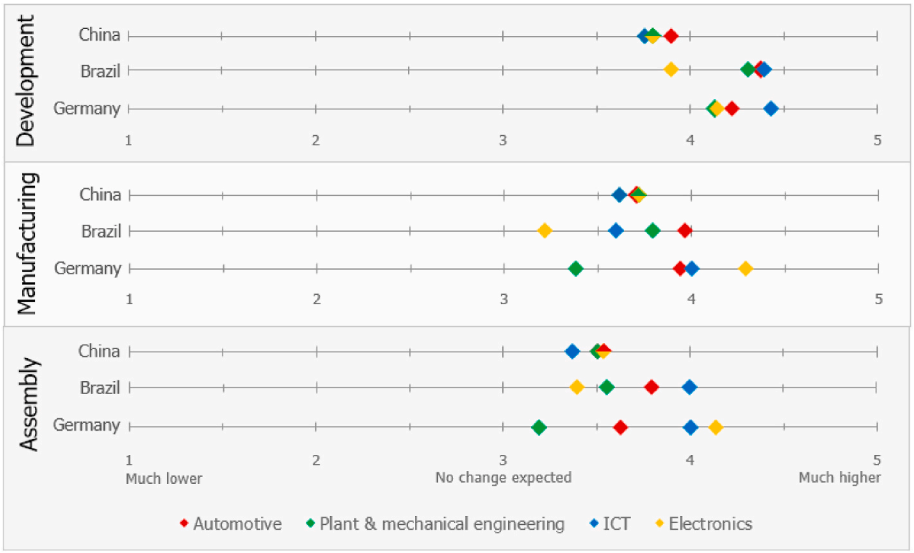

Fig. 4. Average values for expectations regarding changing skill requirements in the domains development, manufacturing and assembly per sector.

Table 12
Share of respondents expecting employee support for complex tasks through intelligent assistance systems per country and company size.

Often or much more often	GER (n = 105)	BRA (n = 116)	CHI (n = 441)
1 < employees <250	41.0%	79.2%	65.9%
250 < employees <5000	72.4%	83,9%	69.3%
5000 < employees	89,2%	83.3%	67.4%

previous study [65] and can be related to the more general discussion around skill-biased technological change [66,67]. However, even though our data adds to the findings in literature that are forecasting an increasing polarisation in industrial employment, the quality of this change is expected to be less significant compared to many publications from the early years of the Industry 4.0 concept [5,8]. Another factor underlining this impression is the relatively high share of participants (especially in Germany and Brazil) expecting no change to staffing requirements at all. This could strengthen the position of authors raising caution to consider a wider range of socio-technical factors when predicting the development of industrial employment [27,28,32,41].

It is also noticeable that the values in China for the two combined options expecting decreasing numbers of jobs for all three domains are significantly higher than the values for the other two countries. One possible reason for this trend could be that China (even though it has also recorded a temporary decrease during the pandemic) has been the biggest market for industrial robots in recent years [68]. With regard to the differences in company sizes, we have found a significant correlation suggesting that bigger companies are more likely to reduce positions in the manufacturing and assembly domains. Interestingly, small German companies had hardly any intention to reduce their staff for these two domains. One possible explanation could be that SMEs are facing difficulties and barriers SMEs when trying to implement the Industry 4.0 concept [61–63] and therefore cannot fully exploit the efficiency potentials. A look at the sector values reveals a rather heterogeneous picture between the countries. In contrast to the other sectors, values for the automotive sector were the most similar ones between countries. This could be an indication of a high level of global process standardisation in this sector. At the same time, the values between the sectors for all three domains in China are surprisingly similar. Future research could try to investigate the influence of policies aiming to increase the level of digitalisation in certain industrial sectors. Moreover, we deem it necessary to bear in mind that the effects of Industry 4.0 on staffing requirements should be investigated in the light of the global fragmentation of production and both potential direct and indirect effects. That is, not only does digitalisation within a company or within a national industrial sector impact staffing requirements, but also do global changes impact local conditions. Although authors are sceptical of substantial reshoring of previously outsourced production [69], future research should account for the complexity that Industry 4.0 entails given that there is a general focus on certain technologies or applications (e.g. automation) and their direct effects.

5.2. Employee qualifications

In all three countries, all analysed domains are subject to some degree of up-skilling in Industry 4.0 settings compared to traditional companies, with development being the domain where the participants of our study expect the biggest change. These findings support previous studies which drew the conclusion that the complexity of tasks will require different type of skills as well as higher levels of education [47–49]. If these developments turn into reality, they will bear the risk that Industry 4.0 could increasingly polarise industrial employment [6]. The results of our study also show that the discussion around the effects of Industry 4.0 on qualifications could be enriched by further investigating how it impacts the quality of work, and not only the quantity of available jobs. As authors such as Spencer [38] mention the dehumanizing effect of automation on work for certain domains and tasks, it should be investigated if this is at odds with a trend of up-skilling in all domains. More likely this is a further indication of changes in the range of tasks fulfilled in specific positions, calling for further research on more in-depth insights. Our findings also provide an indication that larger companies' employees may face a relatively high increase in the skill intensity and task complexity of their job profiles, leading to further increases in the skill premium. Adding to that aspect, the more frequent expectations of rising requirements in the development domain are indicative of the relatively high skill-intensity of this sector, which could pave the way for a rising wage gap as anticipated by Frey and Osborne [5].

However, there is an uncertainty regarding the time frame for these changes in required qualifications, which further emphasizes the need for adaptability both organisationally and individually [6,24–26]. These adaptations should be accompanied by policies for improving the situation and opening opportunities for educational measures explicitly addressing the low-skill sector [31].

5.3. Intelligent assistance systems

Intelligent assistance systems are one way to support employees in Industry 4.0 factories discussed in the literature. However, certain capacities will be required to acquire, implement, maintain and run these systems. According to our study, big German companies are significantly more likely to take advantage of intelligent assistance systems in the future compared to their smaller counterparts. One economic reason for this development are the bigger human and financial resources available to bigger companies, supporting the argument, that smaller companies are facing higher barriers in the transformation towards Industry 4.0 [61–63].

5.4. Limitations

Our research is suffering from some limitations. Our sample is not large enough for statistical tests to have significant strength and generalisability. For this to be possible, the sample would have needed to be an order of magnitude larger. This is of special relevance for some subcategories (especially the ICT and electronics sector) in Germany and Brazil, where the low number of respondents limits the validity of these sector specific results. The composition of the sample is also not representative for the national economies of the participating countries, limiting the validity and generalisability of our findings. We have only controlled for company size and sector but did not consider how other factors such as differences in personal and company characteristics determine the differences between the samples. Moreover, we note the inconclusive interpretability of some of the survey items and highlight the need for additional and higher-scaled constructs for stronger statistical inferences. A precise assessment of complex relationships, such as the necessary qualifications within a domain, requires a differentiation according to types of different job profiles, which our method did not contain. Our findings should therefore be interpreted as an exploratory first approach to these complex issues with the major aim of broadly comparing the effects of Industry 4.0 in the three countries. There is a multitude of additional factors which should be investigated more closely in future studies. However, our results can serve as preliminary evidence of the trends we present in this paper. The aforementioned limitations do not disprove our conclusions but they require some level of caution when interpreting our findings.

6. Conclusions

Industrial employment is undergoing fundamental change due to Industry 4.0. Both scientists and practitioners have portrayed different outlooks concerning the severity of the impacts of automation and digitalisation on both job availability and task profiles in industry.

However, empirical investigations remain scarce. Against this backdrop, this study contributes both to the advancement of the scientific discourse and to the broader societal transformation in which entrepreneurial and political decision-makers seek to deepen their knowledge of the impacts of Industry 4.0 on employment when implementing new technologies. We do so by analysing differences (and similarities) between different countries, industrial sectors, and for different company sizes for three overarching employment-related effects of Industry 4.0: Staffing requirements, employee qualifications, and digital assistance systems. Our empirical study provides evidence that its effects on staffing requirements differ between domains. More specifically, domains generally associated with larger shares of relatively low-skilled labour (manufacturing, assembly) are expected to experience declines in staffing requirements, suggesting an increase in the polarisation between high- and low-skilled labour in terms of job opportunities. This effect is observable especially in larger companies. Moreover, company representatives expect increases in the required employee qualifications in all domains – specific digital skills and analytical competences for the more complex activities are likely to gain in importance. Unlike in the other two countries, the inter-sectoral variability of perceptions is very small in China, while the size of a company seems to have the reverse effect with regard to the required qualifications there compared to Brazilian and German companies, where less respondents expect higher qualifications for SMEs. Although we find sectoral differences both within and between countries, there is no clearly discernible trend allowing for generalizable sectoral conclusions, highlighting that impacts of Industry 4.0 on qualification should be further investigated under consideration of underlying contextual factors, especially in the context of globalised industrial production. We also encourage future research to focus on the effects of specific policy interventions accompanying the digital transformation of industries. An international and transdisciplinary exchange of best practices involving a broad range of relevant stakeholders could be an effective method in the effort to transform industries towards more socio-economic sustainability and therefore support the overall endeavour to ensure dignified and fair working conditions for as many employees in industry as possible.

Funding information

Alexander von Humboldt foundation, 3.4–1149468 - CHN – IP, Grischa Beier, Ting Guan. Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES), Finance Code 001, David Iubel de Oliveira Pereira Grudzien. Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), 308137/2018-3. 409350/2018-4, Edson Pinheiro de Lima. German Federal Ministry of Education and Research, 01UU1705A, Grischa Beier. National Natural Science Foundation of China, 41971166, Bing Xue. Liaoning XinLiaoRenCai Program, XLYC2007201, Bing Xue.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to express our sincere gratitude to Simon Terhorst (data collection) and Frieder Schmelzle (data visualization) for their tireless efforts and incredible work. We would also like to thank our respondents for taking the time to participate in the survey – as well as our partners who supported us in the distribution of the survey. These include the Bundesverband der Deutschen Industrie e.V., Plattform Industrie 4.0, a number of Mittelstand 4.0 competence centres, VDI Zentrum Ressourceneffizienz, econsense, Verband für Nachhaltigkeits- und Umweltmanagement e.V., and the competence platform nachhaltig.digital.

Appendix I. Questionnaire

Explicatory text

In the context of industrial production, what is meant by Digitalisation and Interconnectedness (or Industry 4.0)?

Through the integration of digital technologies, industrial production is undergoing a profound transformation whereby interconnected objects organize themselves in the production process – thus forming an Industrial Internet of Things. Such a digitalized and interconnected industrial environment entails that during production processes, digitally enabled manufacturing machines automatically exchange and process information and autonomously optimise their performances. This may occur within one company, as well as across multiple suppliers and manufacturers.

In this survey, we use the term 'Digitalisation and Interconnectedness' to denote this technological development. It follows that a higher level of 'Digitalisation and Interconnectedness' within a given production process entails more flexibility, autonomy and self-organisation of machines, as well as a higher degree of interconnection between humans, machines and systems. Here, it is important to note that there are many stages between being fully 'digitally interconnected' (the status described in the paragraph above) and not 'digitally interconnected' at all. We therefore assume that many companies are partially 'digitally interconnected' – in many cases with the intention to increase the level of interconnectedness in the future.

Personal Characteristics

Age: [enter number].
Sex:

a) Male
b) Female
c) Other: [please specify]
d) No answer

Position of respondent:

a) Management level
b) Operational level

c) Other [please specify]:

In what area/department do you work?

a) Development
b) Manufacturing
c) Administration
d) Marketing
e) Other: [please specify]

Company Characteristics

In which area is your company located? [enter ZIP code].
In which country is your company headquartered? [enter name of country].
How many employees (E) does your company have?

a) 250 E
b) 250–1000 E
c) 1000–2500 E
d) 2500–5000 E
e) =>5000 E
f) Don't know

In what sector is your company operating?

a) Automotive industry
b) Plant and mechanical engineering
c) Information and communication technology
d) Electronics
e) Other: [please specify]

What kind of production is your company mainly involved in?

a) Single-item production
b) Serial production
c) Other [please specify]:

'Digitalisation and Interconnectedness' and labour conditions

How will 'Digitalisation and Interconnectedness' affect staffing requirements in your company (in the different phases of production)? The company will require:

	1 – Far less workers	2	3 – No change expected	4	5 – Far more workers	Don't know	No answer
Development							
Manufacturing							
Assembly							

To what extent will 'Digitalisation and Interconnectedness' affect the qualifications that your company requires of its employees (in the different phases of product creation)?
The required qualifications will become …

	1 – Much lower	2	3 – No change expected	4	5 – Much higher	Don't know	No answer
Development							
Manufacturing							
Assembly							

How often will your employees be supported **in complex tasks by intelligent assistance systems in the next 5 years (e.g. by explanatory software on tablets or per head-mounted display)?**

1 – Much less often	2	3 – No change expected	4	5 – Much more often	Don't know	No answer

Feedback

Open feedback. [Text box].

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