Industry 4.0 and corporate sustainability: an exploratory analysis of possible impacts in the Brazilian context

Technological Forecasting and Social Change 167 01 Jun 2021 DOI

https://www.sciencedirect.com/science/article/abs/pii/S0040162521001736?via%3Dihub

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Abstract

This paper aims to analyse the impacts of Industry 4.0 on corporate sustainability, considering the Brazilian context. From a literature review, 12 impacts were identified and used to structure a questionnaire. This questionnaire was applied in a survey with experienced Brazilian researchers. The data was analysed using Hierarchical Cluster Analysis, Descriptive Statistics and TOPSIS, which allowed for impact ordering. It was evidenced that all the presented impacts will be evident in the Brazilian context in a ten-year horizon. Of these impacts, six stand out: 1) the reduction of job offers for manual and repetitive activities and the emergence of new, high value-added professions; 2) the emergence of innovative business; 3) the reduction of work accidents due to the expanded use of robots in dangerous tasks for humans; 4) problems with the employees' qualification pace in the required modernisation changes; 5) the integration of all value chain activities, allowing for a better analysis of environmental, social and economic impacts; and 6) improvements in physical and cognitive ergonomics due to the use of sensors. These findings can contribute to the expansion of the debates related to the theme and can be used as a base for defining future industrial policies in Brazil.

Keywords: Sustainability; Industry 4.0; Impacts; Exploratory Study.

1. Introduction

Humanity has faced several important changes throughout its existence, all of which have influenced social structures and economic systems. Focusing particularly on industrial systems, Schwab (2016) and Ghobakhloo (2018) mention four great revolutions, three of which occurred in the past and one which is currently being observed. The three previous revolutions were related to processes of mechanisation, electrification, the use of information technologies and automation (Kagermann et al., 2013). The current revolution is called Industry 4.0 or the Fourth Industrial Revolution (Nam, 2019; Schwab, 2016).

The term Industry 4.0 was first introduced in Germany in 2011 at one of the most important technology fairs in the world, the Hannover Messe (Brettel et al., 2014; Konrad and Böhle, 2019; Min et al., 2019). It stands for the comprehensive transformation of industrial production through emerging technology and internet adoption, generating advancements for artificial intelligence, an unprecedented capacity to process large amounts of data (European Commision, 2012; Gottge et al., 2020; Leahy et al., 2019), and an accelerated innovation velocity (Mubarak and Petraite, 2020). This concept enables the integration of processes related to production and logistics, since it involves all stages of the value chain, from new product development to production and the aftermarket (Oliveira and Simões, 2017). For Coelho (2016), this new industrial reality requires new forms of business management and organisational processes.

Industry 4.0 is characterised by six principles: interoperability, virtualisation, decentralisation, real-time capability, service orientation and modularity (Hermann et al., 2016). The concept of interoperability aims to ease communication between systems, and, to this end, it is recommended that users adopt open standards (Schwab, 2016). Virtualisation enables the creation of virtual copies of physical systems in the cloud, facilitating real-time simulation processes. Decentralisation is the constant exchange of information that allows cyber-physical systems to make real-time decisions without human interference (Hermann et al., 2016). Real-time capability consists of collecting information instantly, facilitating fast and agile decisions (Sniderman et al., 2016). Service orientation consists of software customisation services according to the needs of each organisation (Buxmann et al., 2009). Finally, modularity is characterised by the flexibility of the entire production process, allowing for the rearrangement of production lines through coupling and decoupling modules (Shahid and Aneja, 2017). Based on these six principles, the following pillars are defined as Industry 4.0 concepts that can be adopted by enterprises: Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), Autonomous Vehicles, 3D printers, Advanced Robots, Artificial Intelligence, Big Data, Cloud Computing, Virtual and Augmented Reality, Nanomaterials and Nano sensors, among others (Schwab and Mackenzie, 2016). Büchi et al. (2020) and Lin et al. (2017) argue that these concepts can improve productivity and management of company activities.

The government support is essential in the transition towards digital economy. An interesting example is the case of European Commission that is creating an environment to enable new digital business models (European Commission, 2015) In Brazil, this approach is still superficial, and the industrial sector needs to be agile to avoid a large gap in competitiveness in relation to other nations (Oliveira and Simões, 2017). Despite its relevance among emerging countries, the Brazilian industry has been facing several challenges in recent years that might compromise the necessary investments related to Industry 4.0 technologies (Cezarino et al., 2019). Some examples of Brazilian challenges in this context are: investments in new equipment and the updating of existing ones; changes in layouts and processes; changes in the relationships among companies, problems with job offers; and new product development, among others (Oliveira and

Simões, 2017). Dalenogare et al. (2018) corroborate this point of view, arguing that few Brazilian companies are prepared for all the necessary changes. This is not an exclusive characteristic of Brazilian companies, since organisations in different countries need to perform drastic changes (Weber et al., 2019). The challenges can be more accentuated for emerging markets, due to the lower financial capacity for investments of many companies (especially small and medium enterprises) in these countries and the higher instability of these economies (Frank et al., 2016; Nara et al., 2020).

The impact of Industry 4.0 concepts on business activities generates many debates. Among them, studies related to sustainability stand out (Baxandall, 2017; Nascimento et al., 2019). For Machado et al. (2020), social sustainability issues will be characterised as one of the main research topics related to Industry 4.0. Despite the importance of sustainability theme for Industry 4.0, several companies still consider sustainability in a secondary place when they define their strategies for digitalization. A typical example of this is presented in Chiarini et al. (2020), in which authors evaluated the presence of six strategy types in projects related to the Industry 4.0 (Information and communications technology integration; servitization; integration of supply chain; lean; green manufacturing/logistics; and Design-to-cost). The authors identified that only the environmental issue (one of the sustainability aspects) "does not seem to be an objective achieved by sampled companies through these technological solutions" (p. 9).

Stock and Seliger (2016) and Bai et al. (2020) identify interesting opportunities in the interface of these themes. Regarding the social dimension, Lin et al. (2017) discuss the employee qualifications needed in the technological context. Regarding the environmental dimension, Moreno et al. (2014) and Ghobakhloo (2020) emphasise that the adoption of Industry 4.0 concepts will provide an efficient use of resources, contributing to global sustainable development goals. However, for Da Silva et al. (2020), there is a lack of practical studies about how Industry 4.0 concepts will impact sustainability.

It is evident that Industry 4.0 concepts will impact corporate sustainability in different ways, varying from country to country, since economic, political, technological, and cultural issues will influence the transition process to this new reality. In this sense, Weber et al. (2019) argue that the changes will be significant, and governments need to act in order to conduct processes that consider social consequences. In Brazil, Industry 4.0 related concepts are relatively new and are in an initial implementation stage (Da Silva et al., 2020). When focusing on the relationship of the theme with the sustainability aspects, the discussions and debates become limited, as highlighted by Oliveira and Simões (2017). For these authors, sustainability in the context of Industry 4.0 is an essential issue for conducting Brazilian industries to this new reality. Corroborating with this statement, Nascimento et al. (2019) describe the need for more debates and research in order to evaluate the impact on society and the economy by adopting these new technologies. For them, social factors cannot be neglected throughout the implementation of Industry 4.0-related technologies.

Based on the above statements, this article aims to analyse the possible impacts of the adoption of Industry 4.0 concepts in Brazilian companies, considering environmental and social aspects. Perceptions from Brazilian academics were considered for this analysis, and the data was analysed using Hierarchical Cluster Analysis, Descriptive Statistics and TOPSIS (the mentioned characteristics differentiates this study). In addition to this introduction, the article provides four more sections. Section 2 is devoted to the theoretical framework, Section 3 presents the methodological procedures employed, Section 4 presents the main results, and finally, in Section 5, we present the conclusions and final remarks.

2. Theoretical Framework

Based on the literature, it was possible to identify 12 impacts that Industry 4.0 may have on company sustainability. These 12 impacts constitute the theoretical framework of the present study. They are presented in Table 1 and detailed in the sequence. The codes used to identify each impact are also presented in Table 1. These codes will be used in the quantitative analyses.

Table 1: Industry 4.0 impacts on business sustainability. Source: (vide Table)

Code	**Description**	**Authors**
I_1	Industry 4.0 will enable a decentralised production; consequently, there will be a reduction in the logistics flow, energy and fuel consumption, reducing the environmental impact.	(Chen et al., 2015; Guliyeva et al., 2018; Hermann et al., 2016; Kagermann et al., 2013; Oliff and Liu, 2017; Saunila et al., 2019; Schumacher et al., 2016; Yin and Qin, 2019)

I_2	Industry 4.0 will enable the use of energy resources and raw materials in a more efficient way; as a consequence, there will be less environmental impact from production processes.	(Beier et al., 2017; Chen et al., 2015; Kagermann et al., 2013; Machado et al., 2020; Sartori et al., 2015; Stock and Seliger, 2016)
I_3	Industry 4.0 will enable companies to better understand the real customer needs. Therefore, it will be possible to produce only the batches ordered, causing less environmental impact.	(Chen et al., 2015; Coelho, 2016; Guliyeva et al., 2018; Hermann et al., 2016; Kagermann et al., 2013; Monostori, 2014; Saunila et al., 2019; Schwab, 2016; Shafiq et al., 2015; Stock and Seliger, 2016)
I_4	Industry 4.0 will enable "mass customisation", increasing the consumption of products and services, since they will be more attractive for customers. However, this will generate more waste from final disposal.	(Borlido, 2017; Coelho, 2016; Kagermann et al., 2013; Neto et al., 2009; Oliveira and Simões, 2017; Schwab, 2016)
I_5	Industry 4.0 will make manufacturing processes more autonomous and efficient, demanding less humans in manual and repetitive tasks; this change will provide fewer jobs and it will affect employees that cannot qualify themselves according to the modernisation pace.	(Aires et al., 2018; Buhr, 2015; Hermann et al., 2016; Machado et al., 2020; Schwab, 2016)
I_6	Industry 4.0 will provide for the emergence of new, high value-added professions and will require employee qualifications, contributing to their professional development.	(Hermann et al., 2016; Kagermann et al., 2013; Schwab, 2016)
I_7	Industry 4.0 will enable the expanded use of robots in dangerous tasks for humans; therefore, there will be a reduction in the number of occupational accidents. Technologies will also enable a better work environment for employees.	(Kagermann et al., 2013; Kuznaz et al., 2015; Oesterreich and Teuteberg, 2016; Roblek et al., 2016; Yin and Qin, 2019)
I_8	Industry 4.0 will increase job opportunities for professionals with special needs, since many processes will operate through voice recognition and virtual reality; this will contribute to the insertion of people with special needs in the labour market.	(Roblek et al., 2016; Rübmann et al., 2015)
I_9	Industry 4.0 will demand professionals with intellectual and cognitive skills, besides multidisciplinary knowledge and teamwork ability. These characteristics can increase the number of women in organisations, since in general women stand out in the aforementioned characteristics.	(Hecklau et al., 2016; Hermann et al., 2016; Kagermann et al., 2013; Schwab, 2016)
I_10	The use of sensors in products and production equipment will allow for the identification of harmful situations to human, contributing to physical and cognitive ergonomics.	(Bauer et al., 2015; Chen et al., 2015; Kagermann et al., 2013; Roblek et al., 2016; Saunila et al., 2019)
I_11	Industry 4.0 will enable the integration of all value chain activities. In this sense, it will be possible to act in a collaborative format from raw material supply to final disposal, making possible a better analysis of environmental, social and economic impacts.	(Guliyeva et al., 2018; Hermann et al., 2016; Kagermann et al., 2013; Machado et al., 2020; Oliveira and Simões, 2017; Saunila et al., 2019)
I_12	Industry 4.0 will enable the emergence of innovative business, and this fact will increase the market share of start-ups and small companies.	(Buhr, 2015; Kagermann et al., 2013; Machado et al., 2020; Oliveira and Simões, 2017; Stock and Seliger, 2016)

In general, it can be noted that impacts I_1 and I_2 are related to the use of resources. Acting on a decentralised basis, there will be a reduction in the flow of logistics activities, which can reduce the environmental impact caused by the use of fuel for transportation (Chen et al., 2015; Guliyeva et al., 2018; Hermann et al., 2016; Kagermann et al., 2013; Oliff and Liu, 2017; Saunila et al., 2019; Schumacher et al., 2016; Yin and Qin, 2019). It will also be possible, with the adoption of the Industry 4.0 concepts, to use energy resources more precisely, mainly due to new technologies embedded in the equipment (Beier et al., 2017; Chen et al., 2015; Kagermann et al., 2013; Machado et al., 2020; Sartori et al., 2015; Stock and Seliger, 2016). Sartori et al. (2015) discusses how equipment will be "smart" and will have the ability to optimise energy consumption at different stages of the production process. Thus, impacts I_1 and I_2 can contribute positively to reducing negative environmental impacts. Beier et al. (2017) corroborate this argument.

Impacts I_3 and I_4 are related to consumption issues and their environmental impacts. The adoption of Industry 4.0 concepts will enable a better understanding of the real needs of customers, making it possible to produce small batches to meet demands and produce customised products. This will result in a production process with a reduced environmental negative impact, since "no demand" items will not be produced (Chen et al., 2015; Coelho, 2016; Gerlitz, 2015; Hermann et al., 2016; Monostori, 2014; Saunila et al., 2019; Schwab, 2016; Shafiq et al., 2015; Stock and Seliger, 2016). On the other hand, Shafiq et al. (2015) also argue that smart factories will be able to receive the customisation of each client, adapting them according to the customers' requirements (Neto et al., 2009). However, this can make products more attractive, increase their consumption and generate more post-use waste (Borlido, 2017; Coelho, 2016; Kagermann et al., 2013; Neto et al., 2009; Oliveira and Simões, 2017; Schwab, 2016). Therefore, companies need to analyse the negative impacts generated by products and services in all phases, from development to disposal (Kagermann et al., 2013).

Impacts I_5, I_6, I_7, I_8, I_9 and I_10 are related to employability issues and the reduction of occupational accidents. Initially, it is argued that Industry 4.0 concepts adoption will make manufacturing processes more autonomous, requiring a reduced number of workers when compared to traditional industrial processes (Aires et al., 2018; Buhr, 2015; Hermann et al., 2016; Machado et al., 2020; Schwab, 2016). Kagermann et al. (2013) argue that Industry 4.0 will allow for a set of technological advances, resulting in intelligent factories, with minimal interactions or without human intervention. New high value-added professions will be created. However, a significant number of workers will be negatively affected, since they will not be able to qualify themselves according to the modernisation requisites (Hermann et al., 2016; Kagermann et al., 2013a; Schwab, 2016). For Schwab (2016), the need for requalification will be among the foremost challenges that must be overcome by the Fourth Industrial Revolution. Buhr (2015) argues that Industry 4.0 will be responsible for creating "technological unemployment", leading to an increase of social inequalities. Hermann et al. (2016) and Aires et al. (2018) corroborate this view, arguing that several jobs will disappear.

Regarding the desired characteristics for new employees, Industry 4.0 will require intellectual and cognitive skills, as well as multidisciplinary and team working skills (Schwab, 2016). This can increase the number of women in organizations, since generally they stand out in the mentioned characteristics (Hecklau et al., 2016; Hermann et al., 2016; Kagermann et al., 2013; Schwab, 2016). In addition, the adoption of these concepts will provide greater opportunities in the labour market for people with special needs, since many processes will work through voice recognition and virtual reality (Roblek et al., 2016; Rübmann et al., 2015).

In general, Schwab (2016) and Hermann et al. (2016) argue that Industry 4.0 professionals should have multidisciplinary skills and be qualified to handle new technologies in the industrial environment. Hermann et al. (2016) argue that companies will need to prepare professionals with critical perspectives. Hecklau et al. (2016) highlight the relevance of investment in the company's intellectual capital.

Regarding quality of work and security, robots can replace humans in tasks considered dangerous (Kagermann et al., 2013; Kuznaz et al., 2015; Oesterreich and Teuteberg, 2016; Roblek et al., 2016; Yin and Qin, 2019), and as a consequence, there will be a reduction in the number of accidents at work (Kagermann et al., 2013; Yin and Qin, 2019). The work environment will also become more pleasant and provide a better quality of life for employees. The large number of sensors in products and production equipment will support the identification of situations harmful to humans, contributing to physical and cognitive ergonomics (Bauer et al., 2015; Chen et al., 2015; Kagermann et al., 2013; Roblek et al., 2016; Saunila et al., 2019).

Industry 4.0 concepts and technologies will enable a better integration among all activities in a productive network. As result, it will be easier to map product or service impacts on environmental and social sustainability, as argue some authors (Gerlitz, 2015; Hermann et al., 2016; Kagermann et al., 2013; Oliveira and Simões, 2017).

Finally, Industry 4.0 concepts and technologies will enable the emergence of new businesses, enhancing the chances of success for start-ups and small businesses, which, in turn, contributes to social sustainability (Buhr, 2015; Kagermann et al., 2013; Oliveira and Simões, 2017; Schwab, 2016; Stock and Seliger, 2016). With innovation and an increased use of technology in industrial processes, there will be opportunities for new business models, thereby expanding the market and generating opportunities for new entrepreneurs. Kagermann et al. (2013) and Stock and Seliger (2016) discuss how start-up companies will directly impact large industries, as many will offer services associated with management systems and process control. The structuring of new companies will allow for the creation of new job opportunities for qualified professionals (Buhr, 2015).

3. Methodological Procedures

This research was carried out through the performance of 5 stages, summarised in Figure 1 and detailed in the text. With this information, other researchers may replicate the study.

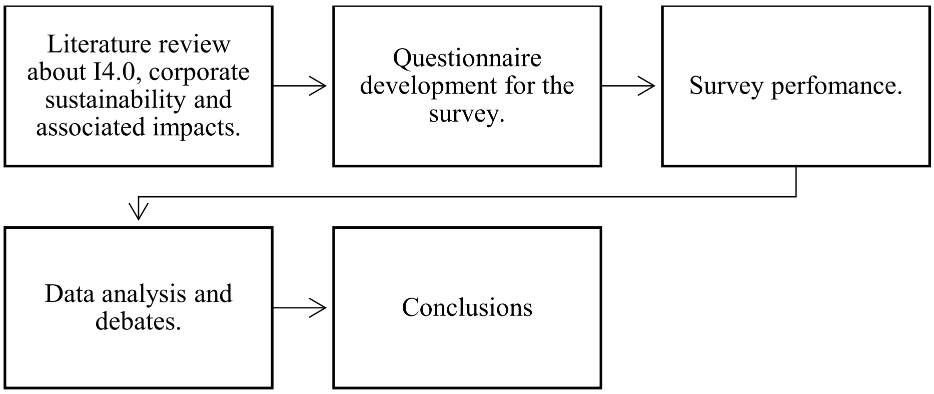

Figure 1. Stages carried out in this study. Source: Authors.

The first stage was characterised by a literature review. This stage made it possible to better understand Industry 4.0 concepts and technologies and to identify the 12 impacts on corporate sustainability (Table 1). To develop Table 1, a search was carried out in the databases Elsevier, Taylor and Francis Online, Emerald Insight, and Scopus, using combinations of the following terms: “Industry 4.0”, “Sustainability”, “Corporate sustainability”, “Impacts” and “Consequences”. After filtering the articles for those presenting the mentioned impacts, 27 articles were left. Analysing the content presented in these articles, 12 impacts were identified. The 12 impacts listed in Table 1 served as the basis for the development of the questionnaire. This questionnaire was used in a survey performed with 41 experienced Brazilian researchers. The respondents selection was non-probabilistic, due to the exploratory character of this study (Malhotra, 2012). The impacts investigated were considered as the variables in the survey.

For each of the variables (impacts), the respondent needed to assign a score from 0 to 10, considering a ten-year horizon. To better guide the participant, score strips were defined, as shown in Table 2. The existence of two scores in five of the strips allowed for a fine-tuning in the participants' answers. It is worth mentioning that the research presented in this article was approved by a research ethics committee.

Table 2. Scores and specifications used in questionnaire (Source: Authors)

Score 0: I believe that in a ten-year horizon the impact mentioned will not be observed.
Score 1 or 2: I believe that in a ten-year horizon the impact mentioned will be observed very punctually in some specific sectors of higher technology.
Score 3 or 4: I believe that in a ten-year horizon the impact mentioned will be observed in a small way, however widespread for most of the sectors.
Score 5 or 6: I believe that in a ten-year horizon the impact mentioned will be observed in a median way and widespread for most of the sectors.
Score 7 or 8: I believe that in a ten-year horizon the impact mentioned will be observed in an intensive way and widespread for most of the sectors
Score 9 or 10: I believe that in a ten-year horizon the impact mentioned will be observed in an intensive way, widespread for most of the sectors and much academic and industrial research will be carried out.

The questionnaire link was sent by email and data was collected for two months. After this period, 41 valid questionnaires returned (rate of 13.44%) and data was tabulated in electronic spreadsheets for quantitative analysis.

The objective of this study, as mentioned in the introductory section, was to analyse the possible impacts caused by Industry 4.0 concepts on the sustainability of Brazilian companies, and, in a specific way, ordering these impacts through the TOPSIS technique. An important characteristic of the TOPSIS technique is that it allows weightings, and in this study, the respondent's experience was used to base this weighting. Perceptions of more experienced professionals received more weight.

To define groups of respondents according to experience level and to define the weightings, the codification showed in Table 3 was used.

Table 3. Codification used to define the group of respondents according to experience level (Source: Authors)

Academic background level	Time in the function	Research type carried out	Type of advisory
1= Specialization Degree	1 = Up to 10 years	1 = Research associated with the Brazilian industrial sector.	1= Does not advise master or PhD studies
2 = Master Degree	2 = Between 11 and 20 years	2 = Research associated with the Brazilian industrial sector and Industry 4.0 aspects.	2= Master degree advisor
3= PhD	3= More than 21 years	3 = Research associated with the Brazilian industrial sector and the interface among Industry 4.0 aspects and sustainability.	3= PhD advisor

Considering the codes mentioned in Table 3 and the information of each respondent, a Hierarchical Cluster Analysis was performed generating a dendrogram. Through the dendrogram, it was possible to identify the groups of respondents. According to Xu and Wunsch (2008), Hierarchical Cluster Analysis allows one to group items according to their similarity. The software used to perform this analysis was SPSS 24, and the cut-off point for defining the groups was 10. As will be shown in the results section, three groups of respondents were identified according to experience levels. The groups received weights of 50%, 30% and 20%, following guidelines of Rampasso et al. (2019a), in which more experienced professionals received higher weights than professionals with less experience.

After the identification of the respondents' groups, a descriptive analysis was carried out, and subsequently, the 12 impacts were ordered using the TOPSIS technique. This technique was developed by Ching-Lai Hwang and Kwangsun Yoon (1981) and can be characterized as a tool for Multi-Criteria Decision-Making (MCDM). The main goal of it is to evaluate the alternative with the shortest distance from the positive ideal solution and the greatest distance from negative ideal solution. The positive ideal solution can be understood as the best score for each analysis criterion; complementary, the negative ideal solution is obtained via the worst score for each analysis criterion. The concept of what is the best for each criterion should be considered as the greater the better or the lower the better, according to what is under analysis. The same logic is used for the negative ideal solution (Singh et al., 2016).

Another interesting feature of TOPSIS is the possibility of weighting the criteria considered in the analysis, enabling a better adaptation of the tool to what is being analyzed. TOPSIS has been widely used in academic research (Yoon and Kim, 2017), in studies of areas such as management (Singh et al., 2016; Yu et al., 2019), education (Rampasso et al., 2019b), among others. Indeed, the combined use of TOPSIS with other research techniques (Araujo et al., 2018; Sari, 2021) can generate robust findings too.

The technique allows for the weighting of items according to their importance level for the study.

To perform the calculations of the TOPSIS technique, we used guidelines presented by Singh et al. (2016). In the first stage, matrix D is defined. Matrix D is composed of elements x_{ij}, in which (i) represents each item and (j) represents each analysis criteria. The mathematical representation of matrix D is presented by Matrix 1.

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad \textit{Matrix 1}$$

The second stage corresponds to the normalisation of Matrix D, using the formula presented in Equation 1. As a result, a new matrix named R is obtained (Matrix 2).

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2} \quad \textit{Equation 1} \quad R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad \textit{Matrix 2}$$

The third stage is dedicated to the weighting of Matrix R values, using Equation 2. In our specific case, the weighting will be given for the group's experience level. Matrix 3 represents mathematically the resulting Matrix V.

$$v_{ij} = w_j r_{ij} \quad \textit{Equation 2} \qquad \mathrm{V} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} \quad \textit{Matrix}\ 3$$

The fourth stage is dedicated to the definition of the ideal positive solution (vj +), followed by the fifth stage, in which the negative ideal solution (vj-) is established. The ideal positive solution is composed of the maximum value for each column from Matrix V; in turn, the ideal negative solution consists of the minimum value of each column from the same matrix. Having identified the positive and negative ideal solutions, the calculation of Euclidean distances, using Equations 3 and 4, should be performed.

$$s_i^* = \left[\sum_j \left(v_{ij}^* - v_j^+ \right)^2 \right]^{1/2} \quad \textit{Equation}\ 3; \quad s_i' = \left[\sum_j \left(v_{ij}' - v_j^- \right)^2 \right]^{1/2} \quad \textit{Equation}\ 4$$

With the Euclidean distances, the sixth stage is characterised by the calculation of the Ci* indicator, using Equation 5. The value of this indicator varies from 0 to 1, and the values are used to compare analysed items (Singh et al., 2016).

$$c_i^* = \frac{s_i'}{(s_i^* + s_i')} \quad Equation\ 5$$

Finally, the results obtained were debated considering statements from the literature, and the conclusions were established.

4. Results and discussions

In order to identify and group respondents according to their experiences, Table 4 was constructed to consider information provided by respondents and the codification present in Table 3. The data presented in Table 4 were analysed through Hierarchical Cluster Analysis, generating the dendogram presented in Figure 2.

Table 4. Respondents' experience information. Source:(Data from survey)

Respondent	**Academic background level**	**Time in the function**	**Research type carried**	**Type of advisory**	**Respondent**	**Academic background level**	**Time in the function**	**Research type carried**	**Type of advisory**
R1	2	1	3	1	R22	3	3	3	2
R2	2	1	3	1	R23	2	1	2	1
R3	2	3	2	1	R24	2	2	2	1
R4	2	1	2	1	R25	2	1	2	1
R5	2	3	3	1	R26	2	3	1	1
R6	2	3	2	1	R27	3	2	2	3
R7	2	1	2	1	R28	2	1	3	1
R8	3	3	2	2	R29	3	3	3	3
R9	3	2	3	1	R30	2	3	3	1
R10	3	2	2	2	R31	3	3	2	3
R11	2	1	3	1	R32	3	2	3	2
R12	3	2	3	1	R33	3	1	2	3
R13	2	2	1	1	R34	3	1	2	2
R14	3	3	2	2	R35	2	1	2	1
R15	3	3	3	3	R36	2	2	3	1
R16	2	2	2	1	R37	2	2	2	1
R17	2	3	3	1	R38	3	2	2	1
R18	2	3	3	1	R39	3	1	2	1
R19	3	3	2	1	R40	2	2	2	2
R20	3	3	2	3	R41	2	1	2	1
R21	2	1	3	1					

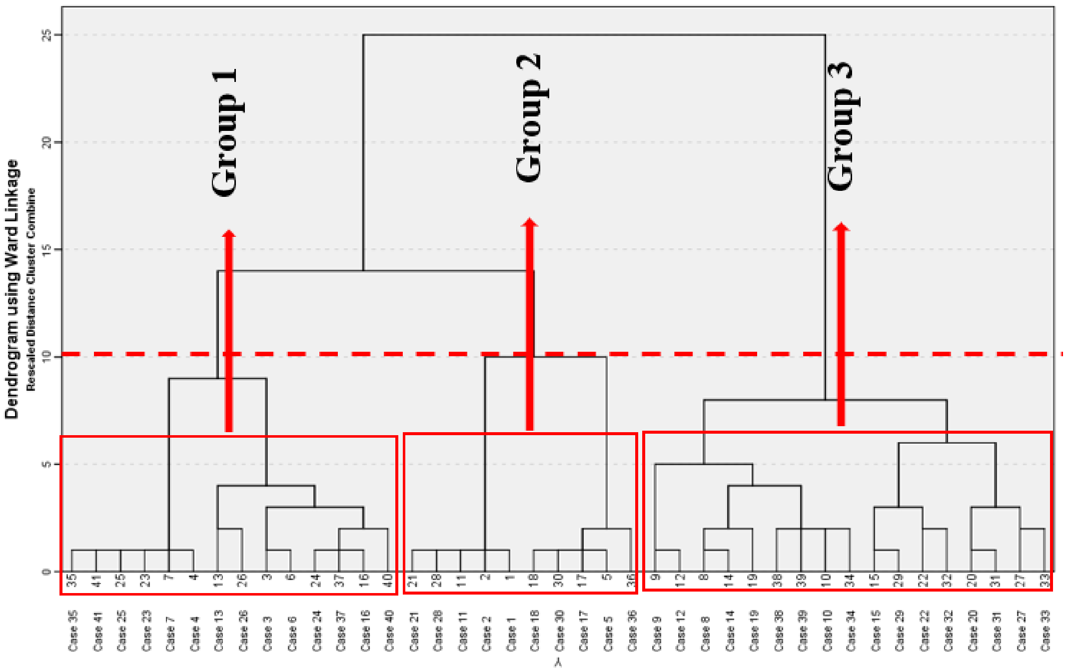

Figure 2. Dendrogram generated from Hierarchical Cluster Analysis

Considering the cut off in the dendogram (value = 10), it was possible to identify 3 groups according to experience level. Weights for the groups were established according to their experience, as explained in Section 3. For Group 1, the weight attributed was 20%. Most of the respondents hae a masters degree (93%), they have between 11 and 20 years of experience, they carry out research on issues related to Industry 4.0 but not related to sustainability, and they have little or no experience in academic advisoring. For Group 2, the weight attributed was 30%. Most respondents have a masters degree (90%), 50% of them have more than 21 years of experience and carry out research on Industry 4.0 and sustainability; however, they have little experience in academic advisoring. Finally, for Group 3 the weight attributed was 50%, since 94% hold a PhD, they have much experience, they carry out research on Industry 4.0 and sustainability, and they have much experience in academic advisoring.

Continuing the analysis, the averages attributed to impacts by each group were evaluated. Considering Group 1, it is possible to note that 75% of the averages were above 7.0 (in a scale from 0 to 10). Group 2 presented some similarity regarding the previous group, since 83% of the respondents believe that most of the impacts on sustainability generated by Industry 4.0 concepts will be observed intensely and in most sectors. Similar findings were identified in Group 3, which presented 66% of the averages above 7.0.

To rank the impacts through the TOPSIS technique, the first stage was to structure Matrix D, considering groups' averages for each impact, and subsequently, to standardise the mentioned matrix using Equation 1. The obtained Matrix R is presented in Table 5.

Table 5. Matrix R with standardised values (Source: authors)

Impact	r_{ij} (Group 1)	r_{ij} (Group 2)	r_{ij} (Group 3)
I_1	0.21	0.21	0.26
I_2	0.27	0.29	0.26
I_3	0.30	0.26	0.30
I_4	0.24	0.24	0.22
I_5	0.32	0.33	0.29
I_6	0.31	0.35	0.34
I_7	0.31	0.28	0.32
I_8	0.25	0.29	0.27
I_9	0.28	0.26	0.26
I_10	0.30	0.27	0.31
I_11	0.31	0.30	0.30
I_12	0.33	0.35	0.31

With the Matrix R value weights assigned to each group, it was possible to obtain Matrix V, whose values are presented in Table 6.

Table 6. Matrix V with weighted values (Source: authors)

Impacts	r_{ij} (Group 1)*0.20	r_{ij} (Group 2)*0.30	r_{ij} (Group 3)*0.50
I_1	0.04	0.06	0.13
I_2	0.05	0.09	0.13
I_3	0.06	0.08	0.15
I_4	0.05	0.07	0.11
I_5	0.06	0.10	0.15
I_6	0.06	0.10	0.17
I_7	0.06	0.09	0.16
I_8	0.05	0.09	0.13
I_9	0.06	0.08	0.13
I_10	0.06	0.08	0.15
I_11	0.06	0.09	0.15
I_12	0.07	0.10	0.16

The next stage consisted of defining the positive and negative ideal solutions (v_j^+; v_j^-), presented in Table 7. Using Equations 3 and 4 and the values presented in Table 6 and 7, it was possible to calculate the Euclidean distances for each value in relation to the ideal solutions mentioned. The distances obtained, named S_i^+ and S_i^-, are presented in

Table 8. Using the values of S_i^+, S_i^- and Equation 5, it was possible to determine the coefficient C_i^*, also presented in Table 8.

Table 7. Positive and negative ideal solution (Source: authors)

Ideal solutions	Group 1	Group 2	Group 3
Positive ideal solution (v_j^+)	0.07	0.10	0.17
Negative ideal solution (v_j^-)	0.04	0.06	0.11

Table 8. Euclidean distances for each value in relation to ideal solutions and coefficient C_i^* (Source: authors)

Impact	**Distance from S_i^+**	**Distance from S_i^-**	**Coefficient Ci***
I_1	0.06	0.02	0.24
I_2	0.04	0.03	0.42
I_3	0.04	0.04	0.54
I_4	0.07	0.01	0.12
I_5	0.02	0.05	0.69
I_6	0.00	0.07	0.95
I_7	0.02	0.06	0.72
I_8	0.04	0.03	0.45
I_9	0.05	0.03	0.36
I_10	0.03	0.05	0.63
I_11	0.03	0.05	0.65
I_12	0.01	0.07	0.83

Finally, the analysed impacts were ordered according to C_i^* coefficient values obtained, as presented in Table 9.

Table 9. Impact ordering according to C_i^* values. (Source: authors)

Rank	**(C_i^*)**	**Impact**
1º	0.95	I_6
2º	0.83	I_12
3º	0.72	I_7
4º	0.69	I_5
5º	0.65	I_11
6º	0.63	I_10
7º	0.54	I_3
8º	0.45	I_8
9º	0.42	I_2
10º	0.36	I_9
11º	0.24	I_1
12º	0.12	I_4

The results obtained evidence the six impacts that will be observed more in the Brazilian companies' context, considering a ten-year horizon, according to the sample. The first of them is related to the emergence of high value-added professions and the need for greater employee qualifications (I_6). This is in line with the Brazilian National Confederation of Industry (CNI, 2016), since it argues that the inclusion of Industry 4.0 technologies will demand changes in the profile of Brazilian employees, who should be more qualified. CNI (2018) also points out the need for Brazilian companies to minimise manual tasks in their processes and increase employees knowledge.

New business models may arise in Brazil within the next ten years due to Industry 4.0 concepts (I_12), and this is the second-best ranked impact. This is in line with Vermulm (2018), who argues that emerging countries will need to invest in technologies, and as a result, new business models will emerge.

Due to industrial automation expansion, robots may replace humans in tasks considered dangerous, and consequently, there will be a reduction in the number of occupational accidents when compared to current processes (I_7). This was the third highest ranked impact, and it is corroborated by CNI (2016), since CNI recognizes that automation expansion will reduce unforeseen events between man and machine.

Employability (I_5) is also highlighted in the ranking. As previously mentioned, Industry 4.0 concept adoption may cause a fewer number of jobs to be available for Brazilian employees. In this sense, it is important to highlight that social factors cannot be neglected during the implementation of Industry 4.0 (Nascimento et al., 2019). Weber et al. (2019) also point out an interesting statement for this situation, since they argue that the changes will be significant and will require government actions in order to minimise social negative consequences.

The integration of all stages in a productive chain (I_11) was also highlighted in the ranking (fifth position). Once again, this fact is corroborated by CNI (2018), since the organisation considers that Industry 4.0 technologies will have an intensive impact in the entire value chain, from product development to consumption, disposal and recycling.

In the sixth position, it is possible to observe the impacts associated with physical and cognitive ergonomics (I_10). Considering the arguments of Kagermann et al. (2016) and Roblek et al. (2016), technologies will enable companies to better evaluate processes and reduce damage to employees, including both physical and psychological issues.

It is important to emphasise that the first six impacts highlighted here sum up the Brazilian researchers' perceptions for a ten-year horizon, and some considerations were assumed. This is an exploratory study performed in order to provide information that can expand debates on how Industry 4.0 will affect the sustainability of Brazilian companies.

5. Conclusions

Based on the results presented, it is possible to state that the main objective of this study was achieved, since it was possible to analyse the perception of experienced Brazilian researchers regarding the possible impacts caused by Industry 4.0 concepts on the sustainability of Brazilian companies in a ten-year horizon.

The scores attributed by the groups of respondents were high, indicating that all of the impacts mentioned can be observed in the Brazilian business context, according to the sample. When the comparative analyses through TOPSIS technique was performed, six impacts stood out: 1) the reduction of job offers for manual and repetitive activities and the emergence of new high value-added professions; 2) the emergence of innovative business; 3) the reduction of occupational accidents due to the expanded use of robots in dangerous tasks for humans; 4) problems with the employees' qualification pace for the required modernisation changes; 5) the integration of all value chain activities, allowing for a better analysis of environmental, social and economic impacts; and 6) improvements in physical and cognitive ergonomics due to the use of sensors. In view of the mentioned results and the current Brazilian reality, there will be many challenges to be overcome. In special, social challenges should be highlighted since they demand greater magnitude and long-term actions for their results to be effective.

When analysing the literature, a large amount of Industry 4.0 studies in developed countries are observed, but there is a smaller amount of research on the subject in developing economies, in which social issues are usually more critic. In relation to previous studies, the findings presented in this article stand out mainly for considering the perspective of academics that study the subject and for ordering the impacts of Industry 4.0 on sustainability, showing those more critical to be debated by policy makers.

Regarding practical implications, the information presented here has several application possibilities, such as: a) contributing to the debates in public sphere to define policies for creating an economic environment favorable to the emergence of new digital businesses that contemplate sustainability, and b) using the impacts mentioned here for managers to critically analyze their business models.Evidently, this study has some limitations, especially regarding its exploratory character. It is noteworthy, however, that the information presented here can be useful to expand debates on how Industry 4.0 concepts will influence the sustainability of Brazilian companies. From these results, public policies can be debated and new research can be originated, among other actions. It is expected that there will be impact differences among companies of different sizes and segments. However, the findings of this study contribute to expanding the debates on the Brazilian reality and can also serve as a useful basis for other emerging economies to establish their own analysis and compare their differences with those evident in Brazil.

For future studies, the authors of this article suggest the conduction of this analysis in other countries and the comparison of the results with those presented here.

Acknowledgment

This work was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001; processes 88882.435248/2019-01; and 88887.464433/2019-00; Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) 307536/2018-1; and 305442/2018-0.

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