**Luma AL-QUDAH**
*Faculty of Economics and Business, University of Debrecen,*
*Károly Ihrig Doctoral School of Management and Business, Debrecen, Hungary*

# THE PERCEPTION OF IMPLEMENTING INDUSTRY 4.0 ON SUPPLY CHAIN: A REVIEW ON SUSTAINABILITY PILLARS

*Review Article*

**Keywords**
*Industry 4.0;*
*Supply chain;*
*Sustainability;*

**JEL Classification**
*L60; Q01; O13*

**Abstract**

*Over the last few years, the topic of supply chain's sustainability has been receiving more attention in order to attain positive sustainability results during the era of Industry 4.0. Supply 4.0 is seen as an approach to major sustainable progress being achieved. There is, however, no evidence to suggest what and how supply chain's sustainability is affected by embracing Industry 4.0. The purpose of this research is to explore how supply chain is affected by integrating Industry 4.0 from sustainable point of view and to identify the economic, social and environmental factors resulted from this integration. Thus, 35 articles have been analyzed to explain the current status of the study and to delineate the key sustainability factors and subthemes for future studies. The paper suggests sub-goals or subthemes that could improve the understanding of how sustainability can be affected during the adoptions of digital technologies.*

## INTRODUCTION

Why the sustainability and supply chain in the context of Industry 4.0? "Ministry of Education and Research" and the "Ministry for Economic Affairs and Energy" of the German government presented a report titled "Industrie 4.0" (Industry 4.0) that proposes a new strategy that focuses on building a digital economy and society and increasing the interconnection of goods, value chains and business models with digital manufacturing (Dastbaz & Cochrane, 2019). It can be seen that the performance and quality of this change would increase. The fact that the entire cycle of production is handled, managed and controlled in an integrated way, makes the production process combined, yet flexible (Pedersen et al., 2016). The evolution of the industrial sectors has had a huge effect on people's lives at both local and global levels.

The challenges for remaining sustainable in the fourth Industrial revolution era are expanding (Thomas et al., 2018). The need to pursue sustainable development while constantly evolve the production systems and meet the changing market demand and remain competitive in the global environment are increasingly recognized by industries. Organizations are seeking to make a balance between the triple bottom line (TBL) perspectives (environmental, economic and social) (Kiel, Müller, Arnold & Voigt, 2017). A conceptual model has been proposed by Duarte and Cruz-Machado (2018) that integrates concepts of Industry 4.0 into green and sustainable supply chains. However, developing sustainability in the operations of industries is not an easy job to do (Luthra & Mangla, 2018b). Therefore, researchers are giving more attention to the impacts of Industry 4.0 on supply chain in terms of sustainability (Ghobakhloo, 2020). The generated inequality of job opportunities in various economic sectors of the world, the waste, pollution and emissions generated by industries during the entire life cycle of the supply chain are just some of the issues that call for a change and shift towards a more sustainable world. Where does the scholarly world stand in sustainability and supply chain? What are the main areas of sustainability in supply chain 4.0? What is the contribution made? Those research gaps need to be filled. The aim of this research to provide an overview of sustainability from economic, social and environmental point of view as a result of integrating Industry 4.0 on supply chain.

A comprehensive review of how literature has been dealing with the topics of supply chain and sustainability in the context of industry 4.0 was provided. 35 articles were selected for analysis in line with the aspects of sustainability represented, their criteria and novelty. The remainder of the article is arranged in the following manner: The methodology is set out in section one, descriptive analysis of the articles is defined in section two, the thematic analysis is presented in section three, the discussion is given in section four and last section provides the conclusion.

## METHEDOLOGY

To achieve the objective of this study, a systematic literature review in the fields of Industry 4.0 and sustainability, with specific reference to the supply chain was first developed. "A systematic literature review has been defined as objective, transparent, and complete, and it should allow replicability" (Tranfield, Denyer & Smart, 2003). To ensure reliability and validity of the process, specific steps should be carried out, the four main stages of the systematic review of literature are 'planning', 'searching', 'screening' and 'Analysis. The following subsection describes the steps in further details.

**Step 1: Planning**

In order for the systematic method to be achieved, a review has been planned to establish the whole procedure. First step includes limiting and narrowing the target of the research by developing the research questions. Thus, the following research questions are highlighted:

- Research Question 1: What is the present status and concerns of research about supply chain related to Industry 4.0 and sustainability?
- Research Question 2: In future studies, what potential subject areas should be explored?

**Step 2: Systematic Literature Research**

To explore the developed research questions, previous studies should be summarized using literature review (Fink, 2019). Literature review demonstrates existing knowledge, variation between different papers and current gaps in the research field. Gough, Oliver and Thomas (2017) pointed out that using this method, the strength of previous and current researches could be interpreted and assessed, and the direction of future research could be guided in a successful way. During this step, Scopus, science direct and IEEE were used as a source for literature data. A structured keyword search was performed in order to identify the papers, Industry 4.0 and sustainability are the major topics of this paper, and the context of the research is the supply chain. Therefore, the initial keywords used in the search string are 'sustainability' AND 'Industry 4.0' AND 'supply chain', limiting them to the title, keywords, and abstract. Search period was limited to 2017-2020. The search has showed 160 papers and some additional papers has been selected as potentially

relevant to the objective of this article, making a total of 172 papers.

**Step 3: Screening**
A specific criterion for including and excluding papers was followed for further in-depth analysis, see Table 1, two rounds of screening were used to choose relevant articles. During the first screening, title and abstract were scanned roughly. Secondly the papers were read more intensively, and researches that did not focused specifically at the sustainable level were removed. At last, 35 papers were chosen for the systematic literature review.

**Step 4: Reporting**
Tranfield et al. (2003) said that an important step in systematic literature review is reporting. A descriptive and thematic analysis has been carried out, focusing on the sustainability approaches used in the study (empirical/theoretical), area subjects and sustainability pillars (economic/environmental/social) referring to the supply chain integrated with Industry 4.0. Thus, qualitative approach has been adopted for analyzing the papers. Figure 1 summarizes stages of systematic review of literature.

## DESCRIPTIVE ANALYSIS

After identifying the articles of sustainability and supply chain in the context of Industry 4.0 with total number of 35 articles, a descriptive analysis was performed. Table 2 shows sources of the papers chosen for the study of literature and the frequency of each source. The dominant sources for discussing sustainability issues are Sustainability and Proceedings.
Regarding the research institution's country of origin, Figure 2 represents percentage of contributions by each country. The United Kingdom has shown highest number of contributions (31%) followed by Switzerland and United states (20%). This can be explained by the fact that that United Kingdom Research and Development expenditure as a percentage of GDP stood at 1.7% in 2017 and they are aiming by 2027 to reach 2.4%, where the sector of manufacturing will play a huge role in reaching that target. In the United Kingdom, automation has been integrated in almost every manufacturing and logistics sectors.

## THEMATIC ANALYSIS

The thematic analysis was performed in two phases. Firstly, the papers were reviewed and the sustainability three pillars (economic, environmental and social) were classified into factors that are influenced positively and negatively by supply chain four. Papers were explored in depth and have been divided into different factors. Some articles addressed issues of ecology specifically pointing to the energy conservation (De Man & Strandhagen, 2017). The Key points and findings for each sub-theme are then discussed in the following sections.

**Environmental Sustainability**
The first dimension of supply chain sustainability to be analyzed was the environmental dimension. The use of upgraded industry and technology will promote energy savings and environmental protection. Recent literature of supply 4.0 has focused on the area of productivity and efficiency of processes, adoption of Industry 4.0 pillars in the supply chain like big data, 3D printing, IoT has showed flexibility and efficiency of processes which enable them to production mass customization, making them more energy and environmentally efficient (Manavalan & Jayakrishna, 2019; Ding, 2018). Several studies have emphasized that the green issue is one of the main aspects of environmental sustainability, a mathematical model was proposed by (Tsai & Lu, 2018). It should be mentioned that searches about IoT technology of Industry 4.0 are stressing to improve energy efficiency for the environmental aspect. Table 3 presents a brief list of the environmental factors of sustainability that are impacted by industry 4.0 on supply chain.

**Economic Sustainability**
When it comes to economic sustainability, the struggle is to control expenses while achieving sustainability, the need to achieve both goals has led the economic logic to evolve. Usually, reduction of services or quality can be the result of cost-cutting, instead of focusing on efficiency improvements or waste reduction, etc. Researches has shown that standardization of processes can improve efficiency, which can happen by introducing protocols and standards in service delivery. In Nascimento et al. (2019) study, a circular economy business model has been raised for waste recycling according to the Industry 4.0 approach. In addition, several studies have given attention to the financial performance while applying supply chain 4.0, especially for those implementing green and eco-friendly practices. Table 4 lists the economic factors of sustainability and how they are affected by supply 4.0.

**Social Sustainability**
In regards to the third pillar of sustainability in supply chain 4.0 environment, which is the social pillar, a literature review was created by (Stock, Obenaus, Kunz & Kohl, 2018). The aim of this literature was to build value through an approach focused on social and environmental aspects in the

I4.0 sense. An "intelligent cube production", was used by the authors to analyze and evaluate results of Industry 4.0 potential on both social and environmental dimensions. This "intelligent cube production" consists of RFID technology smart product based in (the Sino-German Research Institute), a Chinese institute. Chaim, Muschard, Cazarini and Rozenfeld (2018) have discussed the opportunity to integrate (KPIs) key performance indicators for measuring sustainability outcomes of I4.0 context in a virtual learning environment. Indicators such as work conditions and job opportunities can be authenticated as social issues. Challenges in this field can be linked to the effects of technological systems substitution of many jobs. Table 5 shows the impacted factors of social sustainability.

**Sustainability sub-themes Analysis**

After classifying the factors of sustainability which are affected by Industry 4.0 and supply chain management, it is clear that supply chain 4.0 impacts different areas of each pillar of sustainability. Based on the synthesis of the created factors and classifications, the relations between supply chain management, Industry 4.0 and sustainability have been analyzed, leading to developing sub-goals or subthemes of sustainability. The subthemes were divided as follows: Production & Resourcing, Technology and Innovation, Macro-economics, Materials & Energy, Environmental Management, Emission, Waste and Pollution Prevention, Community, Individuals) through the triple bottom line. Based on the content analysis the eight subthemes of sustainability will improve to understand how sustainability can be affected during the adoptions of digital technologies. Table 6 shows a thematic analysis synthesis organized by each dimension and subtheme of sustainability after integrating both Industry 4.0 and supply chain management pillars. The most-valued sustainability factors include outcomes of Industry 4.0 integration on supply chain management.

## DISCUSSION

An era of revolutionary supply chain has been brought by I4.0 through smart technologies and digitalization. Universally, industries are step by step advancing to-ward the adoption of such advanced machinery trying not to die in this unstable, dubious, sophisticated and vague time. Industry 4.0 will make production processes more flexible and efficient, allowing mass production and mass customization in the network of supply chain. The application of green practices across the whole product life cycle can allow energy efficient and more environmentally sustainable supply chain. However, during the pre- and post-stages of Industry 4.0 implementation, Industry 4.0 has gloomy side which can impact the sustainability of inventory networks of supply chain. Some of the significant issues include lower job opportunities and the need to modify education systems in order to align with the emerging fourth industrial revolution. These issues can make more vulnerabilities and increase risks that can cause unsustainable results of supply chain 4.0 adoption. Such issues can be nursed by addressing factors of sustainability that will be impacted through digitalizing supply chain.

The reviewed articles showed key factors and subthemes of sustainability to the Industry 4.0 and supply chain integration. Apparently, supply chain 4.0 apply to all three dimensions of sustainability. It has been recognized that supply chain 4.0 will generate more sustainable practices like monitoring the carbon footprint, enhancing cognitive support for real-rime dynamic decision and making the connections between companies completely digital. Moreover, attributes to be cost effective, flexible and robust to be efficient, sustainable, and durable in the long term will be adopted by the new digital supply chains.

Regarding the functionality necessary to enable a fourth supply chain, Industry 4.0 can enable the customer centric and driven supply chain to be digitally linked where information could be provided on the usage of smart goods and their status at various supply chain stages. Energy efficiency of the product can be visualized by these features, lowering maintenance and allowing end-of-life tracking, which enables preparation for recycling. From that perspective, it is vitally important to be aware of the factors of sustainability that are affected through the design, function and control stages of Industry 4.0 and to allow sustainable business models through the implementation of I4.0 technologies.

Here, it is important to highlight the challenge of narrowing sustainability factors due to the unrestricted existence of different industries. Indicators such as pollution, working conditions, profit and cost reduction can be focused and addressed by different sectors of industry. The research showed that the Industry 4.0 innovations have the tendency to make the current manufacturing measures more sustainable.

## CONCLUSIONS

In conclusion, the review paper highlights different sustainability aspects that digital transformation of Industry 4.0 has on supply chain management. The effect of integrating Industry 4.0 and supply chain on sustainability represents a field of study that has yet to be deepened in its various aspects by

academic literature. The standardized and sustainable Industry 4.0 models on supply chains can leave a better world for centuries to come and can improve the quality of life of individuals. This will rely on how academic research contributes in delivering new information in this field. A number of different projects that have adopted sustainability were analyzed such as "agri-food 4.0/agriculture 4.0", "Taiwan Productivity 4.0", "Making Indonesia 4.0" and "Made in China 2025". Dealing with sustainability and Industry 4.0 can be verified by concepts, as well as models of supply chain 4.0 and sustainable manufacturing.

The key focus of current literature is linking Industry 4.0, supply chain and sustainability through a systematic analysis. A classification of sustainability outcomes that can be linked to supply chain 4.0 has been established. These areas can lead into having better sustainability outcomes. The knowledge and solution offered as classification and framework for sustainably subgoals in the Industry 4.0 era is the key contribution of this work. Instead of implementing innovative technology without strategic guidance, companies can concentrate on sustainability based on sub-themes targets.

Despite the fact that scholars have a growing interest on sustainability issues of Industry 4.0, there is a lack in providing a systematic image of the present state of study in this area. According to the verification made by this review, dealing with particular can be used to approach sustainability. The novelty of the paper lies in the value of presenting a comprehensive review of the current literature. For future academic research, the paper has identified eight areas on sustainability among supply chain 4.0. The paper, amongst these, proposed subfactors which are closely linked to the subject of supply chain 4.0 in terms of the three pillars. In that context, future research may focus on how the sustainability issue applies to other related key topics and understanding how the supply chain 4.0 relates to various issues of sustainability. In conclusion, this paper proposes considerations that make it possible to understand how the topic of sustainability in the supply chain 4.0 has been addressed in previous literature thus providing scholars with some preliminary food for thought for the future study of the sector and the topic of sustainability.

## REFERENCES

[1] Axelsson, J., Froberg, J., Eriksson, P. (2018). Towards a System-of-Systems for Improved Road Construction Efficiency Using Lean and Industry 4.0. *2018 13th Annual Conference on System of Systems Engineering (SoSE)*, Institute of Electrical and Electronics Engineers Inc, 576-582.

[2] Belaud, J.-P., Prioux, N., Vialle, C., Sablayrolles, C. (2019). Big data for agri-food 4.0: Application to sustainability management for by-products supply chain. *Computers in Industry*, *111*, 41–50.

[3] Bibaud-Alves, J., El-Haouzi, H.B., Thomas, P., Boucinha, V. (2019). Toward a Sustainable New Product Development Approach Based on Industry 4.0 Assets. *Service Orientation in Holonic and Multi-Agent Manufacturing*. Springer International Publishing: Cham, Switzerland, *803*, 156–167.

[4] Birkel, H., Veile, J.W., Müller, J.M., Hartmann, E., Voigt, K.-I. (2019). Development of a Risk Framework for Industry 4.0 in the Context of Sustainability for Established Manufacturers. *Sustainability*, *11* (2), 384.

[5] Bonilla, S.H., Silva, H.R.O., Da Silva, M.T., Gonçalves, R.F., Sacomano, J.B. (2018). Industry 4.0 and Sustainability Implications: A Scenario-Based Analysis of the Impacts and Challenges. *Sustainability*, *10* (10), 3740.

[6] Braccini, A.M., Margherita, E.G, (2018). Exploring Organizational Sustainability of Industry 4.0 under the Triple Bottom Line: The Case of a Manufacturing Company. *Sustainability*, *11* (1), 36.

[7] Chaim, O. Muschard, B. Cazarini, E. Rozenfeld, H. (2018). Insertion of sustainability performance indicators in an industry 4.0 virtual learning environment. *Procedia Manufacturing*, *21*, 446–453.

[8] Dastbaz, M., Cochrane, P. (2019). *Industry 4.0 and Engineering for a Sustainable Future.* Springer Nature Switzerland AG.

[9] De Man, J.C., Strandhagen, J.O. (2017). An Industry 4.0 Research Agenda for Sustainable Business Models. *Procedia CIRP*, *63*, 721–726.

[10] Del Campo, G., Calatrava, S., Canada, G., Olloqui, J., Martinez, R., Santamaria, A. (2018). IoT Solution for Energy Optimization in Industry 4.0: Issues of a Real-life Implementation. *2018 Global Internet of Things Summit (GIoTS)*, Bilbao, 2018, 1-6, doi: 10.1109/GIOTS.2018.8534537.

[11] Ding, B. (2018). Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains. *Process Safety and Environmental Protection*, *119*, 115–130.

[12] Duarte, S., Cruz-Machado, V. (2018). Exploring Linkages between Lean and Green Supply Chain and the Industry 4.0. *Proceedings of the Eleventh International Conference on Management Science and Engineering Management.* Springer, Cham, pp 1242-1252.

[13] Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, *252*, 119869.

[14] Fink, A. (2019). *Conducting Research Literature Reviews: From the Internet to Paper*. Thousand Oaks, CA: Sage Publications.

[15] Franciosi, C., Iung, B., Miranda, S., Riemma, S. (2018). Maintenance for Sustainability in the Industry 4.0 context: A Scoping Literature Review. *IFAC-PapersOnLine*, *51* (11), 903–908.

[16] Fritzsche, K., Nieho, S., Beier, G., (2018). Industry 4.0 and Climate Change—Exploring the Science-Policy Gap. *Sustainability*, *10* (12), 4511.

[17] Gough, D., Oliver, S., Thomas, J. (2017). *An Introduction to Systematic Reviews*. Los Angeles, CA: Sage Publications.

[18] Hidayatno, A., Destyanto, A.R., Hulu, C.A. (2019). Industry 4.0 Technology Implementation Impact to Industrial Sustainable Energy in Indonesia: A Model Conceptualization. *Energy Procedia*, *156*, 227–233.

[19] Jabbour, A.B.L.D.S., Jabbour, C.J.C., Foropon, C., Filho, M.G. (2018). When titans meet—Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. *Technological Forecasting & Social Change*, *132*, 18–25.

[20] Kamble, S.S.; Gunasekaran, A.; Gawankar, S.A. (2018). Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. *Process Safety and Environmental Protection*, *117*, 408–425.

[21] Kamble, S.S., Gunasekaran, A., Sharma, R. (2018). Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry. *Computers in Industry*, *101*, 107–119.

[22] Kiel, D., Müller, J.M., Arnold, C., Voigt, K.-I., (2017). Sustainable industrial value creation: benefits and challenges of industry 4.0. *International Journal of Innovation Management*, *21* (08), 1740015.

[23] Kumar, R.,Singh, S.P., Lamba, K. (2018). Sustainable robust layout using Big Data approach: A key towards industry 4.0. *Journal of Cleaner Production*, *204*, 643–659.

[24] Luthra, S., Mangla, S.K. (2018). Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process Safety and Environmental Protection*, *117*, 168–179.

[25] Luthra, S., Mangla, S.K. (2018b). When strategies matter: adoption of sustainable supply chain management practices in an emerging economy's context. *Resources, Conservation & Recycling*, *138*, 194–206.

[26] Manavalan, E., Jayakrishna, K. (2019). A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. *Computers & Industrial Engineering*, *127*, 925–953.

[27] Miranda, J., Ponce, P., Molina, A., Wright, P., (2019). Sensing, smart and sustainable technologies for Agri-Food 4.0. *Computers in Industry*, *108*, 21–36.

[28] Moghaddam, M., Cadavid, M.N., Kenley, B., Deshmukh, A.V. (2018). Reference architectures for smart manufacturing: A critical review. Journal of Manufacturing Systems, *49*, 215–225.

[29] Monteleone, S., de Moraes, E.A., Maia, R.F. (2020). Analysis of the Variables That Affect the Intention to Adopt Precision Agriculture for Smart Water Management in Agriculture 4.0 Context. *2019 Global IoT Summit (GIoTS)*, 1-6, doi: 10.1109/GIOTS.2019.8766384.

[30] Müller, J.M., Voigt, K.-I. (2018). Sustainable Industrial Value Creation in SMEs: A Comparison between Industry 4.0 and Made in China 2025. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *5* (5), 659–670.

[31] Müller, J.M., Kiel, D., Voigt, K.-I. (2018). What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability. *Sustainability*, *10* (1), 247.

[32] Nascimento, D.L.M., Alencastro, V., Quelhas, O.L.G., Caiado, R.G.G., Garza-Reyes, J.A., Rocha-Lona, L., Tortorella, G. (2019). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of Manufacturing Technology Management*, *30* (3), 607–627.

[33] Paravizo, E., Chaim, O.C., Braatz, D., Muschard, B., Rozenfeld, H. (2018). Exploring gamification to support manufacturing education on industry 4.0 as an enabler for innovation and sustainability. *Procedia Manufacturing*, *21*, 438–445.

[34] Pedersen, M.R., Nalpantidis, L., Andersen, R.S., Schou, C., Bøgh, S., Krüger, V., Madsen, O. (2016). Robot skills for manufacturing: From concept to industrial deployment. *Robotics and Computer-Integrated Manufacturing*, *37*, 282–291.

[35] Roda-Sanchez, L., Garrido-Hidalgo, C., Hortelano, D., Olivares, T., Ruiz, M.C. (2018). OperaBLE: An IoT-Based Wearable to Improve Efficiency and Smart Worker Care Services in Industry 4.0. *Journal of Sensors*, *2018*, 1–12.

[36] Sherazi, H.H.R., Imran, M., Boggia, G., Grieco, L.A. (2018). Energy Harvesting in LoRaWAN: A Cost Analysis for the Industry 4.0. in *IEEE Communications Letters*, *22*, 11, 2358-2361, doi: 10.1109/LCOMM.2018.2869404.

[37] Shrouf, F., Ordieres, J., Miragliotta, G. (2020). Smart Factories in Industry 4.0: A Review of the Concept and of Energy Management Approached in Production Based on the Internet of Things Paradigm. *2014 IEEE International Conference on Industrial Engineering and Engineering Management*, Bandar Sunway, 697-701, doi: 10.1109/IEEM.2014.7058728.

[38] Stock, T., Obenaus, M., Kunz, S., Kohl, H. (2018). Industry 4.0 as enabler for a sustainable development: A qualitative assessment of its ecological and social potential. *Process Safety and Environmental Protection*, *118*, 254–267.

[39] Thomas, A., Haven-Tang, C., Barton, R., Mason-Jones, R., Francis, M., Byard, P. (2018). Smart Systems Implementation in UK Food Manufacturing Companies: A Sustainability Perspective. *Sustainability*, *10* (12), 4693.

[40] Tranfield, D., Denyer, D., Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, *14*, 207-222.

[41] Tsai,W.-H., Lu, Y.-H. (2018). A Framework of Production Planning and Control with Carbon Tax under Industry 4.0. *Sustainability*, *10* (9), 3221.

[42] Tsai, W.-H. (2018). Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques. *Energies*, *11*(8), 2072.

[43] Wisniewska-Sałek, A. (2018). Sustainable Development in Accordance with the Concept of Industry 4.0 on the Example of the Furniture Industry. MATEC Web Conference, *183*, 04005.

[44] Yazdi, P.G., Azizi, A., Hashemipour, M. (2018). An Empirical Investigation of the Relationship between Overall Equipment Efficiency (OEE) and Manufacturing Sustainability in Industry 4.0 with Time Study Approach. *Sustainability*, *10* (9), 3031.

**LIST OF TABLES & FIGURES**

Table 1
**Inclusion criterion for the selected papers.**

| Filter | Inclusion Criteria |
|---|---|
| Document Type | Article |
| Databases | Science Direct, Scopus and IEEE |
| Keywords | Sustainability, sustainable, Industry 4.0, supply chain, social, economic, environment |
| Years | 2017-2020 |
| Language | English |
| Selected articles | 35 |

*Source: Author's own elaboration.*

Table 2
**Academic Journal of articles**

| Journal Name | Frequency |
|---|---|
| Computers and Industrial Engineering | 3 |
| Energies | 1 |
| Energy Procedia | 1 |
| IFAC-PapersOnLine | 1 |
| International Journal of Innovation Management | 1 |
| International Journal of Precision Engineering and Manufacturing—Green Technology | 2 |
| Journal of Cleaner Production | 1 |
| Journal of Manufacturing Systems | 1 |
| Journal of Manufacturing Technology **Management** | 1 |
| Journal of Sensors | 1 |
| Procedia CIRP | 1 |
| Procedia Manufacturing | 2 |
| Proceedings | 6 |
| Process Safety and Environmental Protection | 4 |
| Studies in Computational Intelligence | 1 |
| Sustainability | 6 |
| Technological Forecasting and Social Change | 1 |
| Waste Management and Research | 1 |

*Source: Author's own elaboration.*

Table 3
**Positive and negative factors of environmental pillar.**

| Related subjects in Articles | Positive | Negative |
|---|---|---|
| **Natural Resource/Renewable Energy use** | Kiel et al., (2017); Monteleone, de Moraes & Maia (2020); Stock et al., (2018); De Man & Strandhagen (2017); | Kumar, Singh & Lamba (2018); Birkel, Veile, Müller, Hartmann & Voigt (2019); |
| **Life cycle/ Resource circularity/Circular economy/Resource optimization** | Axelsson, Froberg & Eriksson (2018); Nascimento et al. (2019); Stock et al., (2018); Jabbour, Jabbour, Foropon & Filho (2018); Ding (2018); Franciosi, Iung, Miranda & Riemma (2018); Miranda, Ponce, Molina & Wright (2019); | Birkel et al., (2019); Moghaddam Cadavid, Kenley & Deshmukh (2018); Wisniewska-Sałek (2018); Bonilla, Silva, Da Silva, Gonçalves & Sacomano (2018); |
| **Energy savings/Conservation** | Sherazi, Imran, Boggia & Grieco (2018); Kumar et al., (2018); Braccini & Margherita (2018); | Hidayatno, Destyanto & Hulu (2019); Stock et al., (2018); Franciosi et al., (2018); |
| **Performance** | De Man & Strandhagen (2017); Stock et al., (2018); Belaud, Prioux, Vialle & Sablayrolles (2019); Braccini & Margherita (2018); Shrouf, Ordieres & Miragliotta (2020); | Luthra & Mangla (2018); Bibaud-Alves, El-Haouzi, Thomas & Boucinha (2019); |
| **Cleaner Processes** | Nascimento et al. (2019); Stock et al., (2018); Braccini & Margherita (2018); Shrouf et al., (2020); | Luthra & Mangla (2018); Bonilla et al., (2018); Franciosi et al., (2018); |
| **Productivity** | Belaud et al. (2019); Ding (2018); Müller, Kiel & Voigt (2018); | Moghaddam et al., (2018); |
| **Efficiency** | Franciosi et al., (2018); Del Campo et al., (2018); Monteleone et al., (2020); Fritzsche, Nieho & Beier (2018); Miranda et al., (2019); | Luthra & Mangla (2018); |
| **Green logistics/SC/Manu/design** | Braccini & Margherita (2018); Kamble, Gunasekaran & Gawankar (2018); Nascimento et al. (2019); Kumar et al., (2018); Jabbour et al., (2018); | Kamble, Gunasekaran & Sharma (2018); Birkel et al., (2019); |
| **Biodiversity** | Müller et al., (2018); Fritzsche et al., (2018); Stock et al., (2018); | Kamble et al., (2018); Birkel et al., (2019); Franciosi et al., (2018); |
| **Solid Waste** | Ding (2018); Nascimento et al. (2019); Stock et al., (2018); Belaud et al. (2019); | Manavalan & Jayakrishna (2019); Birkel et al., (2019); |
| **Hazard Materials** | Jabbour et al., (2018); Nascimento et al. (2019); Kumar et al., (2018); | Kumar et al., (2018); Franciosi et al., (2018); |
| **Low carbon processes** | Manavalan & Jayakrishna (2019); Kumar et al., (2018); Tsai (2018); Tsai & Lu (2018); Stock et al., (2018); Nascimento et al. (2019); | Kumar et al., (2018); |
| **Emission reduction** | Wisniewska-Sałek (2018); Nascimento et al. (2019); | Manavalan & Jayakrishna (2019); Birkel et al., (2019); Franciosi et al., (2018); |

*Source: Author's own editing, 2021.*

Table 4
**Positive and negative factors of economic pillar.**

| Related subjects in Articles | Positive | Negative |
|---|---|---|
| Increase profit and cost reduction | Kiel et al., (2017); Manavalan & Jayakrishna (2019); Braccini & Margherita (2018); Kamble et al., (2018); | Luthra & Mangla (2018); De Man & Strandhagen (2017); Kumar et al., (2018); Kamble et al., (2018); Paravizo, Chaim, Braatz, Muschard & Rozenfeld (2018); |
| Productivity and efficiency | Manavalan & Jayakrishna (2019); Yazdi, Azizi & Hashemipour (2018); Braccini & Margherita (2018); Sherazi et al., (2018); Franciosi et al., (2018); | Luthra & Mangla (2018); Moghaddam et al., (2018); Bibaud-Alves et al., (2019); |
| Product longevity and durability | De Man & Strandhagen (2017); Ding (2018); Kamble et al., (2018); Miranda et al., (2019); | Luthra & Mangla (2018); |
| Transparency between companies | Kiel et al., (2017); Ding (2018); Shrouf et al., (2020); | Luthra & Mangla (2018); Birkel et al., (2019); |
| Reliability of Data | Shrouf et al., (2020); Axelsson et al., (2018); De Man & Strandhagen (2017); | Kiel et al., (2017); Luthra & Mangla (2018); Birkel et al., (2019); Moghaddam et al., (2018); |
| Business models product and process quality supply chain integration | Kiel et al., (2017); Müller & Voigt (2018); Stock et al. (2018); Nascimento et al. (2019); | Luthra & Mangla (2018); Birkel et al., (2019); Moghaddam et al., (2018); |
| Competitiveness | Kiel et al., (2017); Braccini & Margherita (2018); Wisniewska-Sałek (2018); | Luthra & Mangla (2018); Birkel et al., (2019); Müller & Voigt (2018); |
| Economic Growth | Hidayatno et al., (2019) | Luthra & Mangla (2018); Birkel et al., (2019); |
| Circular economy | Hidayatno et al., (2019) | Luthra & Mangla (2018); |

*Source: Author's own editing, 2021.*

Table 5
**Positive and negative factors of social pillar.**

| Related subjects in Articles | Positive | Negative |
|---|---|---|
| Standard of living | Chaim et al., (2018); De Man & Strandhagen (2017); Paravizo et al., (2018); Franciosi et al., (2018); Hidayatno et al., (2019), | Birkel et al., (2018); Bonilla et al., (2018); Braccini & Margherita (2018); |
| Education | Müller et al., (2018); Paravizo et al., (2018); Stock et al., (2018); | Luthra & Mangla (2018); Kiel et al., (2017); Birkel et al., (2019); Wisniewska-Sałek (2018); |
| Include employees with some degree of disability | Kamble et al., (2018); Kiel et al., (2017); | |
| Job Opportunities | Braccini & Margherita (2018); | Birkel et al., (2019); Ding (2018); Miranda et al., (2019); Müller & Voigt (2018); Stock et al., (2018); Tsai (2018); |
| Quality of work conditions | De Man & Strandhagen (2017); Kiel et al., (2017); Müller et al., (2018); Kamble et al., (2018); Miranda et al., (2019); | Birkel et al., (2019); Luthra & Mangla (2018); Moghaddam et al., (2018); |
| Relationship between organizations | Ding (2018); Kamble et al., (2018); Müller & Voigt (2018); | Birkel et al., (2019); Kiel et al., (2017); Luthra & Mangla (2018); Müller et al., (2018); |
| CSR | De Man & Strandhagen (2017); Paravizo et al., (2018); Kamble et al., (2018); Müller et al., (2018); Roda- | Birkel et al., (2019); Kamble et al., (2018); Luthra & Mangla (2018); Moghaddam et al., (2018); |

| | | |
|---|---|---|
| | Sanchez, Garrido-Hidalgo, Hortelano, Olivares & Ruiz (2018); | |
| Workplace safety management (decrease working accidents) | Manavalan & Jayakrishna (2019); Braccini & Margherita (2018); Kamble et al., (2018); Roda-Sanchez et al., (2018); | Franciosi et al., (2018); Kumar et al., (2018); |

*Source: Author's own editing, 2021.*

Table 6
**Positive and negative factors of social pillar.**

| PILLAR | SUB-THEME | FACTORS |
|---|---|---|
| **ECONOMIC** | 1. Production & Resourcing | Increase profit and cost reduction |
| | | Productivity and efficiency |
| | | Product longevity and durability |
| | 2. Technology and Innovation | Transparency between companies |
| | | Reliability of Data |
| | | business models product and process quality supply chain integration |
| | 3. Macro-economics | competitiveness |
| | | Economic Growth |
| | | Circular economy |
| **ENVIRONMENTAL** | 4. Materials & Energy | Natural Resource/Renewbale Energy use |
| | | Life cycle/ Resource circularity/Circular economy/Resource optimization |
| | | Energy savings/Conservation |
| | 5. Environmental Management | Performance |
| | | cleaner Processes |
| | | Productivity |
| | | Efficiency |
| | | green logistics/SC/Manu/design |
| | 6. Emission, Waste and Pollution Prevention | Biodiversity |
| | | Solid Waste |
| | | Hazard Materials |
| | | low carbon processes |
| | | Emission reduction |
| **SOCIAL** | 7. Community | Standard of living |
| | | Education |
| | | Include employess with some degree of disability |
| | 8. Individuals | Job Opportunities |
| | | quality of work conditions |
| | | Relationship between organizations |
| | | CSR |
| | | Workplace safety management |

*Source: Author's own editing, 2021.*

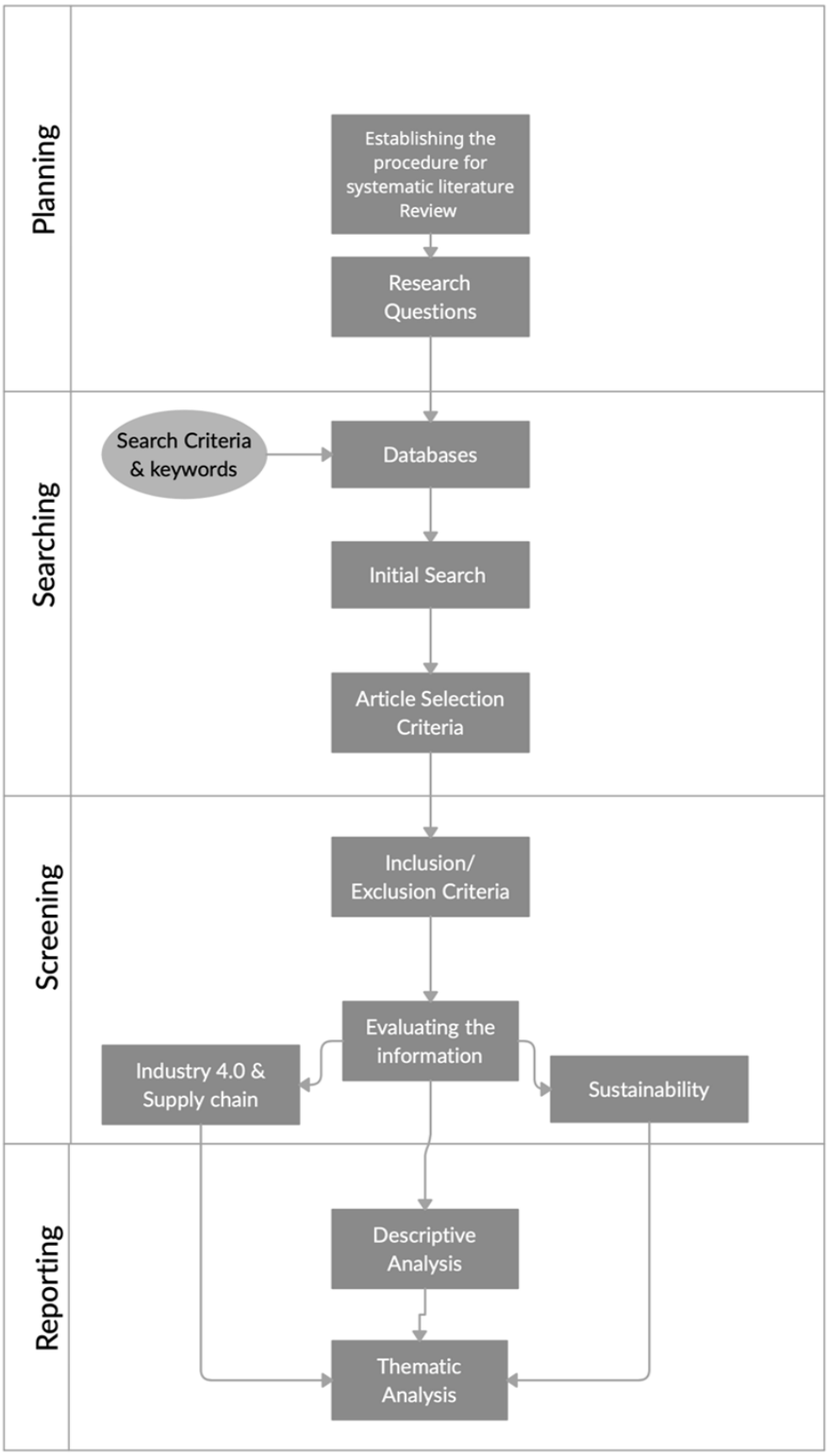


Figure 1
**Systematic analysis of literature process**
*Source: Tranfield et al. (2003)*

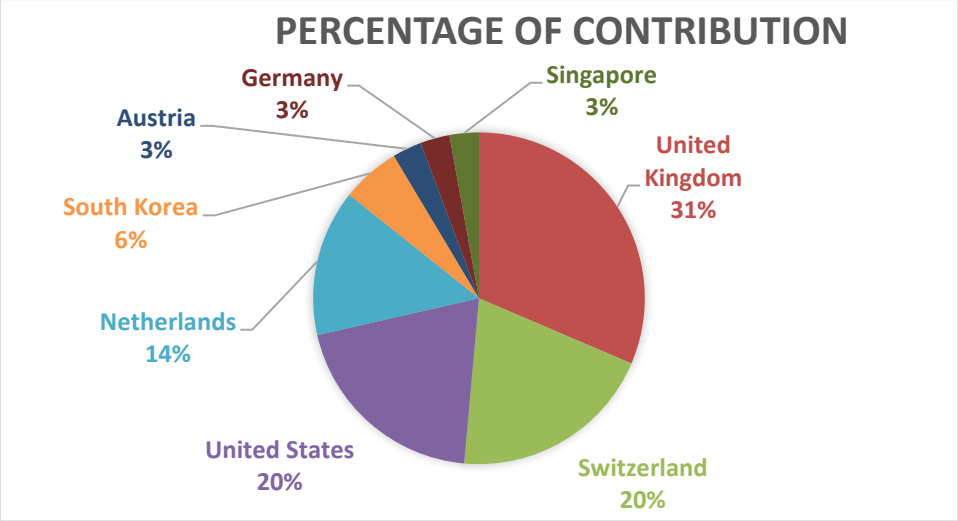


Figure 2
**Percentage of contribution by each country**
*Source: Authors elaboration based on academic literature*