The Environmental, Economic and Social Impact of Industry 4.0 in the Food Sector: a Descriptive Literature Review.

Roberta Stefanini*, Giuseppe Vignali**

*Department of Engineering and Architecture, University of Parma – Parco Area delle Scienze 181/A, 43124, Parma (Italy) (email: roberta.stefanini@unipr.it)

**Department of Engineering and Architecture, University of Parma – Parco Area delle Scienze 181/A, 43124, Parma (Italy) (email: giuseppe.vignali@unipr.it)

Abstract: Industries today are facing new technological changes. Thanks to the introduction of new tools and technologies of the so-called Industry 4.0, industrial processes are becoming more automated and interconnected. In the meantime, laws and international meetings, such as the 2030 Agenda, ask companies to be more sustainable. Considering these premises, this study aims to analyse the available studies that focus on a possible link between these two topics, investigating the sustainability of 4.0 innovations in the food sector. The work carried out a literature analysis on the Scopus scientific database, looking for papers published in English all over the world. Results highlight that among the three pillars of sustainability, the environmental is the most studied one. More efforts should be done, instead, from an economic and social point of view. However, even if the available studies are still few, they are increasing over the last few years, also spreading geographically, underling the importance of these topics in the near future.

Keywords: Industry 4.0; Food sector; Sustainability; Life Cycle Assessment; Social Life Cycle Assessment; Life Cycle Costing; Literature Review.

1. INTRODUCTION

The new paradigm of Industry 4.0 is becoming widespread in the context of developed countries. Several national programs have promoted, during the last 10 years, the introduction of Industry 4.0 systems to increase the productivity of industrial fields. In the Italian context the food industry has an important role and for this reason many industry 4.0 applications concern this sector (Clairand, et al., 2020) (Kodan, et al., 2020) (Konur, et al., 2021). As far as the advantages of the introduction of Industry 4.0 enabling technologies are concerned, studies have shown the economic advantages of their implementation (Bader & Rahimifard, 2020) (Van Geest, et al., 2021). On the other hand, not many studies until now have reported an evaluation of the social and environmental impact of solutions that substantially reduce the workforce and enhance the energetic consumption of factories (Lertpiromsuk, et al., 2022).

In the meantime, many national and international regulations highlight the commitment of companies to adopt sustainable strategies (United Nations, 2021) in order to contribute to reaching a sustainable development, as signed in the 2030 Agenda, defining the word "Sustainability" as a sum of three main pillars i.e. the economic, environmental and social one. Among the others, the food sector resulted as one of the most impactful ones in all the three dimensions of sustainability (Baldini, et al., 2018) (Food and Agriculture Organization, 2021) (Plastic Europe, 2021).

Besides these two main changes in the food industry, it is interesting to understand if the introduction of Industry 4.0 in this sector can lead also to a more sustainable industry. In particular, a review of the existing studies in the scientific literature will be helpful to better understand how the three sustainability pillars could be evaluated in 4.0 Food Industry. This preliminary work will be the baseline in order to propose, in future developments, a framework to evaluate the sustainability of an Industry 4.0 implementation, considering all the sustainability pillars, in a real case study.

The next section of the article presents the methodology used to carry out the literature review: the Scopus database is used to find papers that investigated, until now, the link between Industry 4.0 in the food sector and the three sustainability dimensions. Then, chapter 3 describes in a qualitative way the types of articles found, their geographical and temporal distribution, topic and relevance. Finally, key findings are discussed and conclusions about future research are drawn.

2. LITERATURE REVIEW METHODOLOGY

The methodology used is a systematic literature review: works published in English e.g. conference papers, articles, book chapters, short surveys, were found on Scopus Database. A computerized search was made looking for keywords in "title, abstract and keywords" which, according to the authors, could better investigate the possible relation between the implementation of Industry 4.0 in the food sector and their environmental, economic and social sustainability assessment. No temporal or geographical limits were introduced in the search. In particular, considering the three main pillars of the sustainability definition, three main categories of keywords were found: for the economic pillar, the keywords *economic*

impact, economic sustainability, Life Cycle Costing and *LCC* were used; for the social one: *social impact, social sustainability, Social Life Cycle Assessment* and *S-LCA*; finally for the environmental pillar: *environmental impact, environmental sustainability, Life Cycle Assessment* and *LCA*. These terms were combined, in turn, with the two main keywords of the analysis: *Food* and *Industry 4.0*. After the first search, the replications were eliminated: only relevant papers were considered for the next step of the analysis. Overall, the procedure used is illustrated in Figure 1.
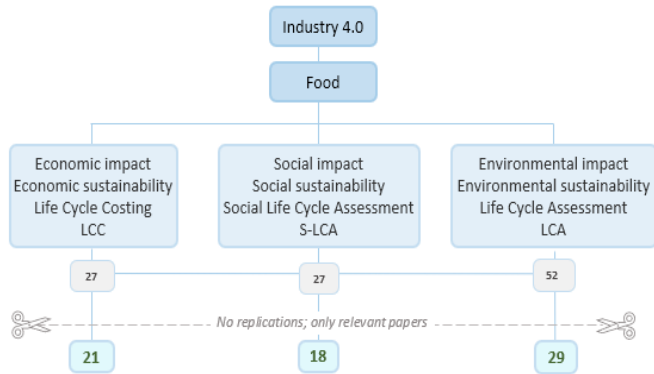

Figure 1. Keywords and papers samples

The next step of the methodology aimed at analysing, from a qualitative and descriptive point of view, the samples of papers. Excel was used to create different charts and tables to elaborate on the main results presented in the next chapter.

3. RESULTS AND DISCUSSION

Overall, the environmental issue resulted as the most studied pillar of sustainability: 52 works were found at the first step of the analysis, while only 27 were collected both for the economic and the social pillars (Figure 2).

Figure 2. The keywords used and the respective number of papers found, divided in the three sustainability pillars

Since the wording "Industry 4.0" was used for the first time in 2011, some considerations were made considering the relevant papers, without replications, published in the 10 last years. Figure 3 demonstrates that the number of works that focus on some environmental, economic and social issues related to Industry 4.0 in the food sector is gaining interest. The authors decided to stop in 2021 since the search is carried out in February 2022, and few works are available for this year yet.
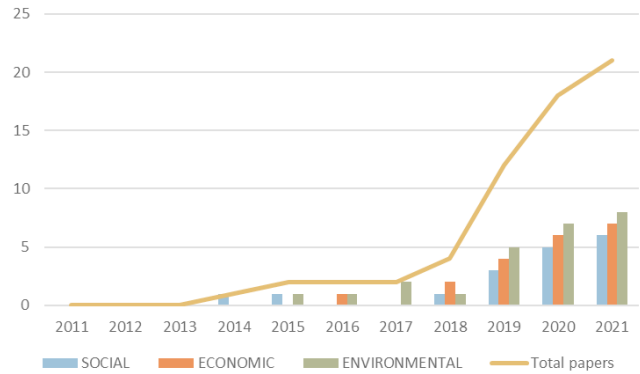

Figure 3. The number of works that study the environmental, social, and economic issues in Food Industry 4.0 in the last 10 years.

Considering the total sample of works on the three pillars of sustainability, without replications, the following map resumes the countries where the research was conducted. In particular, the address of the corresponding author of each paper was taken as a reference. In particular, the United Kingdom and Italy resulted as the main countries where researchers carried out works on the sustainability of Industry 4.0 related to the food sector (Figure 4).

Figure 4. Distribution of published papers, all over the world, on the sustainability (environmental or economic or social) of Industry 4.0 in the food sector.

Besides these results, it can be stated that even if the number for work on these topics is still low, the link between Industry 4.0 and sustainability is geographically and temporally gaining interest. In particular, to help the reader in the consultation of the papers, the following table resumes the works related to the evaluation of the environmental/economic/social sustainability of Industry 4.0 in the food sector, regardless the keywords used by the authors.

Table 1. List of papers on the environmental (EN), social (SO) and economic (EC) sustainability of Industry 4.0 implications in the food sector

AUTHORS	DOI	EN	SO	EC
(Lertpiromsuk, et al., 2022)	10.1007/978-981-16-2380-6_54		X	
(Siekierski & Ponchio, 2014)	-		X	X
(Fleming, et al., 2021)	10.1016/j.agsy.2021.103120		X	
(Galanakis, et al., 2021)	10.1016/j.tifs.2021.02.002		X	X
(Ojo, et al., 2020)	10.1504/IJISM.2020.107851	X	X	X
(Meinke, 2019)	10.1016/B978-0-12-813411-5.00003-X		X	X
(Yusuf, 2021)	10.1111/rsp3.12463			X
(Ronzoni, et al., 2021)	10.1016/j.jmsy.2021.10.008		X	X
(Sardjono, et al., 2021)	10.24507/icicel.15.04.397		X	X
(Rodríguez-Mireles, et al., 2021)	10.1016/j.jval.2020.12.005		X	
(Chaveesuk, et al., 2020)	10.1145/3396743.3396781		X	X
(Accorsi, et al., 2019)	10.1016/j.promfg.2020.01.044		X	X
(Demartini, et al., 2018)	10.1016/j.ifacol.2018.08.337			X
(Jagtap, et al., 2021)	10.1016/j.compind.2021.103397	X		
(Balogun, et al., 2020)	10.1016/j.scs.2019.101888	X	X	X
(Diaz, et al., 2020)	10.1109/ACCESS.2020.3041357		X	X
(Prasetyawan, et al., 2019)	10.1088/1757-899X/528/1/012025		X	X
(Watson, et al., 2021)	10.3389/fsufs.2021.642786	X		
(Prayogo & Bayu, 2020)	10.1088/1755-1315/456/1/012041	X		
(Tseng, et al., 2019)	10.1016/j.resconrec.2019.01.015	X	X	X
(Özoğul & Baran, 2019)	-	X	X	X
(Motesharezadeh, et al., 2017)	10.1007/s10661-017-5812-y	X	X	X
(Shaheen & Rinklebe, 2017)	10.1016/j.jenvman.2016.07.060	X		
(Muñoz-Zamponi & Mardones-Poblete, 2016)				
(Tassou, et al., 2007)	10.1016/j.enconman.2007.06.049	X		X
(Pless-Mulloli, et al., 2005)	10.1136/oem.2004.018754	X	X	
(May, et al., 2001)	10.1007/s002440010142	X	X	
(Fallahpour, et al., 2021)	10.1108/IMDS-06-2020-0343	X	X	X
(Ada, et al., 2021)	10.3390/su13126812	X	X	X
(Yong, et al., 2021)	10.1016/j.biotechadv.2020.107684	X	X	X
(Mohamed, et al., 2021)	10.1016/B978-0-323-88506-5.50281-3	X	X	X
(Agnolucci, et al., 2020)	10.1016/j.fm.2020.103598	X		
(Bai, et al., 2020)	10.1016/j.ijpe.2020.107776	X	X	X
(Cañas, et al., 2020)	10.3390/su12197978	X	X	X
(Corallo, et al., 2020)	10.1080/00207543.2020.1771455	X		
(Symeonaki, et al., 2020)	-	X	X	X
(Ruggieri, et al., 2020)	10.3280/RISS2020-001009	X	X	
(Valecce, et al., 2019)	10.1109/ICCW.2019.8756735	X		
(Pérez Perales, et al., 2019)	10.1007/978-3-030-28464-0_43	X	X	
(Gružauskas, et al., 2018)	10.1016/j.jclepro.2018.02.302	X		X
(Siemieniuch, et al., 2015)	10.1016/j.apergo.2015.04.018		X	
(Cooreman-Algoed, et al., 2022)	10.1016/j.resconrec.2021.106089	X		
(D'Agaro, et al., 2021)	10.2478/ebtj-2021-0022	X		
(Jambrak, et al., 2021)	10.3390/app11020686	X	X	X
(Belaud, et al., 2019)	10.1016/j.compind.2019.06.006	X		

4. CONCLUSIONS

The food sector today is interfacing with two main changes: the implementation of industry 4.0 technologies and the need for sustainability. The present research aimed to perform a literature analysis on the Scopus database, trying to understand if there were already studies that considered the relationship between the two issues. Based on the results shown, it can be said that studies relating to the sustainability of 4.0

introductions in the food company are present and, even if they are yet few, they are increasing over the years, especially in Europe. In particular, environmental sustainability seems to be the most studied topic, compared to the social and economic ones, maybe due to the national and international regulations that invite companies and people to respect the Planet. The present study has some limitations: to be short and incisive, it does not investigate in deep the findings of the papers found, but it offers the reader a table to consult all the articles that may be useful on the subject. Moreover, a bibliometric software, such as BibExcel, could have been used for citation and co-citation analysis. Therefore, in the future developments, the authors will improve these aspects and, based on the premises of this work, they will aim at proposing a framework for the assessment of the sustainability of an Industry 4.0 application that considers both the economic, the social and the environmental aspects. A case study will be developed to show the results achievable and the difficulties in a real application.

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