Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 103 (2021) 26–31

www.elsevier.com/locate/procedia

9th CIRP Global Web Conference – Sustainable, resilient, and agile manufacturing and service operations : Lessons from COVID-19

Circular economy as a key for industrial value chain resilience in a post-COVID world: what do future engineers think?

Michael Saidani[a,b,*], Francois Cluzel[b], Bernard Yannou[b], Harrison Kim[a]

[a]*Department of Industrial and Enterprise Systems Engineering, University of Illinois at Urbana-Champaign, USA*
[b]*Université Paris-Saclay, CentraleSupélec, Laboratoire Genie Industriel, France*

* Corresponding author. Tel.: +1-217-305-3955. *E-mail address:* msaidani@illinois.edu

Abstract

While the COVID-19 pandemic has led to many disruptions in industrial value chains, the adoption of circular economy (CE) principles appears to be a commendable solution for more robust, resilient, and sustainable industrial supply chains. In this study, the standpoints and visions of two consecutive classes of engineering students – following the course "Circular Economy & Industrial Systems" at the Université Paris-Saclay – are given on how they value CE strategies to mitigate the impact of COVID-19 on industrial practices. Capturing and understanding the viewpoints of the engineers of tomorrow on such a pressing issue is key to train and provide them with the suitable methods and tools to build a more circular and sustainable society. At the end of their eight-week training class, including theoretical background on industrial ecology tools, workshops, and a hands-on project, part of the final exam included a one-hour essay in which the students had to argue their position on the following questions: (i) "Circular Economy as an answer to the COVID-19 crisis?" for the class of 2020, and (ii) "Circular Economy as an answer for green recovery and value chain resiliency in the COVID-19 context?" for the class of 2021. Interestingly, the evolution of viewpoints between the beginning of the COVID-19 crisis (exam conducted in May 2020 for the first class) and one year after (exam conducted in Mars 2021 for the second class) is discussed and illustrated. Also, the answers and insights provided by engineering students on these questions are positioned within the state-of-the-art literature on the topic. Last but not least, key recommendations and challenges on how CE could alleviate COVID-related disruptions and production shortages are synthesized in a SWOT (strengths, weaknesses, threats, and opportunities) diagram.

Keywords: Circular economy; industrial systems; supply chain resilience; COVID-19; engineering students.

1. Introduction

The year 2020 initiated the discussion on lessons learned from the COVID-19 crisis to transitioning towards a more sustainable and resilient society [1]. The concepts of industrial value chain resiliency, sustainability, and circular economy (CE) became indeed more imperative in the wake of the recent coronavirus pandemic [2-5]. Notably, it is increasingly acknowledged that the application of CE principles could alleviate the socio-economic disturbances caused by the pandemic and provide credible solutions [6]. In fact, design for repairability, reusability, and remanufacturing offers considerable opportunities for the resilience (e.g., in terms of stock availability) of industrial value chains [7]. Yet, this unprecedented COVID-19 situation led several sectors to both unsustainable waste management and many disruptions all along the supply chain [8, 9]. Moreover, in the current COVID-19 context, strong divergences appear in our

2212-8271
10.1016/j.procir.2021.10.003

industrialized society. On the one hand, some industrial lobbies militate for a return to a "business-as-usual" environment after the crisis, with low environmental considerations. On the other hand, some institutions or organizations claim that CE is a solution to reinvent the "world after". In the meantime, the engineers, designers, and managers of tomorrow, will be in charge of shaping – or at least influencing – the future state of industrial systems. Understanding the viewpoints of the engineers of tomorrow on such a pressing issue is therefore key to train and provide them with the suitable methods and tools to build a more sustainable society. With this background, the present research work aims to capture, analyze, and discuss the visions and opinions of engineering students – who followed a CE-related training program – on solutions and best practices to cope with the disruptions caused by the pandemic.

2. Materials and methods

2.1. "Circular Economy & Industrial Systems" engineering classes of 2020 and 2021 at the Université Paris-Saclay

In this study, the standpoints and visions of two consecutive classes of engineering students (Master 1 level) – enrolled in the course "Circular Economy & Industrial Systems" at the Université Paris-Saclay – are collected and analyzed on how they value CE strategies to mitigate the impact of COVID-19 on industrial practices. Among the 87 engineering students participating in this course, 32 and 31 of them, for the classes of 2020 and 2021, respectively, selected the COVID-related subject for their essay (n.b.: two other subjects were available each year). At the end of their eight-week training class, including theoretical background on industrial ecology tools, workshops, and a hands-on industrial project, part of the final exam included a one-hour essay in which the students had to argue their position on the following main questions, after reading short and *ad-hoc* articles on the topic: (i) "Circular Economy as an answer to the COVID-19 crisis?" for the class of 2020 (sub-section 3.1), and (ii) "Circular Economy as an answer for green recovery and value chain resiliency in the COVID-19 context?" for the class of 2021 (sub-section 3.2). Each main question has been divided into three sub-questions to guide the students in their essays. Each of the two subjects is built on the same pattern with one question of general understanding, and two questions of personal reflection. The detailed exams for the classes of 2020 and 2021, are given in Appendix A, with all supporting references. Interestingly, the evolution of engineering students' viewpoint between the beginning of the COVID-19 crisis (exam conducted in May 2020 for the first class, i.e., about two months after the beginning of the first sanitary lockdown in France) and one year after (exam conducted in Mars 2021 for the second class, i.e., just before the third lockdown in France) is analyzed both manually by the authors and using text mining and sentiment analysis tools to further discuss and illustrate their answers. In the present case, without any specific training dataset, the Google Natural Language API appeared to be the most accurate tool for sentiment analysis compared to other tools (e.g., Textanalyzer, Free Sentiment Analyzer) when looking at the results (sentiment score) given by the API and our personal readings and interpretations of the answers.

2.2. Literature survey: contribution of circular economy for industrial resiliency in the COVID-19 context

Additionally, the answers and insights provided by engineering students on these questions are positioned within the state-of-the-art post-COVID literature (i.e., from the past 18 months) on this topic (sub-section 3.3). To identify and select relevant articles, the Google Scholar database has been used with search queries combining the following keywords: ("COVID-19" OR "Coronavirus" OR "pandemic") AND ("circular economy" OR "closed loop") AND ("resilient" OR "resilience" OR "industrial" OR "value chain" OR "supply chain"). Note that the reading materials provided to the students are based on state-of-the-art publications (e.g., released in the press a couple of days before the exam). As several statements written by the students are directly reported in this paper, they have been selected according to the following criteria: (i) statements that summarize well a consensus among different students (to illustrate an argument concretely), (ii) originality of the statement (e.g., a positioning that stands out from the others), (iii) clarity of the statement, and (iv) interest and added value for the reader. Eventually, the key recommendations and remaining challenges on how CE could alleviate COVID-related production shortages are summarized through a SWOT (strengths, weaknesses, threats, and opportunities) diagram.

3. Results and discussion

3.1. Insights from engineering students (class of 2020): "Circular Economy as an answer to the COVID-19 crisis?"

The three sub-questions guiding this first essay for the class of 2020 are detailed in Appendix A. In total, all students (32 out of 32) answered the first sub-question in 230 words on average, 30 students answered the second sub-question in 194 words on average, and 30 students answered the third sub-question in 170 words on average. The most frequent words used by the engineering students are illustrated in the tag cloud of Fig. 1.

Fig. 1. Word cloud of most frequent terms used by the engineering students

First, the students were asked to identify which pillars of CE could contribute to building a resilient circular economy during the COVID-19 recovery. The pillars that were cited the most often are: (i) responsible consumption and sustainable sourcing, (ii) functional economy, (iii) industrial and territorial ecology, and (iv) ecodesign. Specifically, several students mentioned the importance of the 3R (repair, reuse, recycle) principles to extend the lifespan of products and thus increase resource availability and supply chain resilience.

Second, they had to give their opinions on whether or not the requests of several companies or industrial sectors to loosen environmental regulations are well justified by the economic and social issues raised by the COVID-19 crisis. A large majority of students agreed on rejecting these demands and pressures to suspend regulatory constraints regarding environment protection. The Google Natural Language API, AutoML Natural Language, has been used to automatically perform sentiment analysis on students' answers. AutoML Natural Language provides a breakdown of the sentiment per sentence, an overall score from 1.00 (very positive) to -1.00 (very negative), and a magnitude score, from 0 to infinity, which represents the strength of the sentiment, regardless of the score. The results revealed that 28 out of the 30 engineering students answering this question had a negative opinion regarding these claims, as illustrated in Fig. 2. More precisely, the average score is -0.27, with a standard deviation of 0.17. While most engineering students following this course were strongly against the requests made by some industrial companies to loosen environmental regulations (e.g., "I do not think that these requests are justifiable by anything", or "Some of the measures presented in the article are plainly scandalous for anyone aware of the challenges of green energy"), one understood and supported these requests: "I think these requests for relief are understandable given the very sudden nature of this pandemic. In order to revive the economy, environmental constraints have been eased to allow for more production, which is necessary for some industries." Interestingly, a group of students is more balanced in their opinions by trying to understand both sides, e.g., arguing that:

- "The pressure on governments to relax environmental regulations on companies is based on two arguments: The economic one which consists in saying that the recovery would be faster. And the social one which consists of saying that companies in difficulty need help if they do not want to lay off their employees. Although these two risks are very real, wanting to make concessions on environmental regulations is a short-term logic that many, including large investors, denounce. In fact, there are many other means than relaxing environmental standards to support businesses (e.g., tax relief, debt restructuring)."
- "I do understand the urge of companies to avoid bankruptcy; however, this pandemic may be a key inflection point on the curve of circularity. Short-term survival solutions must be held with the engagement to develop long-term resilience strategies."

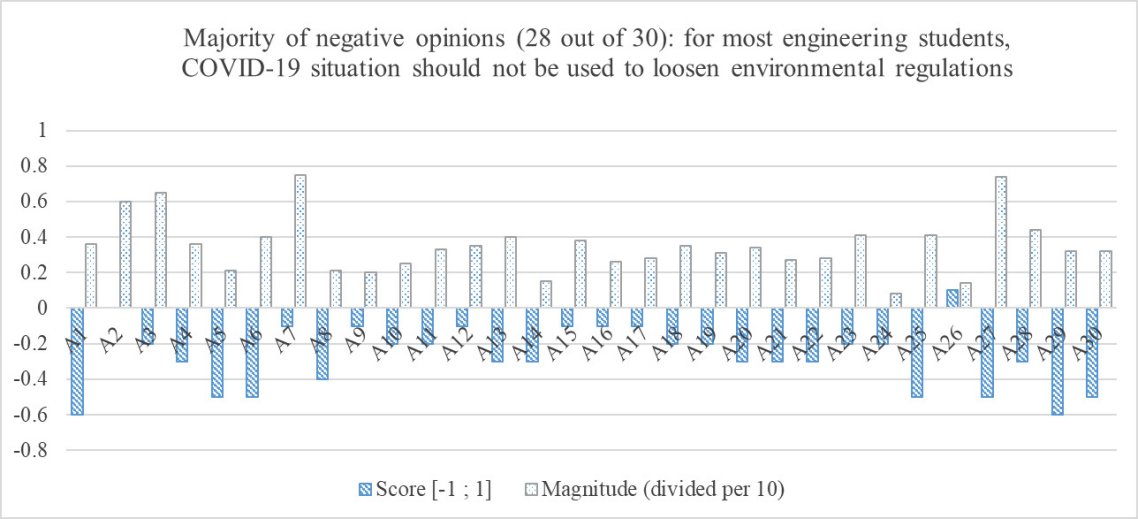

Fig. 2. Sentiment analysis results

Then, the engineering students had to reflect on how and to what extent CE is an appropriate and sufficient answer to tackle the COVID-19 crisis from an industrial standpoint. Most of the responses were well balanced, i.e., in favor of transitioning towards more CE strategies while stating, for example, that "the reality seems more complex than simply choosing between business-as-usual and the circular economy". Another student added that "although circular economy has a lot to bring to the table (it decreases a lot the waste production, resource exploitation, toxic emissions), it is not a full solution to the problem. […] We will still consume, and still have to tackle our impact on the environment while producing and consuming energy So, circular economy is the next step, but not the final one". Importantly, a couple of students could consider the CE as "a solution to reinvent the world after" but only under certain conditions, arguing, e.g.:

- "Not only should we improve the transformation into CE, but we should boost the international cooperation between the countries. […] The CE is not limited to waste management and recycling policies, and the economic opportunities therein are very broad and diverse. The development of CE is conducive to increasing economic diversity and promoting the skills of workers."

- "I think we should - as a first step - go back to "business-as-usual". Admittedly, the switch to a more circular economy just after the pandemic would bear fruit, but several sectors are not yet ready for this kind of transition and will be in difficulty. In addition, I believe that the CE can only be truly beneficial if those who promote it explicitly recognize its limits and work with complementary approaches. It is therefore our duty as future engineers to consider the CE as an important asset to progress together towards a fairer and more sustainable world."

3.2. Insights from engineering students (class of 2021): "Circular Economy as an answer for green recovery and value chain resiliency in the COVID-19 context?"

In this sub-section, complementary insights from the class of 2021 are given. First, taking the examples of two companies, the students had to identify how the application of CE principles could contribute to achieving the Sustainable Development Goals (SDGs) during the COVID-19 crisis. As illustrated in Fig. 3, the SDGs #6, #7, #8, #9, #11, #12, #13, and #17 have been the most cited by the engineering students. Then, they have been asked to give their understanding of the notion of the resiliency of value chains regarding the macro-disruption generated by the COVID-19 pandemic. Interestingly, one student argued that "the pandemic and global warming have shown the limits of globalization and companies cannot afford anymore to split their value chains all over the planet." This student added that "when aiming for circularity, companies also target resiliency". In this line, another engineering student stated that "during the pandemic, companies which depend on local recycled resources, are less likely to be impacted by lockdowns or travel restrictions". These points illustrate the positive correlation between circularity and resiliency of industrial value chains.

Next, they had to give their personal position on the following statement, extracted from an article they read: "Shifting nations to a circular economy could be key in delivering a green recovery that champions sustainable income and environmental stewardship." Their answers were well-aligned with the ones from the class of 2020, highlighting a *sine qua non* condition, i.e., CE is a necessary but not sufficient answer to the problem. In addition, some students provided supplementary solutions that could work hand-in-hand with the implementation of CE initiatives:

- "Shifting nations to a circular economy is essential, but not an easy task. It requires collaboration and participation of all the industries for a holistic and systemic, well-organized implementation."
- "Shifting nations into a circular economy can be a key in delivering a green recovery. But it is not sufficient. From my point of view, circular economy is an enabler of sustainable development, but only if it comes with other measures. In particular, it is important to increase education and environmental policies, with taxes as incentives for the adoption of circular economy models."
- "I agree that shifting nations to a circular economy is key in delivering a green recovery that champions sustainable income and environmental stewardship, but I think it is not sufficient. I think we need to establish a global voluntary carbon market in order to fully address climate change."
- "The COVID-19 crisis has shown the importance of relocating some industries, and if done in a circular way, it could benefit the environment, reducing transport, waste or production impacts but also the economy. […] It requires governments to make companies pay for the externalities of their activities, by paying for the true cost (environmental and economic) of a product."

Note also that one has been more skeptical or dubious, mentioning that the expression "green recovery" is an oxymoron, and that deploying a complex CE (compared to a simple linear "business-as-usual") in developing countries might not be a viable solution to ensure rapid economic growth, due to the current lack of recycling infrastructures, technologies and scientific knowledge. Last but not least, one student reminded that "CE principles have to be applied in an intelligent manner. For instance, it is not always more environmentally friendly to recycle a product than energy recovery/revalorization".

Fig. 3. Sustainable Development Goals covered by the adoption of CE principles, according to engineering students' answers

3.3. Synthesis and comparison with state-of-the-art studies

The engineering students' standpoints from the classes of 2020 and 2021 are positioned within the state-of-the-art literature dealing with industrial resilience and CE in the COVID-19 context. In their position paper "Circular economy as a COVID-19 cure?', Wuyts et al. (2020) initiated the discussion on the challenges and opportunities of CE principles to increase resilience in the healthcare sector during the COVID-19 pandemic [7]. Hereafter, the key takeaways, from both the viewpoints of engineering students and an up-to-date literature survey, are finally synthesized in a SWOT

map (see Fig. 4) to highlight the commendable practices and the remaining challenges to tackle. In line with many students' answers, Singh et al. (2021) highlighted the value of a resilient, responsive and robust supply chain during a pandemic [8]. Besides, as mentioned by the majority of engineering students, the adoption of CE principles should be coupled with other measures to build more resiliency in industrial value chains, as confirmed by the following international peer-reviewed studies:

- Belhadi et al. (2021) identified the integration of localized supply sources and the development of industry 4.0 technologies as enablers of industrial value chain resilience. In particular, real-time information sharing and cooperation among supply chain stakeholders are critical to mitigate the disruption risks related to COVID-19 [10].
- Linkov et al. (2021) pinpointed two main strategies that could be complementary to enhance resilience in post-COVID societies: industrial systems can either (i) be designed to be resilient through self-reorganization or (ii) rely on intervention by external stakeholders such as policies or financial incentives [11].
- Appropriate localization, agility, and digitization of industrial organizations also appear as key measures to make supply chains more resilient, transparent, and sustainable in a post-COVID ecosystem [12].
- Resilience through intertwined supply networks is another essential and commendable feature to ensure the long-term viability of supply chains in such an uncertain and changing environmental [13].
- The roles of consumers and policies are finally essential in the design of sustainable supply chains, and notably for their recovery in a post-pandemic period [1].

4. Conclusion and perspectives

To conclude, this study showed that the engineering students, following the "Circular Economy & Industrial Systems" class at the Université Paris-Saclay, are well aware of the opportunities and challenges brought by CE principles for more resilient industrial value chains in a post-COVID world. On the one hand, we acknowledge that the new knowledge gains obtained by analyzing students' answers are rather limited here. On the other hand, we believe that it could inspire commendable actions and galvanize further work to better deal with such potential pandemics in the future, by integrating such approaches and critical thinking in other curriculum areas. In fact, new trade-offs between profitability, environmental sustainability, safety, viability, and supply chain resilience have been highlighted by numerous students. In practice, the engineers, designers, and managers of tomorrow will play a vital role in the optimization of these trade-offs when designing, developing, and launching new or remanufactured products in a post-pandemic period.

In the present study, note that a potential bias in the students' answers may lie in the fact they have *a priori* interest in the field of CE and sustainability as they picked up this class on "Circular Economy & Industrial Systems". This could imply that more students would be in favor of environmental measures. In this line, to complement the rather limited new findings reported in this study, further investigations could include students from different majors or universities from different countries. For instance, also note that a non-negligible amount of students surveyed in this study were coming from other universities, in exchange with other French (business schools) and non-French (from a lot of different countries) universities.

Last but not least, as the consequences of the COVID-19 pandemic are still emerging and evolving, adjustment to the current theories or new theoretical developments may be necessary [14]. As such, future research should further explore how the methods, tools, and models developed by the industrial engineers and researchers [15] could be deployed, adapted, or fine-tuned to foster sustainable decision-making and profitable CE practices in industry in the post-pandemic period? Notably, it becomes relevant to question the validity of current models (e.g., for optimal product recovery, reverse supply chain) under the COVID-19 crisis constraints (e.g., high demand, uncertainty on the number of returned products, disruption of recycling streams), as well as to think on how to make these models more resilient, flexible or modular to rapidly adapt in such crisis situations.

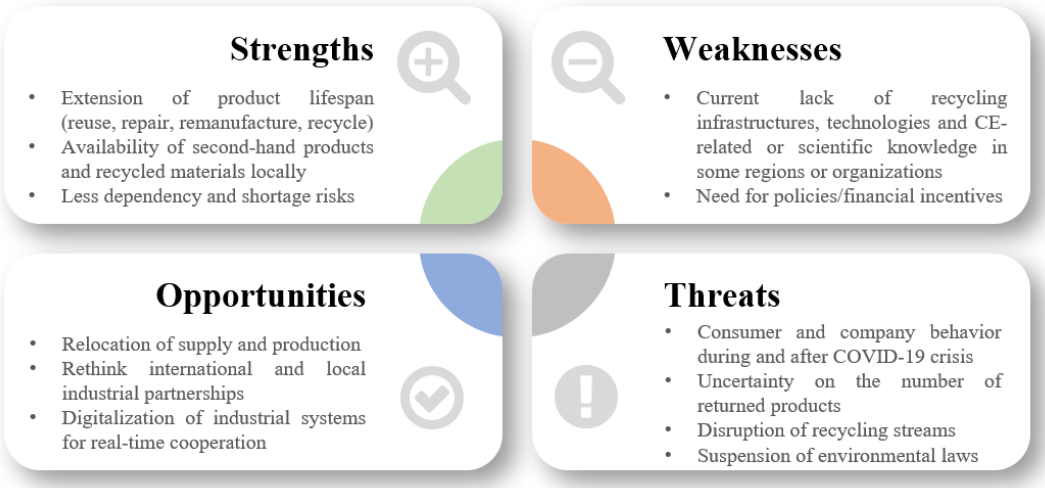

Fig. 4. Circular economy as an answer for industrial value chain resilience in a post-COVID world: a SWOT analysis

Appendix A. Final individual exams

A.1. Class of 2020: Circular Economy as an answer to the COVID-19 crisis?

Humanity is currently facing an unexpected and unprecedented crisis with the COVID-19 pandemic. More than a simple sanitary issue, this crisis questions our way of living, the organization of our global industry, as well as the resilience of our society. During this crisis, the shutdown of the economy led to a mitigation/reduction of environmental impacts in many sectors but at the cost of a huge social crisis. For numerous authors, scientists, politicians, Circular Economy may be part of the answer.

- Carrington, D., Polluter bailouts and lobbying during Covid-19 pandemic, The Guardian, April 17, 2020.
- Ellen MacArthur Foundation, The Covid-19 recovery requires a resilient circular economy, Medium, May 7, 2020.

1. What pillars of Circular Economy can you identify by reading the Ellen MacArthur Foundation paper. Do you consider that all aspects of Circular Economy are encompassed in their proposal? If not, what could you propose to complement this vision?
2. You can see in the second paper that a lot of companies or industrial sectors are putting pressure on governments to loosen environmental regulations to survive the crisis. Do you think these requests are justified by the social issues of the COVID-19 crisis?
3. These two papers highlight the strong divergences that appear in our industrialized society. What is your position? More than your personal point of view, do you consider that Circular Economy is an appropriate and sufficient answer? What decisions should the governments take and when?

A.2. Class of 2021: Circular Economy, green recovery and value chain resiliency

Multinational companies drive value chains all over the world. For most of these companies, Circular Economy deals with the management of their internal operations. But some other companies aim at going further by considering a broader perimeter of action. This subject deals with social impacts and the notion of the resiliency of territories and value chains.

- Mace, M., Why the circular economy is primed to improve social sustainability and value chain resiliency, edie.net, March 24, 2021.

1. The paper particularly highlights the example of two companies. For each of these two examples, identify which pillars of CE and SDGs are illustrated in the paper.
2. The paper evokes the notion of the resiliency of value chains or territories with regards to a “macro-disruption” due to climate change and/or the COVID-19 pandemic. How would you define this notion? Please illustrate as much as possible with your own examples.
3. “Shifting nations to a circular economy could be key in delivering a green recovery that champions sustainable income and environmental stewardship.” What is your personal position on this statement from the abstract of the paper? Then, to go further than your personal point of view, do you consider that CE is an appropriate answer, and that the strategies proposed by governments and companies are sufficient? If not, what decisions should the governments and companies take and when?

References

[1] Sarkis, J. (2020). Supply chain sustainability: learning from the COVID-19 pandemic. International Journal of Operations & Production Management, 41(1).

[2] de Sousa Jabbour, A.B.L., Jabbour, C.J.C., Hingley, M., Vilalta-Perdomo, E. L., Ramsden, G., Twigg, D. (2020). Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic: lessons and trends. Modern Supply Chain Research and Applications, 2(3).

[3] Ivanov, D. (2020). Viable supply chain model: integrating agility, resilience and sustainability perspectives – lessons from and thinking beyond the COVID-19 pandemic. Annals of Operations Research, 1-21.

[4] Karmaker, C.L., Ahmed, T., Ahmed, S., Ali, S.M., Moktadir, M.A., Kabir, G. (2020). Improving supply chain sustainability in the context of COVID-19 pandemic in an emerging economy: Exploring drivers using an integrated model. Sustainable Production and Consumption, 26, 411-427.

[5] Taqi, H.M., Ahmed, H.N., Paul, S., Garshasbi, M., Ali, S.M., Kabir, G., Paul, S.K. (2020). Strategies to manage the impacts of the COVID-19 pandemic in the supply chain: implications for improving economic and social sustainability. Sustainability, 12(22), 9483.

[6] Ellen MacArthur Foundation. (2020). The Covid-19 recovery requires a resilient circular economy. Medium, May 7, 2020.

[7] Wuyts, W., Marin, J., Brusselaers, J., Vrancken, K. (2020). Circular economy as a COVID-19 cure?. Resources, Conservation, and Recycling, 162, 105016.

[8] Singh, S., Kumar, R., Panchal, R., Tiwari, M.K. (2021). Impact of COVID-19 on logistics systems and disruptions in food supply chain. International Journal of Production Research, 59(7), 1993-2008.

[9] You, S., Sonne, C., Ok, Y.S. (2020). COVID-19's unsustainable waste management. Science, 368(6498), 1438.

[10] Belhadi, A., Kamble, S., Jabbour, C.J.C., Gunasekaran, A., Ndubisi, N. O., Venkatesh, M. (2021). Manufacturing and service supply chain resilience to the COVID-19 outbreak: Lessons learned from the automobile and airline industries. Technological Forecasting and Social Change, 163, 120447.

[11] Linkov, I., Trump, B.D., Golan, M., Keisler, J.M. (2021). Enhancing Resilience in Post-COVID Societies: By Design or By Intervention?. Environmental Science & Technology, 55(8), 4202-4204.

[12] Nandi, S., Sarkis, J., Hervani, A.A., Helms, M.M. (2021). Redesigning supply chains using blockchain-enabled circular economy and COVID-19 experiences. Sustainable Production and Consumption, 27, 10-22.

[13] Ivanov, D., Dolgui, A. (2020). Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. International Journal of Production Research, 58(10), 2904-2915.

[14] Sarkis, J., Cohen, M.J., Dewick, P., Schröder, P. (2020). A brave new world: lessons from the COVID-19 pandemic for transitioning to sustainable supply and production. Resources, Conservation and Recycling, 159, 104894.

[15] Saidani, M., Kim, H., Kim, J. (2021). Designing optimal COVID-19 testing stations locally: A discrete event simulation model applied on a university campus. PloS one, 16(6), e0253869.