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Agricultural biomass supply chain resilience: COVID-19 outbreak vs. sustainability compliance, technological change, uncertainties, and policies



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ABSTRACT

The COVID-19 pandemic has caused a confounding collection of transportation, supply chains, and logistical disruptions, which needs to be well addressed by businesses and governments. During this pandemic, several researchers have concentrated on the sustainability and resilience of supply chains in various industry sectors. Nevertheless, the impacts of the pandemic on sustainability pillars, technological change and uncertainties, and resilience approaches in various sectors have not been clarified yet. More specifically, the agricultural biomass sector has experienced serious disruptions induced by the COVID-19. This paper aims to analyze and assess the agricultural biomass supply and production systems during the COVID-19 and their recovery in post-COVID-19. To the best of our knowledge, this is the first study to evaluate the economic, environmental, social, and technological change effects of the COVID-19 on Biomass Supply Chain resilience. Uncertainties of oil and palm energy demand, price, consumption, export, and production of leading producers and suppliers worldwide are analyzed considering the pre-COVID-19 and current COVID-19 period. It is then followed by recommendations for specific strategies, policies for the biomass industry, and general action plan to overcome the problems of resilience in medium, short, and long-term horizon plans. The findings from this study are valuable resources for the governments, biomass industry, and other stakeholders to provide cleaner post-pandemic energy production and supply and enhance the employees' engagement.

1. Introduction

In recent decades, some extraordinary disease outbreaks have confounded business companies and brought about significant challenges to business processes. The scope of such challenges is mainly dependent on the rigorousness of the outbreak in question. In general, every epidemic or pandemic substantially affects the businesses and supply chains by decreasing their efficiency and performance quality (Ivanov, 2020) and disrupting the supply chains (known as ripple effects), which negatively impacts their resilience and sustainability (Ivanov, 2020). Statistics released by the World Health Organization (WHO) indicate that 1438 epidemics have happened in seven years, from 2011 to 2018 (Hudecheck et al., 2020). Yet, the current COVID-19 pandemic is an exceptional case with much more severe, diversified, and dynamic effects compared to, for instance, the SARS epidemic (in 2003) or the H1N1 epidemic (in 2009) (Koonin, 2020).

Coronavirus disease, briefly termed COVID-19, appeared in December 2019 and was declared a pandemic on March 11, 2020, by the WHO's Director-General (WHO, 2020). By March 2020, the WHO

reports indicated that positive cases rose 13-fold in China, 109,594,835 positive cases were found globally, and 2,424,060 deaths were recorded in February 2021 (WHO, 2020). This disease rapidly spread across the world and was recognized soon as a significant infectious illness. Millions of people were hospitalized following the hospitalization of the first patient on 12 December 2019 (Ryu et al., 2020). The most infection and death rates were recorded in Spain, the United States, and Italy (Guo et al., 2020). Public health has been influenced all over the world due to the pandemic. Most companies went bankrupt due to the devastating effects of this disease (Klemeš et al., 2020). The COVID-19 crisis has a detrimental effect on the energy sector at a global level. Production and supply chains have been disrupted by the response measures such as widespread lockdowns, shrinking goods and services demand, depressing prices of commodities, and causing a substantial economic contraction worldwide. In addition to the health crisis, the pandemic caused several people to lose their jobs, threatening their livelihoods. However, countries such as Australia have taken some strict measures to prevent COVID-19 leading to better livelihoods conditions (Eroğlu, 2020).

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Before the classification of the COVID-19 as a pandemic by WHO on 11 March 2020, an article published by *Fortune* magazine on 21 February 2020 reported that the COVID-19 pandemic had caused 94% of the Fortune 1000 companies to face disruption in their supply chains (Kwon, 2020). In addition, it was just the COVID-19 pandemic that could affect all the nodes (supply chain members) and edges (ties) in a supply chain at the same time (Gunessee and Subramanian, 2020), which resulted in a substantial disruption in the flow of the supply chain. It led to an increase, for example, in demand for basic items such as dried and canned foods, personal protective equipment, and ventilators. In the meantime, the capacities of vital sectors such as manufacturing, supply, and transportation dramatically decreased. This situation was because of border closures, lockdown in the supply market, labor shortage, interruption in vehicle movements and international trade, the obligation to maintain physical distance in manufacturing facilities, etc. All of these disruptions were caused by the COVID-19 pandemic (Amankwah-Amoah, 2020). Because of such multidimensional impacts on supply chains, together with many other financial/economic challenges (Dontoh et al., 2018), COVID-19 is likely to severely affect international trade worldwide. For instance, the world trade organization (WTO) reported a 13–32% drop in world trade in 2020 due to the pandemic (WHO, 2020). These tremendous impacts of the COVID-19 pandemic on supply chains caused the academic community to focus on the topic. This resulted in a huge volume of research (especially in developed countries) into the COVID-19 pandemic and its relationship with the supply chain. Dasaklis et al. (Dasaklis et al., 2012) investigated the impacts of epidemics on logistics from a general perspective. Queiroz et al. (Queiroz et al., 2020) provided an analysis on the impacts of past epidemics upon supply chains by suggesting a framework in terms of six perspectives that include: sustainability, recovery, ripple effects, digitalization, adaptation, and preparedness. It is noted that most of the investigations focused on the healthcare and food sectors (Sharma et al., 2020). Some works reflected different industries such as the computer and home furnishing industry (Ishida, 2020), tourism (Ibn-Mohammed et al., 2020), transportation and construction (Veselovská, 2020), airline (Amankwah-Amoah, 2020), and clothing industry sectors (Majumdar et al., 2020). Hosseini (Hosseini, 2020) addressed renewable and sustainable energy development during COVID-19 to recover green power generation and low carbon approaches. Some industries, such as fertilizers, have not been significantly affected by the COVID-19 pandemic (Ilinova et al., 2021). The crisis has generally shocked the renewable energy sector and caused a shutdown of many factories in China that accounted for 50% of the global wind power supply chain. This resulted in the global “ripple effect” that decreased the deployment speed of renewable energy in several parts of the world (International Renewable Energy Agency and Post-COVID, 2020).

The enormous impact of the COVID-19 on various segments of the renewable energy value chain was reported by International Renewable Energy Agency (IRENA) (International Renewable Energy Agency and Post-COVID, 2020) in “*The post-COVID recovery*”. As indicated by the report, the pandemic has had a considerable impact on construction and installation, manufacturing and procurement, and transport and logistics. On the other hand, only a low effect was reported on project planning, operation, and maintenance. More specifically, in regard to the solar energy sector, the materials and components utilized to build solar arrays and panels have slowed down. This is due to the fact that the majority of the manufacturing firms are operating in countries seriously affected by the pandemic, i.e., China, Vietnam, South Korea, Malaysia, Singapore, and Thailand (Vaka et al., 2020). China was exposed to the near-total blockade, which caused to ban on the import and export of goods/people. In addition, the renewable energy sector of India has been seriously affected since this sector imports around 80% of PV modules from

China (Pradhan et al., 2020). The pandemic interrupted the wind industry, too. In the context of India, many problems (for instance, the deficiency of financing and obstacles to the supply chain) caused great firms such as Siemens Gamesa, Vestas, and LM Wind Power (which are three of the key competitors in the wind energy market of this country) stopped their production. This caused a delay in generating 600 MW of wind power by 2022 (Pradhan et al., 2020). In Europe, however, 96% of manufacturing plants did not stop their production despite the pandemic. Only 18 of the most affected factories (mostly placed in Spain and Italy) stopped their activities (Azam et al., 2021).

Biomass is a key renewable energy source based on which the policymakers reduce greenhouse gas (GHG) emissions (Zahraee et al., 2021). The biomass supply chain (BSC) will inevitably be impacted by continuing the COVID-19 lockdown due to clear implications for business continuity in the biomass feedstock processing sector and wider forest. For example, in the case of palm oil biomass, due to the large dependence of the palm oil BSC on the lower value raw materials such as forest residues resulting from the forest management, biomass fuel supply chains will see that higher value products continually flow to the sawmill and other processors as a key factor. Due to closing the most important production facilities or reducing their operations, some implications are felt down the supply chain. The focus of biomass industry stockholders is on increasing the efficiency and agility of their supply chains (Zahraee et al., 2019). These suppliers critically experiment with unexpected types of cooperation with customers, suppliers, and even competitors in different geographies and sectors to improve the sustainability of their supply chains (International Renewable Energy Agency and Post-COVID, 2020). The firms attempt to make high-payback investments because of the benefits for both environment and business through greener supply chains (International Renewable Energy Agency and Post-COVID, 2020). The COVID-19 impacted social, economic, and environmental conditions of the BSC, production, transport, and use of agricultural bioenergy through decreasing the number of skilled workers and disrupting the industries along with the woody BSC. The COVID-19 pandemic has enduring impacts on people's work and the way supply chains operate. To appropriately manage the future challenges, the biomass-related industries must build long-term resilience in their value chains. Biomass firms and stakeholders should give rapid and confident responses to the crisis and provide effective short-term tactical plans to alleviate the risks to human health and maintain the functionality of the global BSCs. To this end, there is a need for strong data and analytics capacities to well understand the complexity of the situation, anticipate the potential disruptions, and rapidly develop an effective response. The COVID-19 effects, BSC activities, and resilience action plans are all summarized in Fig. 1.

2. Research gaps, scope, and objective of the study

Biomass feedstocks include dedicated energy crops, agricultural crop residues, forestry residues, algae, and municipal waste (Zahraee et al., 2020; Zahraee et al., 2020). This paper focuses on the two main categories of biomass products, including woody residue and palm oil. To date, there is a lack of investigation to assess the COVID-19 effects on the economic, environmental, and social objectives of the BSC, transportation, and logistics operations. Thus, this study will fill the following gaps:

- The dearth of research focuses on analyzing the impacts of practicing sustainable strategies on companies' performance quality and resiliency to effectively manage the effects of large-scale disruptions such as the COVID-19 pandemic.

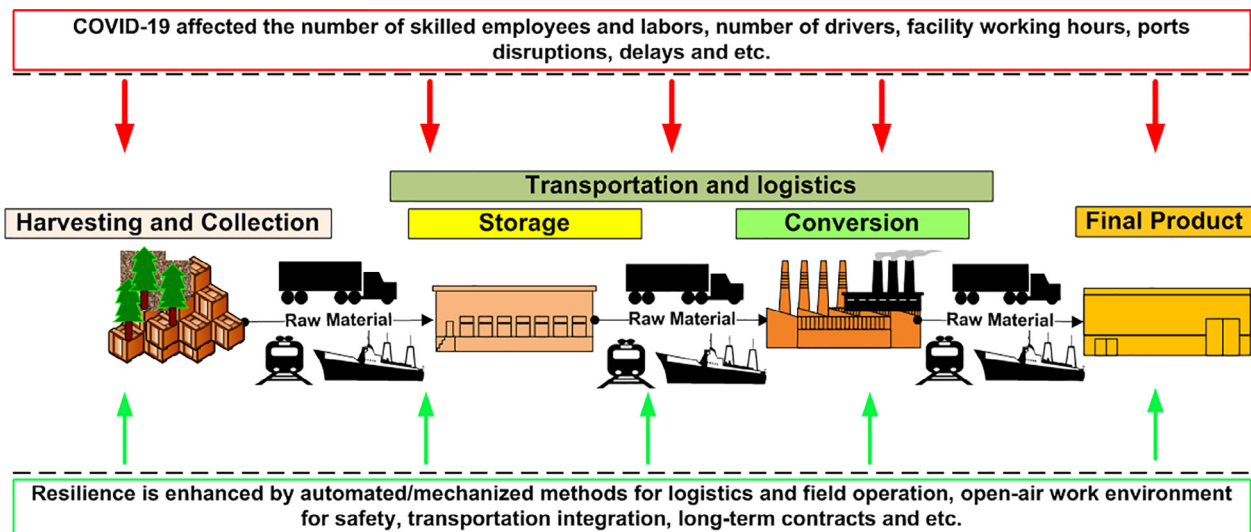


Fig. 1. Agricultural BSC vs. COVID-19 effects and resilience plans.

- The shortage of evidence regarding the challenges and requirements associated with the implementation of resilience strategies for supply chains in various sectors. The literature has not yet discussed the specific challenges and recommended policies and practical implications in long, medium, and short-term plans.
- The absence of research on the biomass industry focuses on building long-term resilience in their value chains to properly manage future challenges. The COVID-19 has posed distinctive challenges on BSCs.
- The deficiency of quantitative studies shows that the academic community has had limited opportunities to gather and analyze real-world data during the pandemic. As a result, there is still a need for quantitative studies to investigate the impacts of COVID-19 on uncertainties, supply chain issues, and challenges encountered in various contexts.

This paper addresses those gaps in the literature by assessing the current situation and measurements for three case studies in the UK, Malaysia, and Indonesia. This study aims to fill this gap of knowledge by covering the following point:

1. To investigate the economic, environmental, and social effects of COVID-19 on different sectors.
2. To analyze the effects of COVID-19 on uncertain parameters in the biomass industry such as oil price, energy demand, and electricity generation.
3. To explore the effects of COVID-19 on woody biomass and palm oil production, demand, and price.
4. To provide practical implications, policies, and recommendations for governments and stockholders to consider the resilience of the BSC

The remainder of this paper is organized as follows. [Section 2](#) analyzes the literature review. [Section 3](#) provides the methodology adopted for analyzing the literature and statistics. [Section 4](#) analyzed the general and specific impact of COVID-19 on sustainability compliance for different industries and the biomass sector. [Section 5](#) provides a detailed description of epidemic disruptions' effects on oil and biomass sectors. In addition, a comprehensive analysis of three main woody and palm oil biomass production and supply regions are discussed. Based on the results and findings, recommendations and action plans are discussed in section 6. Finally, section 7 concludes the paper and highlight future research opportunities.

3. Literature review

According to economists' predictions, the COVID-19, in developing and developed countries, can lead to the bankruptcy of numerous companies and organizations in the industry sector, the closure of many factories, and the removal or suspension of long-term investments (Shakibaei et al., 2021). Ramelli and Wagner (Ramelli and Wagner, 2020) demonstrated how an unusual catastrophe (e.g., the COVID-19) could be transformed from a health crisis to an economic crisis. Haleem et al. (Haleem et al., 2020) maintained that the COVID-19 rapidly affected human beings' daily lives, industrial activities, global trade, and movement. Some of the most affected industries and sectors were tourism, pharmaceutical, information and electronic, and solar power. The pandemic, on the one hand, the preventive measures are taken into action to control its expansion, on the other hand, have adversely and seriously influenced the economic, social, and religious activities worldwide.

In many countries, the governments had to impose full or partial lockdowns, which highly restricted vehicle movement and international transportation as a whole. These measures caused suppliers to be failed in the on-time delivery of the products to customers (Ivanov and Das, 2020). In the globalization era, many firms in many sectors usually source their required materials from other countries. Accordingly, the abrupt closing of the operations of international suppliers to satisfy the lockdown regulations requirements led to tremendous disruptions in supply for manufacturers. This phenomenon caused firms to be exposed to severe production levels disruption and backlog (Richards and Rickard, 2020). In addition, many policies made by governments, for instance, reducing the office hours and forcing the employees to work on alternative days, significantly decreased the firms' production capacities (Leite et al., 2020). Such social distancing and other safety measures caused employees and workers not to work full time, resulting in workforce shortage (Trautrimis et al., 2020). In addition, limited operations in the factory led to the uselessness and impairment of machinery and capital assets (Dente and Hashimoto, 2020).

A number of recent studies have reviewed and discussed the existing literature from a wide-ranging perspective, considered the supply chain resilience modelling and its implications for COVID-19 (Golan et al., 2020), and discussed the reasons behind the panic buying phenomenon when a health crisis takes place (Yuen et al., 2020). Some researchers have considered several countries from different continents to demonstrate the impacts of the COVID-19 on the global supply

chain system. These studies compared the situation in China, the USA, New Zealand (Guan et al., 2020), India, Germany, the USA, the UK, Singapore (Nikolopoulos et al., 2021), as well as the global context of numerous countries (Xu et al., 2020). Several scholars have utilized simulation modelling to predict the COVID-19 effects and demonstrate the necessity for real-time visibility and structurally adaptable supply chains during a pandemic (Zhu and Krikke, 2020; Ivanov and Dolgui, 2021). Several studies have applied mathematical modelling techniques such as mixed-integer linear modeling (Lozano-Diez et al., 2020), game-theoretical modelling (Kargar et al., 2020), stochastic optimization (Mehrotra et al., 2020), etc. An integrated mathematical and simulation model was used by Lozano-Diez et al. (Lozano-Diez et al., 2020) to suggest the best ways for reducing the shortage of medicines.

The restrictions in vehicles movements induced by the COVID-19 significantly disrupted various transportation modes such as ocean shipping, trucking, air freight, and rail (Gray, 2020). Such disruptions have caused many delays and interruptions in the smooth flow of products (Chiaramonti and Maniatis, 2020), which adversely affected international trade (Deaton and Deaton, 2020). The patterns of distribution and logistics are shifting quickly. Physical channels had been the major distribution mode for many years; however, the COVID-19 forced many firms to shift their business model to entirely online or select the combined online-offline method. In addition, to the restrictions, physical distribution channels are either closed or have only limited operations (Dente and Hashimoto, 2020). Despite many efforts made by firms to enhance their capacities for online sales, the closed or confined operations of physical channels have negatively affected the flow of supply chains. Furthermore, the dramatic rise of online sales has outstripped the supply chain's capacity. For instance, whereas many retailers have developed 'dark-warehouses, which is defined as a distribution center for serving exclusively online customers, some other retailers attempt to use rapid logistical solutions to satisfy the new demands (Mollenkopf et al., 2020). The current pandemic has also affected supply chain relationship management. The authors in (Baveja et al., 2020) reported a limited scope of social interactions amongst supply chain partners. Such interaction limitation has caused information incompleteness, which may result in ambiguity and, consequently, the deficiency of precision and clarity (Gunessee and Subramanian, 2020). In addition, it has reduced suppliers engagement, which has made it more difficult for firms to develop a collaborative approach through the integration of all the involved parties (Remko, 2020).

There is an increasing number of researchers focusing on the impacts of the COVID-19 upon the transportation sector. In the context of Germany, Schlosser et al. (Schlosser et al., 2020) utilized cell phone data to analyze the structural differences in mobility patterns. They reported a considerable decrease in mobility and substantial changes to the structural properties of the mobility network. Their findings also revealed a decline in long-distance trips. Aloï et al. (Aloï et al., 2020) used the data collected from traffic counters, environmental sensors, Intelligent Transport Systems (ITS) in public transportation, and videos recorded by traffic control cameras to examine impacts of the COVID-19-induced lockdown and restrictions upon urban mobility in Santander, Spain. They found out that the total mobility had reduced by 76%, with a 93% decrease in the number of public transportation users. Arellana et al. (Arellana et al., 2020) concentrated on the impacts of the current pandemic upon the travel behavior and transport system due to the policies established by the Colombian government for the mitigation of the virus spread. They analyzed the obtained data with the help of official and secondary data from Colombia's first seven most crowded metropolises. They recognized a drop in the trips across all these cities.

It should be noted that renewable energies, during this crisis, succeeded to enhance their share in the energy market, which are cheaper than fossil fuel, according to the IRENA. In some countries, the

share of fossil gas increased, too. On the other hand, a reduction was reported in the production of energy from fossil coal and nuclear sources (Werth et al., 2021). In the United States, a comparison between April 2020 and April 2019 indicates that, in the PJM energy market, the production of coal was around 38% lower, while the natural gas production was 13% higher during the COVID-19 pandemic (Eryilmaz et al., 2020). In the course of the pandemic, in the EU, the production of electricity from nuclear sources, natural gas, and coal reduced by 20%, 25%, and 35%, respectively, compared to 2019 (Ghenai and Bettayeb, 2021). In the same period, in Spain, the electricity production from non-renewable sources reduced, whereas the share of renewable energies (e.g., PV) increased (Santiago et al., 2021). In Italy, the share of energy generated by renewable energy sources grew, which reached a daily renewable penetration of more than 40%, whereas the average seasonal value was recorded at about 23% (Ghiani et al., 2020). In Ukraine, a comparison between March 2020 and March 2019 showed that energy production at the solar/wind power plants doubled (Morva et al., 2020). In Belgium, Hungary, Germany, Italy, and East U.S., a considerable increase was observed in the renewable energy sources in the electricity production mixed with an hourly record of renewable energy shares (Mofijur et al., 2021). During the lockdown, India witnessed a 26% reduction in the daily supply from coal-based thermal power plants. Such decrease leads to 15 and 65 MtCO₂ reductions in emissions (Kanitkar, 2020). In Bangladesh, although grid-connected renewable electricity production can be considered insignificant, the solar contribution reached the highest production record in the pandemic-induced lockdown (Sied et al., 2020). In Israel, on the 5th of April 2020, the share of solar energy touched the level of 29% of the total generation, which was the highest fraction of renewable energy ever reported in this country (Carmon et al., 2020). Such data on the renewable sources in the energy mix shows the feasibility of a future that would be enriched with renewable energies. This also can result in an optimistic view of some scholars regarding the protection of the Earth against climate change. For example, according to Watts and Ambrose (Watts and Ambrose, 2020), it is possible that the coal industry never recovers to its post-pandemic levels since the COVID-19 crisis demonstrated that consumers could be provided with cheaper renewable energy. Also this type of energy could be a safer bet for investors.

The review of the case studies reported in the literature shows a lack of research that has assessed the impacts of the COVID-19 on the sustainability (economic, environmental, and social) and uncertainties (demand, price, production, export, and import) of BSC production, transportation, and logistic network. Table 1 summarizes the recently published papers that examined different aspects of sustainability compliance, supply, and production chains of different industry sectors versus the COVID-19 disruptions. According to the literature analysis (Table 1), no study has systematically investigated the effects of COVID-19 on the biomass and bioenergy industry sector. However, the global supply chain is adversely affected by the COVID-19 outbreak for different renewable energy sources. It has been predicted that there will be a remarkable decrease in clean energy investments and the occurrence of the domino effect due to the failure of the to-be-made incentives to achieve renewable energy goals (Eroglu, 2020).

4. Methodology

The present study follows a systematic *meta*-analysis of literature and statistics pertinent to the effects of the COVID-19 on various sectors. The relevant studies are systematically reviewed and analyzed to synthesize the themes investigated and other aspects, e.g., the theories, methodologies, and context of these studies. In addition, the current paper analyses the studies carried out in two closely related fields, i.e., transportation and logistics, as well as supply chain and the dis-

Table 1
Breakdown of literature in terms of sustainability compliance and industry sectors vs. COVID-19.

Author	Sustainability			Industry
	Economic	Environmental	Social	
Hosseini (Hosseini, 2020)	✓	✓	X	Renewable energy projects
Chiaromonti and Maniatis (Chiaromonti and Maniatis, 2020)	✓	✓	X	Oil
Hakovirta and Denuwara (Hakovirta and Denuwara, 2020)	X	X	✓	Different industry sectors
Sarkis et al. (Sarkis et al., 2020)	✓	✓	X	Different industry sectors
Sharma et al. (Sharma et al., 2020)	X	✓	✓	Food solid waste
Sharma et al. (Sharma et al., 2020)	X	✓	✓	Different industry sectors
Sharma et al.(Sharma et al., 2020)	✓	✓	✓	Healthcare and food
Yuen et al. (Yuen et al., 2020)	X	X	✓	Retail
Baveja et al. (Baveja et al., 2020)	✓	X	✓	Service
Dente and Hashimoto (Dente and Hashimoto, 2020)	✓	✓	✓	Different industry sectors
Amankwah-Amoah (Amankwah-Amoah, 2020)	X	✓	X	Airline
Jabbour et al. (A.B. Lopes de Sousa Jabbour et al., 2020)	✓	X	✓	Different industry sectors
Trautrimis et al. (Trautrimis et al., 2020)	X	X	✓	Different industry sectors
Majumdar et al. (Majumdar et al., 2020)	X	X	✓	Clothing
Rahman et al.(Rahman et al., 2021)	X	✓	X	Ship
Kargar et al. (Kargar et al., 2020)	✓	✓	X	Medical waste
Ibn-Mohammed et al. (Ibn-Mohammed et al., 2020)	✓	✓	✓	Tourism
Zhou et al.(Zhou et al., 2021)	✓	✓	X	Solid waste
Ilinova et al. (Ilinova et al., 2021)	✓	✓	X	Fertilizer
Paul and Chowdhury (Paul and Chowdhury, 2020)	✓	X	X	Manufacturing
Guan et al. (Guan et al., 2020)	✓	X	X	Electronics and automotive
Current study	✓	✓	✓	Biomass and bioenergy

ruptions arising in this system to provide some distinctive directions for future research. Biomass renewable energy is selected as the main theme in the current study to investigate the sustainability compliance, uncertainties of oil price, demand, electricity generation, biomass demand, supply, and production system. Finally, effective BSC resilience approaches, general recommendations, managerial implications, and future studies are explored.

Boolean searches of electronic databases were conducted to obtain literature from the databases. We searched in Scopus, Web-of-Science, ScienceDirect, Engineering Village, and Google Scholar for extracting the literature using keywords such as “supply chain”, “biomass supply chain”, “Sustainability”, and “COVID-19” or “Coronavirus” or “Novel coronavirus” or “SARS-CoV-2” for articles published since 2020. Only publications in English are considered in this study as they are widely accessible. Also, information and database available at credible organizations such as World Health Organization (WHO) and IRENA, along

with statistics available at various governments and industries web-pages, reports, and documents, were reviewed and analyzed to achieve our objective. Fig. 2 shows a summary of the research methodology framework of this study.

5. Social, environmental, and economic effects of COVID-19 of biomass and the bioenergy sector

Sustainability is the ability to recognize, develop, and promote sustainable practices and strategies to keep up a healthy natural environment in a financially stable and additionally socially practical way (Golroudbary et al., 2019). As discussed in the introduction section, a handful of investigations focused on sustainability during the current COVID- 19 pandemic. It is vital to rigorously analyze the effect of the current pandemic on sustainability compliance. This section has dis-

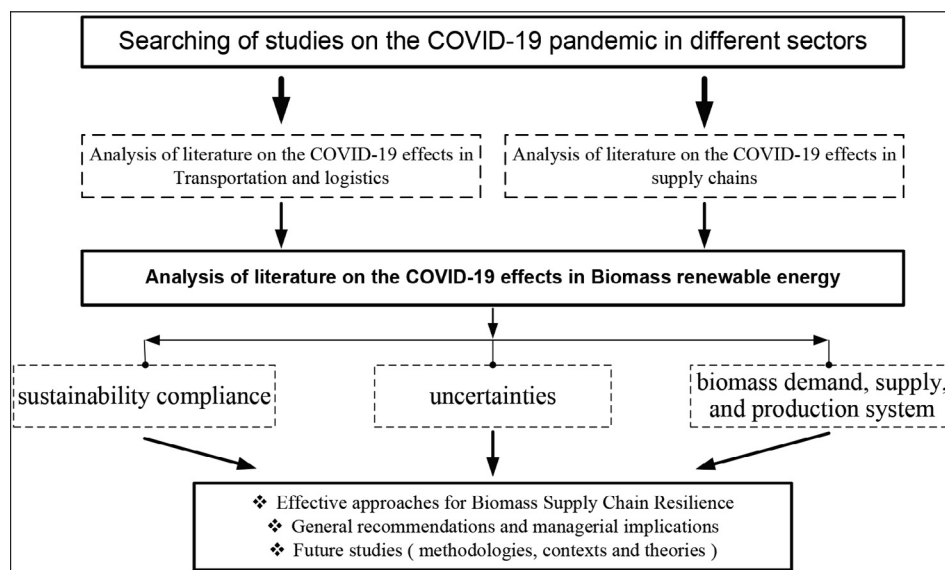


Fig. 2. A framework of methodology process.

cussed the general and specific pandemic impacts on economic, environmental, and social aspects.

5.1. Economic effects

Next to the manufacturing industries, the transportation sector consumes the largest portion of fossil oil (Zahraee et al., 2021). In the Organization for Economic Co-operation and Development (OECD) member countries, fossil consumption accounts for road transport 50%; the residential, agricultural, and commercial sectors sector 9%; petrochemicals 14%; and aviation 8% (Jefferson, 2020). Miscellaneous industrial activities account for about 15%. The COVID-19 pandemic has affected the private road transport and aviation sectors, commercial and industrial sectors, and petrochemicals sections. Many airline passengers have been stuck due to flight changes and cancellations. Those in the industry believe that recovering the airline passenger demand may take three to five years (Jefferson, 2020). The individual airline will significantly depend on the government's subsidies to tide them over.

Many workers in different sectors have lost their jobs. They are not sure about the exact time they would be allowed to return to their jobs, which leads to less usage of road transportation and petrol consumption. Also, some workers have turned into working from home for a longer-term despite such a large scale of working from home not occurring for more than fifty years (Jefferson, 2020). The transportation sector may be adversely affected by these forces despite the end of the pandemic. Producers of petrol, lighter crudes, and diesel demand will benefit from the recovery of the transport sector (Jefferson, 2020).

The effect of the pandemic on the global gross domestic product (GDP) is projected widely. This is dependent on the assumptions about the duration of national shutdowns, the extent of reduced demand for services and goods, and the speed of fast monetary and fiscal policy support. As predicted by the International Monetary Fund (IMF) in April 2020, there would be a 3% contraction of GDP this year, starting the most severe recession since the Great Depression. On the contrary, the World Bank suggests a 5% contraction (World Bank, Global Economic Prospects, World Bank Group, June, Washington, D.C., 2020). Cambridge Econometrics sees the 5–6% reduction of pandemic global GDP in 2020, depending on the government interventions' effectiveness (Kiss-Dobronyi, Coronavirus: initial results from economic modelling, Cambridge Econometrics, 2020). Among the hardest-hit sectors, travel, transport, and retail generally consume the largest amounts of energy.

Based on the OECD estimation, the global GDP will be reduced by 7.6% in case of a COVID-19 outbreak until the end of 2020 and by 6% to stop the second outbreak. The GDP almost regained its level before the crisis by late 2021, only in the condition of preventing the second outbreak. There would be a contraction of 11–12% in the economies worst affected by the pandemic in 2020 and 13–14% in the condition of occurrence or stopping COVID-19 outbreak. Nevertheless, at least per capita, real income growth in five years could be lost by 2021 (OECD, Economic Outlook: Preliminary version, 2020).

The COVID-19 played a significant role in the West Texas Intermediate prices collapse in April 2020, mainly on April 20th, due to factors other than continual production in the face of storage limitations and simply a demand weakness. The International Energy Agency, which recognizes the uncertainties about the oil market outlook, has stated that the transport fuel demand was the most affected sector (International Energy Agency, 2020). The COVID-19 will adversely impact several national economies while some others can show resilience to some extent.

There were various disruption risks in transportation and infrastructure facilities due to both human-made and natural disasters resulting in significant losses in the supply chain (Wang et al., 2020). As a result, creating reliable and resilient supply chains is vital

to mitigate the losses and disruptions repercussions. There are widespread concerns on biomass supply planning, including seasonality, uncertainty, scattered and widespread resources. In this respect, BSC performance is significantly influenced by the uncertainty of the demand due to the competitive business environment (Ji et al., 2020). Furthermore, since raw materials such as biomass harvesting periods are available, biorefineries are usually congested. This increases the costs of the supply chain and reduces the biorefineries' efficiency. Based on this perspective, the repercussions of congestion issues could be alleviated using a queuing system (Poudel et al., 2016).

5.2. Environmental effects

Unlike the economic aspect, the environment is positively impacted by the COVID-19 outbreak. Studies that were performed for the duration of the pandemic on the home community revealed an increase in the applications of a home office. It could limit individuals' movements in their external environment, thereby minimizing carbon dioxide emissions associated with travel to the workplace (Eroğlu, 2020). The majority of countries prevented individuals from travelling around as a part of lockdown measures, which resulted in a reduction of GHG emissions. The COVID-19 reduced GHG emissions emitted by some countries such as Italy and China (Le Quére et al., 2020). Carbon emissions were reduced by about 25% in China (Brief, 2020). CO₂ is widely known as the key member of GHGs; as a result, carbon trading has been taken into account as essentially measuring the Kyoto Protocol implementation (Zahraee et al., 2020).

The pandemic provided an opportunity to reflect on the environmental impacts. It reduced the demands for oil and other polluting fuels for industries and transportation systems, and as a result, considerable changes to the environment were observed. The research conducted into the COVID-19 epicenters, e.g., Spain, Wuhan, and the US, indicated a reduction of pollution by 30% (Muhammad et al., 2020) with Delhi, the megacity of India, which registered about 40% to 50% improvement in the quality of air during the four-day lockdown (Mahato et al., 2020). Rio de Janeiro also showed that average CO₂ levels substantially reduced from 30.3% to 48.5% (Dantas et al., 2020). In France, in comparison with the baseline path, there was a reduction in CO₂ emission by 6.6% in 2020 (Acharya et al., 2021). In the same year in Pakistan, NO₂ emitted from coal-based power plants reduced by 40%, which was followed by a 30% reduction in major urban regions compared to 2019. In addition, Aerosol Optical Depth thickness reduced by 25% in the industrial and energy sectors. It is to be noted that there was no report of any considerable reduction in emissions in the urban regions of Pakistan (Ali et al., 2021). The emissions records in 2020 in Kuwait showed a decrease of emissions by 119, 0.335, and 3.39 kilotons for CO₂, CO, and NO_x, respectively. In May 2020, this country recorded the maximum decrease of CO₂ emis-

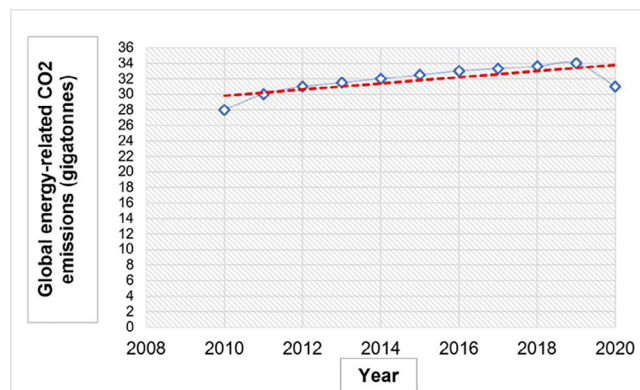


Fig. 3. The global trend of CO₂ emissions for 10 years.

sion compared to the predicted values (which was because of the total curfew), whereas, in March, the minimum level had been recorded (Alhajeri et al., 2020). In Ontario, Canada, reliable reports showed the reduction of nearly 40,000 tons of CO₂ emissions in April 2020 (Abu-Rayash and Dincer, 2020). The United States is expected to undergo the largest absolute declines at about 600 Mt while European Union and China would also be not too far behind.

This provides an opportunity for the world to re-think the way businesses were being conducted before the pandemic and start investing more in reliable and clean energy resources and facilitate the companies to move towards the renewable energy sectors.

In Fig. 3, the global emission of CO₂ is shown to decrease even faster, reaching 30.6 gigatonnes (Gt) for 2020, which is nearly 8% lower than that in 2019 (Agency, 2020). Since 2010, this was the lowest level. This is the most significant decline ever, which is six times as large as the previously recorded decrease of 0.4 Gt in 2009 due to the global recession and twice as large as the previous reductions since the ending of World War II (Agency, 2020).

5.3. Social effects

Social aspects play a vital role in achieving a successful outcome of the world economy (Zahraee et al., 2018). Communities are affected differently. Reduced new tax revenues and reduced air pollution from renewables were regarded as positive impacts. Nevertheless, there were some negative impacts such as loss of jobs and tax revenues after closing coal mines, large fossil fuel generation facilities, and restricting the public income related to the mine reclamation.

Such interventions significantly affect the world economy; they can easily predictably disrupt employment. Twenty million jobs were lost in April 2020 only in the United States, leading to an increased unemployment rate beyond 14%. The first six weeks of the epidemic saw the emergence of more than 30 million people claiming unemployment benefits (Schwartz et al., 2020). The total employment rate was declined in Canada since the COVID-19 economic shutdown began until mid-April leading to the loss of three million jobs (Canada, 2020). Europe and most of the countries saw similar social impacts. One out of two in the private sector, which is more than 10 million employees, in France lost their job due to the lockdown (Independent Electricity System Operator, 2020). Most industries had to obey the regulations and stop their businesses or work from home, causing these industries to face grave crises. The manufacturing industries had to shut down their operations in the long run during these periods downgrading their businesses. Therefore, most of them could not easily cope with the losses until the industries were permitted to operate again.

Job losses were accelerated by the present challenges, including the COVID-19 pandemic and the 2020 oil crash in other parts of the energy sector, particularly gas and oil (Brad Handler, 2020). It is not clear whether these oil vulnerabilities will continue to be the permanent characteristics of the energy landscape, but before the spread of the virus, there were job losses and some level of consolidation (Barbosa et al., 2020). The managed change to a low-carbon energy system prioritizing healthy and secure communities and family-sustaining jobs is needed to transition, considering the emerging multipliers risk for those involved in a shifting labor and energy landscape. The pandemic has the potential to make 40–60 million people extremely poor (Mahler and Lakner, 2020). The informal workers' incomes were reduced by an estimated 60% globally, doubling the acute hunger by the end of 2020, within the first month of the crisis. There could be a drop in remittances from migrant workers by 20% in 2020 (World Bank, 2020).

Some governments attempt to confront these severe outcomes in the biomass industry. The UK government issued the guidance on 7 April 2020, stating that key workers should consider engaging in the supply chain of wood for key goods such as heating materials, pellets,

Table 2

Impact of COVID-19 on the job in different industries (International Renewable Energy Agency and Post-COVID, 2020).

Sector	Impact of COVID-19	
	High	Low
Biomass and Biofuel	✓	
Production and manufacturing	✓	
Transportation and logistic	✓	
Construction industry	✓	
Maintenance		✓
Project planning		✓

tissue paper, timber harvesting, packaging, and sawmills (Biomass Heat Works, 2020). Only the essential workers who produce key goods were permitted to continue to work. The administrative staff was encouraged to work from home. It was instructed that the workers providing a critical role in the BSC and providing fuel products to keep people and communities safe and protect lives should continue to work and support their role (Biomass Heat Works, 2020).

In Table 2, the comparative extent of impacts is broadly characterized in various segments. Job loss was high in the biomass and biofuel industry. Despite varying situations among countries and over time, renewable technologies, equipment transport, construction, and distributed renewables projects were affected more than project operations and maintenance and planning. The remote working of the staff has limited direct impacts on project planning, component pricing, the fate of tax credit and other incentive schemes, and the demand for new projects is faced with uncertainty. These factors could prevent or delay the development of novel projects and have negative consequences on the supply chain.

Investment and procurement may be delayed by uncertainty. According to announcements in some countries, several countries except France and Germany changed the tender schemes to give higher flexibility due to the possible cancellation or postponement of renewable energy auctions (Enkhardt and Bollet, 2020). Equipment production is more seriously impacted. Different manufacturing plants for renewable energy technologies were closed temporarily worldwide due to lockdown measures. Different countries have had closures at other times, but the border closures have nevertheless resulted in the increasingly disrupted globalized operations, particularly wind and solar energy sectors. There was a significant fall in solar module production due to the Chinese factory closures in January and February, but production greatly started in March (Mackenzie, 2020). There was the occurrence of production closures later in other countries such as parts of Europe and India. Diversifying supply chain dependencies were noted due to these challenges.

The social distancing measures, lack of parts, and border control can impact logistics and transport sectors. The timely delivery of components can be delayed by the logistics challenges related to ground transportation and shipping, preventing the further progress of activities along the value chain.

Considering that the construction of an energy facility is not regarded as an essential activity in several countries, there were delays and shutdowns in locations heavily affected by the pandemic. Small and medium enterprises (SMEs) that work in the solar energy-related sectors have been severely affected. One of the timeline delays is the main effect on construction in the utility-scale segment of the solar PV industry. Installers of residential solar PV face lower demand when households face higher financial challenges caused by job loss or uncertainty. For this reason, several contractors are forced to discharge staff. The pandemic has not relatively affected the maintenance and operation activities. Considering the necessity of energy generation, the power plant workers are usually excused from orders to stay home.

A serious challenge that arose due to the pandemic is the scarcity of workforce in BSC. The measures taken to mitigate the virus spread

(e.g., movement restrictions) have substantially interrupted the BSC's usual activities. This disruption is because of the highly labor-intensive tasks that need to be conducted by individuals in BSC, especially the procedure of harvesting and collecting biomass. For instance, Malaysia (as the second largest country in the ranking of palm oil producers) is around 70% dependent on foreign labor in upstream activities such as oil palm biomass harvesting and collecting processes. It covers approximately 30% to 40% of the total cost of palm oil generation (Mei, 2020). In the same way, in India and Brazil, the sugarcane industry that serves as the most important source of energy matrix for biofuels is extremely dependent on manual works for the procedures such as cutting, slashing, and stacking the cane before the sugar production (Kamali et al., 2018). Therefore, due to the obligation of staying at home in the course of the pandemic as well as the uncertainties induced by it (i.e., severity, duration), numerous foreign workers had to return to their own countries. Due to the necessity of overcoming the COVID-19 pandemic with a green recovery investment push, there will be substantial socio-economic benefits, particularly creating much-needed economic benefits and jobs due to accelerating the energy transition.

6. Effects of COVID-19 on oil price, energy demand, electricity generation, and technological change

Due to the COVID-19 disruptions, technological change and adoption of emerging technology and services are expected to occur across farmers, suppliers, production, storage, and transportation sectors in BSC. Likewise, there have been effects on oil price, energy demand, and electricity generation. In the following sub-sections, these COVID-19 effects are investigated in detail:

6.1. Effects of COVID-19 on oil price

Oil prices were reduced as the largest reduction since 2002 due to the COVID-19 pandemic. In addition to the weakening of the demand, there was a reduction in Brent oil prices to USD 19/barrel within 18 years in April 2020, while the deteriorating demand and constraints of storage in the US even led to a negative result (International Energy Agency, 2020). Oil prices will be expected to be \$44 per barrel in 2021 on average, from \$41 per barrel predicted in 2020. Some predictions indicate that there will be a slow rise in demand due to restrictions on travel and tourism caused by health concerns and anticipation of the global economic activities to return to levels before the pandemic year by year basis. There may be steadily eased restraint on supply. In general, the energy prices, involving natural gas and coal, are anticipated to rebound sizably in 2021, after considerable declines in 2020, an upward revision from April's prediction. Energy prices will be reduced more than forecast in case of the resurgence of the pandemic second wave, lockdowns and reducing consumption, and delays in vaccine distribution and development. Although COVID-19 related conditions improved, oil, gas, and chemicals are still affected by financial factors. All business units will reduce cost, protect cash, and operate operationally to control this pandemic and price crisis.

As the global economic activities and mobility were considerably restricted during the first four months of 2020, the global energy demand lowered by 3.8% as compared to the first three months of 2019. Lockdowns occurred for several months in 2020, and much of the world saw slow recoveries, leading to a 6% decline in annual energy demand in 2020 and reducing the demand growth in the last five years. The past 70 years have not seen such a decline (International Energy Agency, 2020). According to some reports, demand has reduced differently in different regions of the same country. For instance, in Brazil, compared to the time previous to the COVID-19-induced confinements, the southern regions recorded a 20% decrease in the energy consumption rate, whereas, in the north-

ern regions (hosting higher residential consumption), the reports indicated only a 7% reduction (de Mello Delgado et al., 2021). The electricity demand in Canada decreased by around 5% compared to the levels predicted for New Brunswick, Alberta, and British Columbia, but this percentage doubled in Ontario after control measures were taken into action in each province (Leach et al., 2020). In the study of Ruan et al. (Ruan et al., 2020), a data hub was introduced, which aggregated multiple data sources to analyze how the pandemic affected the electricity sector of the United States. According to their findings, the change to the total electricity consumption rate was in correlation with three factors: 1) the number of cases confirmed with the virus, 2) the social distancing measures, and 3) the level of commercial activities performed in each region. In the same way, a comparative regression and neural network model was proposed by Norouzi et al. (Norouzi et al., 2020) to analyze the influence of the pandemic upon the demands for electricity and oil in China. They found that the electricity demand reduced by 0.65% once the daily death cases grew by 1%.

There could be a limited decline in energy demand to below 4% due to more successful efforts to curb spreading the virus and start economies again (Fig. 4). Nevertheless, growth could be curtailed even further through disrupting the supply chains at a global level, the second wave of infections, and a bumpier restart in the second part of the year. Curtailed aviation and mobility strongly hit oil demand nearly 5% in the first quarter, accounting for about 60% of the global oil demand. Global aviation and road transport activities were recorded nearly 60% and 50%, respectively, below the average of 2019 by the end of March (International Renewable Energy Agency and Post-COVID, 2020).

It is expected that the generation of electricity from biomass will slow down due to the interruptions of supply chains and logistical challenges for delivering solid biomass to huge power plants. As Fig. 5 shows, due to the COVID-19 pandemic, there was a sharp reduction in the renewable electricity generation from biomass sources which grew every year compared to 2019.

6.2. Effects of COVID-19 on woody biomass residue production, demand, and price

Wood-based bioenergy industry is growing rapidly due to climate change, developing renewable energy policies, and challenging environmental and economic conditions (Zahraee et al., 2022). In a survey-based study that was carried out from 29 April to 14 May (Queiroz et al., 2020), researchers gathered data on the current and future effect of the COVID-19 pandemic on global supply chains of woody biomass. The negative effect on 58% of the wood pellet producers during COVID-19 was noted, and it was reported that 33% had finally decreased production. It was found that most of the producers

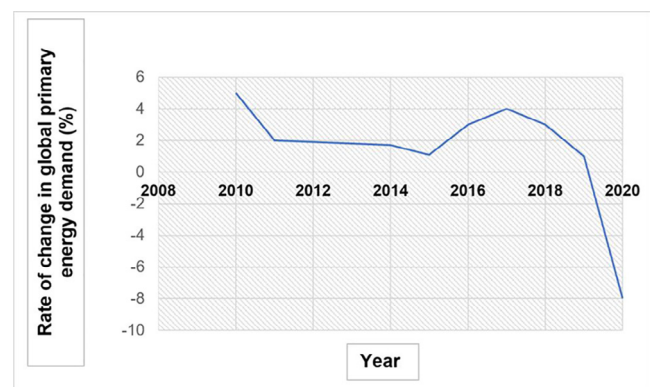


Fig. 4. The global trend of energy demand for 10 years (International Renewable Energy Agency and Post-COVID, 2020).

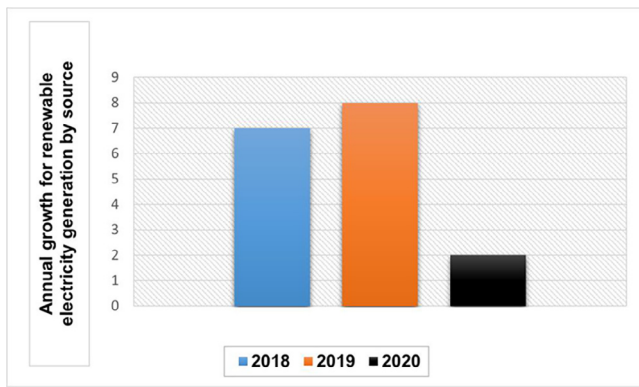


Fig. 5. Annual growth for renewable electricity generation by source, 2018–20 (International Renewable Energy Agency and Post-COVID, 2020).

were affected by lower sawmill availability. COVID-19 was reported to negatively affect 82% of the producers. It was found that almost 14% were severely impacted. The results showed that sawmill residue availability was regionally impacted. Based on the current abundant supply of raw materials in Europe, 33% of the European companies were adversely affected by COVID-19 but were not affected by the reduced availability of sawmill residue, while all those in South East Asia and North America were affected differently. It is worth noting that COVID-19 did not negatively affect all North American or Southeast Asian participants. Some countries such as Malaysia and Indonesia in Southeast Asia and the US in North America have been affected seriously. The survey also found a reduction of the end-user demand beyond the seasonal norm with an effect. Reduced end-user demand affected 73% of those who were negatively impacted by the pandemic. Participants expect the cost of raw materials to increase, especially as access to the sawmill debris is reduced. However, 68% of the manufacturers expect this increase in costs to be below 10%. As a result, several manufacturers used in-wood and roundwood chips and other fibers to use the lower amount of sawmill residues in 2020. Also, 48% of the survey respondents think the maximum cost of raw materials will be seen over the next 3–6 months (Wright, 2020).

Another survey recently completed by ENplus shows that 75% of the wooden pellet merchants and manufacturers certified by ENplus have been affected by the COVID-19 negative pandemic, many of which have been impacted by the reduction in the demand end-users (Voegelé, 2020). Three-quarters of the surveys stated that COVID-19 had a negative impact on their trade. Almost 19% reported no effect, and almost 6% stated that the outbreak positively impacted their work. Those who reported a positive impact primarily reported that end-user demand increased unusually.

Of the three-quarters of respondents who reported a negative impact of COVID-19, above 83% stated that end-user demand for wood pellets declined unusually in the first half of the year. Nearly half said that such reduced demand severely affected them (Voegelé, 2020). Furthermore, 74% of those affected negatively said logistical restrictions resulting from lockdowns would harm their trade. More than half of those who were affected by logistics stated the moderate effect. Most of them reported no effect of COVID-19 on the availability of raw materials for pellet supplies or pellet manufacturers or merchants. More than half of the respondents to the survey said that they expected to experience a decline in pellet production and trading this year. Of the group expecting a decline, almost 45% expect it to decline from 21% to 50% of their allowed volume. Almost 49% of the respondents to the survey said that they expected the effect of the COVID-19 pandemic on the higher production costs, a majority of which expected to increase from 11 to 20%. Above 64% of the respondents stated that they would consider changing their pellet prices. 38% of them had a price increase, and 26% had price cuts (Voegelé, 2020).

6.2.1. Effects of COVID-19 on woody biomass suppliers in the UK

In some countries, important measures were implemented to keep the woody biomass industry active during the outbreak. For example, leaders of the woody biomass industry in the UK asked the government to fully open the wood fuel supply chains. They believe that it would ensure that suppliers would be able to deliver required material to home heating customers and key frontline organizations and businesses that had been already under the stresses induced by the COVID-19. Numerous healthcare and social facilities, hospitals, large-scale food producers, etc., primarily rely on biomass wood fuel to provide hot water and heating. For that reason, the industry asked the ministers to completely assure that the wood pellet imports, production system, and biomass fuel transportation in the UK would all stay open (Biomass Heat Works, 2020). As a result, Biomass Heat Works (UK Pellet Council and Wood Heat Association) issued an urgent request to the Department for Trade, Energy and Industrial Strategy (BEIS), the Department for International Trade (DIT), and the Department for Transport (DfT) to ensure that vital sources of fuel are kept open and have close cooperation with them (Biomass Heat Works, 2020).

In addition, the Department for Environment, Food, Agriculture and Rural Affairs (DEFRA) has a crucial role in guaranteeing that the supply chains of wood fiber remain open to the UK biomass production as well as the supported jobs. In the case of the rural/agricultural regions, this is particularly common. Many great agricultural food manufacturers playing a vital role in the UK food supply chain determine the biomass wood fuel for heating needs (Biomass Heat Works, 2020). For example, one of the largest chicken producers in the UK uses almost 20,000 tonnes of wood pellets nationwide every year across sites. Likewise, one of the leading chain markets in the country, which is currently at the cutting edge of supply chain efforts, used biomass wood pellets to heat about 100 of its sites. This is equal to 30,000 tons per year through delivery per store every 2–3 weeks (Biomass Heat Works, 2020). The annual consumption of wood pellets in the UK is almost 700,000 tonnes, but this demand is expected to increase due to many people working from home. Representatives of Biomass Heat Works, while fully supporting the contingency plans and current emergency of the government, now search for the ministers' collaborative approach so that the industry can support the national effort. Therefore, the weaknesses of complex global supply chains are exposed with the crisis in lean manufacturing. Intermediate goods, raw materials, and final products have become less available almost everywhere due to the disrupted supply chain (Biomass Heat Works, 2020).

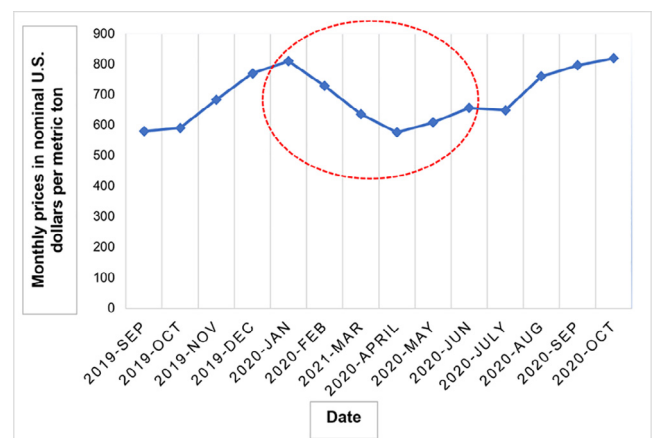


Fig. 6. Monthly prices for palm oil from Sep 2019 Oct 2020.

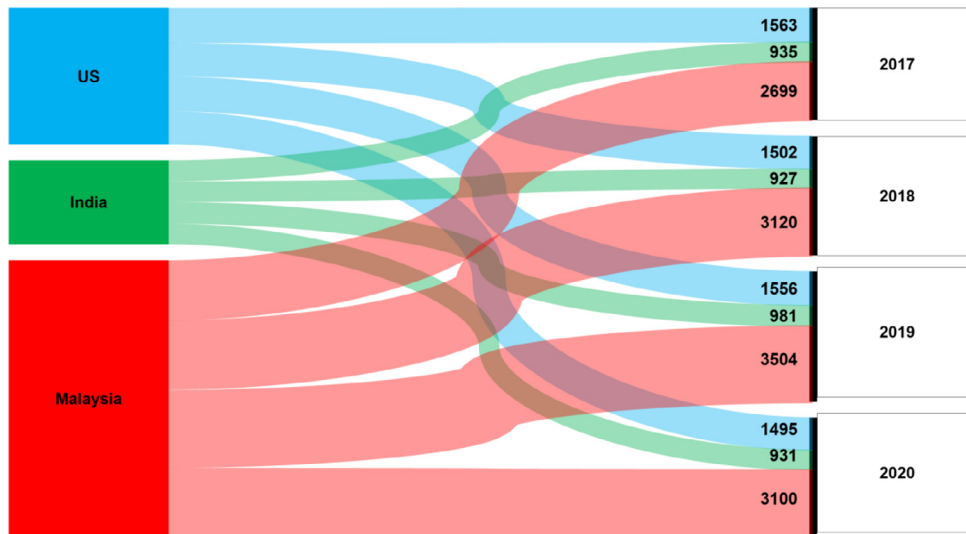


Fig. 7. Palm oil consumption in the US, India, and Malaysia from 2017 to 2020.

6.3. Effects of COVID-19 on palm oil biomass production, demand, and price

The demand, production, and price of palm oil biomass have been severely affected by the necessity of lockdown economies to control the virus. The palm oil price rate was reduced during the lockdown in the world from Jan 2020 to July 2020 (Fig. 6) (World Bank, 2020). As Fig. 7 shows, the palm oil consumption rate among the three main consumers was reduced from 2019 to 2020. In addition, Fig. 8 highlighted the reduction of the palm oil production volume in 2020 compared to 2018 and 2019 of IOI company, a leading palm oil company worldwide (World Bank, 2020). It is expected that imports of palm oil from key destinations will improve slightly in 2021 as compared to 2020, except in Europe (-8.22%), as indicated by Renitive Agriculture Research, Singapore (Fig. 9) (World Bank, 2020). There is a much faster than expected recovery of the economic activities in key palm oil destinations due to financial stimuli and business activities. It is expected that demand for palm oil from India and China will grow in 2021. It is expected that Indian palm oil imports will spike by 4.8% – 8.7 million tonnes, promoted by low inventories and a gradual recovery of demand (World Bank, 2020). Palm oil demand will be restocked and increased from bulk buyers in the HORECA (Hotel/Restaurant/Cafe) sectors after the multi-month stretches of COVID-19 lockdowns led to slower demand. It appears that the cultivation of

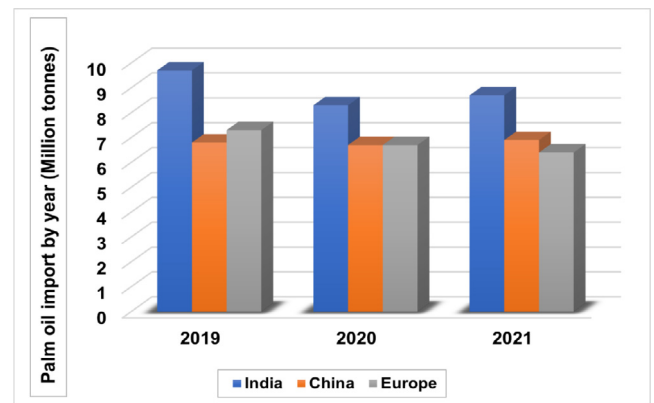


Fig. 9. Import of Palm oil by three key markets from 2019 to 2021.

the domestic crop, particularly soybeans, has risen despite the surge of palm oil exports to India. Thus, very good harvests of groundnut, rapeseed, and soybean crops in 2021 could reduce palm oil purchases. It is anticipated that demand for palm oil in China will go up to 6.9 million tonnes by 3% in 2021. Palm oil has seen strong demand in this market, especially during Chinese New Year celebrations typically falling in January or February, and re-stock activities (World Bank, 2020).

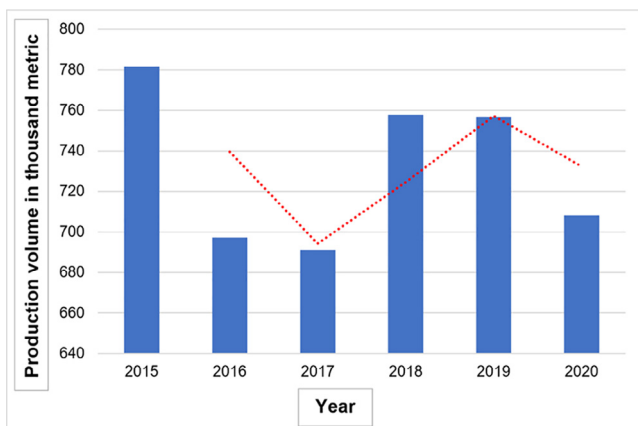


Fig. 8. Palm oil production volume of IOI Corporation from 2015 to 2020.

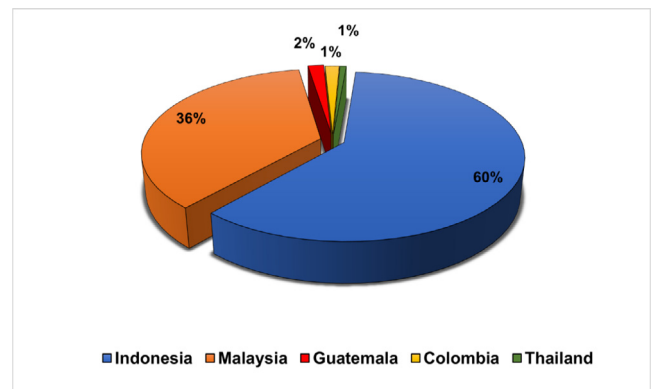


Fig. 10. Share of palm oil exports by main suppliers in 2020.

6.4. Effects of COVID-19 on two main global palm oil supply regions

Malaysia and Indonesia produce approximately 85% of the total global palm oil supply, and 96% are exported by them (Fig. 10) (Council, 2020). Both drought and reduced fertilizers implementation have caused significant negative impacts on the palm oil export of Malaysia and Indonesia in 2019, accompanied by restrictions of movement and shortage of workers caused by the COVID-19 pandemic in 2020. The supply of other edible oils, especially rapeseed oils and sunflower, lower than expected led to the significant rise of vegetable oil prices, with a spill-over effect on crude palm oil prices (CPO) (Council, 2020). Despite the imposition of the partial lockdowns caused by the COVID-19 pandemic in many countries worldwide, curbing edible oils demand, there was a short-term reduction in palm oil exports. The countries with the largest quantity of imported palm oil had started to re-stock by late 2020. Some biodiesel producers were also encouraged by the shortage of animal fats and used cooking oil due to the pandemic to change their feedstocks to vegetable oils, strengthening palm oil global demand. The following two sections summarized and analyzed the outcome and situation for the palm oil industry for two leading suppliers in the pre-and post-pandemic world (Council, 2020).

6.4.1. Indonesia palm oil industry

Indonesia is the first country to produce and export palm oil in the world. GAPKI data showed that in 2019, 6 million tons of palm oil were imported by China from Indonesia, representing 16.5% of the overall palm oil exports. The export of this oil from Indonesia to China dropped by nearly 50% in the middle of global uncertainties (Fig. 11) (Iswara, 2020). Indonesia took large-scale social distancing measures to control the outbreak of the COVID-19. By taking plantations with strict hygiene measures and restricting workers' movement, it is expected that supply disruption will be limited due to the lack of plants for the palm oil producers to stop operations. The Indonesian Palm Oil Producers Association (GAPKI) said that there was a reduction in China's export volume by 381,000 tons (57%) (Iswara, 2020). This led to the considerable reduction of total palm oil exports in the country, declining from 3.72 million tons in December 2019 to 2.39 million tons in January by 35.6%. The association stated in the statement that the reason for the significant reduction of export in January is that importing countries waiting for the Indonesian government to execute a 30% of blended biodiesel, were not still losing their stock under B30 program (B30 program: the diesel sold at the pump contains a 30% blend of palm oil-derived biodiesel). The continuation of the decline could drag down the overall export performances in 2020 since palm oil has remained the country's top export.

It is to be noted that China is not the only destination that saw a decline in palm oil exports in January. There was a reduction in palm

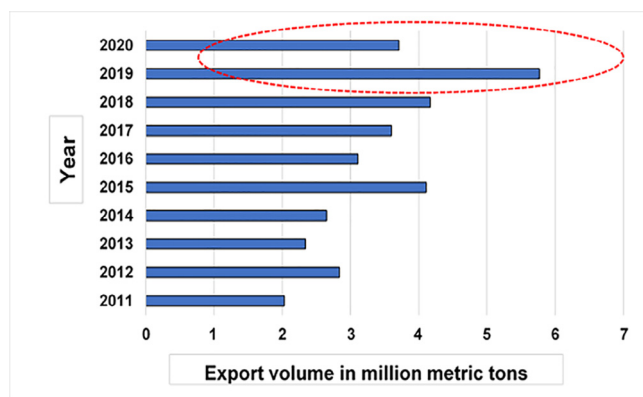


Fig. 11. Export volume of palm oil from Indonesia to China from 2011 to 2020.

oil exports to 141,000 tons (22%) for India, 188,000 tons (30%) for European Union, and 129,000 tons for the U.S. (64%) (Fig. 12) (Hirschmann, 2020). Based on the statistics in (Hirschmann, 2020), Only Bangladesh saw a month-to-month increase by 52% to 40,000 tons in January.

6.4.2. Malaysia palm oil industry

The second largest producer of palm oil in the world is Malaysia (Zahraee et al., 2021). In 2019, a better performance was shown by the Malaysian palm oil industry than in 2018. There were improvements in main performance indicators such as exports, production of crude palm oil, and palm oil stocks. However, since some movement control measures have been taken during the COVID-19 pandemic, the foreign workforce was banned from entering Malaysia. Since 75% of Malaysia's oil palm plantation workforce is foreign labour, there would be delays in palm oil production, resulting in crop losses due to such shortages. It is expected that there will be a decrease in CPO output larger than expected this year and in 2021. There will likely be a more extended shortage of labour.

Before the COVID-19 pandemic, imports and exports of palm oil and CPO production increased while CPO prices, palm oil stocks, and total export earnings of oil palm products were reduced. At the same time, a marginal increase was found in the fresh fruit bunches (FFB) yield. Planted area of oil palm increased in 2019 to 5.90 million hectares by 0.9% compared to 5.85 million hectares in 2018 (Malaysian Palm Oil Board, 2016). For the third year, Sarawak continued to be one of the largest states of oil palm plantation, which had 26.9% of the total Malaysian oil palm planted area, i.e., 1.59 million hectares, followed by Sabah that had 26.2% or 1.54 million hectares. Planted size of oil palm in Peninsular Malaysia was 46.9%, or 2.77 million hectares (Malaysian Palm Oil Board, 2016).

In the case of Malaysia, the statistics demonstrate a minimal growth in the CPO production to 19.86 million tonnes (1.8%) in 2019 compared to 19.52 million tonnes recorded in 2018 (Malaysian Palm Oil Board, 2016). In this country, a marginal rise in the FFB yield to 17.19 tonnes per hectare (0.2%) was reported in 2019 compared with 17.16 tonnes per hectare in the preceding year (Zahraee et al., 2020). A 2.9% growth in the FFB yield was also reported to 17.95 tonnes per hectare in 2019. This growth offset the decrease of FFB in Sarawak and Sabah from 18.16 to 17.66 tonnes per hectare (2.8%) and from 15.74 to 15.56 tonnes per hectare (1.1%) in 2018, respectively (Zahraee et al., 2020). The National Oil Extraction Rate (OER) performance recorded a growth of 1.3% to 20.21% in 2019 compared to 19.95% in the preceding year (MPOB, 2019).

Figs. 13 and 14 highlighted the palm oil Malaysia's export and import for each month in 2019 and 2020. As can be seen, there was a reduction in export and import during the COVID-19 lockdown. Total exports of oil palm products from Malaysia in 2019 accounted for 27.88 million tonnes, increasing from 24.88 million tonnes by 12.1% in 2018. However, there was a total export revenue reduction from 16 billion dollars to 16.72 billion dollars in 2018 since world trade had lower prices. There was a 1.6% reduction in the palm oil export earnings alone in 2019, to 9.42 billion dollars compared with 9.57 billion dollars in 2018. On the contrary, there was a sharp increase in the export volume of palm oil to 18.47 million tonnes by 12.0% compared to the previous year since there was higher demand, particularly from China, India, Vietnam, and the European Union (EU), and Turkey.

The export trend of palm oil from Malaysia to the most important destinations in 2019 and 2020 is summarized in Fig. 15. As can be seen, in 2020, a considerable drop occurred in the CPO export from Malaysia to key destinations (except China). Since 2014, India kept its position as the largest palm oil export market (around 3.9 million metric tonnes) from Malaysia for the sixth succeeding year. In 2019, the value of this export accounted for 23.9% (4.41 million tonnes) of the total export of Malaysian palm oil. China ranked the second coun-

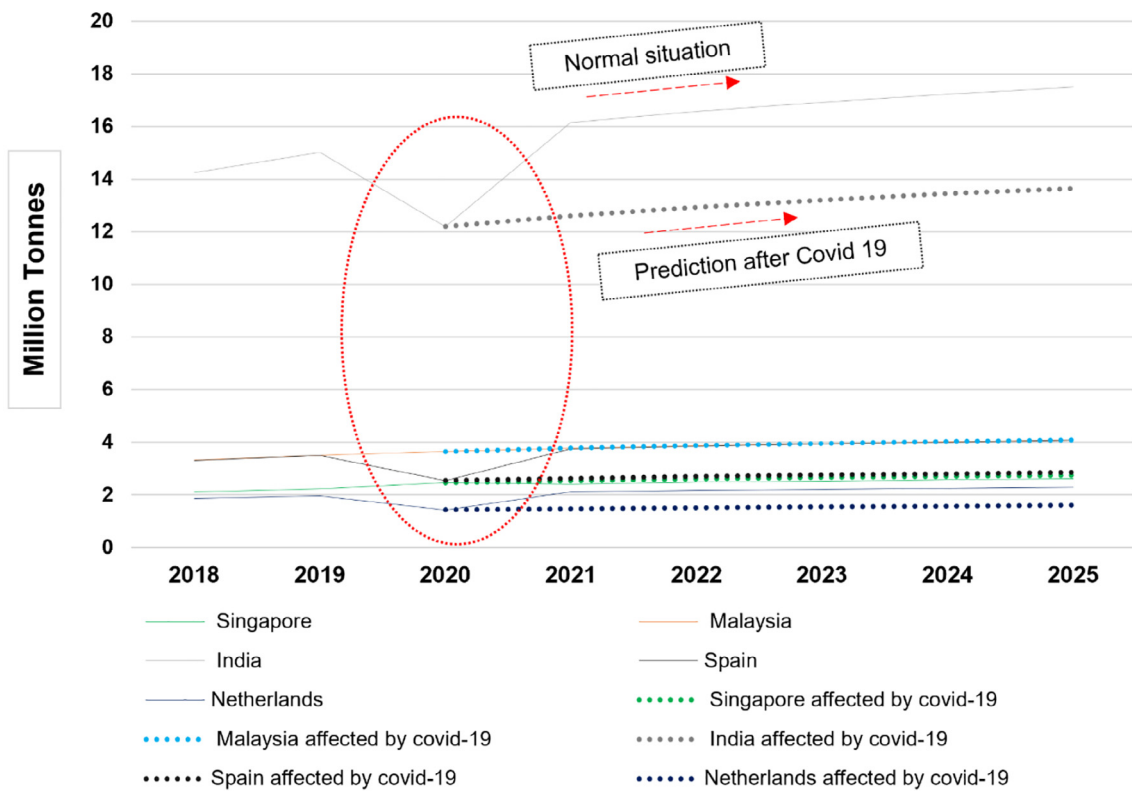


Fig. 12. Prediction of palm oil export from Indonesia (After pandemic vs. Normal situation) (Source: created by authors, data from (Zahraee et al., 2020)).

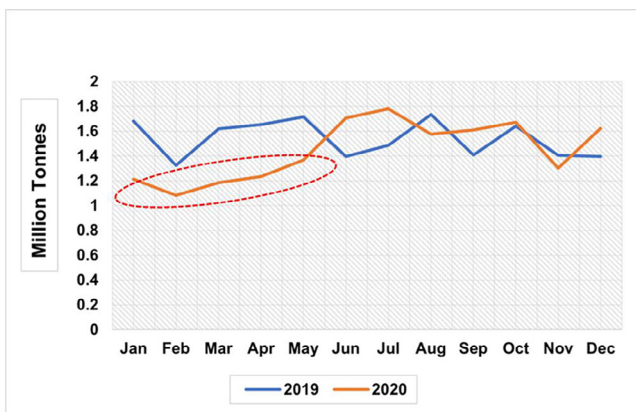


Fig. 13. Palm Oil Malaysia's Export (2019 vs. 2020).

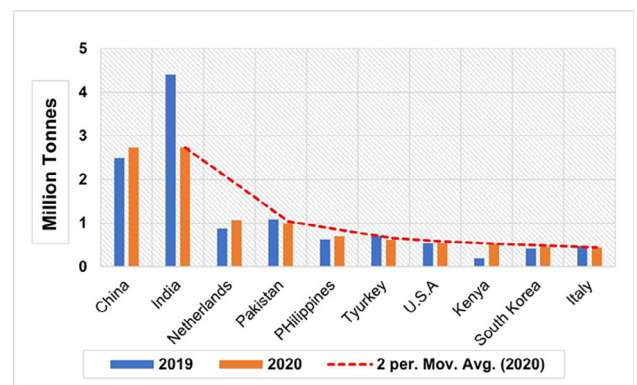


Fig. 15. Export of Palm Oil to Major Destinations from Malaysia.

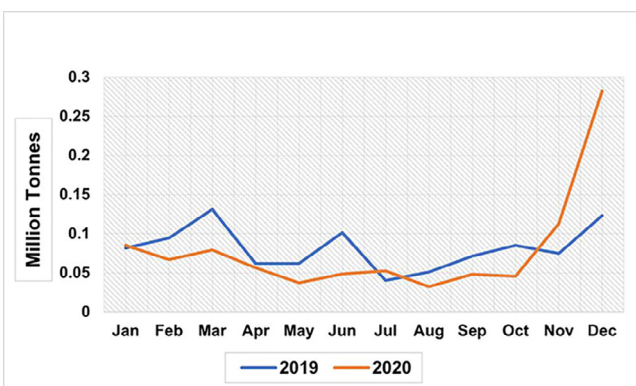


Fig. 14. Palm Oil Malaysia's import (2019 vs. 2020).

try after India with 13.5% (2.49 million tonnes), then the EU with 11.3% (2.09 million tonnes), Pakistan with 5.9% (1.09 million tonnes), Turkey with 3.8% (0.71 million tonnes), the Philippines with 3.4% (0.63 million tonnes), and Vietnam with 3.2% (0.60 million tonnes). The palm oil exports were 12.01 million tonnes or 65.0% among the top seven markets in 2019 (MPOB, 2019). Palm oil increased significantly in India from 2.51 in 2018 to 4.41 million tonnes by 75.4% in 2019. There were lower prices of processed palm oil products in the worldwide market in 2019. This decrease continues in 2020 due to COVID-19 disruptions affected by lower oil prices in the world market.

6.5. Technology role in BSC resilience before and during the COVID-19

Information systems and technology have a main role in integrating suppliers and producers in a supply chain to conduct operational activities to respond to market changes in a timely and cost-effective man-

ner (Bargshady et al., 2016). Sustainability matters have led to an application of a wide variety of technologies targeting to improve the efficiency of BSC from precision farming through to intelligent storage and logistics through to optimal exploitation by the end-user. Different technology tools and services have been developed for farmers, suppliers, production, storage, and transportation sectors in BSC. Before the pandemic, some technology tools have been used for online databases, farming (social), quality control and storage (production), markets and trading platforms (economic), logistics and transportation (environmental). But, to effectively manage the BSC during and after the COVID-19 pandemic, it is suggested to implement several different technologies, e.g., industry 4.0, digital twins, artificial intelligence, 3-D printing technology, mobile service operation, etc. The innovative technologies could greatly help manage the COVID-19 effects during and after the pandemic. The government can adopt different new new-age technologies as an initial response strategy. It is suggested to use emerging technologies like the Internet of Things (IoT), Internet of Medical Things (IoMT), and other smart emerging technologies like drones, robots, autonomous vehicles, Bluetooth, and global positioning system (GPS), which can help handle this pandemic to achieve the BSC resilience. Fig. 16 visualizes the potential technology developments in BSC activities. IoT Would help to transmit data over the network without any human intervention. In recent times, IoMT has captivated major attention from the field of healthcare (Saher and Anjum, 2021). In order to make a safe environment for the labors in the biomass industry, medical devices and technological applications such as Bluetooth and GPS technologies would help to monitor labors and staff's health such as COVID-19 symptoms and their day-to-day stress levels and other parameters in the working environment such as farms or working from home for other sectors.

Data analysis and management tools also play a significant role to keep a secure production level based on storage capacity and quality

considering available resources (Flak, 2020), especially during the uncertain condition of COVID-19. Quality control plays a very important role in different stages of the BSC. Parameters, such as moisture content and temperature, should be monitored to assure the product quality based on regulations to optimize the production process of bio-waste to energy. GrainSense (GrainSense, 2020) and Celnignisrapid biomass analysis (Monitoring, 2020) are examples that apply to quickly analyze such parameters for feedstock. Enterprise resource planning is another method used for decades that is suited to monitor agricultural production and have the potential to maximize the production level for BSC resilience (Flak, 2020). There are some different technological tools used for different BSC production activities, such as ERPagro (ERPagro, 2020); WinforstPro (WinforstPro, 2020); Olivia (Olivia, 2020); Solania (Solania, 2020), and Berria (Berria, 2020) for production planning, wood waste management and logistics, profit and sustainability of production.

Monitoring the storage facility is another concern for the BSC resilience. To detect the fire or maximize quality of feedstock and minimize the energy costs, some technology tools such as Haytech (Haytech, 2020) are useful to control and monitor the temperature. Odoo Fleet (Fleet, 2020) is another technology tool to track the transportation system. Due to transportation system disruption during COVID-19, it would be helpful for monitoring transportation mode description, fuel consumption, and route optimization to optimize the number of trips and logistic costs (Fleet, 2020).

Covid-19 disruption also has a considerable effect on biomass marketing and trading worldwide. Using global online market platforms such as Ositrade (Ositrade, 2020) and Agri Marketplace (Marketplace, 2020) would help to supply the international market and meet customers' demands. Biomass availability is another concern to map harvesting and collection in the regions of BSC. The Scottish Bioresource Mapping (Tool, 2020) and MooV (MooV, 2020)

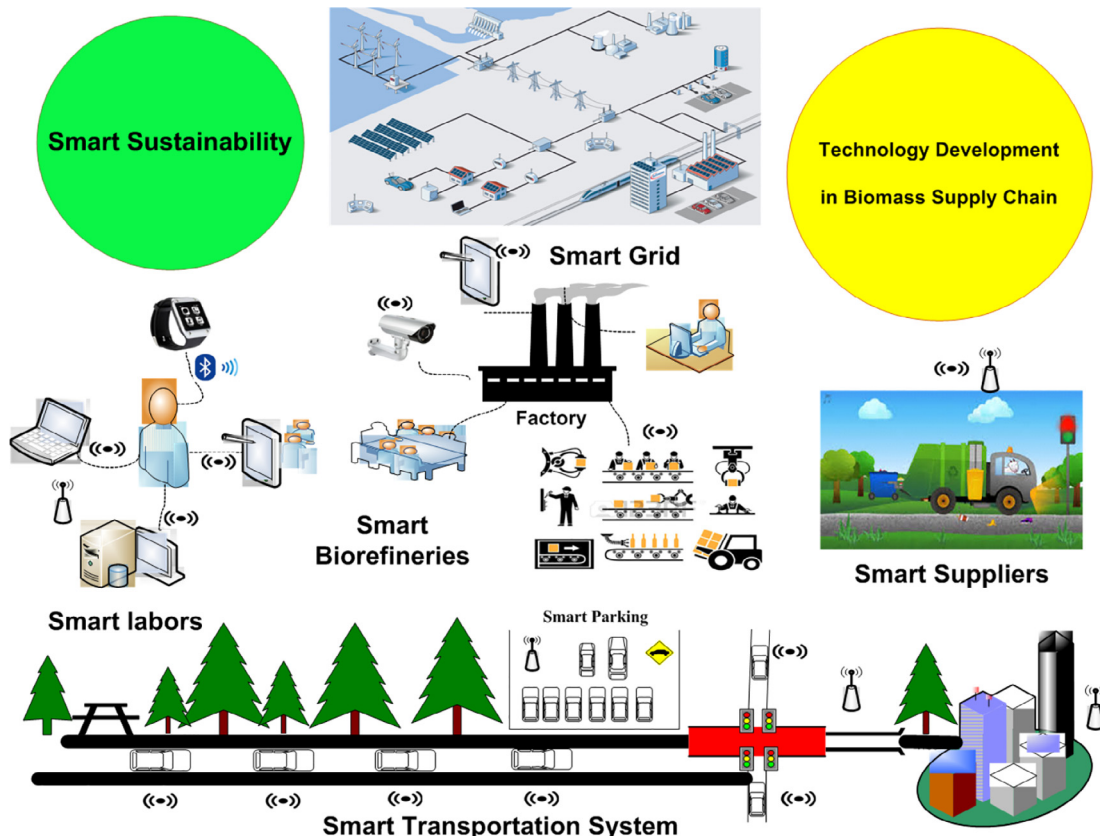


Fig. 16. Potential technology development in BSC resilience activities.

approaches are helpful tools to monitor and model the bioresources plantation yearly. These technology tools have been used in the region of Scotland, Ireland, and Andalusia, Spain. However, other main biomass suppliers are encouraged to apply these technology tools to optimize the BSC by reducing the cost, improving sustainability, and designing the distribution centers and transportation modes.

From the general perspective, these emerging technologies could facilitate the operations of the medical/healthcare supply chains when providing personal protective equipment such as ventilators and other medical equipment during COVID-19. Such products can be produced quickly using 3-D printing techniques (Iyengar et al., 2020). In addition, the authors in (Quayson et al., 2020) proposed using drones or hybrid truck-drone devices to ensure both on-time and contactless delivery of products to customers. It is essential to develop different intelligent platforms to predict storage network optimization and automatic replenishment. The automated logistics technology would help biomass suppliers overcome the pandemic disruptions and improve high operational flexibility. There is a lack of research to analyze how the last mile of delivery for the BSC during a pandemic are affected by technologies to achieve higher responsiveness and reliability.

In summary, implementing technological developments during and after COVID-19 to achieve the BSC resilience should be counted as an investment rather than a cost, since the benefits outweigh the expense. The reviewed technology approaches have the potential to bridge the gap between biomass suppliers, stakeholders, and customers and help them to select suitable transportation and logistics for BSC resilience to meet local and global demand.

7. Discussions

Energy demand has been impacted profoundly by the COVID-19 crisis, and measures adopted to reduce its speed have not been experienced for 70 years. The period of the recovery paths and lockdown measures taken worldwide will determine the full effect of the present situation, which has been unknown yet. The energy sector will be shaped by this unexpected situation and the stimulus packages applied by the governments for the next years, significantly affecting the energy industry at large, clean energy, and energy security transitions. The financial impact is felt in the biomass energy industry across the value chains, in which most of the energy companies lost considerable revenues. Lower demand for their products, including gas, coal, oil, and electricity, and lower prices affect them. There was a sharp reduction in the average oil prices, in which West Texas Intermediate affected negative prices first in history due to scarcity of excessive storage.

The emergence of the biomass industry from the COVID-19 crisis might considerably differ from what occurred formerly. In all subsectors, low demand and price may weaken the energy firms with weak financial positions and often strain the balance sheets. There will be the emergence of business lines insulated somewhat from market signals, including those with renewable electricity projects in the best financial position. Private companies that experience high exposure to market prices will see the most severe economic effects. There will be market consolidations and concentration.

The COVID-19 crisis along the biomass energy sector will significantly affect the investment, raising concerns about energy security due to the necessity of investment even if it takes a long time for the global energy demand to return to the trajectory before the crisis. The existing energy supply levels are sustained through a high share of global energy investment, such as keeping palm oil production at the present levels, reinvesting in ageing electricity networks, and replacing ageing power generation capacities with a capital-intensive combination of flexible sources and renewables. Even a subdued recovery cannot strengthen investment in these activities.

The supply chain of biomass renewable energy technologies is globally disrupted, causing a supply shortage. Therefore, the biomass industry needs to focus on localizing the manufacturing of renewable energy technologies. The huge risk is due to the complete dependence on imports of technology. Hence, different mechanisms and options should be explored to improve the manufacturing industries' capacity. In several countries, the renewable energy generation has been slowly limited due to some reasons among which the main items include: 1) immature renewable energy supply chains, 2) ambiguity in the actual capacity of renewable energy, 3) the absence of skilled workforce and capital, and 4) the deficiency of the research & development (R&D) projects. Consequently, the nonexistence of local capacities and disruption in the biomass energy technology supply chains results in the slow facilitation of energy access, particularly in the pandemic situation that affects the unsustainable businesses involved in the off-grid energy sector. Such conditions force biomass suppliers and stakeholders to adopt state-of-the-art methods and adopt effective policies to support the local industrial capacities. It is needed to generate and develop their energy technologies and facilitate energy access to reach development objectives concerning the sustainability pillars (economic, social, and environmental).

Producing the biomass renewable energy technologies could be promoted by the implementation and development of effective, internationally-proven policy tools, for example, manufacturing industries, renewable energy-based power generation, financial incentives for R&D projects, carbon trading/pricing, introduction of Feed-in Tariffs, and other related policies (Zahraee et al., 2020). It is clear that extensive incentive options currently exist; however, the options having potential for great effects on the localization of biomass renewable energy technologies need to be prioritized. Such options might involve tax deduction and grants for investments in R&D projects, performance-based financial awards from different financial resources without the need for any repayment. Similarly, some other measures could also be taken into account, for instance, lowering the income tax for selling power generated by renewable energy technologies locally produced, giving financial subsidies to power produced with locally-made renewable energy technologies, etc.

In addition, manufacturing industries could adopt particular incentives, including:

- The provision of free worker recruitment services,
- The provision of a ready-to-start workforce,
- Labor cost tax deductions involved in the local manufacturing industries,
- The provision of land at nominal prices for potential producers, particularly for the producers focusing on import replacements of energy technologies,
- The reduction of the income tax for joint ventures engaged in the local manufacturing of energy technologies to encourage the technology, and
- The provision of a stage for transferring the knowledge obtained from making the direct foreign investment to the local companies.

In addition to the incentives provided and policies established by some development partners, the funding organizations and governments have mobilized resources to attain the sustainable development goals to use the opportunities brought about by the crisis in the best way.

For issues related to biomass feedstock waste, the issue of BSC anomaly will be solved through local consumption and production under a future pandemic. The measures to cut taxes and ensure financial security during global crises will take a long time to create strong local consumption and production demand. In addition, the main principles of the circular economy should be the optimization of the biomass waste amount transported, produced, and stored in the biomass value chain implemented both at the customer and supplier levels.

Decision-makers and policymakers should regard the existing crisis as a good occasion for finding the best solutions to the problem of the BSC's economic prospect by developing new sustainable optimization models based on the circular economy principles. The strategies pertaining to the biomass logistics and supply chain restructurings (e.g., size and location) need to be well considered to diminish the current impacts as much as possible to ensure the resilience of the BSC in the years after the COVID-19 pandemic.

The intricacies of waste management should be handled to upgrade biomass production systems. Solutions based on technology, including the automated processes of waste valorization (e.g., gasification, pyrolysis, and hydrothermal carbonization), promise to provide by-products of high quality while ensuring that the staff involved have maximum safety and job security. Additionally, it is suggested to analyze how the biomass closed-loop supply chain or circular economy concept could support waste management during the COVID-19 pandemic.

In addition, the COVID-19 crisis affects the transition path of clean energy. Global CO₂ emission is expected to reduce in 2020 significantly, but ongoing efforts and commitment are needed towards a sustainable energy pathway. There may be only a temporary unexpected reduction of emissions in 2020 without making structural changes. There have been fast rebounds in CO₂ emissions due to recoveries from past crises, including the highest increase on record every year in 2010.

Therefore, considerable support is needed from the development partners along with dedicated and committed leadership that will provide a real opportunity to succeed in addressing the resilience of BSC. This crisis can facilitate energy access (especially renewable and clean energy) because of the readiness of the political leadership to take this opportunity and to alter the ways of business continuing before the pandemic. Therefore, the biomass industry can facilitate universal energy access through prosperity through the effective use of the opportunities caused by the crisis, rather than continuing the use of conventional energy resources that is not sustainable in the longer term.

7.1. General recommendations and managerial implications

It is imperative to be ambitious and strategic and act decisively to make the shift structurally required to fulfill the agenda for sustainable development in 2030 and preserve 1.5 °C degrees of global warming. The "Recovery after COVID: An Agenda for Resilience, Development, and Equality" clarifies such connection ([International Renewable Energy Agency and Post-COVID, 2020](#)). The post-COVID recovery agenda which was proposed here can be achieved. Public finances alone would not accept the burden significantly as costs increase and technologies continue to develop. Notably, there will be a fast job creation due to stimulus investments. A sustained shift can be supported in local economies, tomorrow's workforce will be built, and diverse value chain segments will be fostered using the targeted education and training programs and industrial policies.

The present study inferred some managerial implications from the existing literature regarding disruption propagation in supply chains, logistics, and transportation. Also, it revealed some directions for future research in this domain. Reliable sources of data and dependable websites were considered regarding the sustainability pillars, uncertainties variables for the biomass industry's demand, supply, and production. The findings and recommendations from this study can assist managers of the biomass industry in developing a resilience strategy to recover from the COVID-19 effects and combat disruptions in the supply chain from similar pandemics in future. Due to the relevance of the current findings in managing the resiliency of the supply chain in different energy sectors, both scholars and practitioners in various energy industry sectors (e.g., solar, wind) could apply the present study's findings to develop the decision-support systems to guide

supply chains amid the COVID-19 pandemic and their subsequent recovery.

Agricultural BSC has been a rather traditional and conservative sector ([Flak, 2020](#)). The COVID-19 provides an opportunity to raise awareness of emerging technology solutions and facilitate the adoption of technologies that can increase the efficiency and resiliency of BSC. Technology-based solutions such as industry 4.0, digital twins, artificial intelligence, 3-D printing technology, mobile service operation, etc., may assist in managing the COVID-19-effects to BSC. There are also suggestions on using drones or hybrid truck-drone devices to ensure both on-time and contactless delivery of products to customers ([Quayson et al., 2020](#)).

The governments should link the short- to medium- and long-run strategies to see if the Sustainable Development Goals (SDGs) align with agreements on climate change to recover the BSC resilience through basic measurements. There can be a more extensive change through the policy measures and investments for recovery and stimulus, reinforcing the regional and national energy transition strategies which are taken decisively to build resilient societies and economies.

The economy can be boosted through the energy transition investment in the recovery phase of 2021–2023, creating a broad scope of jobs. The stimulus measures can accelerate positive continual. Renewable energy sources and other transition-based technologies require investments valued at 824 billion US dollars in 2019 ([International Renewable Energy Agency and Post-COVID, 2020](#)). There should be double investments to about 2 trillion US dollars during the 2021–2023 recovery phases, then continuing to grow to 4.5 trillion US dollars averagely per year until 2030 ([International Renewable Energy Agency and Post-COVID, 2020](#)). Additionally, green bonds and institutional investors should be provided, in addition to the dedicated investment, credit, and funding programs. Now, it appears that the pandemic has increased investors' interest in sustainable assets. Institutional investors may tend to focus on renewables in the recovery phase and beyond. When their investment portfolios are aligned to a climate-safe future, investors may additionally expect evolving fiduciary standards and new regulatory demand.

The current Nationally-Determined Contributions (NDCs) under the Paris Agreement lags compared to already-apparent market trends to the extent that they set renewable power targets. There should be consistency between economic stimulus plans and the Paris Agreement on Climate Change, the 2030 Agenda on the SDGs, and the procedures established to implement them, e.g., the plans provided in the Addis Ababa Action Agenda on financing for development ([United Nations and Agenda, 2015](#)). Long and short-run opportunities may come one after another for entering the investment flows in major areas. Inclusive, equitable, and resilient economies can be applied beyond decarbonization and renewable biomass investments in the energy system following the COVID-19. To reinforce a fair transition, the social and labour protection policies should be aligned with each country's particular requirements and region. For labour market interventions, employment services such as facilitating on- and off-job training, matching jobs with qualified applicants, and providing safety nets, in addition to relocation grants and taking other measures to ease labour mobility if needed. The programs could also support the retention of fossil-fuel workers with reoriented skills for the energy transition.

Therefore, it can be concluded that BSC could significantly contribute to the solution of the energy security-related issues, green energy development, and cleaner supply/production processes, particularly at the time of the pandemic. Due to the COVID-19-induced economic recession, scholars expect an aggravated situation in the near future. The existing evidence shows the promise in the biomass industry and a worldwide intent for supporting sustainable development. Although there are not adequate green stimulus packages for reviving the local biomass industries, coordinated efforts are required to support the cleaner supply chain. The present study highlighted a number

of key issues related to the measures needed before BSC could lessen the heavy reliance of the world on fossil fuels. The current research findings could considerably contribute to the provision of cleaner post-pandemic energy production and supply, supporting the manufacturers to reduce long-term costs, lowering the risks, driving new revenue, improving brand value, and enhancing the employees' engagement. With the further maturity of technologies and regulations, firms need to re-evaluate their energy procurement strategies in a way to take the most advantage of these benefits.

Table 3 summarizes some policy recommendations for planners and decision-makers to assist in developing plans to encompass the resilience of the social, economic, and environmental sustainability of the BSC disrupted by the COVID-19 pandemic.

8. Conclusions and policy implications

This paper analyzed the global challenges and pressing issues of the BSC under the current COVID-19 crisis. Specifically, given the lack of studies on the effects of COVID-19 on the supply chain disruptions of agricultural biomass, this study analyzed and assessed the biomass supply and production systems during the COVID-19 and their recovery in post-COVID-19. The nature of the COVID-19 crisis is understood to differ from any economic crises experienced in recent years. Results

showed a considerable reduction in woody residue and palm oil biomass production, supply, export, and demand globally. At the same time, oil prices and energy generation were affected severely. It is noted that electricity generation from biomass will slow down due to the interruptions of supply chains and logistical challenges for delivering solid biomass to huge power plants. Global gross domestic product was affected due to the pandemic worldwide. However, the COVID-19 outbreak decreased GHG emissions in many countries such as Italy and China due to lockdowns, disruption of industry activities, and travel restrictions. The supply chain of many products was affected by delays in delivery and shipping, border controls, and transportation and logistics disruption. From the social aspect, job loss was high in several industries such as bioenergy, equipment transport, construction, and distributed renewables projects.

This work addressed the challenges for maintaining the resilience, prosperity, equity, and capability of the BSC after COVID-19. Governments will play important roles in shaping the recovery of the biomass energy sector from the COVID-19-induced crisis due to their capability in orienting investment in energy sectors. Particularly, the governments have an opportunity to connect economic recovery efforts with a cleaner supply chain and energy transitions by designing economic stimulus packages and directing the energy system toward a more sustainable path. There should be a coordinated policy effort to take this opportunity to develop a more modern, resilient, and cleaner biomass

Table 3
Sustainable strategic action plans for BSC resilience.

Plans	Actions
Investments in the transportation sector (Economic)	<ul style="list-style-type: none"> Adopting motivated mandates and targets in transport and fiscal and financial incentives for supporting the uptake of the renewable solution (e.g., EVs). Connecting stimulus packages to decarbonization requirements such as the collection of transportation taxes to provide cleaner transport. Strengthening the curtail of non-essential travel and behavioural changes.
Protect existing jobs and support new job creation (Social)	<ul style="list-style-type: none"> Taking social-protection measures for those workers who have been influenced by COVID-19. Creating employment benefits through attracting new investments in the distributed generation. Creating new job opportunities using local capacities across the energy transition technologies biomass value chains. Re-training the workers who are at risk of losing employment or have lost, including fossil fuel workers. Adopting active labour market policies to match skills supply and demand. Giving support to workers in terms of income during the full transition. Providing realistic retraining/training programs leading to decent work. Sharing knowledge and adopting the best practices from other jurisdictions. Using a framework to support collective bargaining and labour standards. Adopting a sectoral approach based on the work processes and regions
Diversify supply chains	<ul style="list-style-type: none"> Reducing barriers to entry of local firms that seek access to biomass value chains. Developing fruitful capacities to contribute to renewable energy supply chains. Promoting change to regional value chains to reinforce global resilience to external shocks. Allocating resources to enhance BSC capabilities during large-scale disruptions. Redesigning biomass logistics and supply chain networks to decrease vulnerability. Sharing the cost of contracts or coordinating contracts. Increasing capacity and managing transportation costs. Being connected drives of BSC partners to satisfy the needs of each other. Using knowledge management by sharing important data, ideas, and expertise. Integrating and combining warehouses at different levels.
Ensure that there is access to reliable energy during the disruptions	<ul style="list-style-type: none"> Utilizing the solutions for distributed biomass renewable energy to strengthen responses of COVID-19 and reinforce sanitation, health, and other critical infrastructures. Involving partnerships among sectors to mobilise fast responses. Ensuring the continuation of the vulnerable populations using modern decentralized solutions (such as adopting relief measures to energy providers to restructure or defer payments) and not reverting traditional fuel use because of income shocks. Satisfying the fast financing requirements of distributed energy enterprises for operating capital, bridge loans, and grants. Addressing logistical challenges that may be faced by suppliers when giving service to off-grid areas. Considering the gender for the COVID-19 support programs.
Develop local industries	<ul style="list-style-type: none"> It strictly requires local suppliers in return for government support (for instance, tax breaks and subsidies). Establishing green financing programs supported by national development banks to enhance financing for industrial activities. Establishing supplier development programs with the aim of promoting practical learning for local suppliers. Making industry clusters for energy technologies related to transition.
Green environmental recovery (Environmental)	<ul style="list-style-type: none"> Prioritizing green investments to decrease the risks presented by climate change and biodiversity loss. Promoting energy-efficient and renewable energy systems that support sustainable energy transitions and environmental dimensions. phase out fossil fuel subsidies

energy sector as the clean energy transitions are becoming more successful and popular. In the following points, generally short, medium, and long term policies implications that the businesses may adopt to deal with the problem resulting from COVID-19 have been suggested.

- Response in the short term (0–6 + months)
 - Government incentives and grants – China and other parts of the world have received trillions of dollars of stimulus packages. Benefits include claims, employee wage payments, cancellation/deferral of taxes, business interruption loans, and other tax credits.
 - Tax installments – tax installment payments will be deferred or reduced based on the revised economic forecasts.
 - Contract reviews- the contractual nature of several agreements may be changed under the applicable force majeure clauses due to unforeseen circumstances.
 - Employee costs – related employer and employee tax costs, the absence of mobility, trapped employees, and allowances may be seen
- Recovery in the medium term (6–24 months)
 - Dealing with lower earnings expectations by making adjustments in transfer pricing.
 - Repayments of Input Tax Credit (ITC) and resolving tax disputes to manage outflows and collect cash.
 - Planning for losses (how to utilize within a country or region, how to minimize and offset other taxable entities).
 - Permanent establishment (PE) and tax residency – higher risks of PE issues and tax residency because of the difficulty of convening offshore board meetings.
 - Promoting the adoption of emerging technology solutions (e.g., Industry 4.0, drones, artificial intelligence, etc.) that can increase the efficiency and resiliency of BSC.
- Resilience in the long term (24 + months)
 - Changes in the supply chain; Base erosion and profit shifting (BEPS) changes combination.
 - Tax operations transformation, delivery centers, and outsourcing models to decrease operating costs.
 - Innovation and technology.
 - Mergers and acquisitions (M&A) opportunities.

Implementing the adopted approaches and suggested strategies mainly relies upon data; however, in the case of COVID-19, numerous uncertainties still exist to attain resilience. To recover effectively from the COVID-19-induced shock, the governments collaborating with the OECD can adopt the suggested models and other analytical resources to develop strategic priorities and resilience in national and regional responses to the crises. In both cases, policy interventions and priorities to address the COVID-19 need to incorporate the principles of system resilience to systemic disruption; ignoring this subject will limit future socio-economic recovery for the next decade at least. Institutional and fiscal capacities are the main limitations of the governments and OECD to making and implementing plans for economic recovery.

From the generalizability aspect of our work, the findings can help researchers investigate the impact of the COVID-19 pandemic in the other cleaner supply chains, such as the solar and wind energy sector. The findings from this study are valuable resources for the governments, biomass industry, and other stakeholders to tackle the challenges the pandemic posed in the biomass energy sector as they can predict and plan to offset the actual effects of the COVID-19 pandemic on the global cleaner supply chain. In the future, there is a need to develop a model to analyze various disruptions related to biomass production and supply, local and export demand, and delivery. The model should incorporate strategic, tactical, and operational decisions to redesign and optimize the BSC network as well as to select a proper facility location for minimizing the COVID-19 impacts to achieve a quick recovery. Future studies should also focus on the scenario analysis of the economic, environmental, and social effects of COVID-19 on

production and supply costs, transportation, and logistics costs, GHG emissions, and job opportunities in the global and regional BSC.

Declaration of Competing Interest

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

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