Particle-Gaseous pollutant emissions and cost of global biomass supply chain via maritime transportation: Full-scale synergy model

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Particle-Gaseous Pollutant Emissions and Cost of Global Biomass Supply Chain via Maritime Transportation: Full-scale Synergy Model

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Abstract

Environmental and economic issues in the maritime transportation and logistics industry have historically received less stakeholder attention than aviation and overland freight sectors. Stakeholders in the port industry have gradually started paying attention to emissions and cost issues across all the sectors, such as supply chains. Global biomass supply chain is one of the main sectors which has not been addressed in published literature. To address this gap, this study aims to develop a dynamic full-scale synergy model to assess cost-mass flow and particulate matter emissions, and air pollutants for maritime transportation of the global crude palm oil biomass supply chain. Focusing on leading producers of palm oil worldwide, we have analyzed a total of 93 sea routes from Malaysia and Indonesia to main export markets in the US, Europe, and Asia. The analysis distinguishes three freight categories: light, medium-weight, and heavy for different sizes of capacity and types of container ships based on the twenty-foot equivalent unit (TEU). The findings highlight the dependency of greenhouse gas emissions (GHG) level on other factors such as technology, size, and mass flow used for container ships. The results also show a strong relationship between GHG emitted and the type of container ship in a systemic view. A ship with higher TEU contributes to the higher transported amount and lower GHG emissions in the long term. The results would increase port industry stakeholders' understanding of developing energy policies and managerial strategies for low cost and low carbon fuels technologies.

Keywords- Global biomass supply chain, Crude palm oil, Maritime transportation, Export market, Transportation cost, Environmental emissions

1. Introduction

Despite many efforts, a global energy crisis has arisen in recent decades due to several reasons, e.g., the risk of fossil-fuel depletion and numerous negative effects exerted on the environment because of the non-renewable energy generation. This has led scientists and practitioners to explore sustainable energy alternatives with the capacity of satisfying the rising demand for energy [1]. Biomass, the organic material stored in animals/plants, has been extensively used as an alternative source of energy [2]. Biomass would account for more than 5% of the national primary energy consumption by 2025 [3]. Currently, biomass covers approximately 10 percent of the global energy supply, of which two-thirds is used in developing countries for cooking and heating [4]. As reported in [5], biomass fuel generation at the global level has roughly tripled in the past ten years; for example, based on statistics, it had surged from 2.78 million tonnes in 2006 to 8.2 million tonnes in 2016. Such a situation has encouraged practitioners to renovate bioenergy products, e.g., crude palm oil (CPO) [6]. Crude palm oil, as one of the main biomass products, contributes to 73 million metric tons worldwide. That figure increased to approximately 75.45 million metric tons in the following year [7]. As a result, the economic and environmental welfare of biomass use might be displaced because of the separation between consumers and producers in the global market [8].

Numerous countries and regions, e.g., European Union (EU), the United States, Japan, China, India, etc., have long-run plans for increasing the use of bioenergy as a significant effort to reduce greenhouse gas (GHG) emissions [9]. The international market has greatly helped bioenergy products to be frequently traded commodities among different regions in the world [10]. The international biomass trade involves numerous challenges like the relationship between market forces and policies made by authorities, and many studies have been conducted on this topic. For instance, Lamers [11] attempted to examine the problems arising in the sustainable international trade of bioenergy. They assessed the effects of two factors, i.e., sustainability and policy, on both future and past bioenergy supply and trade and how they affect the international trade of bioenergy. As Matzenberger et al. [8] anticipated, by 2030, the international trade volume of bioenergy products can reach up to 14% to 36% of the total worldwide demand for bioenergy.

Biomass utilization can exert a global effect along the worldwide supply chain via international trade, which supports the generation of bioenergy-based products and all other commodities in the environmental and economic network [12]. Consequently, there is a need to conduct further research into the sustainable aspects of international biomass trade, which includes analyzing the environmental and economic factors to define potential criteria of future sustainability in the context of the world biomass trade. The environmental and economic requirements can have considerable effects on the future biomass trade in the global market [13].

The geographically dispersed distribution of biomass resources and the global misalignment of biomass supply and demand have caused a knowledge gap to effectively develop the international biomass trade. The international biomass market typically undergoes rapid changes, with more and more countries being added to this market. According to the authors in [14], for the establishment of a sustainable biomass industry in which biomass-derived products could be produced on a large scale, it is a must to unceasingly evaluate the global biomass supply chain (GBSC) maritime transportation network considering both economic and environmental aspects. To obtain the maximum benefits of the local and export market, it is important to adopt production and transportation technologies in line with sustainable development goals (SDGs) by focusing on affordable and clean energy (SDG7) and climate actions (SDG13) while designing Biomass Supply Chain (BSC) transportation network [15].

The main concern of transportation industries has corresponded to a long-term environmental impact and health issues through toxic emissions such as carbon dioxide (CO_2), and nitrogen oxides (NO_X), and particulate matter (PM) [16]. The environmental impact of shipping includes air pollution, water pollution, acoustic, and oil pollution. Ships are responsible for more than 18 percent of some air pollutants [17]. International Maritime Organization (IMO) member states and organizations are developing a roadmap to determine the amount of air pollution such as GHG emissions that need to be reduced from the shipping sector, by when, and by what means. One of the objectives of the IMO is to decrease the average carbon intensity (CO_2 emissions per transport work) by 40% in 2030 and 70% in 2050 compared to the levels recorded in 2008. Another objective of this international organization is to reduce the total GHG emitted from the shipping sector by at least 50% in 2050 compared to the volumes recorded in 2008 [17]. Furthermore, the analyses carried out on the maritime Industry 4.0 investments have shown considerable potential cost reductions [18]. Those industries with an investment in digitalization can reduce operational costs by 3.6% on average and enhance their efficiency by 4.1% [19]. International trade and long-distance transportation have significant impacts on the GBSC maritime transportation network; it supports the countries with insufficiently developed national or regional markets for trading biomass [13]. High transportation cost is another critical issue, mainly due to the remote locations, especially for the export market. So, policies and strategies are necessary to decrease these projected costs, emissions, and export challenges to design a sustainable GBSC maritime transportation network.

This study aims to conduct a comprehensive environmental assessment of particulate matter-pollutant gas emissions and an economic analysis of transportation cost-mass flow for GBSC by maritime transportation. To achieve this aim, a novel dynamic full-scale synergy model is developed using the Anylogic software simulation modeling. This study attempts to assist maritime export companies, governments, biomass suppliers, and stockholders towards solutions for economic challenges, environmental regulations, and global trade by embracing technological advancements. This is augmented by suggesting actions based on the global sustainable production agenda and maritime Industry 4.0. The remainder of this paper is structured as follows: Section 2 describes the literature review and knowledge gaps. Section 3 displays the methodology, data source, and case studies. Section 4 shows the main results and discussion for global trade flows of CPO biomass of two leading suppliers: Malaysia and Indonesia, along the GBSC. Conclusions are drawn in Section 5.

2. Literature review

In recent decades, transportation has been a critical subject in line with world trade growth. The transport of woody biomass from timber industries and forests is done most commonly utilizing roads available in regions [20]. The use of the road for transporting products is advantageous for the following reasons: 1) it provides shorter distances in the biomass industry, and 2) it provides higher flexibility than other modes. On the other hand, sea or rail transportation can also be considered in the case of long-distance transportation of biomass [21]. Many studies have offered and discussed various ideas regarding the economic feasibility of utilizing these heavy vehicles [22] or agricultural/forestry equipment [23] to transport biomass to end-users [24]. To consider the suitability of the vehicles for these purposes, several factors like biomass density, average transport distance, vehicles' speed, load capacity, and the vehicles' accessibility need to be well considered [25]. As a result, the enhancement of handling efficacy and transportability is an effective strategy for improving overall efficiency. Processing can be done at any phase of the supply chain; however, it precedes road transportation, which finally causes enhanced throughput and lower overall costs [26].

With the current globalization and highly complicated intertwined trade connections, the biomass resources are dispersed through the global market by global supply chains, which might pass across several countries before being used as final goods or services by end-users. Thus, there is a need to explore the biomass utilisation hidden in both intermediate and final trades to investigate the flows of biomass utilization between regions, rather than simply considering biomass consumption only for end-users [27]. In this world in which the economic states of different countries are highly interconnected, in most cases, the genuine biomass exploiters are not final consumers. Utilizing the ways provided by international trade and considering the geographical splitting of consumption and production activities [28], the environmental benefits realized by the biomass utilization can be transferred gradually between the countries that import biomass and those that export it via interregional trading processes [29]. As a result, it is important to find out who is an exploiter and who is a consumer of biomass to make a good balance between environmental welfare and economic benefits. Among other transportation types, maritime transport has received the most attention due to economic considerations and sustainability in the mobility of freight and people [30]. This type of transportation in the biomass industry has created a wide-ranging and well-organized biomass product supply chain network around its global and local markets. Nonetheless, the currently spreading Covid-19 pandemic has caused global supply chains to face logistic problems [31]. Biomass SMEs and suppliers have been called on to support shipping, ports, and transport operators to realize best practices during this economic situation. The maritime transportation of biomass could be a potential sustainable transportation mode to deliver biomass production with an acceptable level of safety, efficiency, and reliability across the local and global markets to minimize pollution, maximize energy efficiency, and ensure profit.

Several researchers have attempted to find out the resource utilization embodied in the international trades with the use of a global viewpoint, e.g., carbon emissions [32], energy [33], land [34], and water [35]. Particularly, using a source to sink manner, many studies in this context have been dedicated to the exploration of the total consumption of energy [36], crude oil [37], coal [38], and natural gas [39] through the international trade flows via the global supply chains. Concerning biomass, several scholars have used the concept of the embodied human appropriation of net primary production (HANPP) to estimate the geographical disconnection of biomass exploiters and consumers, which has been caused by international trade [40, 41]. Erb et al. [42] displayed the upstream withdrawal of biomass resources caused by consuming those bio-products that are traded in international markets and studied their effects upon the natural environment using the HANPP concept. HANPP was also used by Saikku and Mattila [43] to trace the utilization of biomass products traded by Finland during one decade (between the years 2000 and 2010). They revealed that this country was a prominent importer of embodied HANPP. These studies have provided deep insights into the virtual biomass use transfer between different regions via international trade of bio-products. However, the biomass utilization is induced along the bio-products supply chains and also any other type of products. There is a need for tracing the biomass consumption embodied within the global supply chains from the exploitation sources to the final consumption sink in a way to provide an inclusive view of the shift of environmental welfare associated with biomass resources between regions in the global economic network.

For the analysis of the existing BSC transportation system, the literature consists of some mathematical, static, and simulation methods [14]. One of the best ones is simulation modeling since it is highly flexible and can simulate and evaluate both static and dynamic systems considering variability and uncertainty between systems —like manufacturing lines [44], ports and maritime industry [45], healthcare systems [46], supply chains [47], construction sector [48], and buildings [49]. This method has been recognized as a key technique in BSC research. In [50], the authors provided and applied the discrete-event simulation model to the delivery system of the cotton gin to schedule the trucks that operate in the biomass logistic systems. Zhang et al. [51]

proposed a simulation model to investigate the woody residue supply chain. The supply chain of biofuel was simulated using the Arena software. Their proposed model consisted of necessary supply chain activities, e.g., harvesting/processing, storage, and crop delivery. To evaluate the model efficiency, they considered several performance measurements such as energy consumption, GHG emissions, and delivery feedstock cost.

The literature contains only a few papers focusing on dynamic simulation in BSC. For instance, the Anylogic software was implemented by Akhtari et al. [52] to develop a dynamic simulation model to compare demand fulfillment, cost, and emission of a forest-based biomass supply chain for two inventory systems. In another study, a computer simulation model was proposed by Zahraee et al. [53] with the help of the Arena software, which considered the existing situation of the EFB biomass supply chain in Perak, Malaysia. They analyzed 16 potential palm oil sites based on their current oil production capacity, distance to the closest power plant, and the minimum amount of produced palm oil. The model was run with two different scenarios by reducing the number of labors and providing more trucks. Similarly, Zahraee et al. [54] constructed a dynamic simulation model to evaluate the impacts of the modification to the efficiency level of the production and transportation technology concerning the environmental sustainability of BSC for palm oil for 50 years (between 2000 and 2050). Recently, the authors in [50] proposed a combined life cycle and dynamic simulation model to assess the water-energy nexus in the biomass industry (especially under existing uncertainties) and predict the GHG and particulate matter emissions induced by BSC by 2050 [55]. Several studies conducted previously focusing upon the BSC transportation analysis with adopting the simulation approach are summarized in Table 1. According to the literature analysis, there has been no study that has comprehensively investigated the economic and environmental effects for GBSC maritime transportation network. The majority of the studies have evaluated the economic aspect of sustainability regarding strategic decisions in the local market. The most important contribution of the current study is analyzing the GBSC at a global scale.

Table 1. Summary of investigation on BSC transportation network using simulation modeling.

Author	Solution method	Objective of study	Decision levels	Sustainability	Scope
Nilsson [56]	SHAM	to analyze the impact of location, climate, and biological parameters on the biomass transportation cost	✓ Strategic	• Economic	• Local
Hansen et al. [57]	Simulation model	to assess the sugar harvest and mill transportation system in South Africa	✓ Strategic	• Economic	• Local
Ravula et al. [50]	Discrete-event simulation model	to design trucks scheduling in biomass logistic system	✓ Strategic	• Economic	• Local
Zhang et al. [51]	Discrete-event simulation method: Arena software	to investigate the transportation raw material cost and GHG emissions of woody residues supply chain	✓ Strategic	• Economic • Environmental	• Local
Prinz et al. [58]	Discrete-event simulation method: Witness software	to examine the impact of chipper and deliver types on the energy efficiency and cost efficiency of BSC	✓ Strategic ✓ Tactical	• Economic	• Local
Zahraee et al. [54]	System dynamics simulation modeling: AnyLogic software	to estimate the effect of changing the efficiency of transportation and production technology on the environmental sustainability of the BSC	✓ Strategic ✓ Tactical	• Economic • Environmental	• Local
Zahraee et al. [53]	Discrete-event simulation method: Arena software	to analyze the transportation mode, labors, and cost of BSC	✓ Strategic ✓ Tactical	• Economic	• Local
Zahraee et al. [21]	System dynamics simulation modeling: AnyLogic software	To predict the delivery cost and GHG emissions for BSC	✓ Strategic ✓ Tactical	• Economic • Environmental	• Local
Zahraee et al. [59]	System dynamics simulation modeling: AnyLogic software	To assess the economic and environmental effect of BSC by considering three transportation modes: include truck, train, and barge	✓ Strategic ✓ Tactical	• Economic • Environmental	• Local
Current study	System dynamics simulation modeling: AnyLogic	To analyze the transportation cost and assess the particulate matter-pollutant gas emissions for CPO GBSC for 50 years predictions	✓ Strategic ✓ Tactical ✓ Operational	• Economic • Environmental	• Global context

3. Materials and methods

3.1 Case study

Malaysia and Indonesia produce approximately 85% of the total amount of global palm oil supply, and 96% of it is exported by them [60]. 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 [60]. The countries with the largest amounts of imported palm oil had started to re-stock by late 2020.

Indonesia encompasses 1,700 small ports, out of which 111 ports have commercial functions, whereas only 11 ports act as a container. This country suffers from a highly ineffective system due to different reasons, such as the lack of large-scale ports that can receive trans-oceanic vessels and also the overcapacity of current ports. Therefore, a great deal of Indonesia's cargo needs to go through neighboring countries like Singapore and Malaysia. On the other hand, the existing facilities are being overloaded with the main port in Jakarta, Tanjung Priok, which handles over 70% of this country's total import/export flow. In 2011, the seaport exceeded its capacity of 5 million twenty-foot equivalent unit (TEU) limit. Such congestion and the resultant blockages have caused the shipping costs in this country to be the highest rate among the ASEAN countries; these costs make up approximately 15% of the final price of goods (KADIN). Due to these conditions, inter-island transportation is costlier compared to international transportation. For instance, the shipping expense of a standard container from West Sumatra to Jakarta is more than three times the cost of Jakarta to Singapore. Such expensive logistics exert negative impacts on the competitiveness of the ports, which could be finally observed in this country's ranking in the international business environment.

Indonesia is considered the largest palm oil producer worldwide, whereas its forests cover the third-largest tropical forests globally. Based on the statistics of the year 2019, roughly 1.2 million hectares of palm oil plantations in the Riau province were situated within a forested region. The rainforest clearing processes for palm oil generation in this country have resulted in some negative reactions against some palm oil-based products; though, the generation of this substance in Indonesia had been increasing gradually during the past few years. It is worth noting that Indonesia is the first country in the world that has exported palm oil.

The second producer of palm oil in the world is Malaysia. 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. The shipment of biomass products from Malaysia to Europe has several difficulties like compliance to their wood pellets-based standards, their sensitivity to the palm oil industry, and the high costs of shipment processes and accompanying risks. Based on the National Biomass Strategy, Malaysia can export biomass fuel pellets to China, Japan, and Korea; these countries currently have high demands for these products. These countries are much closer to Malaysia, with fewer entry obstacles for the Malaysian EFB pellets. In Japan, China, and South Korea, the total demands for biomass fuel pellets by 2020 are predicted to reach approximately 16 million tonnes. It accounts for the total market potential of $1.19 billion per year based on the current price of fuel pellets, which is around $75/ton. Fig. 1 shows the global CPO mass flow from Malaysia and Indonesia to the main export destination countries in 2020. Fig. 2 indicates the distribution routes to export the CPO from Malaysia and Indonesia to main destinations using dotted lines. The different sizes of container ships and environmental emissions are also represented.

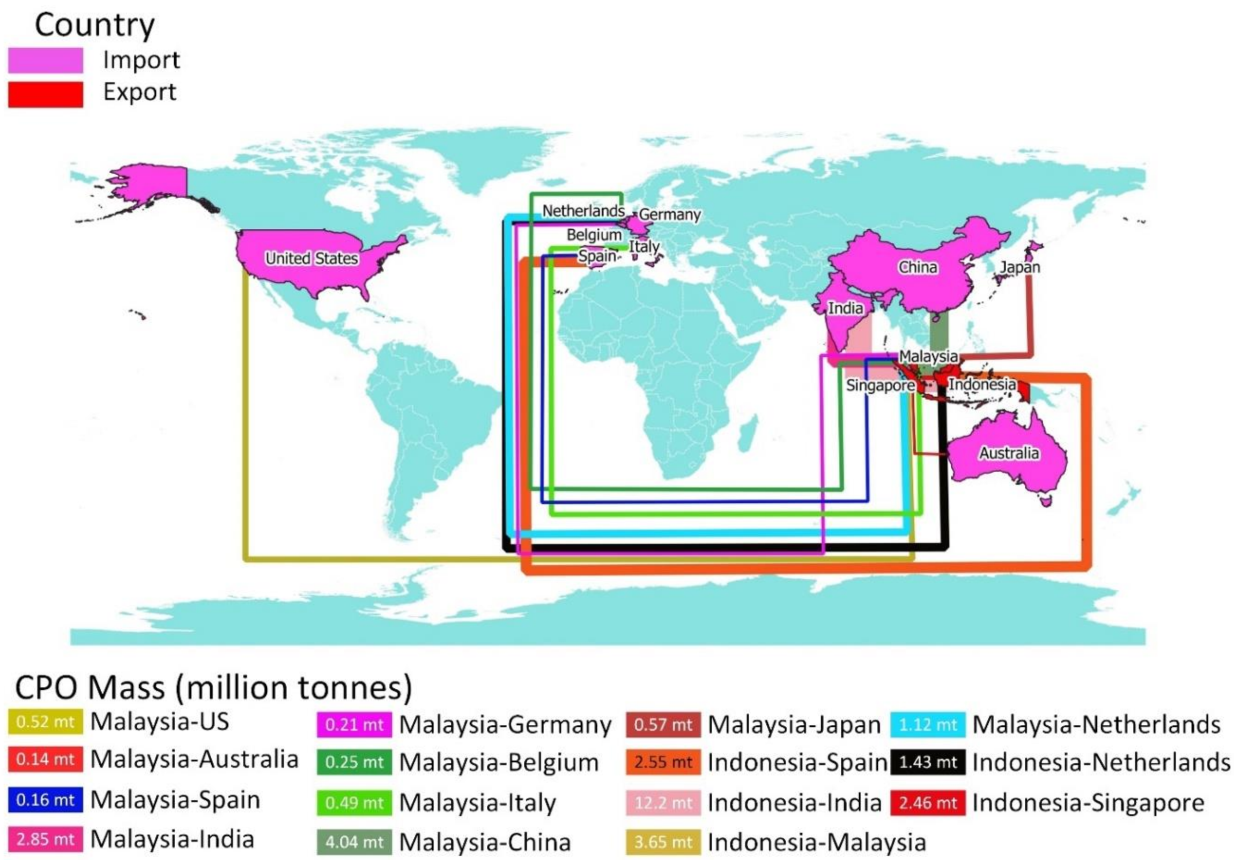

Fig. 1. Global CPO mass flows in 2020.

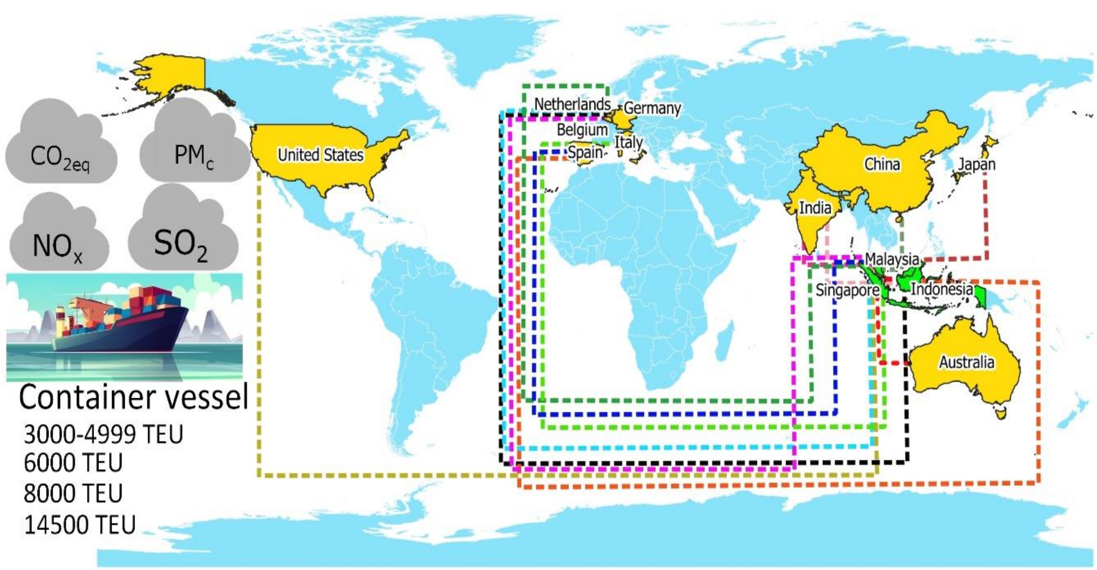

Fig. 2. Maritime routes of global CPO distribution from Malaysia and Indonesia.

3.2 Dynamic full-scale synergy model

We used dynamic modelling to simulate the global transportation of palm oil. The developed model makes a synergy between CPO suppliers, maritime export companies, and destination countries to collaborate and deliver the final product in a cost-effective, timely and sustainable manner. The full-scale model includes 93 sea routes globally – 63 routes from four export ports in Malaysia to 35 import ports in several countries such as the US, Germany, Italy, Belgium, Spain, India, China, Japan, Australia, and the Netherlands (Supplementary Fig. 1) as well as 30 routes from four export ports in Indonesia to nine import ports in several countries such as Singapore, Malaysia, India, Spain, and the Netherlands (Supplementary Fig. 2). Fig. 3 represents a general dynamic model of emissions and costs by CPO distribution. All required data to run the model are collected from case studies and data sources such as IMO [17], database reports [61, 62], and previous studies [63]. The main mathematical equations used in the dynamic model, including mass, emission and cost flows, are presented in the next paragraphs. The definition of variables and the detail of sources and destinations are provided in Table 2. Distance between analyzed seaports is calculated based on the shortest route per kilometre (port to port) on average duration time per day and average speed of container ship per knots.

The model consists of two types of equations (state and rate) for quantifying the stock and flow of transported palm oil, transportation costs, and emissions such as GHG emissions (Carbon Dioxide equivalent (CO_2-eq)), Sulphur Dioxide (SO_2), Nitrogen Oxides (NO_x), and Particulate Matter (PM). The stocks (state equations) assumed in the mass flows of the model to environmentally and economically analyze the dynamic behaviour of export and import ports over time. The flows (rate equations) correspond to transported palm oil, emissions, transportation costs and the possible trips between export and import countries.

The behavior of stock of available palm oil for an export port $(E_{s-ij}(t))$ in a given period is presented as Equation 1), where $i = 1,2,...,8$ represent export ports in Malaysia and Indonesia for transportation of palm oil; $j = 1,2,...,39$ represent import ports in the US, Germany, Italy, Belgium, Spain, India, China, Japan, Australia, Netherlands, Singapore, Malaysia; "t_0" is the initial year and "t" is the final year. The model includes a time integral of the CPO export rate $(E_{r-ij}(t))$ – according to an annual production of crude palm oil $(P_a(t))$ and its local consumption $(C_l(t))$ and coefficient of export distribution $(\varphi_{e-ij}(t))$ for different ports (Equation 2) – minus the annual import palm oil $(I_{r-ij}(t))$ – according to demand for palm oil $(D(t))$ from each country and coefficient of import distribution $(\omega_{ij}(t))$ for different ports (Equation 3) – and the initial value of the stock of exported palm oil $(E_{s-ij}(t_0))$.

$$E_{s-ij}(t) = \int_{t_0}^{t} (E_{r-ij}(t) - I_{r-ij}(t))dt + E_{s-ij}(t_0) \quad (1)$$

$$E_{r-ij}(t) = \left(P_a(t) - C_l(t)\right) * \varphi_{e-ij}(t) \quad (2)$$

$$I_{r-ij}(t) = D(t) * \omega_{ij}(t) \quad (3)$$

The behavior of stock of imported palm oil for each country $(I_{s-ij}(t))$ in the given period (Equation 4), is estimated by a time integral of the annual import palm oil $(I_{r-ij}(t))$ minus the annual use of palm oil $(U_P(t))$ and the initial value of the stock of imported palm oil $(I_{s-ij}(t_0))$.

$$I_{s-ij}(t) = \int_{t_0}^{t} (I_{r-ij}(t) - U_P(t))dt + I_{s-ij}(t_0) \quad (4)$$

Animal and human health are affected by air pollution, such as GHG, SO_2, PM_c, and NO_x emissions, in both acute and chronic ways. As climate change varies the frequency or intensity of severe climate events such as heat waves, drought, and heavy precipitation, the emissions are driven by complex interactions between physical and human systems. The activities in the shipping sector, such as the burning of fuels, are increasing the levels of emissions, e.g., carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) as the main greenhouse gases, as well as SO_2, PM_c, and NO_x emissions in the atmosphere.

Equation 5 is applied to estimate the annual GHG (CO_2-eq), SO_2, PM_c, and NO_x emissions of each transportation sea route of the mass flow of palm oil from export countries to the import one by analyzing container vessels $k = 1,2,...,9$, including light-container (3000-4999 TEU), medium-weight-container (3000-4999 TEU), heavy-container (3000-4999 TEU), light-container (5000-7999 TEU), medium-weight-container (5000-7999 TEU), heavy-container (5000-7999 TEU), light-container (8000-11999 TEU), medium-weight-container (8000-11999 TEU), and heavy-container (8000-11999 TEU).

$$T_{e-kij}(t) = \int_{t_0}^{t} \lambda_{ij} \times (I_{r-ij}(t) \times \delta_k(t))dt + T_{e-kij}(t_0) \quad (5)$$

Where, $T_{e-kij}(t)$ is the annual GHG (CO_2-eq), SO_2, PM_c, or NO_x emissions in sea route started from port *"i"* and ended in port *"j"* in the year *"t"* for the period 2000-2050 for transportation of palm oil globally. Then, $T_{e-kij}(t_0)$ is the annual GHG (CO_2-eq), SO_2, PM_c, or NO_x emissions in route *"ij"* in the initial year "t_0". $I_{r-ij}(t)$is CPO export rate as the amount of transported palm oil in sea route *"ij"* in the year *"t"*, $\delta_k(t)$ is emission intensity by container vessels *"k"*, $k = 1,2,...,9$ in the year *"t"*, and λ_{ij} is the distance between source and destination of transportation in route *"ij"*.

Transportation cost is estimated by Equation 6.

$$T_{c-kij}(t)=\sum_{i=1}^{n}\sum_{j=1}^{m}(\lambda_{ij} \times I_{r-ij}(t)) \times C_k(t) \quad (6)$$

Where, $T_{c-kij}(t)$ is the annual cost of transportation of palm oil in sea route *"ij"* in the year *"t"* for each country, $E_{r-ij}(t)$ is CPO export rate as the amount of transported palm oil in sea route *"ij"* in the year *"t"*, $C_k(t)$ is cost by container vessels *"k"*, $k = 1,2,...,9$ in the year *"t"*, λ_{ij} is the distance between source and destination of transportation in route *"ij"*.

To calculate the total number of required trips (N_{T-kij}) between export and import countries for different types of container vessels, Equation 7 is used.

$$N_{T-kij}(t) =\sum_{i=1}^{n}\sum_{j=1}^{m}\left(\frac{\alpha_k \times I_{r-ij}(t)}{\varrho_k}\right) \quad (7)$$

where, α_k is the unit tonnage of each container vessel *"k"*, $k = 1,2,3$ (6000 TEU, 8000 TEU, 14500 TEU), ϱ_k is the capacity of each container vessel *"k"*.

Table 2. Definition of variables of the global biomass simulation model.

Variable	Term	Unit
$E_{s-ij}(t)$	Amount of available palm oil from export port i* to import port j**	Tonne
$E_{r-ij}(t)$	Net inflows of crude palm oil export rate from export port i* to import port j**	Tonne
$I_{r-ij}(t)$	Net outflows of annual import palm oil from export port i* to import port j**	Tonne
$P_a(t)$	Annual production of crude palm oil	Tonne
$C_l(t)$	Local consumption of crude palm oil	Tonne
$\varphi_{e-ij}(t)$	Coefficient of export distribution from export port i* to import port j**	Dimensionless
$D(t)$	Demand for palm oil from each country	Tonne
$\omega_{ij}(t)$	coefficient of import distribution from export port i* to import port j**	Dimensionless
$I_{s-ij}(t)$	Stock of imported palm oil for each country transported from export port i* to import port j**	Tonne
$U_P(t)$	Net outflows of annual use of palm oil	Tonne

$T_{e-kij}(t)$	Annual GHG (CO_2-eq), SO_2, PM_c, or NO_x emissions in sea route from export port i* to import port j** by container vessels k***	Tonne
λ_{ij}	Distance between source i* and destination j** of transportation	Kilometre
$\delta_k(t)$	Emission intensity by container vessels k***	Tonne
$T_{c-kij}(t)$	Annual cost of transportation of palm oil in sea route between source i* and destination j**	Dollar
$C_k(t)$	Cost by container vessels k***	Dollar
$N_{T-ij}(t)$	The total number of required trips between export and import countries for different types of container vessels	Trip
α_k	The unit tonnage of each container vessel k***	Tonne
ϱ_k	The capacity of each container vessel k***	Tonne

* The index *i* represents export ports: 1) Pasir Gudang port, 2) Penang port, 3) Klang port, 4) Tanjung Pelepas port, 5) Belawan port, 6) Jakarta port, 7) Semarang port, and 8) Surabaya port.

** The index *j* represents import ports: 1) Atlanta port, 2) Boston port, 3) Oakland port, 4) Baltimore por, 5) Houston port, 6) Charleston port, 7) Long Beach port, 8) Miami port, 9) Mobile port, 10) New Orleans port, 11) Antwerp port, 12) Bremerhaven port, 13) Hamburg port, 14) Genoa port, 15) La Spezia port, 16) Barcelona port, 17) Lianyungang port, 18) Shanghai port, 19) Dalian port, 20) Ningbo port, 21) Xiamen port, 22) Qingdao port, 23) Xingang port, 24) Fuzhou port, 25) Nansha port, 26) Tianjin port, 27) Chennai port, 28) Mundra port, 29) Yokohama port, 30) Nagoya port, 31) Brisbane port, 32) Melbourne port, 33) Sydney port, 34) Rotterdam port, 35) Amsterdam port, 36) Penang port, 37) Tanjung Pelepas port, 38) Klang port, and 39) Jurong port.

*** The index *k* represents type of container vessels: 1) light-container (3000-4999 TEU), 2) medium-weight-container (3000-4999 TEU), 3) heavy-container (3000-4999 TEU), 4) light-container (5000-7999 TEU), 5) medium-weight-container (5000-7999 TEU), 6) heavy-container (5000-7999 TEU), 7) light-container (8000-11999 TEU), 8) medium-weight-container (8000-11999 TEU), and 9) heavy-container (8000-11999 TEU).

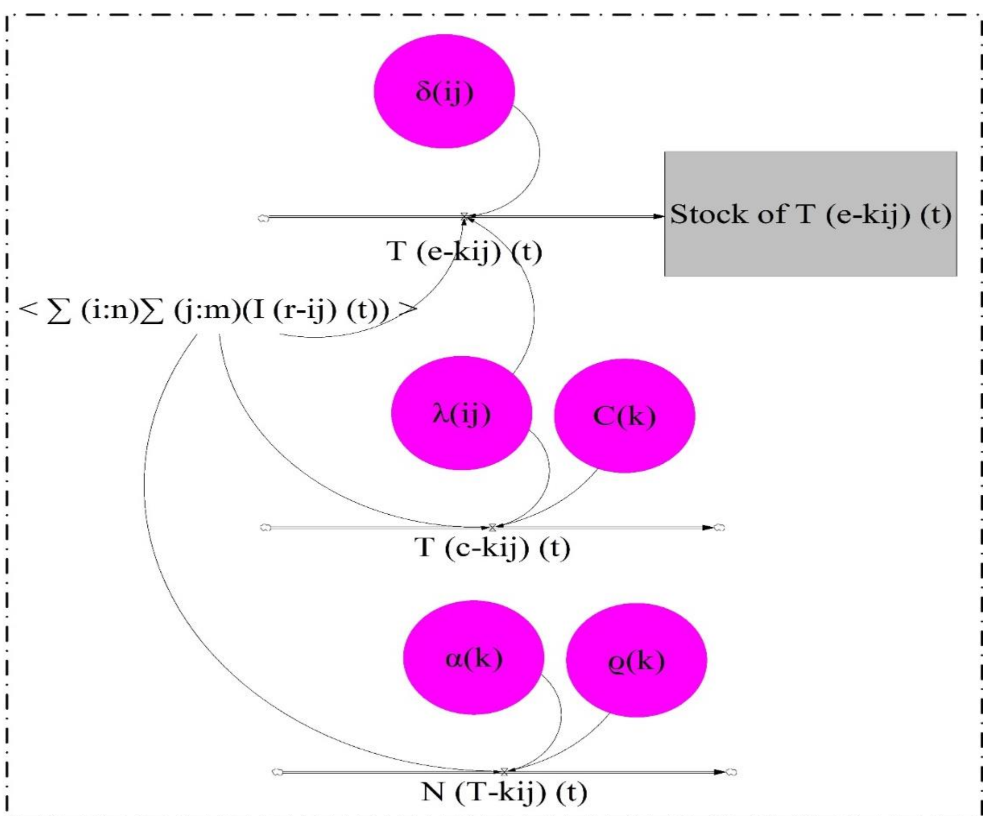

Fig. 3. General dynamic model of emissions and costs by CPO distribution.

4. Results and discussion

4.1 Mass flow analysis

In this study, four main ports in Indonesia are simulated and analyzed for the CPO export market named: Belawan, Jakarta, Semarang, and Surabaya. Fig. 4 shows the CPO mass flow for the export market from the selected ports for 50 years of prediction. As can be seen, Surabaya port has the highest amount of palm oil export compared to other ports. Also, according to the model prediction, the rate of biomass palm oil export trade will increase by almost 20% from 2018 to 2050.

The economic statistics in 2019 indicated that the total palm oil exports of Indonesia reached up to 29.5 million metric tonnes in that year, and in spite of the reduction of demands by a key market, India, it was predicted to continue its growth in 2020. Fig. 5 depicts the trend of CPO export market from Indonesia to five main destinations in South Asia and Europe. India is the most important export market for Indonesian CPO, covering over 60% of the total CPO exports in 2018. Among the EU countries, Spain is one of the main CPO markets imported 2.5 Mt from Indonesia. Malaysia, Singapore, and the Netherlands are in the next stages for CPO export market destination. The results predicted a more than 50% increase in CPO export share during the next 30 years. The mass flow analysis shows that the industry will be hit hard due to the reduction of palm oil exports due to the COVID-19 in 2020. Fig. 5 also indicates that there was a reduction in palm oil exports to 141,000 tonnes (22%) for India, 188,000 tonnes (30%) for European Union [61].

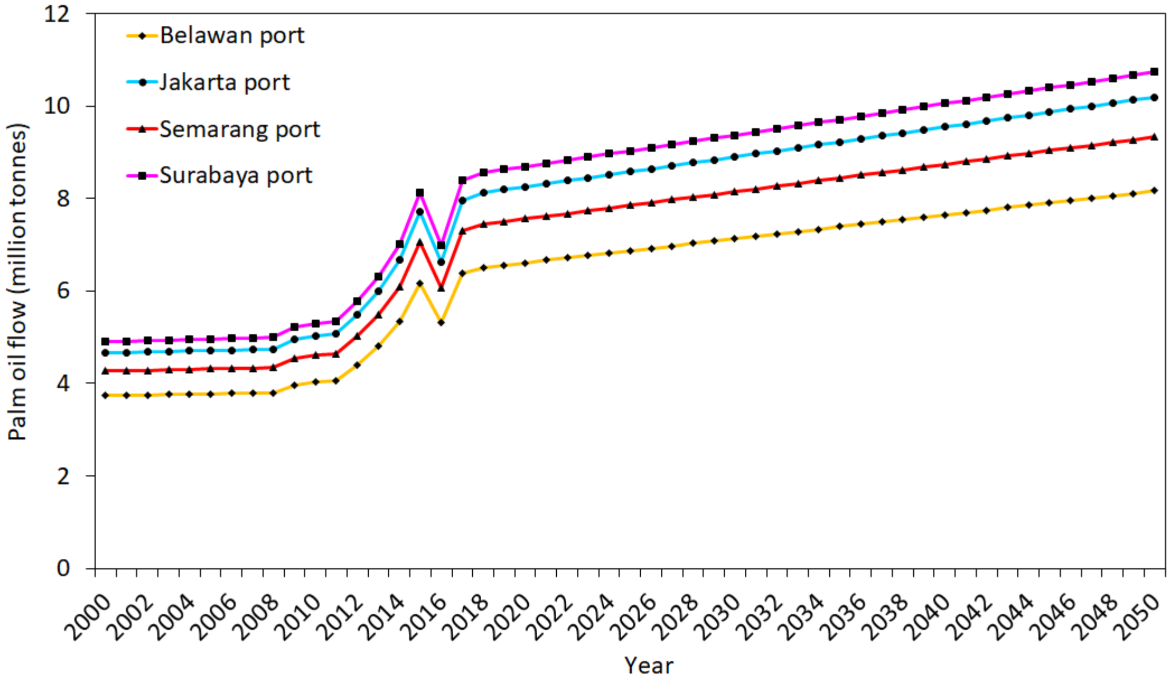

Fig. 4. Palm oil biomass flow from main ports of Indonesia between 2000 and 2050.

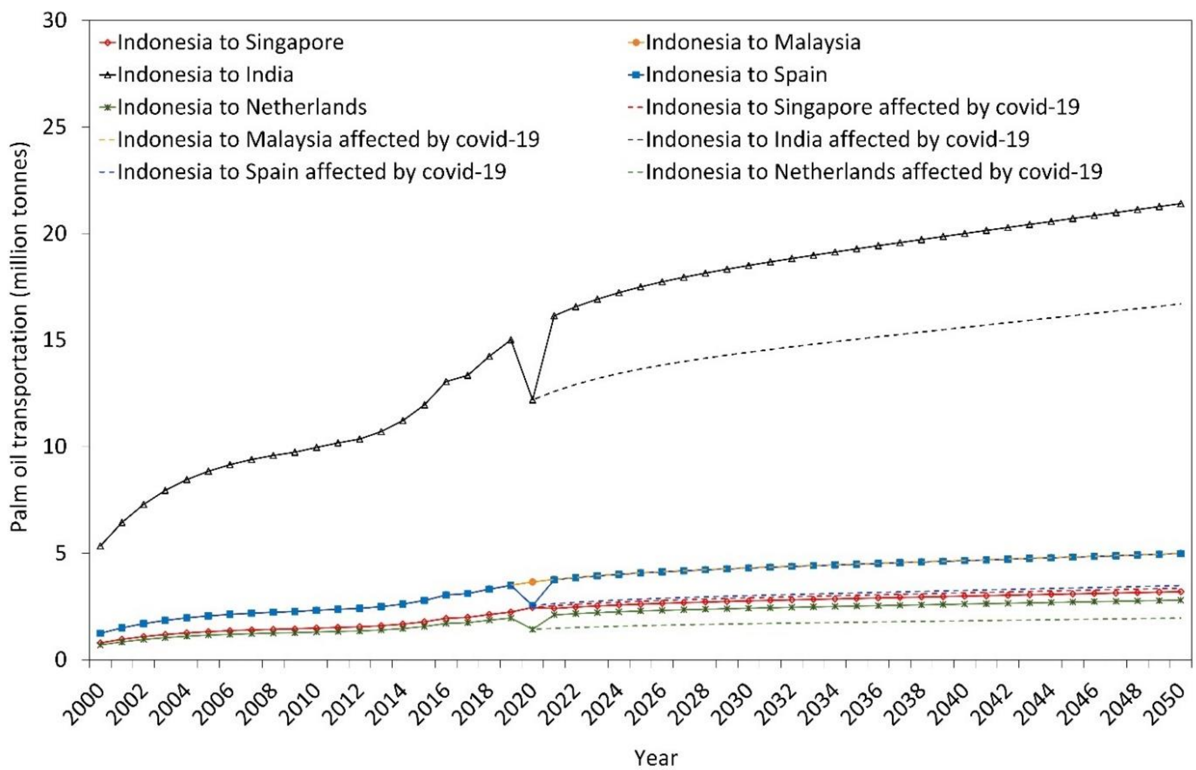

Fig. 5. Palm oil transportation from Indonesia to main export destinations between 2000 and 2050.

Malaysia has ranked 13th globally regarding the quantity of export for raw materials, manufactured products, and petrochemicals [64]. In the year 2018, estimations indicated that the palm oil industry could contribute approximately 38% to the Malaysia agriculture sector. Note that palm oil is one of the biggest exports of this country. In the same year, palm oil recorded a 2.8% contribution to the GDP of Malaysia. Malaysian ports broadly serve as transshipment hubs, which has made them highly valued assets. This country is currently making plans to produce high-value products and make new ways to benefit from biomass waste export [65]. Thus, it is expected to create both domestic and export markets for such products, which needs to establish robust, effective connections between different stakeholders playing significant roles in this industry, e.g., the government ministries and public agencies, biomass suppliers, financiers, different transportation sectors, industry groups, private enterprises, research institutions, etc. [66]. All these are required to commercialize BSC in Malaysia and position the country as an international biomass hub. Malaysia has seven major federal ports: Port Klang, Kuantan, Bintulu Port, Penang Port, Kemaman Port, Johor (Pasir Gudang) Port, and Port Tanjung Pelepas. Note that all the above-mentioned federal ports, except Kemaman, are under private ownership. Among all, the key federal Malaysian ports are as follows:

- Port Klang Authority (PKA)
- Port Tanjung Pelepas (PTP)
- Port Penang Commission (PPC)
- Port Pasir Gudang (PPG)

These ports play significant international roles as they are located in the same major waterway and hold great potential to become transshipment hubs at an international level due to their geographical position [30]. Fig. 6 shows the trend of CPO mass flow in four main ports in Malaysia for the export market. PPC and PTP ports have the highest share of export. As can be seen, the rate of export from 2020 to 2050 has a stable increase compared to Indonesia.

Among the export markets, India kept its position as the largest palm oil export market (around 3.9 million metric tonnes) from Malaysia for the sixth consecutive year since 2014. The export value in 2019 was 23.9% of the exports of total Malaysian palm oil or 4.58 million tonnes. It was followed by China that had 2.49 million tonnes or 13.5%, the EU (2.09 million tonnes or 11.3%). In 2018, 65% of all the palm oil imported into the EU was used for energy. More than half of all palm imports (53%) was used to make biodiesel for cars and trucks - an all-time high - and 12% to generate electricity and heating. The European Commission has concluded that palm oil cultivation results in excessive deforestation, and its use in transport fuel should be gradually phased out. In January 2018, the European Parliament proposed to end public subsidies for palm oil biofuels in 2021. This plan can affect world markets and may lead Malaysia and Indonesia to address the issues of deforestation, certification, and sustainability of palm oil.

The Netherlands, US, and Japan are the next states for Malaysia's CPO export market destinations in 2019. Fig. 7 highlighted that Malaysia’s palm oil export has decreased for most countries, except China (increase almost 50%) from 2019 to 2020 due to the COVID-19 lockdown. The model results predicted the rate of CPO export market during the normal time versus the post-pandemic time using the dotted lines from 2020 to 2050.

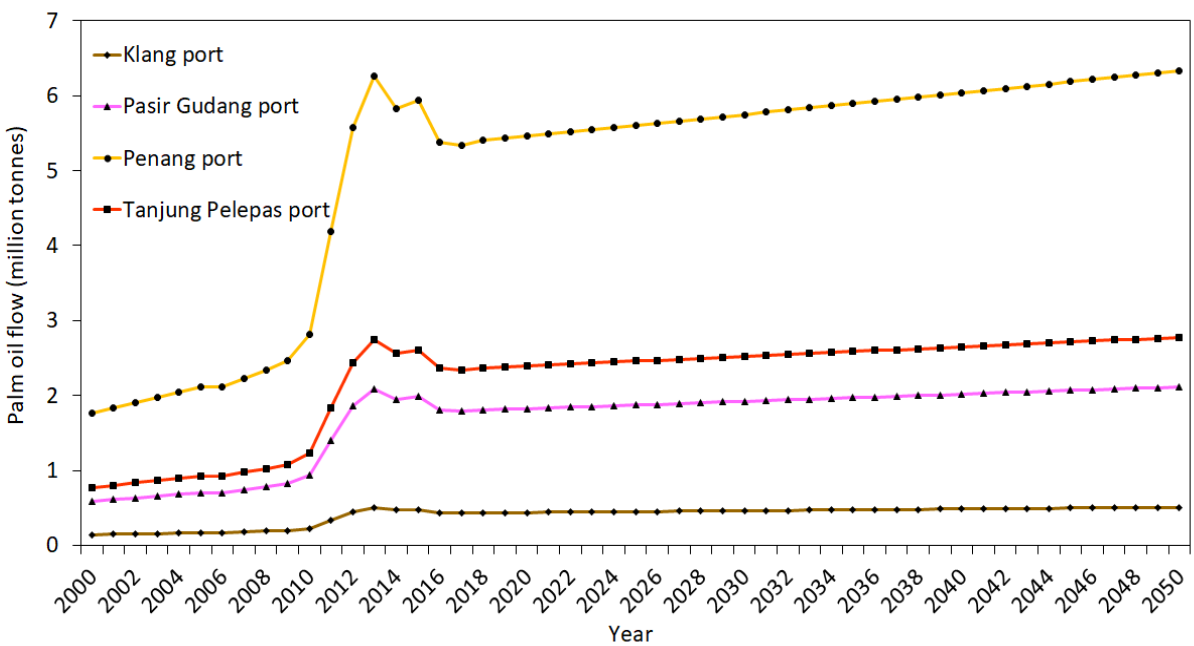

Fig. 6. Palm oil biomass flows from main ports in Malaysia for 50 years.

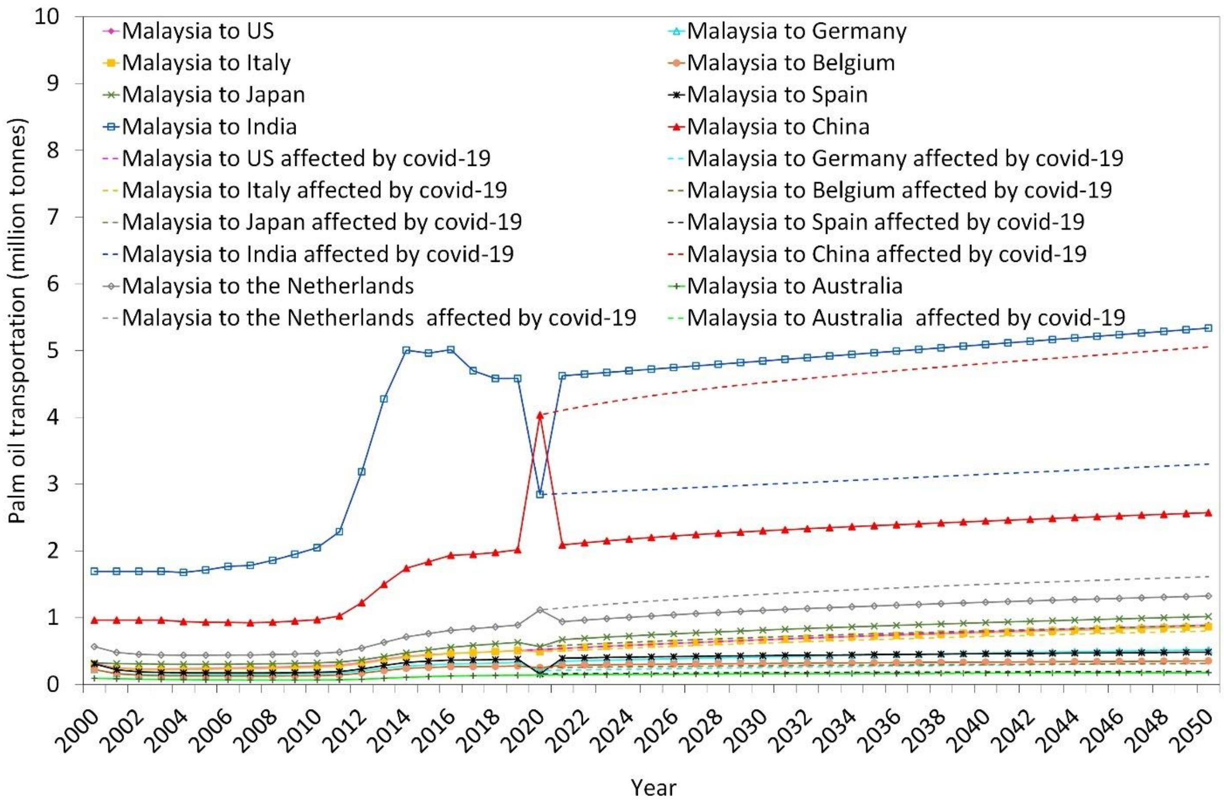

Fig. 7. Palm oil transportation from Malaysia to main export destinations between 2000 and 2050.

4.2 Primary Particulate Matter-Pollutant Gas emissions analysis

The focus of the current study is on containerships, which are much more sizable than most other types of ships. Various ways exist for the measurement of mega-ships. A commonly-used measure is the maximum number of twenty-foot containers a ship can carry: the maximum TEU capacity. The dimensions and characteristics of a ship are effective factors on its TEU capacity. Containerships are generally qualified in various “generations” based on their dimensions. This section investigates a comprehensive environmental analysis based on three types of containers: light, medium-weight, and heavy containers. We have considered three types of TEU (3000-4999, 5000-7999, 8000-11999) for mentioned containers. The cumulative emissions of container transportation from Malaysia and Indonesia from 2000-2050 are shown in Supplementary Tables 1 and 2.

Fig. 8 shows a comprehensive analysis of GHG emissions from three types of containers with three sizes of TEU to export the CPO from Malaysia and Indonesia to the main selected destination for 50 years. The significant results confirmed that using the heavy container with 8000-11999 TEU emitted less GHG emissions than the other container ships for both suppliers. The biggest share of GHG emissions is related to a light container with 3000-4999 TEU for all destinations. India, the US, and the Netherlands destinations produced the highest rate of GHG emissions for all types of container ships for Malaysia's export market. Australia is among the less GHG pollutant gas emissions for Malaysia CPO export market which is equal to 0.011 million tonnes CO2-eq using the large container (TEU 8000-11999) in 2020. The maximum amount of GHG emission is related to the light container (TEU 3000-4999) for the Netherlands in 2050 (0.69 million tonnes CO2-eq). It should be noted that there is a stable increase rate from 2000 to 2050 for all destinations from Malaysia.

Fig. 8 also shows that India, Spain, and the Netherlands are the three main destinations for Indonesia CPO market that emitted the biggest amount of GHG emissions. Singapore and Malaysia generate less GHG emissions equal to 0.02 and 0.05 million tonnes CO_2-eq using the large container (TEU 8000-11999) in 2020. Malaysia CPO export transportation produces higher GHG emissions compared to Indonesia CPO trade market. The trend of results stimulates the need of actions in place to improve the current CPO container cargo capacity and technology to minimize the GHG emissions until 2050, leading to more than 50% emission reduction.

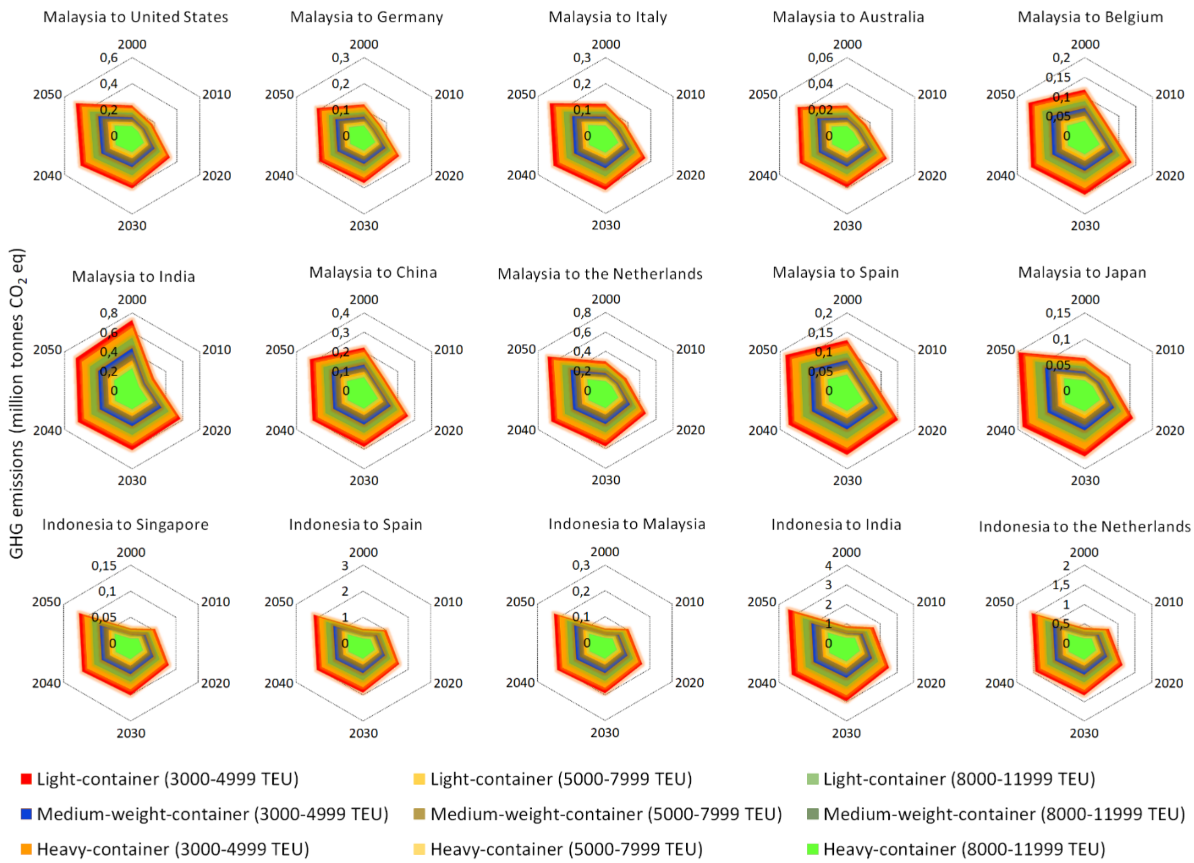

Fig. 8. Trend of GHG emissions of Container Transportation from Malaysia and Indonesia: 50 Years.

Fig. 9 also depicts the trend of SO_2 emissions for Malaysia and Indonesia CPO trade market. The results confirmed that types of container ships and TEU size do not considerably affect the SO_2 emission compared to GHG emissions. However, a heavy container with more than 8000 TEU produced less SO_2 emissions for all CPO export destinations. India, the US, China, and the Netherland destinations are among the highest generators of SO_2 emissions from Malaysia export ports. It is estimated that India and Spain emitted the highest amount of 5.24 and 3.35 thousand tonnes in 2050 compares to Singapore, Malaysia and Netherlands from Indonesia export ports. There is a stable SO_2 emissions increase rate of 37% from 2020 to 2050.

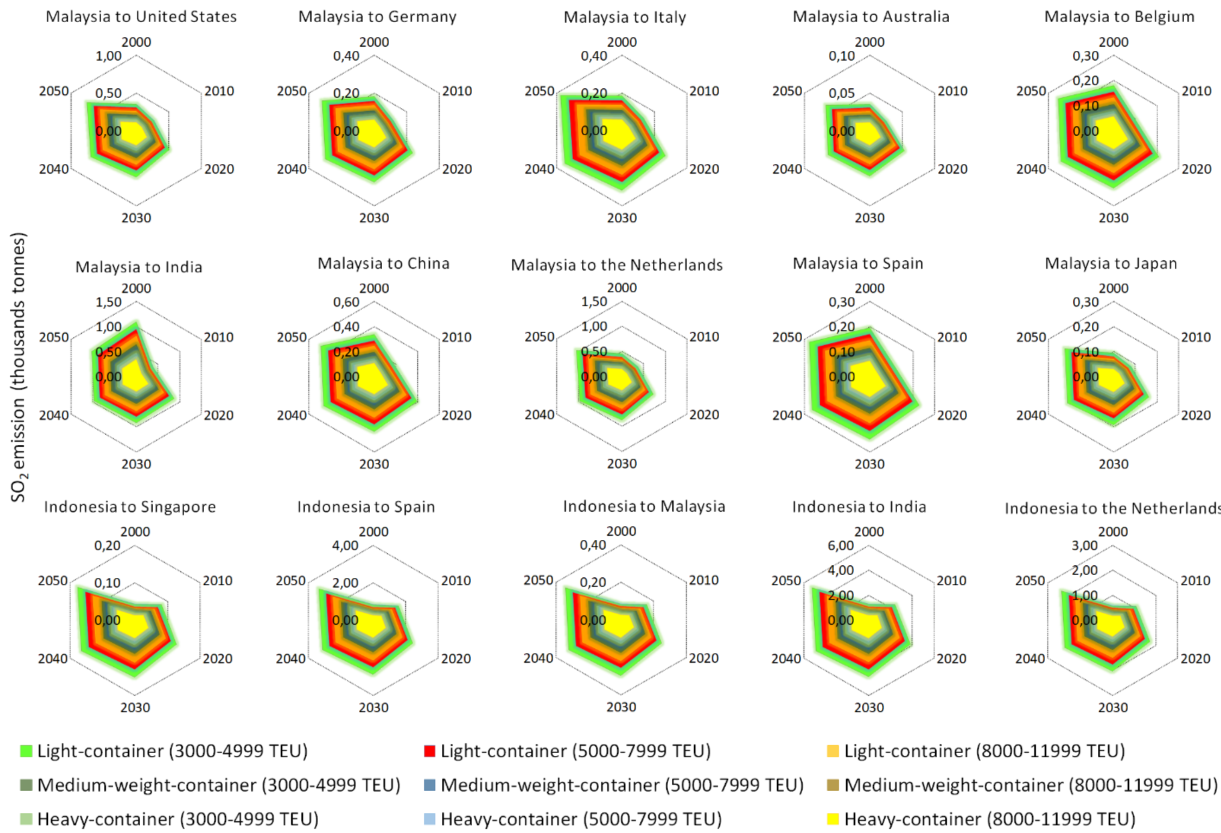

Fig. 9. Trend of SO_2 emission of Container Transportation from Malaysia and Indonesia: 50 Years.

Fig. 10 depicts that the biggest share of pollutant gas emissions is related to NO_x compared to GHG and SO_2. Container transportation from Malaysia ports to India and the US produces the highest amount of NO_x emissions. There is a considerable reduction in NO_x emissions by using a heavy container with more than 8000 TEU compared to using light containers with 3000-4999 TEU. For example, it is estimated that NO_x emissions decrease from 11.5 to 0.39 thousand tonnes during 50 years in India export market by increasing the container size and capacity, which lead to the improved shipment technology.

As can be seen, the rate of NO_x emissions is below 0.1 thousand tonnes for all destinations from Malaysia using the heavy container with TEU 8000-11999 from 2020 to 2050. Sea transportation with light containers (3000-4999 TEU) from Indonesia to India generates the highest amount of NO_x during 50 years, equal to 59.32 thousand tonnes. Spain and the Netherlands are placed on the second stage, respectively. There is a near 75% steady increase rate of NO_x emissions from 2020 to 2050 for all destinations from Indonesia. But NO_x emissions from sea transportation of Malaysia

CPO export destinations have increased near 53% during the 50 years prediction, which is lower than Indonesia.

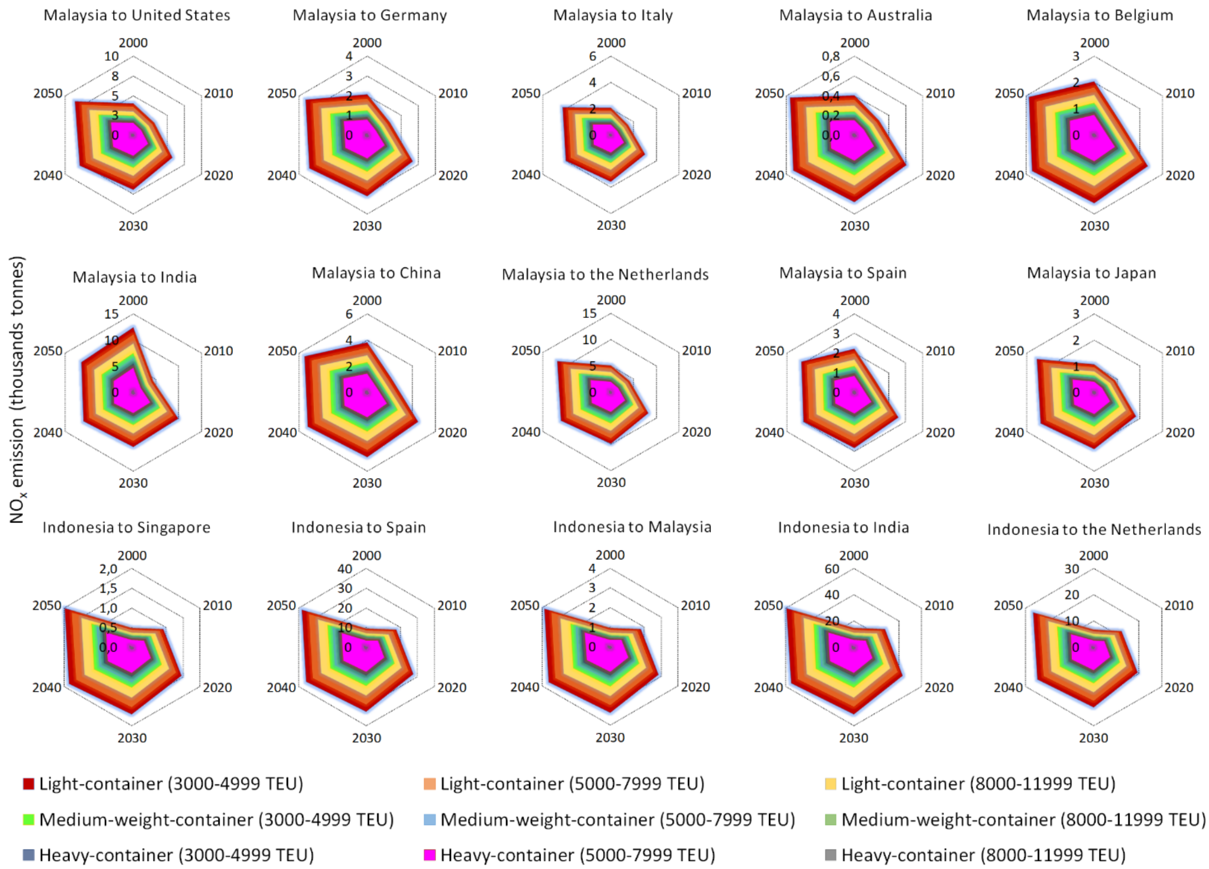

Fig. 10. Trend of NO_x emission of Container Transportation from Malaysia and Indonesia: 50 Years.

Most particulate matters are trapped in the atmosphere through the complex reactions of chemicals like nitrogen oxides and sulphur dioxide, which are generally given off by automobiles, power plants, and factories. The particulate matter pollution can be reduced by decreasing the amount of particulate matters generated by smoke and also it can be alleviated by decreasing the gases emitted from transportation vehicles. So, this emission generated by container ships is also considered in the present study. The results showed that the rate of PM_c emissions from container sea transportation is minimal (Fig. 11). However, it can be inhaled and cause serious health problems. The size and capacity of containers lead to a reduction of near 50% PM_c regardless of destinations. The variation of PM_c emissions from different destinations is so low compared to the pollutant gas emissions. For example, India, the US, and the Netherlands generate almost the same

(0.23, 0.13, 0.16 thousand tonnes) respectively by using the same container cargo (light-container with TEU 3000-4999) during the 50-years period. Among the Indonesia CPO export market, it is predicted that India and Netherlands will generate 20% more PM_c emission from 2020 to 2050, which includes the highest amount of emissions among the other countries.

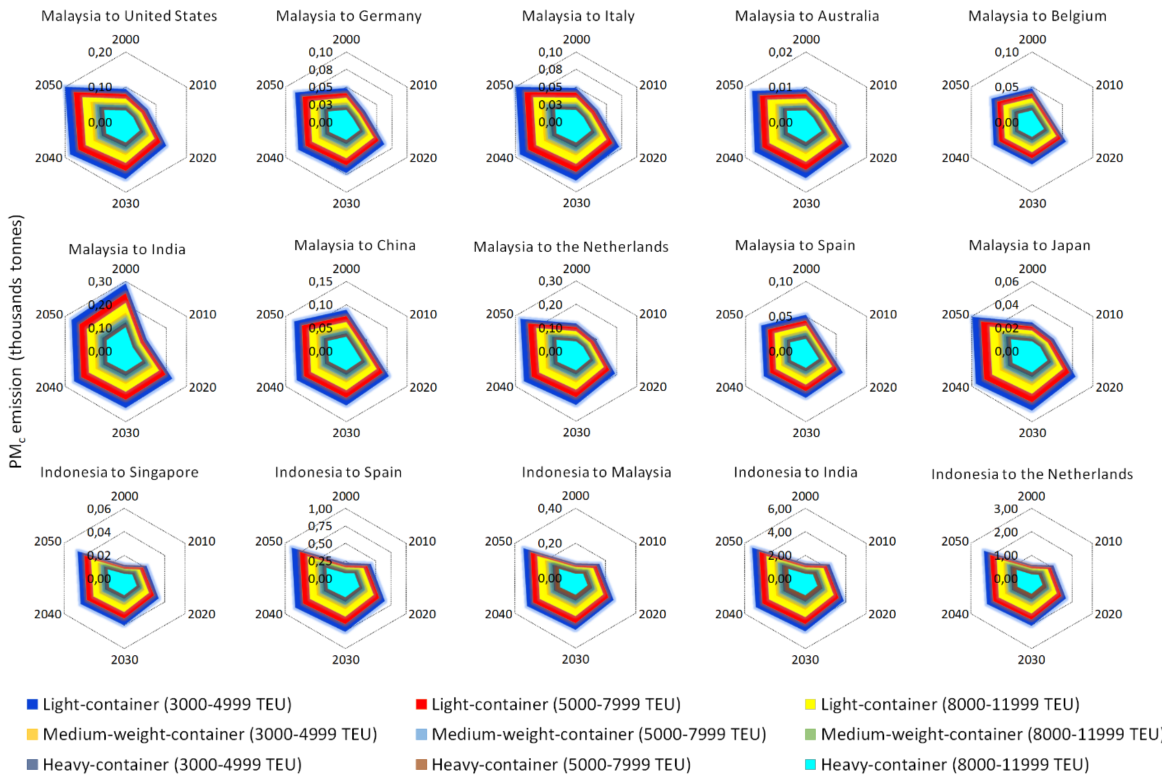

Fig. 11. Trend of PM_c emission of Container Transportation from Malaysia and Indonesia: 50 Years.

4.3 Transportation cost analysis

Technological developments have caused a significant and incessant decrease in the costs of vessel operation during the past decades. Both the financial and environmental costs can be reduced considerably through enhanced fuel efficiency, economies of scale, and automation in port operations.

To ship goods over long distances, there is a need for more fuel (operating costs) and time (capital costs). The cargo type and volume directly affect the costs of carriers. The cargo volume is of high significance since it allows for economies of scale, both on the sea and in port. By considering all key CPO export markets across the world to determine the maritime transport costs, the total freight costs estimated for various country groups can be analyzed and predicted.

Fig. 12 shows the number of trips by three types of containers (6000, 8000, and 14500 TEU) from Malaysia and Indonesia to the CPO export market destination in 2020. It shows that India includes the highest number of trips for both suppliers (64 (TEU 600), 48 (TEU 8000), and 26 (TEU 14500)). It also indicates that India, China, and the Netherlands have the highest amount of demand from Malaysia. The same scenario happens for Spain and Netherlands from Indonesia. Australia, the US, and Belgium include the lowest number of trips from Malaysia origin. The higher capacity of containers leads to a smaller number of trips, which considerably affect pollution and costs. It is essential for governments, suppliers, and stockholders to have a horizon plan for the future of maritime transportation systems to apply technological developments for improving the container ship capacity and sizes until 2030.

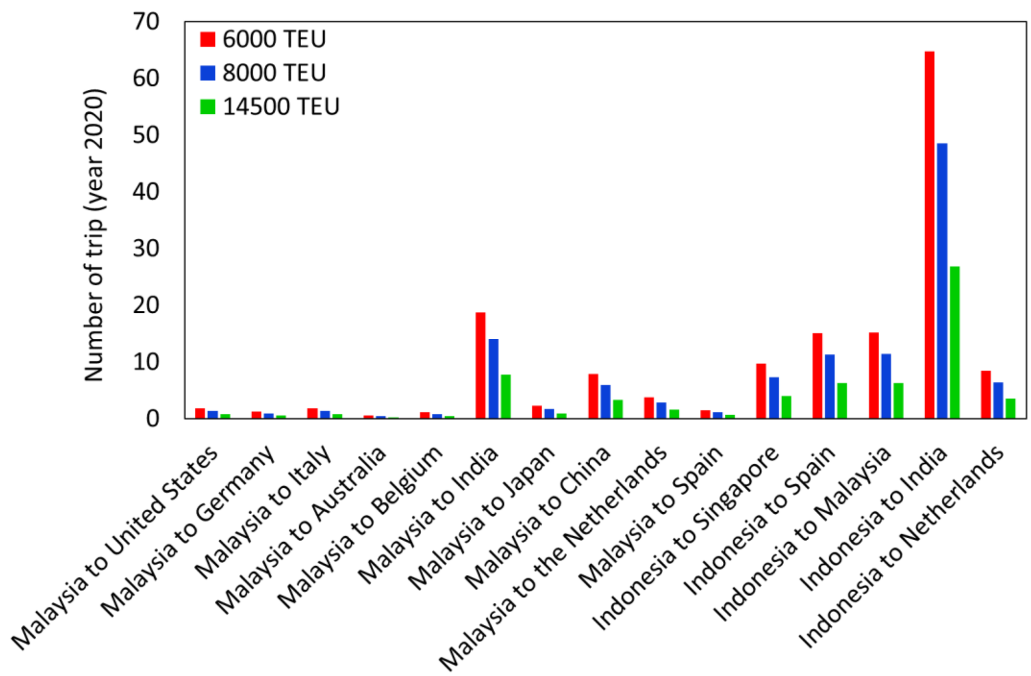

Fig. 12. Number of trips from Malaysia and Indonesia to Main CPO export markets.

Having considered the container capacity, maritime transportation cost, and the number of trips to satisfy the demands, we have done a comprehensive analysis to predict the transportation cost to deliver the CPO from Malaysia and Indonesia to the export destinations. As shown in Fig. 13, India and Spain have the highest transportation cost based on their demands and the number of trips from Indonesia. The US, the Netherlands, and India spend the higher cost for maritime transportation to receive their CPO product from Malaysia compared to other destinations. The current situation leads to an increase in a stable rate of transportation costs from 2020 to 2050. There is an essential need to decrease the number of trips from Malaysia and Indonesia to main destinations such as India, the Netherlands, and the US-based on their higher travel distance and demands.

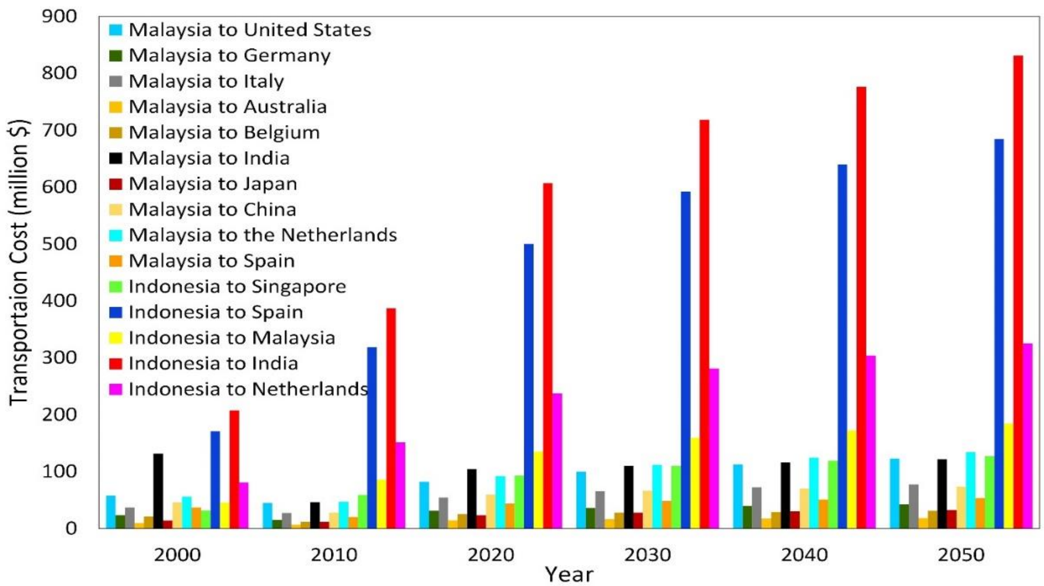

Fig. 13. Transportation costs from Malaysia and Indonesia to the main CPO export market.

The simulation model also predicted the percentage cost of transportation from Malaysia and Indonesia to each ports destination in Asia, Europe, and the US (Supplementary Fig. 3). The biggest share of transportation cost is related to Malaysia Penang port to Boston, Mobile, Houston, and Miami ports in the US. Penang port to Italy (Genoa and La Spezia ports), the Netherlands (Rotterdam port), and Germany (Bremerhaven port) include the highest percentage CPO delivery cost to European destinations. Malaysia transported the CPO product from Klang Port to two Indian ports, which impose the highest transportation cost. TPP port delivery to Amsterdam, Barcelona, Hamburg, Genoa, and Japan ports are placed on the next stages of transportation cost percentage.

The biggest share of CPO transportation cost from Indonesia to main destinations is related to Spain ports. India and the Netherlands ports are in the second stage. Bolawan port to Kang port has a reduction of 50% delivery cost compared to other ports from Indonesia to Malaysia. The Belt and Road initiative established by China, which is known as One Belt, One Road (OBOR) is one of the economic policies with the highest levels of ambitiousness, which is aimed at strengthening the economic leadership of Beijing by a great program for building infrastructures in the countries neighboring to China. Practitioners and scholars expect that OBOR will significantly affect the economic revitalization of the underperforming provinces in the northeast and some other poor regions in the southwest, bordering Southeast Asia. Due to this huge program, the transportation of CPO from Malaysia to China will have a stable rate of transportation cost.

4.4 Sensitivity analysis

To determine uncertainties associated with estimated emissions of palm crude oil transportation through each sea route, a sensitivity analysis was conducted by considering the effects of several factors including (i) distance, (ii) the amount of transported mass, (iii) number of trips and (iv) the type and size of a container ship. The analysis assesses how emission factors may change due to changes in the above factors. Three levels are considered for different factors: low, medium, and high for GHG emitted, transported palm crude oil and number of trips; short, medium, and long for distance; light, medium and heavy for the type of container ships. As shown in Fig. 14, the GHG emitted in the low distance could be varied in a range of low to a high level. Interestingly, the result of the routes for Indonesia to Spain shows that the amount of GHG could remain at the lowest level in a long distance. These findings highlight the dependency of GHG emissions level on other factors such as mass flow and technology used for container ships. Changes in the amount of transported crude palm oil and the number of trips between countries show the identical trend for GHG emissions, e.g., in the route between Indonesia and India, the highest GHG emissions are observed, which is affected by high mass flow levels and consequently, the number of trips. The results show that there is a strong relationship between GHG emitted and the type of container ship in a systemic view. The findings for different routes (e.g., Indonesia-Singapore, Indonesia-Malaysia and Malaysia-Japan) show a ship with higher TEU contributes to the higher transported amount and lower GHG emissions in the long term.

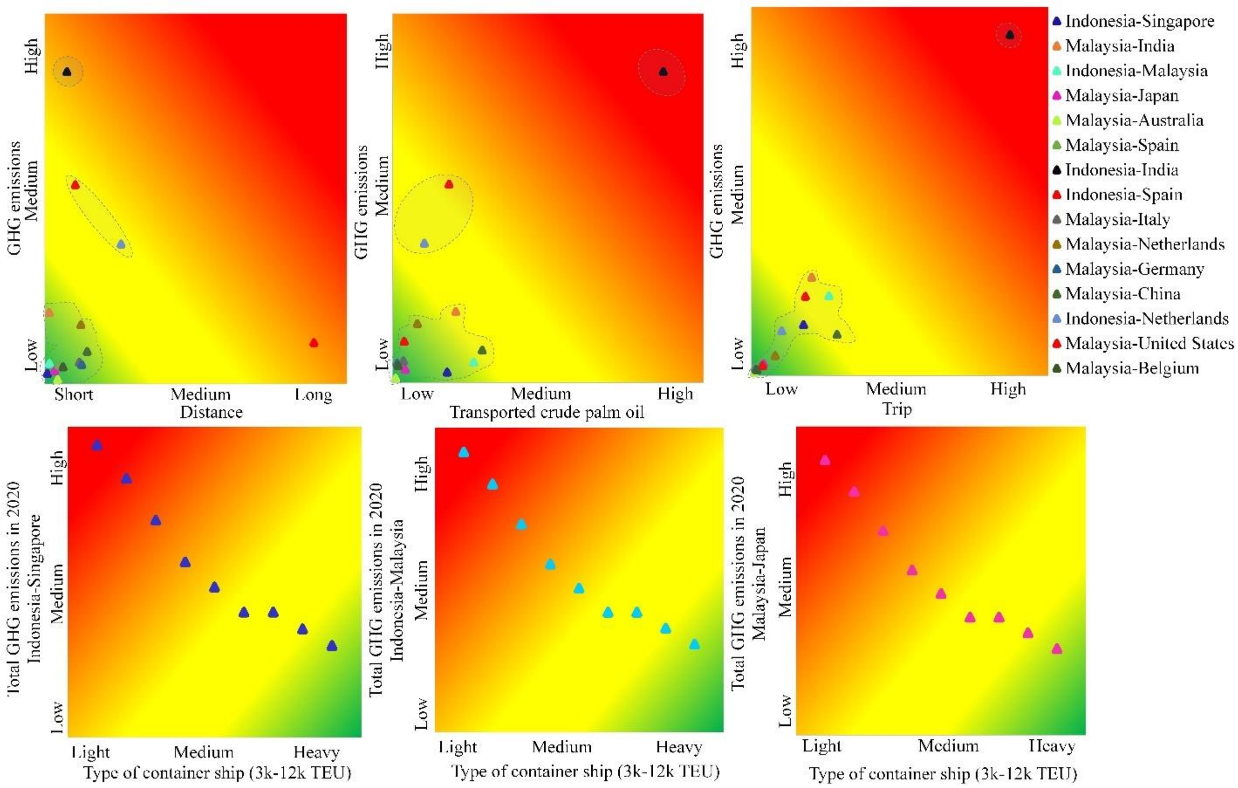

Fig. 14. Trend of GHG emissions vs. distance, the amount of transported mass, trips and the type and size of a container ship.

4.5 Discussions

Many researchers working on biomass-based energy generation have become interested in investigating maritime transportation as an effective way of biomass transportation at a global level. To accomplish the GHG elimination plan objectives, IMO needs a combination of operational and technical solutions in a way to be applicable to ship transportation. A number of these solutions, considering their potential for decreasing GHG and also their transportation costs, are highlighted in the current study. The Global Maritime Energy Efficiency Partnerships (GloMEEP) project supports applying energy-efficiency measures to shipping to decrease the amount of gases emitted from shipping.

This study covered a comprehensive economic and environmental analysis of the CPO GBSC export market from two main suppliers named Malaysia and Indonesia, to South Asia, the US, Australia, and Europe. The results of our full-scale model explore that geographic remoteness and connectivity to CPO main markets, container cargo value and type, transport dependency and transport costs, techno-economic progress, and development have a considerable impact on the GBSC. The current trend of the analysis showed a sharp increase CO_2 and PM and a stable increase of SO_2, NO_x emissions and delivery cost during the 50 years, but long-term measures are vital to reduce the carbon intensity of the fleet by at least 40% from 2023 to 2030 and 70% until 2050 [17]. The results could provide great help to biomass industry suppliers and governments, and stakeholders to apply and test technical solutions to effectively decrease both costs and emissions and also improve the information sharing processes in support of the GHG reduction strategy established by IMO. In addition, the results confirmed that there is a need for developing larger vessels to improve the economics of scale of the global biomass industry. It typically leads to great investments in the construction of enormous containerships, which is not necessarily beneficial to the whole industry because this procedure, in turn, leads to the growth of fleet capacity without considering to be in line with demands.

The size of containerships has grown at a faster pace during the past 10 years. It took only a single decade for the average container ship capacity to be doubled from 1,500 to 3,000 TEU; however, it had taken approximately three decades to get to 1,500 TEU. Mandatory design requirements for new ships such as 14500 TEU, which set increasingly strict carbon intensity standards is an essential need for the GBSC export market to reduce the environmental emissions and transportation cost in terms of improving the engine technology and increasing the capacity to at least 24,000 TEUs in the next generation of containerships. A critical issue highlighted in the current paper is the relationship between transportation costs and ship size. The transportation costs refer to the costs that are related to handling such large containerships. A general assumption is that the PCO transportation costs per TEU are reduced when size is increased. In CPO GBSC, there is a need for strategic plans for concentrating the container port systems in a way to sort the hub and spoke-network for each destination. The appearance of such a hub-and-spoke network and the increase of the containers' sizes result in a reduction in the number of trips to meet the export market demands.

Estimations indicated that most of the shipping-induced emissions in ports would be increased four times by 2050 [63], which will augment the ships-induced CO_2-emissions in ports up to almost 70 million tonnes by 2050 and NO_x-emissions to 1.3 million tonnes. The results obtained by the current study also confirmed it for the biomass industry export market. To decrease such anticipated amounts of emissions, government, practitioners, and scholars must establish strong, active policies. The US, European and South Asia countries that are included in CPO export markets need to construct a massive “Belt and Road” project like China, with Malaysia and Indonesia to speed up the economic scale of CPO trade and decrease the environmental emissions. On the other hand, applying progressive export levies on palm oil exports from Indonesia and Malaysia help to raise revenue from palm oil exports. The increase in Indonesia's export levies and the resultant boost to benchmark CPO prices should benefit Malaysian producers such as Sime Darby Plantation Berhad more than Indonesian palm oil companies in general, as higher levies will trim the benefit from better prices. From the generalizability aspect of our results, the development of automated and semi-autonomous ships with 24000-50000 TEU capacity is a key part of the next wave of digitalization alignment with maritime Industry 4.0 practices which would help the port authorities, terminals, and port users to encourage solutions to tackle environmental problems effectively and increase economic growth for global supply chains in different sectors.

5. Conclusions

To end with, as revealed by analyzing our developed full-scale simulation model results on environmental and transportation costs, developing countries (particularly in South Asia), Europe, and the US are paying more for the international transport of their CPO imports and exports. This is mainly due to trade imbalance in these regions, pending ports, and trade facilitation reforms, as well as lower trade volumes, travel distance, capacity, and shipping connectivity. It is necessary to propose strategies to develop the required infrastructure and facilities in a way to effectively manage the processes of exporting the biomass feedstock. This needs to be accompanied by governmental facilitation, to exploit this potential and acquire better economies of scale and higher power of negotiation. Effective handling, appropriate storage procedures, and transportation of large volumes of feedstock can decrease export expenses and preserve the quality of the raw material. A country's geographical position cannot be changed; however, effective policies can be taken into action to decrease costs by enhancing the ports' infrastructures, design of containerships, and effectiveness of logistic chains through facilitating trade and transport processes. From the energy policy perspective, our results will contribute to increasing port industry stakeholders' understanding of the current environmental situation and assist them in developing appropriate strategies for the port industry. Energy policy is a critical tool to stimulate maritime low-carbon technologies deployment by replacing the existing maritime transportation fleets using carbon intensive fuel with new ships designed for low-carbon fuels. Technological developments, operational changes, and market-based interventions play a vital role in influencing maritime transportation to shift towards low-carbon fuels. Adopting alternative fuels will require close cooperation throughout supply chains between shipowners, operators, ports, fuel producers and distributors, and legislators. It is suggested to develop an optimization model for incorporating other types of ships such as hybrid electric and low-carbon fuels such as biofuels to predict the air pollution and cost for the next 30 years. The scope of this study is limited to the main CPO export destination in South Asia, Europe, and the US. In future studies, developing an optimization model to minimize the transportation costs and environmental emissions would help to make a synergy between the results of the current study and suggest solutions and action plans in alignment with governments' policies, biomass suppliers' strategies, and stockholders' plans.

Highlights

- A dynamic full-scale synergy model of the global biomass supply chain is developed.
- 93 sea routes (35 ports from Malaysia, 9 ports from Indonesia) are analyzed.
- Ship technology, size, and capacity affect transportation costs and emissions.
- Variation of particle matter emissions is low compared to pollutant gas emissions.
- Low transportation costs and low carbon fuels are two priorities for the maritime industry.

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