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Supply chain engineering: Considering parameters for sustainable overseas intermodal transport of small consignments

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A B S T R A C T

An increasingly environmentally conscious global economy is placing new demands on supply chain engineering, with a focus on sustainable approaches to modelling transport chain. In addition to the price and time efficiencies that characterize agile and lean supply chains, strategies for low-carbon and energy-efficient external transport must also be incorporated. This research therefore focuses on the challenges of organizing the supply of small overseas shipments to define how the relationship between land and sea transport in the selected intermodal chain affects environmental and energy performance. Understanding the input parameters and their impacts is a prerequisite for planning CO_2, NO_x, SO_2 and NMHC emissions, as well as energy efficiency (EE) of overseas transportation. The number of individual transport legs and their characteristics are crucial parameters for sustainable transport chains. The applicability of the proposed research framework is carried out on the example of outbound supply chains of the southern part of the Baltic-Adriatic Corridor using intermodal transport chains of small shipments via the ports of Koper and Genoa. The results of the case study show that an additional transport leg representing only 2 % longer land transport to the port of Genoa significantly affects the carbon footprint of the whole supply chain's compared to chains via the port of Koper. Moreover, other results also require special attention in supply chain modeling. The study enriches the field of supply chain engineering, as there is a lack of such studies. The study is part of the project "Green port – Developing a sustainable model for the growth of the green port", co-founded by the Slovenian Research Agency.

A R T I C L E I N F O

Keywords:
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Engineering;
Intermodal transport;
Sustainability;
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1. Introduction

Transporting small shipments is becoming an increasingly important way to operate global supply chains. Purchasing habits, optimization of transportation means, specialization of NVOCC (Non-vessel Operating Common Carrier) on LCL (Less than Container Load) services are some of the basic requirements for efficient use of intermodal transportation in organizing overseas transportation of small shipments. In add-on to the time and price components of overseas supply chains, the necessity to harmonize with the environmental component of the acceptability of transport chain operations is becoming more apparent [1]. Supply chain engineering must incorporate the environmental aspect of optimal intermodal transportation organization, based on the elements of transportation energy efficiency (EE) and lower GHG (Green House gas) emissions. Limiting CO_2, SO_2, NO_x, and NMHC (non-methane Hydro Carbon) emissions is the primary focus, and the impact on the implementation of logistics processes must be considered [2]. Particular challenges arise in the operation of complex intermodal chains from a green and lean supply chain perspective [3]. An adequate support for lean overseas supply chains is provided by general cargo transportation, where several smaller shipments are consolidated in one container to one logistics destination, with cargo from different shippers and destined for different consignees. NVOCCs organize regular LCL services only through selected ports and set up consolidation depots for the provision of LCL containers in environments with a strong and wider gravitational hinterland while maintaining good infrastructural connectivity to the port [4]. Consequently, the commercial and operational implementation of regular weekly services are the basis for service operations, while the environmental aspect is often neglected.

The research contributes to the understanding of these elements that have a significant impact on supply chain engineering from an environmental perspective when relying on complex intermodal transportation chains. The need for a systematic assessment of the elements of environmental impact, time and price is highlighted. The scientific contribution is demonstrated through the prism of designing a more comprehensive approach to sustainable supply chain (SSC) planning in overseas operations, as there is a dearth of such scientific studies [5]. The applicability of the research is expressed in the case study of export supply chain operations using LCL services on the southern course of Baltic-Adriatic Corridor, where the volume of shipments is increasing, also due to the de-rotation of export shipments from northern European ports to the northern Adriatic port of Koper or the Italian port of Genoa. Export-oriented supply chains in the southern part of the Baltic-Adriatic transport corridor are becoming increasingly complex as it is a vast area with hinterland markets that generate regionally fragmented volumes of smaller overseas shipments [6]. Such shipments are routed to only two or three loading ports in outbound LCL services. The distances between loading ports (POL) are as long as 400 km, which has a significant impact on the price and time levels and the environmental components generated by the transport. There are also important differences between sea liner services, vessel size, liner connections and hub ports. Therefore, the applicable part of the research highlights the technological and operational diversity of outbound LCL services for small overseas shipments of Central Europe and Western Balkans and the need to consider environmental components in supply chain engineering. On this basis, the study pursues two research hypotheses:

- H1: A supply chain orientation towards general cargo transport that emphasizes only the most direct maritime link may lead to less environmentally and energy efficient supply chain operations.
- H2: In LCL services, land transport is an important factor for more environmentally friendly overseas transport of small consignments, even if it represents only a small share of the total transport route in the established supply chain.

2. Research background

SSC are based on three pillars: social, economic and environmental. Craig and Easton [7] point out that SSC engineering depends on emphasizing the content of these pillars. Suring [1] notes a greater emphasis on the environmental aspect of supply chain deployment, with global supply chain engineering being highly dependent on transportation infrastructure and logistics processes [8]. Infrastructure elements, POL, and warehouse locations influence the efficient organization of land links [9] and the cost aspect of supply chain performance [10]. It is also necessary to consider the exceptional political and economic conditions that affect the organization of transportation and supply chains. The pandemic COVID -19 showed how vulnerable the transportation system and transportation chains are. It is very difficult to adapt quickly, but sea and land freight transport has not come to a standstill. Colicchia *et al.* [3] analyze broader elements in the context of operating lean and green supply chains through efficient use of intermodal transportation. Indeed, lean global supply chains need to pay special attention to intermodality and LCL transport as part of it. Jamrus and Chien [11] highlight the fundamentals for optimal operation of global supply chains in intermodal transportation, such as higher freight space utilization, stuffing the container as close as possible to the source of the shipments, reducing the shipment handling along the chain, etc. Achieving economies of scale for organising direct LCL services and higher cargo space utilisation is easier and faster in economic areas with higher levels of production and demand [12]. In such environments, NVOCC operators are quicker to decide to establish LCL services [4], contributing to the development of new logistics networks and the possibilities of price and time optimization in supply chains [13].

In addition to operational excellence, reflected in supply chain shortening and price optimization, it is necessary to consider the environmental parameters [14], especially in intermodal transportation, which combines different modes and units of transportation. Liu *et al*. [2] state that increasing the speed of goods movement in supply chains has an impact on the increase in GHG emissions. Therefore, Lopez-Navarro [15] emphasizes the need for a comprehensive development of approaches to estimate the pollutant components, time and cost of intermodal transport, so that focusing on only one component does not have too great a negative impact on the others. The same attention is called for by Žic and Žic [16] when analyzing transport deliveries through distribution centers. A cross-comparison of sustainably oriented transport and logistics processes can only be made by an appropriate evaluation of emissions and time periods [17]. In determining these parameters, information about modern ships and road freight vehicles, the length of overseas connections and reduced travel speeds play a very important role [18-19]. Of particular importance for efficient LCL transport is the operation of the liner service, the container precarriage from the warehouse to POL, which directly affects the total cost of the intermodal chain and GHG emissions [20]. The environmental aspects of port performance also need to be considered [21], not only in terms of emissions generated, but also in terms of wider inclusion in the circular economy [22]. Understanding all parameters and measuring their impact in complex intermodal chains, where last mile delivery is also requested, is a very challenging process [23]. According to Herold in Lee [5] and Qian *et al*. [24] emphasize the lack of such studies in the operation of global supply chains for strategic and operational decisions of cargo owners. Evangelista *et al*. [25] expose the need for research to determine measurement standards and comparability of data between chains, which dictates the need to deepen the knowledge of input variables of environmentally oriented transportation chains. As a result, the engineering of SSC would be simpler and more transparent for all stakeholders.

3. Research methodology

3.1 Research basis

The study is based on previously identified challenges and differences in the operation of complex intermodal transport chains in the Central Europe region and the Eastern Adriatic region supporting export-oriented supply chains on the southern part of the Baltic-Adriatic Corridor [6]. The challenges lie in the management of land transport links between economic production areas and collection depots for overseas shipments to consumer markets. The study is based on the results of a study of container services in the Adriatic Sea and liner services in the Mediterranean Sea, which highlight the importance of container ship size, direct liner shipping, navigation speed, and ship space occupancy for the cost, time, and environmental efficiency of intermodal transport chains and, consequently, supply chains [26]. These elements have a significant impact on sustainable transportation in FCL (Full Container Load), which is directly reflected in sustainable LCL transportation.

The input variables of LCL transportation are much more complex than in FCL transportation, as it is necessary to combine cargo from different shippers and from different locations, with different goods and for different final destinations. Consolidation warehouses, which properly manage cargo flows, play an important role in the operation of the transport chain. Namely, they direct the further flow of goods according to the final locations of the loads, the possibility of packing goods in the same container, and the possibility of stacking them at multiple heights. From an operational point of view, they combine cargo quantities in such a way as to ensure at least one weekly dispatch of LCL containers.

A general and simplified LCL transport chain consists of at least five consecutive transport stages. It starts with the delivery of small consignments to consolidation warehouses by LTL (Less than Truck Load) or FTL (Full Truck Load) transports and continues with the transport of one or more full containers (FCL) to POLs. This is followed by sea transport organized by the container line (CL) to the booked POD and land transportation to the NVOCC operator's consolidation warehouse at the destination. Finally, the NVOCC takes care of the delivery of the shipments to the consignee or organizes the takeover of the shipments in a warehouse (Fig. 1).

The complexity of the commercial-operational process increases the goal of using the largest container, with 40' HC containers with a maximum volume of 76 m^3 being the most commonly used, although 45' containers with a volume of 86 m^3 can also be used. The goal of the NVOCC operator is to use at least 80 % of the selected container volume to achieve profitability of the transport. Indeed, the transport price is formed by volume or weight (weight/measure – w/m), using the higher value (m^3 or ton). The time component is less important for LCL transport, as overseas transportation for more distant markets takes more than 30 days; however, NVOCC operators disclose the total transportation time, as there can be significant time differences between services.

In most cases, elements of EE and GHG emissions are not reported in NVOCC operators' general offers, even though complex intermodal chains between the same POL and final destinations generate different amounts of CO_2, NO_x, SO_2, and NMHC emissions [27]. To ensure sustainably oriented complex intermodal chains in general cargo transport, it is necessary to analyse and properly classify the environmental usurpation values and the commercial components of time and price. It is important to analyse in detail the input variables and their impacts depending on the characteristics of the intermodal transport chain (Table 1).

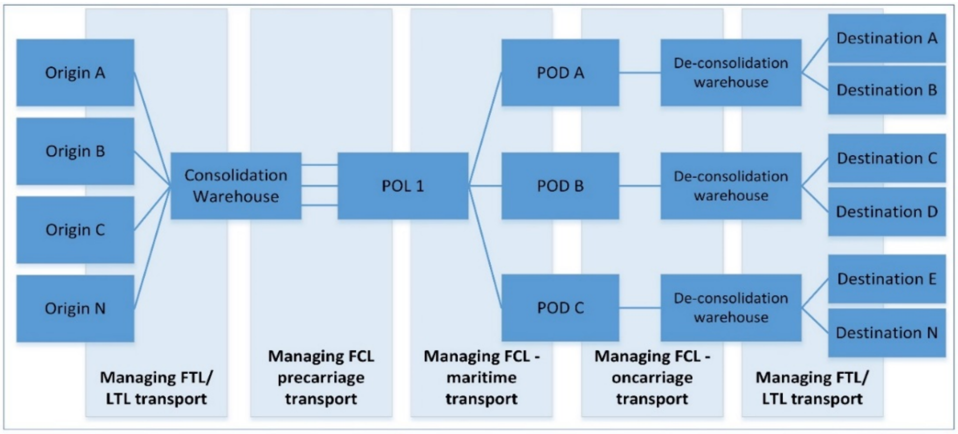

Fig. 1 Simplified LCL transport on direct lines with a larger volume of LCL shipments

Table 1 Input variables and influence parameters of SSC operation from the point of view of intermodal transport chain performance

Input variable	Decision approach	Input variable impact
Place of consignment generation	Determination of land connections and mode of land transport	Distance, type and mode of land connection, number of individual land transport routes
Consignment characteristics	Orientation of the shipment to the land and sea part of a transport	Weight, volume
Location of consolidation warehouse	Direction of incoming and outgoing goods flows	Distance, mode of land transport, number of separate land transport legs
Type of land transport	Selection of optimal technological design, capacity, frequency	Occupancy of the cargo space, frequency, type of engine, ecological standard of the engine
POL location	Routing and grouping of shipments, LCL services operation	Distance, method of land connection
POD location	Direction of export flows of small overseas shipments	Length of sea route between ports, number of individual maritime transport legs
Direct or indirect LCL transport	Combination of sea transport to regional groupage warehouses	Length of sea route, additional handling, number of individual sea transport legs
Sea transport	Choice of CL and liner service	Vessel occupancy, vessel size, sailing speed

Output parameters or comparison results are EE of the supply chain, GHG emissions (CO_2, NO_x, SO_2, NMHC), price, and transport process time. The output parameters can be calculated according to the input parameters (Table 1) and the characteristics and number of transport legs *(k)* of the selected intermodal transport chain. The overall energy efficiency EE_T depends on the size of the transport vehicle, cargo space occupancy, engine, etc. and depends on the partial EE of the transport process TL_{EEk}.

$$EE_T = \sum_{k=1}^{n} TL_{EEk} \tag{1}$$

Total GHG emissions depend on the values of CO_2, NO_x, SO_2 and NMHC emissions. Their value depends on the type of transport, the length of each transport leg, the type of engine, etc. The total CO_{2T} emissions depend on the CO_2 emissions of each transport leg TL_{CO2k}.

$$CO_{2T} = \sum_{k=1}^{n} TL_{CO2k} \tag{2}$$

The same is valid for NO_{xT}, SO_{2T}, and $NMHC_T$ emissions. They mainly depend on the characteristics of maritime transport, where TL_{NOxk} is the NO_x value of single transport leg emissions, TL_{SO2k} is the of SO_2 value and TL_{NMHCk} is the NMHC value of single transport leg emissions.

$$NO_{xT} = \sum_{k=1}^{n} TL_{NOxk}; \qquad SO_{2T} = \sum_{k=1}^{n} TL_{SO2k}; \qquad NMHC_T = \sum_{k=1}^{n} TL_{NMHCk} \tag{3}$$

The total price of C_T is made up of the price of land transport, handling and stowage, port handling, and sea transport, where TL_{Ck} is the value of each of these processes.

$$C_T = \sum_{k=1}^{n} TL_{Ck} \tag{4}$$

The total delivery time of T_T goods in the supply chain is also composed of several time components of individual transport legs and logistics services TL_{Tk}.

$$T_T = \sum_{k=1}^{n} TL_{Tk} \tag{5}$$

Service A is more sustainable and still lean than Service B if the condition is met: $EE_{TA} \leq EE_{TB}$; $CO_{2TA} \leq CO_{2TB}$; $NO_{xTA} \leq NO_{xTB}$; $SO_{2TA} \leq SO_{2TB}$; $NMHC_{TA} \leq NMHC_{TB}$; $C_{TA} \leq C_{TB}$; $T_{TA} \leq T_{TB}$.

3.2 Methodology

The methodology is based on a multiphase approach to the analysis on the sustainable operation of LCL services on the southern part of the Baltic-Adriatic Corridor. The basic research problem aims to understand the environmental performance of LCL services in order to find more balanced transport solutions that do not negatively impact the concept of lean supply chain operations at the same time (Fig. 2). Based on the characteristics of the LCL service, it is possible to simulate EE and the GHG emissions generated. The quantity of LCL shipments for a given destination, the type and mode of inland transport, the location of POL, the location of the regional LCL hub, the operation of container liner services and the size of the vessels and finally the utilisation of the container vessels shape a LCL service.

The study on the LCL services was conducted prior to the epidemic COVID-19 that significantly changed the way supply chains and intermodal transportation chains functioned due to access to empty containers, rising maritime prices, and the unreliability of maritime transportation services and delivery times for LCL shipments.

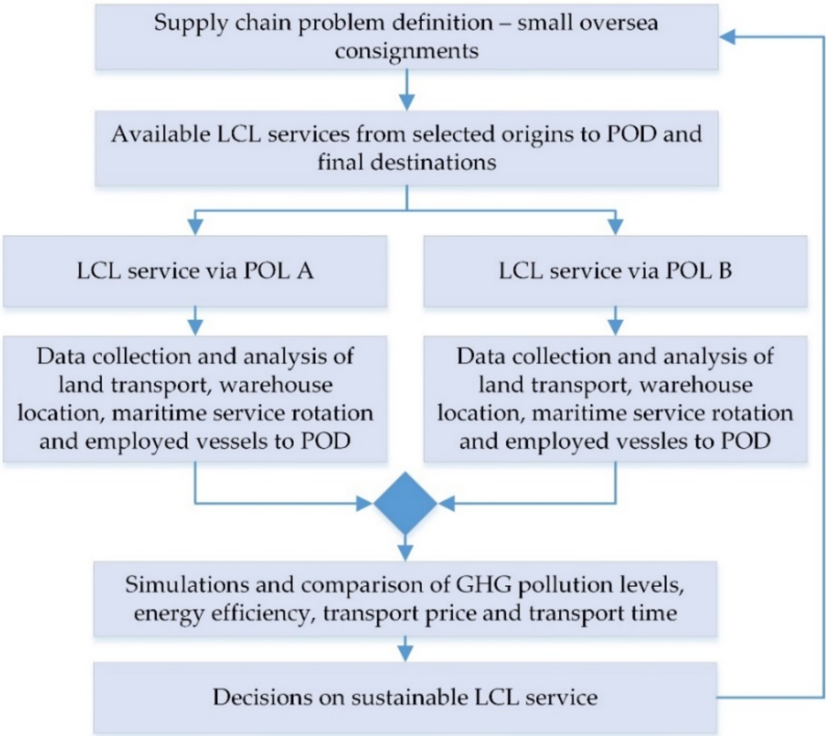

Fig. 2 Research workflow on SSC for small and frequent consignments

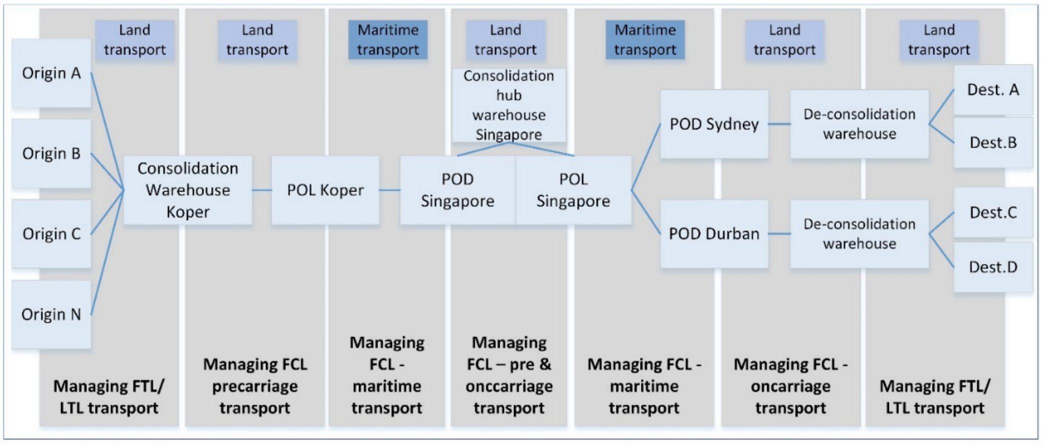

Fig. 3 Case study: LCL service from POL Koper to POD Durban and Sydney

Six places of origin were included in the study: Belgrade (Serbia), Zagreb (Croatia), Sarajevo (BIH), Banja Luka (BIH), Ljubljana (Slovenia) and Budapest (Hungary). In the first part of the transport process analysis, an FTL transport was chosen for the shipment delivery to the consolidation warehouse. In the second transport leg a FCL transport was analysed, as POL Koper and Genoa are used by NVOCC operators for outbound LCL services. The third transportation section of FCL transportation by sea is very complex, as the booking of sea services depends on the regional consolidation location, the rotation of the vessel on a particular liner service, and the number and location of hub ports on route to POD. The elements of price and frequency of the liner service are also important. Selected destinations are Shanghai, Durban, Sydney and Jeddah, which are served by an LCL service via Koper and via Genoa. The selected destinations ensure the spread of the transport networks and thus the relevance of the comparisons.

The ongoing shipping process can be more complex than shown in Fig. 1, as for destinations with less regular shipments the LCL container is un-stowed in a regional consolidation warehouse of an intermediate hub. From there, a new full LCL container is formed for the POD, which is an additional fourth and fifth leg of the transportation process management (Fig. 3). This applies to shipments from POL Koper to Sydney and Durban, where the shipments are brought in a single container to POD Singapore and separated in Singapore into different containers for POD Durban and POD Sydney. The latter has a major impact on EE and GHG emissions from LCL services as the shipment is de-routed from the optimal conventional liner service and additional feeder connections are requested. This is followed by a series of transport process management that includes FCL transport to the final deconsolidation warehouse and on to the final destination.

The price analysis consists of FTL transportation prices from Q3 2018 as well as sea transportation prices of LCL shipments at Incoterms CFR parity, which were much more stable before the COVID-19 epidemic. The input parameters of sea transportation are the chosen CL, the container service between ports and the size of vessels between ports in liner service. An important parameter is the location of the regional hub LCL warehouse as an input for planning the required combination of maritime services. LCL services via Genoa do not require additional handling and grouping of shipments in regional hub warehouses, while LCL hub points in Singapore and Dubai are used for services via Koper for markets with less frequent shipments (Table 2).

To calculate EE and GHG emissions, the EcoTransIT World calculator developed by EWI (Ecotransit World Initiative) is used, which provides a transparent way to calculate projected GHG emissions in intermodal transport [28]. The calculation of EE and GHG emissions is based on the standard EN 16250, which specifies the methodology for calculating EE and GHG emissions for freight transport [29]. The following input parameters are defined for land transport: transport volume 1 ton, diesel engine and EURO 5 standard, 80 % cargo space utilization and no empty transport share. For sea transport, the following parameters are used: 1 ton of cargo, vessel's size as specified in Table 1, load factor 70 %, and slowing down the sailing speed by 25 %, which is also recommended by the IMO, as underwater noise pollution is reduced by more than 66 % and collisions with larger fish are reduced by more than 78 % [30].

Table 2 Input variables and influence parameters of the simulation of SSC operation from the point of view of intermodal transport chain operation

POD	Direct LCL service	Via regional LCL hub	Preferred carrier	Maritime service	Employed vessel capacity (TEU)
			POL Koper		
Shanghai	YES	-	CMA	Direct	12.500
Durban	NO	Singapore	CMA	Port Klang, Singapore, Tanjung Pelepas	12,500; 5,100; 2,500; 8,100
Sydney	NO	Singapore	CMA	Port Klang, Singapore	1,500; 5,100; 5,700
Jeddah	NO	Dubai	MSC	King Abdul, Jebel Ali, Jeddah	15,200; 18,000; 5,600
			POL Genova		
Shanghai	YES	-	COSCO	Direct	13,600
Durban	YES	-	MSC	Las Palmas	5,700; 6,400
Sydney	YES	-	MSC	Gioia Tauro	8,800; 9,200
Jeddah	YES	-	CMA	Direct	11,300

4. Results

The study of LCL services in the analyzed supply chains shows the greater complexity of services through POL Koper due to the lower number of LCL shipments on selected destinations. Therefore, the services have to be routed to regional LCL hubs (Singapore or Dubai). At these points, containers are filled with additional shipments to the final destination. This does not apply to the Shanghai service as the weekly shipment volume is sufficient to organize a direct LCL service. The analysis shows that the sea transport route of the LCL service via Koper is more complex due to the sea container services. On the service to Durban and also to Jeddah, the container is reloaded three times. This is because the LCL services via POL Genoa are direct and the shipments remain in the container. Moreover, as shown in Table 2, on the way to Durban and Sydney, the container is transhipped only once at Las Palams (for Durban) and Gioia Tauro (for Sydney). The vessels used do not belong to the largest class of ULCVs (Ultra Large Container Vessels), which achieve lower GHG emissions per container transported at the same load factor.

Higher efficiency of sea transport has a significant impact on the low total NO_x, SO_2 and NMHC emissions of LCL services to Durban, Sydney and Jeddah via Genoa. On the whole transport route, NO_x levels to Sydney are on average 8.5 % lower than via Koper, to Durban 12 % lower and to Jeddah even 50 % lower. The difference is even greater for SO_2 emissions, as levels are 12% lower via Genoa to Sydney, 14 % lower to Durban and 18 % lower to Jeddah. NMHC levels are also lower via Genoa than via Koper, with the exception of the direct service to Shanghai (Table 3).

Table 3 Emission level of NO_x, NMHC and SO_2 via Genova vs. via Koper (in % Genova to Koper)

	NO_x via GEN vs. via KOP				NMHC via GEN vs. via KOP				SO_2 via GEN vs. via KOP			
	SHA	SYD	DUR	JED	SHA	SYD	DUR	JED	SHA	SYD	DUR	JED
BEG	106.52	91.50	78.55	50.78	110.79	96.67	84.71	63.36	100.19	87.67	75.55	41.88
ZAG	106.74	91.28	78.05	48.30	111.66	96.46	83.80	58.90	100.19	87.60	75.42	41.22
SAR	106.52	91.50	78.56	50.82	110.79	96.67	84.71	63.36	100.19	87.68	75.58	42.05
B. LUKA	106.64	91.38	78.28	49.48	111.26	96.55	84.21	60.98	100.19	87.63	75.49	41.57
LJU	106.82	91.21	77.87	47.41	111.96	96.39	83.50	57.30	100.19	87.73	75.66	42.47
BUD	106.58	91.45	78.43	50.20	111.03	96.61	84.45	62.15	100.19	87.65	75.51	41.70

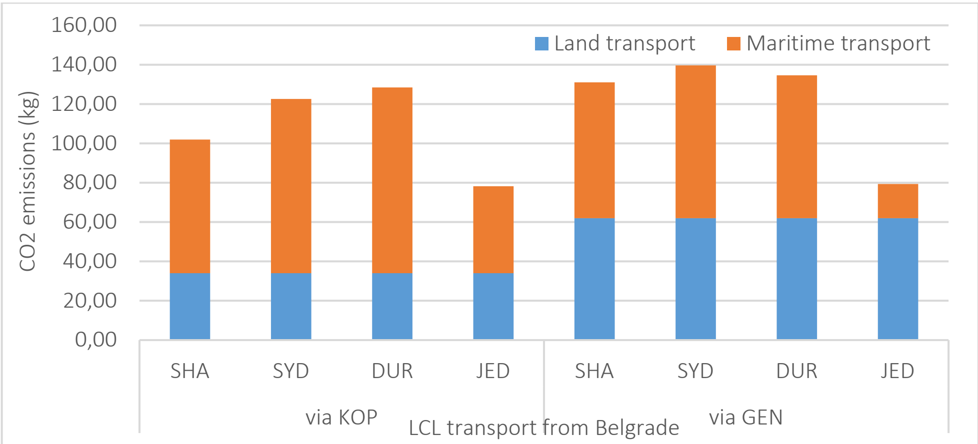

Fig. 4 Comparison of CO_2 emissions from Belgrade via POL Koper and Genoa to final destinations

The analysis of CO_2 emissions also highlights the lower value of the maritime transport leg via Genoa, with the exception of the service to Shanghai, which is direct through both ports. The total emissions are significantly influenced by the road transport from Koper to the LCL warehouse in Milan and then to POL Genoa. As shown in Fig. 4, the land transport of a 1-tonne shipment from Belgrade to Sydney and Durban via Milan-Genoa causes 20 % of the total CO_2 emissions and as much as 35 % of the total CO_2 emissions when transported to Jeddah. Consequently, land transport to Milan and on to Genoa has a significant impact on total CO_2 emissions and LCL transport EE per tonne of each shipment. Due to the direct service to Shanghai, it is not environmentally justifiable to route shipments to Genoa. However, CO_2 emissions to Sydney, Durban and Jeddah via Genoa are also higher. An LCL shipment of one tonne of freight results in up to 18 % more CO_2 emissions to Sydney, up to 6 % more when shipping to Durban and 2 % more CO_2 emissions to Jeddah. From the perspective of EE, LCL transport via Genoa is also less efficient, although LCL shipments routed via Koper are additionally handled at several transshipment ports. As shown in Table 4, LCL transport via Genoa to Sydney is up to 21 % more inefficient and up to 9 % more inefficient for transport to Durban and Jeddah.

The cost aspect illustrates the price advantage of LCL transport via Koper, even if sea freight rates for FCL containers are somewhat higher. The additional cost of land transport to Genoa cancels out the advantages of the cheaper sea connections. The cost of transporting an LCL shipment weighing 1 ton and less than 1 m^3 is 16-19 % higher via Genoa to Shanghai, 12 % higher on average to Sydney and Durban, and 7 % higher to Jeddah (Fig. 5).

Table 4 Emission level of CO_2 and EE levels via Genova vs. via Koper (in % Genova to Koper)

	CO_2 via GEN vs. via KOP				EE via GEN vs. via KOP			
Origin	SHA	SYD	DUR	JED	SHA	SYD	DUR	JED
BEG	128.48	114.00	104.79	101.41	131.43	116.69	107.36	105.76
ZAG	136.31	117.06	105.77	101.96	140.11	120.37	108.89	108.01
SAR	128.48	114.00	104.79	101.41	134.93	116.69	107.36	105.76
B. LUKA	132.28	115.52	105.28	101.66	135.62	118.50	108.12	106.80
LJU	139.52	118.24	106.15	102.21	144.01	121.92	109.53	109.16
BUD	130.26	114.72	105.02	101.52	133.02	117.39	107.66	106.14

The time component is particularly important for supply chain engineering, because shortest delivery time is one of preferences the in fast expanding on-line market [31]. The comparison of the total transport time highlights the higher competitiveness of LCL services via Genoa. For the service to Shanghai, the time is very similar, the only difference being the additional land transport to Milan and Genoa. LCL transport to Sydney takes on average more than 50 days via both selected POLs. Important differences exist for the transport to Durban and Jeddah, as for the service via Koper the shipment for Durban has to be brought to Singapore first and the shipment for Jeddah to the LCL hub warehouse in Dubai. Transport via Koper to Durban takes 25 days longer (+67 %) and transport to Jeddah takes 13 days longer or 50 % of the transport time.

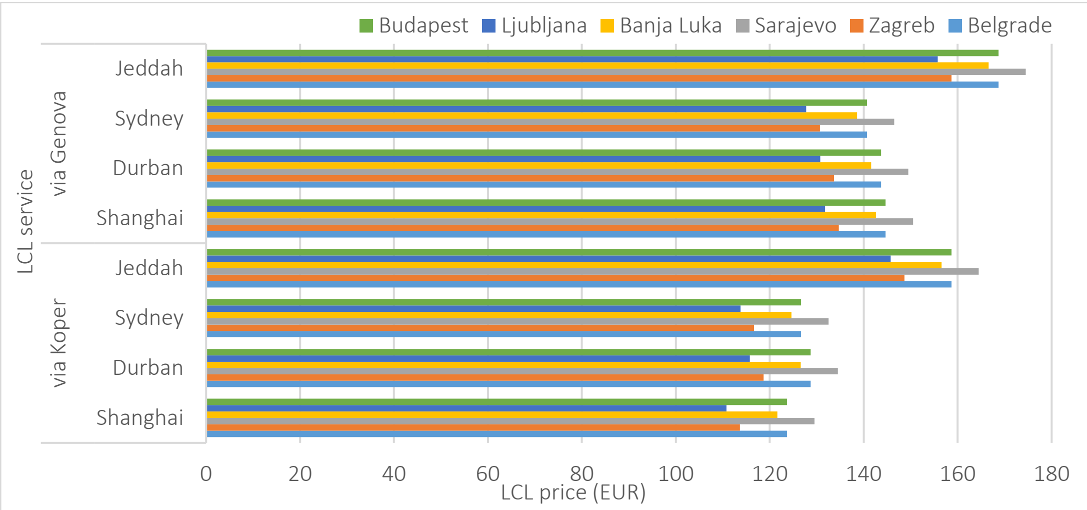

Fig. 5 Price level for LCL shipment of 1 ton and volume less than 1 m3 per destination

5. Discussion and implications for modeling sustainable supply chains with sustainable intermodal transport

Lean supply chains are based on the efficient operation of intermodal transportation and incorporate many elements of modern supply chain engineering. The results of the study highlight the importance of environmental sustainability of overseas transportation. An understanding of the identification and placement of consolidation warehouses and selected POLs is required in SSC engineering. The study highlights the importance of mainland efficiency to ensure low-carbon and higher EE of global supply chains. Total NO_x, SO_2 and NMHC emissions in overseas supply chains mainly depend on the optimal implementation of port access and vessel characteristics (size, load, speed).

If only the time component is pursued in lean supply chain modelling to reduce inventories and financial liquidity, LCL service via Genoa offers better solutions. Thus, shipments are frequently routed through this port, resulting in more direct traffic and greater export freight volumes. In terms of price, transporting a single shipment weighing 1 tonne and with a volume of less than 1 m^3 via Genoa, which is further away, is 10 to 20 EUR more expensive, which represents an average difference of about 50 EUR for a medium-sized shipment of 4 tonnes and up to 4 m^3 in volume. This difference is acceptable for exporters and importers, as they get up to 50% shorter delivery times. On the other hand, 44.6 kg more CO_2 is generated and 300 kWh more energy is consumed to transport such a shipment to Sydney.

Due to fragmentation of overseas consolidated cargoes to various final destinations, LCL transport to less frequent destinations in the southern Baltic-Adriatic Corridor are still routed via Milan and POL Genoa. However, carbon footprint results, EE, and price comparisons do not support these activities. This is reflected in the data on the LCL transport from the most distant location, Belgrade, to selected destinations (Fig. 6). The matrix representation of the main indicators can be a transparent tool for commodity owners in the decision model of supply chain modelling (Table 5).

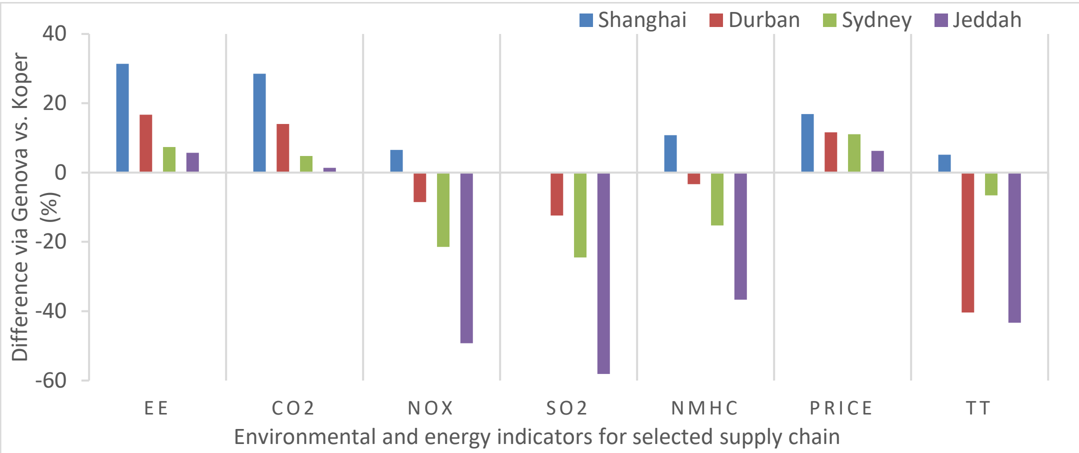

Fig. 6 Environmental and energy indicators of transport from Belgrade (% of value via Genoa vs. Koper)

Table 5 Environmental, price, and time values of transport of LCL shipments from Belgrade (in % via Genoa vs Koper)

	EE	CO_2	NO_X	SO_2	NMHC	Price	TT
Shanghai	+31.43	+28.48	+6.52	+0.19	+10.79	+16.91	+5.13
Durban	+16.69	+14.00	-8.50	-12.34	-3.33	+11.66	-40.32
Sydney	+7.36	+4.79	-21.45	-24.45	-15.29	+11.05	-6.56
Jeddah	+5.76	+1.41	-49.22	- 58.12	-36.64	+6.30	-43.33

The results of the study demonstrate the importance of comprehensive modelling of general cargo transportation that focuses on sustainable aspects of the intermodal transportation chain opera-tions. It is particularly important to adequately inform freight owners about the GHG emissions that result from transporting a small shipment overseas. Due to the significant difference in total transportation time and lower price differential, they often opt for less environmentally friendly and EE efficient transportation solutions. This raises the issue and the need to externalise the indirect costs of a higher environmental impact with the chosen transportation service, further driving up the cost of transportation to Genoa. This would push shippers who want leaner and more flexible supply chains to contribute more to decarbonizing transportation. It is foolish to expect from NVOCC operators to stop providing diversified transportation services just to reduce the carbon footprint and increase EE of transportation services.

The results can be generally applied to similar geographic areas where LCL shipments are transported to more distant ports in order to fill containers more efficiently and achieve higher shipping frequency and regularity of the LCL service. This, of course, requires an in-depth analysis of the input parameters of LCL services and the characteristics of LCL shipments in order to accurately determine the difference between the GHG emissions generated and the EE achieved. It is also difficult to generalize the approach that a more distant port is not the most appropriate for LCL service from the point of view of a sustainable transportation process. It is necessary to take into account the parameters of maritime services to comparable ports, especially the size and age of the vessels, the maritime route, the type of propulsion, the occupancy of the cargo space in the container and on the vessel, etc. It is expected that through the use of machine learning and artificial intelligence, decision models will be available in the future that will take into account a greater number of input data about LCL services and, based on the elements of price, time and environmental impact, will provide fast and efficient sustainable decisions for cargo owners or contracted logistics companies.

6. Conclusion

The environmental aspects of each transport sector are very well developed at the EU level, and strategies are being used to reduce the carbon footprint and improve EE. Building and managing complex intermodal transport chains to support global supply chains brings many other challenges. For example, different modes of transport from different transport sectors, different engines and loading capacities, and different freight space utilisation rates must be used in succession. The latter also applies to the transport of small consignments in cross-border traffic. Global general cargo traffic relies on efficient handling of land and sea transport, with the volume and size of shipments posing an additional challenge, as this is the only way to determine the need for additional handling of shipments and the formation of new consolidated containers along the defined transport chain.

The results of the study confirm research hypothesis H1 that building a supply chain that focuses only on the most direct maritime link may be less environmentally and energy friendly. The CO_2 emissions and energy consumption of maritime transport on direct LCL lines via Genoa are more acceptable than on overseas connections via Koper. However, it is necessary to take into account GHG emissions and energy consumption for land transport, the impacts of which are higher than the benefits of direct maritime services.

The study on the operation of supply chains for the introduction of LCL services on the southern part of the Baltic-Adriatic Corridor supports the basic theses on the complexity of the services. The research results underline the importance of considering environmental aspects in LCL services and confirm the H2 hypothesis that in LCL services land transport is an important factor in achieving greener chains, even if it represents only a small share of the total transport distance. The data on LCL services via Genoa for shipments originating in the Western Balkans and Central Europe confirm that the additional land transport from the collection point near Koper has a significant impact on the carbon footprint and EE, even if it represents only 2 % of the total transport route distance.

The results of the study are limited in that they only consider the selected final destination and the vessel characteristics used by CL at a given time, but they provide a measurable framework for current environmental parameters in complex intermodal chains. The information on CL is at the discretion of the NVOCC operator, which does not imply that it has chosen the route with the most environmentally friendly and EE values. The research results serve as a basis for further elaboration to develop an assessment approach useful for supply chain engineering.

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