An approach to greener overseas transport chain planning in FVL

Beškovnik, Bojan

Source / Izvornik: **Pomorstvo, 2021, 35, 150 - 158**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.31217/p.35.1.16

Multidisciplinary
SCIENTIFIC JOURNAL
OF MARITIME RESEARCH

University of Rijeka
FACULTY OF MARITIME STUDIES

Multidisciplinarni
znanstveni časopis
POMORSTVO

https://doi.org/10.31217/p.35.1.16

An approach to greener overseas transport chain planning in FVL

Bojan Beškovnik

University of Ljubljana, Faculty of Maritime Studies and Transportation, Pot pomorščakov 4, 6320 Portorož, Slovenija, e-mail: bojan.beskovnik@fpp.uni-lj.si

ABSTRACT

The article deals with a very topical issue of environmental suitability of complex transport chains. Overseas transport chains in finished vehicle logistics (FVL) consist of a series of transport routes in which they successively combine rail, road and sea transport. It is necessary to know the input parameters and their impact on the operation of FVL, especially with the aim of evaluating the air pollutants produced and the energy efficiency (EE) achieved. The article gives a systematic approach in defining input parameters and their evaluation for efficient green transport chain planning. The applicability of the approach is demonstrated on an ongoing FVL of the export flow of luxury vehicles from Europe to Asian markets. Transport chains from four production sites in Central Europe to two loading ports in Koper and Bremerhaven, and in maritime RO-RO transport to four Asian unloading ports are analyzed. The results of the study show the need for more comprehensive planning of export FVL, including environmental assessment at the planning stage. Significant savings in energy consumption and reduction in GHG (greenhouse gas) emissions can be achieved by shifting cargo flows to the southern transportation route. The article enriches the current research on sustainable operation of FVL and provides applied results for infrastructural adaptation of the southern transport route.

ARTICLE INFO

Preliminary communication
Received 3 March 2021
Accepted 1 June 2021

Key words:
Finished vehicle logistics (FVL)
Transport chains
Sustainable transport
RO-RO transport
Air pollution

1 Introduction

Transport chains in finished vehicle logistics (FVL) are becoming increasingly complex. Vehicle manufacturers are merging, combining production platforms for different vehicle models, and seeking cost efficiencies in component and final vehicle logistics. In this context, it is important to optimize the operation of complex transportation chains that rely on efficient multimodality (Zeng et al., 2013). Various actors are involved in the delivery of vehicles overseas, such as overland car terminal operators, road transporters, rail operators, maritime car terminal operators, and carriers. In addition to time and cost optimization, the environmental elements of transportation chain optimization are also coming to the fore. The trend is to reduce carbon footprint and other greenhouse gas (GHG) emissions as well as energy efficiency (EE), with end-vehicle logistics being the most environmentally critical process in the automotive industry (Nieuwenhuis et al., 2012), although the assembly supply chain process in automotive logistics is very complex and environmentally damaging (Nakamichi et al., 2016; Masoumi et al., 2019).

Processes and transport chains in FVL can be simple or very complex (Werthmann et al., 2017). Simple ones involve only a few actors, where the main stakeholders are the overland transport companies organising transport between the manufacturing site and the car distributor. Commercial vehicles are usually stored at only one land terminal, from where delivery to regional agents or dealers is organized. In this process, overland hauliers face the challenge of optimizing empty runs, as the import and export flows of vehicles are disproportionately large (Vilkelis and Jakovlev, 2014). Overseas transport chains in FVL are more complex (Torbianelli, 2000). They include sea car terminals and RO-RO services, whose role in FVL is changing (Beškovnik and Zanne, 2018) and has a significant impact on the operational implementation of RO-RO transport (Iannone et al., 2016). Unlike container termi-

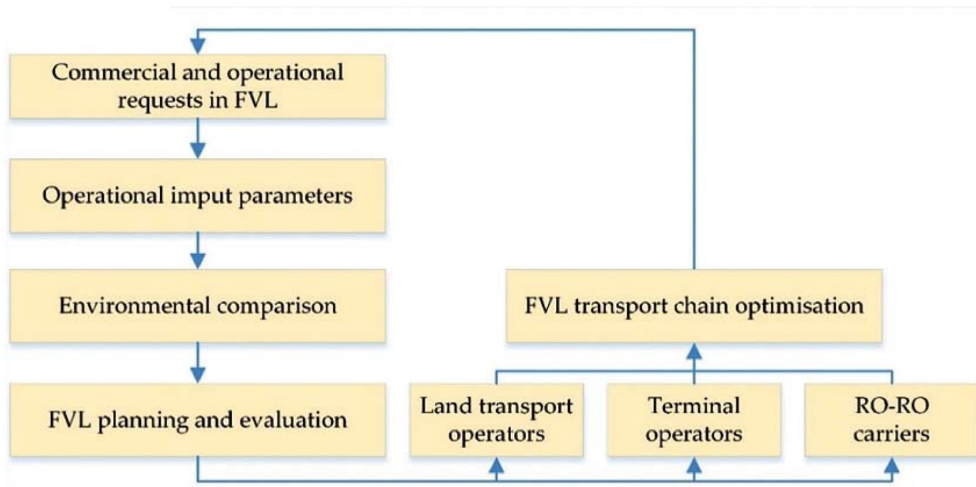

Fig. 1 Planning approach in FVL with environmental evaluation of planned sustainable transport chain

Source: Author

nals, there are only a few dozens of car terminals in the European transport system, which has a significant impact on the cost, time and environmental organization of transport chains. The situation is similar with deep sea RO-RO carriers and their services. This is especially true for deep sea RO-RO services organized from only a few European ports to more distant and growing overseas markets.

Research on the organization of transport chains in FVL is poorly supported scientifically. There is a lack of studies in the field of planning the operation of complex transport chains, focusing on the design and evaluation of greener chains, as conducted by Sim and Sim (2017) in the case of FVL in Hyundai-Kia Group. Thus, the study enriches the field of designing complex transportation chains and provides theoretical basis as well as applicability for evaluating transportation chains in FVL. The applicability is expressed in the analysis of the environmental aspect of FVL operation on the Europe-Asia axis through selected European ports. The results of the study dictate the need for a modified FVL planning approach in overseas delivery of European vehicle production for the growing Asian market.

The study hypothesizes that there are opportunities and needs for an ecological assessment of existing and in the planning of further transport chains in FVL, with the aim of achieving a lower GHG footprint and a higher EE. The modeling approach in the Slovenian research agency co-funded Green Port project enriches the scientific field and stimulates further research in the field of co-development of ports and green transport chains, with the aim of low carbon operation of the transport sector.

2 Research basis and approach

When planning transport chains in FVL, the commercial and operational expectations of stakeholders need to be taken into account, and decisions about FVL are usually made on the basis of the lowest possible cost (Tian and Chao, 2014). Depending on the characteristics of the vehicles, the target market, customer expectations, the responsiveness of land transporters and RO-RO carriers, it is necessary to create an optimally functioning transport chain. The business sub-goals of the parties involved are different (Zis et al., 2019), but along the transportation chain, the aim is to reduce car delivery time, increase the utilisation of transportation equipment, and achieve cost optimization of each transportation process (Hu et al., 2015). Although a car delivery time should be as low as possible, RO-RO carriers sail at reduced speed under slow steaming conditions, which has a positive impact on the level of GHG emissions, but at the same time lengthens the sea voyage (Psaraftis and Kontovas, 2016).

Operational planning elements include infrastructure elements along the transportation chain, technological processes, and capabilities of suprastructural elements. In addition to operational elements, environmental assessment must be included in the long-term sustainable implementation of overseas chains in FVL (Holweg and Miemczyk, 2002). The basic parameters of environmental assessment are based on air pollutants such as emitted carbon emissions of all transport modes, NO_x, SO_2 emissions, which are more pronounced in maritime transport of RO-RO ships and EE of individual vehicle transport (Sim and Sim, 2017). The level of air pollutants is especially dependent on the type of fuel (Stazić et al., 2020).

An environmental comparison of possible transport chains with different ports of loading (POL) and different modes of transport, the size and frequency of RO-RO ship calls allows a more comprehensive assessment of the transport chain. The collected data form the basis for a targeted adjustment of land transporters, terminal operators and RO-RO carriers (Fig. 1). The modeling approach is based on a set of input variables of each FVL planning phase. Basic starting points are the input variables of the

Table 1 Main input parameters and their influence in planning approach of sustainable FVL

Planning phase	Input parameter	Input influence
Commercial and operational requests	Production plant location	Inland transport route, connectivity
	Car type and quantity	Security, transport type and capacity, services
	Delivery time	Transport distance, route and stakeholder selection
	POD and final market	Location, connectivity, handling and storage capacity
Operational planning	Rail infrastructure and operational limitations	Frequency (daily/weekly), transport capacity, reliability, price
	Road infrastructure and operational limitations	Frequency (daily/weekly), transport capacity, reliability
	POL car terminal	Location, connectivity, storage capacity, terminal services
Environmental planning and comparison	Share of rail/road transport from origin	GHG emissions, EE from land transport mode
	Rail/road transport technology (engine, space utilisation)	GHG emissions, EE from land transport mode
	Ship capacity and space utilisation	GHG emissions, EE from sea transport
	Ship sailing speed	GHG emissions, EE from sea transport

Source: Author

commercial and operational requirements of the FVL operation, which depend on the vehicle category (small or large commercial vehicles, SUVs, luxury vehicles, etc.), the end market and the demand. The input parameters of the operation planning differ according to the infrastructure capacity of the land connections between the production sites and suitable POL, the characteristics of the car terminal in POL, the rail and land transport capacity, the deep-sea RO-RO services from POL to the desired port of discharge (POD) according to the commercial input data, the capacity of the RO-RO ships and the regularity of the departures in the scheduled service.

Determining the impact of input parameters in the FVL planning stages is a prerequisite for environmental planning phase. Evaluation of environmental elements (Table 1) should be done by analyzing individual sections of the transportation process, as GHG emissions and EE values differ. The assessment depends on the characteristics and the number of transport sections for which it is valid:

i – transport legs by rail,

j – transport legs by road,

k – RO-RO voyages by sea.

For CO_2 emissions in FVL, the total emissions per vehicle $CO_{2\_total\_veh}$ depend on the emissions of the individual transport route (RL – Rail transport leg; TL – Truck transport leg; SL – Sea transport leg):

$$CO_{2\_total\_veh} = \sum_{i=1}^{n} RL_{CO2\_veh\_i} + \sum_{j=1}^{n} TL_{CO2\_veh\_j} + \sum_{k=1}^{n} SL_{CO2\_veh\_k} \quad (1)$$

SO_2 and NO_x emissions per vehicle dependent mainly on the number of sea transport legs (SL), the size of the ocean going ships, the cargo space utilisation, the sea route and ship's sailing speed. The total SO_2 emissions per vehicle in overseas transport chains ($SO_{2\_total\_veh}$) include the values of precarriage and oncarriage land transport and sea transport on the port-to-port route.

$$SO_{2\_total\_veh} = \sum_{i=1}^{n} RL_{SO2\_veh\_i} + \sum_{j=1}^{n} TL_{SO2\_veh\_j} + \sum_{k=1}^{n} SL_{SO2\_veh\_k} \quad (2)$$

NO_x emissions also dependent strongly on the efficiency of maritime transport. The total value of NO_x emissions per vehicle is the sum of all transport legs, where for $NO_{x\_total\_veh}$ applies:

$$NO_{x\_total\_veh} = \sum_{i=1}^{n} RL_{NOx\_veh\_i} + \sum_{j=1}^{n} TL_{NOx\_veh\_j} + \sum_{k=1}^{n} SL_{NOx\_veh\_k} \quad (3)$$

The *EE* of the entire transport chain is an important element in the efficient use of energy sources. In FVL, it shows the value of energy used to transport a car between the production site and the final customer. It is defined by the value of the energy used to transport the car in each transport leg, which depends very much on whether the transport is done by road or by rail, what the loading factor is, and what proportion of the transport leg is done by sea. The following applies to EE_{total_veh}:

$$EE_{total\_veh} = \sum_{i=1}^{n} RL_{EE\_veh\_i} + \sum_{j=1}^{n} TL_{EE\_veh\_j} + \sum_{k=1}^{n} SL_{EE\_veh\_k} \quad (4)$$

The value of GHG emissions and EE of the whole transport chain depends on the number of transported vehicles (N_i, N_j *in* N_k) in each transport leg *i, j* and *k,* and where $N_k = N_i + N_j$ applies for the total GHG emissions valuation as in equation No. 5:

$$GHG_{total} = \sum_{i=1}^{n} RL_{GHG\_i} * N_i + \sum_{j=1}^{n} TL_{GHG\_j} * N_j + \sum_{k=1}^{n} SL_{GHG\_k} * N_k \quad (5)$$

The comparability and selection of the transport chain via POL_A should be guided by the assessment of $GHG_{total\_A} \geq GHG_{total\_B}$ and/or $EE_{total\_A} \geq EE_{total\_B}$. Land transport companies, car terminal operators and RO-RO carriers need to adapt technological processes to ensure environmentally sustainable transport chains in FVL operations (Fig. 1).

3 Methodology

The research methodology is based on the presented approach of planning and evaluating green transport chains in sustainable FVL. Considering the presented starting points, the export flow of European luxury vehicle production for Asian markets is simulated and analyzed. Commercial and operational requirements dictate the transportation of thousands of vehicles with a weekly frequency of overseas shipments by RO-RO ships from European ports. The luxury vehicle market in Asia is growing rapidly (McKinsey, 2019), increasing pressure on regularity of delivery.

The luxury vehicle segment of various European manufacturers is produced in different locations. The study includes potential production sites in Munich and Stuttgart (Germany), Linz (Austria), and Kecskemet (Hungary). The current commercial conditions are determined by selected PODs which are Singapore, Shanghai, Hong Kong and Hitachi (Japan). Land transportation to POD is organized by rail and road. Car terminals in the ports of Koper and Bremerhaven, which are already used in the overseas RO-RO connection for the Asian market, were selected. The input parameters and impacts are analysed according to methodology presented in Table 1 and are shown in Table 2.

Table 2 Input parameters and their influence in outbound FVL to Asia via Koper and Bremerhaven

Input parameter via Koper	Input influence	Input parameter via Bremerhaven	Input influence
Munich, Stuttgart, Linz, Kecskemet	Enabled transport route, risky rail connectivity due to infrastructural bottlenecks	Munich, Stuttgart, Linz, Kecskemet	Enabled transport route, risky rail connectivity due to infrastructural bottlenecks
Car type and quantity	Luxury cars, lower load factor (LF), higher security standards	Car type and quantity	Luxury cars, lower LF, higher security standards
Delivery time	Shorter transport distance and delivery time	Delivery time	Longer delivery time
Singapore, Shanghai, Hong Kong, Hitachi	No limitations and restrictions at port, liner service	Singapore, Shanghai, Hong Kong, Hitachi	No limitations and restrictions at port, liner service
Rail infrastructure and operational limitations	Limited capacity, lower reliability, lower price competitively	Rail infrastructure and operational limitations	Enough capacity, higher reliability, price competitively
Road infrastructure and operational limitations	Frequency (daily/weekly), enough transport capacity, high reliability	Road infrastructure and operational limitations	Frequency (daily/weekly), enough transport capacity, high reliability
Koper car terminal	Good sea connectivity, enough storage capacity and high terminal services	Bremerhaven car terminal	Good sea connectivity, frequent congestion and high terminal services
Share of rail/road transport from origin	Eventual higher GHG emissions due to the lower share of rail transport	Share of rail/road transport from origin	Eventual lower GHG emissions as higher share of rail trans., terminal congestion
Rail/road transport technology (engine, space utilisation)	Train length reduction with higher GHG emissions and lower EE	Rail/road transport technology (engine, space utilisation)	Train length reduction on some corridors with higher GHG emissions and lower EE
RO-RO vessel capacity and space utilisation	Present lower flows of finished cars can cause higher GHG emissions and lower EE from sea transport	RO-RO vessel capacity and space utilisation	Higher flows of finished cars with lower GHG emissions, lower EE from sea transport, longer route, port congestion
RO-RO vessel sailing speed	Reduced speed lowering GHG emissions, with higher EE	RO-RO vessel sailing speed	Reduced speed lowering GHG emissions, with higher EE

Source: Author

For land transport, LF 7 (seven cars) per truck for road transportation and LF 10 per wagon for rail transportation are considered. Trucks with a total mass of up to 40 tons are used, with a loading factor of 60% of the maximum total weight of the vehicle, assuming that the transport is carried out only by the loaded trucks, without any empty runs. A similar assumption applies to rail transport (0% empty running), even if the wagons in most cases have to be delivered empty to the production sites. The train weight is set as 1,100 tons. The RO-RO transport simulations use vessels with a cargo capacity of approximately 6,500 cars, but the values in the EcoTransIT World (EWT) calculator use values for the largest class of RO-RO vessels over 5,000 DWT. The latter is a limitation in the assessment of pollutants, as emissions differ depending on the carrying capacity of the deep-sea RO-RO ships and their age, which is not taken into account in the parameterisation. This methodology is defined by the IMO with EEDI – Energy Efficiency Design Index and EEOI – Energy Efficiency Operational Indicator (Sui, 2020). In addition, it is assumed that the RO-RO carrier attempts to fill up to 70% of the ship's deadweight capacity while the ship is traveling at a speed 24% lower than the design speed. An ETW calculator with extended input mode is used to calculate the GHG emissions and the EE of transport process. The calculator is based on the standard EN 16258 and allows the comparison of GHG emissions between different services in complex transport chains. The ETW with the methodology of 29.9.2019 (ETW, 2021) was used, although the GHG emissions of maritime transport are lower after 2020 due to the use of low sulphur fuel and/or ship scrubbers.

4 Results

GHG emissions are highly dependent on the transport route, the type of transport means and their use. The transport route through the port of Koper is certainly shorter, due to the 3,600 NM shorter sea connection. The land transport route from Munich, Linz and Kecskemét to Koper is also shorter, only the land transport from Stuttgart is shorter by about 100 km by road to Bremerhaven.

The comparison of CO_2 emissions per car via Bremerhaven and Koper after each transport leg shows a significant difference in rail transport (even up to 160% from Kecskemét and 250% from Linz), if the same input parameters are considered (length and weight of the whole train, LF, electric drive). Road transport causes 7.69% less CO_2 emissions from Stuttgart to Bremerhaven, while the transport from Kecskemét to Bremerhaven caus-

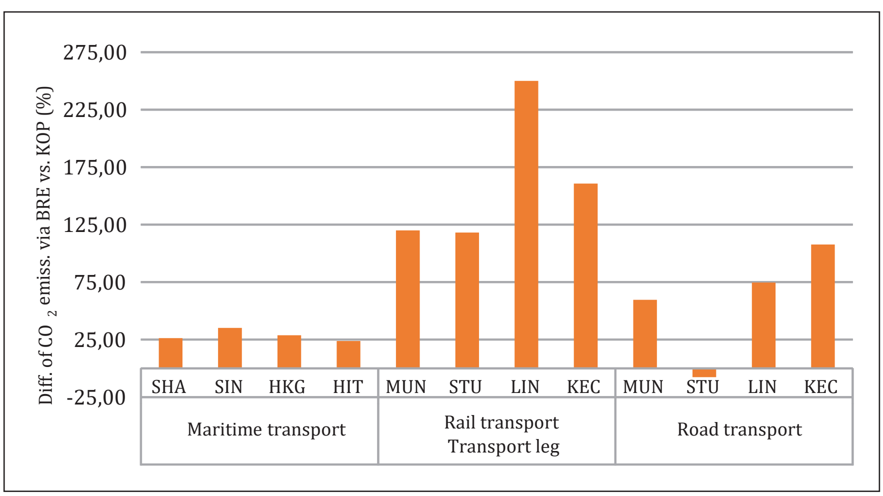

Fig. 2 Comparison of CO_2 emissions when transporting a car via Bremerhaven vs. via Koper (% Bremerhaven vs. Koper)

Source: Author with ETW tool

Table 3 Comparison of NO_x and SO_2 emissions in FVL (% via Bremerhaven vs via Koper)

	NO_x by sea transport				NO_x by rail transport				NO_x by road transport			
POD	SHA	SIN	HKG	HIT	MUN	STU	LIN	KEC	MUN	STU	LIN	KEC
BRE/KOP	*+22*	+41	+27	+21	+150	+26	+238	+142	+59	-8	+82	+105
	SO_2 by sea transport				SO_2 by rail transport				SO_2 by road transport			
POL	SHA	SIN	HKG	HIT	MUN	STU	LIN	KEC	MUN	STU	LIN	KEC
BRE/KOP	*+18*	+23	+22	+16	+54	-9	+14	+103	+57	-6	+78	+107

Source: Author with ETW tool

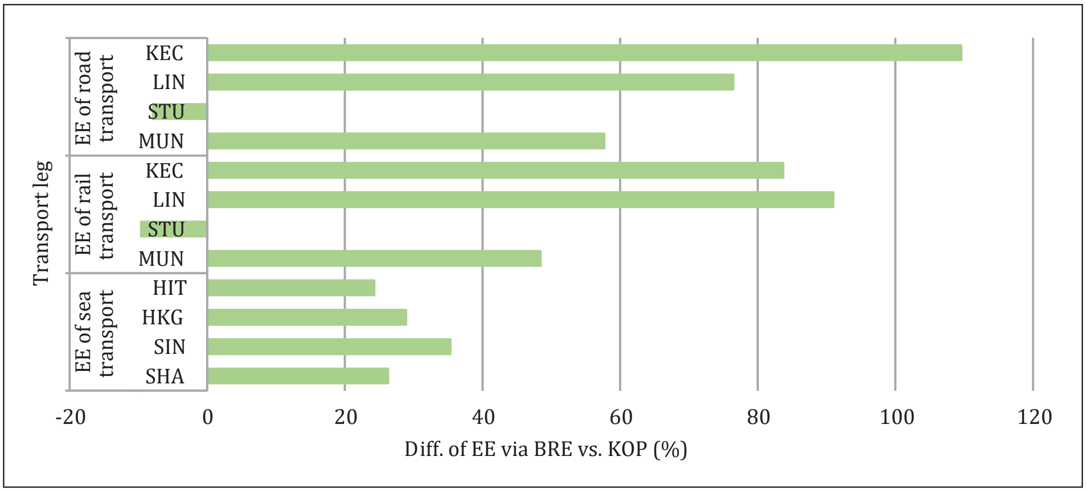

Fig. 3 Comparison of EE transport per transported car via Bremerhaven vs. via Koper (% Bremerhaven vs. Koper)

Source: Author with ETW tool

Table 4 Comparison of total GHG emissions as CO_2e between rail and road transport to POL (% via Bremerhaven vs. via Koper)

	Land transport by rail via BRE vs. via KOP				**Land transport by road via BRE vs .via KOP**			
	POD				**POD**			
Origin	SHA	SIN	HKG	HIT	SHA	SIN	HKG	HIT
MUN	+26.58	+35.60	+29.64	+24.91	+26.52	+35.34	+29.52	+26.81
STU	+25.82	+34.54	+28.80	+24.22	+24.80	+32.94	+27.61	+23.31
LIN	+27.02	+36.22	+30.14	+25.32	+27.16	+36.20	+30.24	+25.48
KEC	+27.31	+36.54	+30.44	+25.59	+27.93	+37.16	+31.06	+26.20

Source: Author with ETW tool

es 107% more CO_2 emissions compared to the route to Koper. Sea transport via Koper is also more environmentally friendly as the carbon footprint to the selected PODs is about 25 to 35% lower or between 2 and 3 tons of CO_2 in value (Fig. 2).

The comparison of NO_x and SO_2 emissions also shows an important advantage of the FVL organization by POL Koper. Sea transport with the RO-RO ship from Koper generates 41% less NO_x emissions and 23% less SO_2 emissions to Singapore. Such a sea transport route generates about 34 kg of NO_x and 30 kg of SO_2. NO_x and SO_2 emissions to the Japanese port of Hitachi are 21% and 16% lower, respectively, with almost the same difference to Shanghai. The land transport to POL Koper is also significantly more environmentally friendly, with the exception of transport from Stuttgart, where road transport produces 8% less NO_x emissions and 6% less SO_2 emissions.

The EE results of transporting a car from production sites in Central Europe illustrate the need to re-consider the organization of FVLs overseas. Road transport from Munich to Koper is 58% more energy efficient and an even higher percentage is achieved when transporting from Linz and Kecskemét. Rail transport from Munich to Koper achieves 48% better EE, and the percentage from Linz and Kecskemét is even higher, exceeding 80%. Road transport from Munich to Koper consumes about 253 kWh. Considering the shorter sea route and taking into account that the ships reach a load factor of 70% from both Bremerhaven and Koper, the RO-RO connection via Koper is more efficient from the point of view of energy consumption. Such a liner service consumes 24% less energy to POD Hitachi and even 35% less energy to Singapore POD (Fig. 3).

Taking into account the total GHG emissions as CO_2e equivalent between the production site and POD, the transport chain with truck transport to POL Koper is about 24.22% (STU to HIT) to 36.54% (KEC to SIN) more environmentally friendly. With rail transport to POL, there are about 23.31% (STU to HIT) and 37.2 % (KEC to SIN) less GHG emissions expressed as CO_2e equivalent (Table 4).

The analysis of the environmental elements underlines the need for FVL planning also from the point of view of the environmental performance of transport chains. Only one third of the weekly RO-RO shipment of luxury cars is transported via Koper. Two thirds of the cars are loaded in Bremerhaven and the RO-RO ship enters the Adriatic Sea to load the remaining amount of cars to completely fill the ship's capacity. Currently there are not enough weekly commercial vehicle volumes for the Asian markets to justify just a direct service from the northern Adriatic, without calls to Northern European ports. Due to market growth and analysed environmental parameters, it is necessary to include the results of the study in the further planning of FVL on the axis Europe-Asia.

5 Discussion

The weekly line of the RO-RO deep-sea service Europe-Asia provides 50 to 52 RO-RO departures between ports on the service, so it is important to know the GHG emissions and EE by a single service. GHG emissions and EE per vehicle are used to simulate energy savings and the possibility of lower emission levels. For the simulation of total GHG emissions and energy savings, the value of 5,400 vehicles is used as a potential total weekly shipment to Asia by a RO-RO service. Further, it is assumed that a quarter of all vehicles are shipped from each selected production point and that the vehicles are evenly distributed to deliver 1,350 vehicles to each POD. For land transportation, the simulation assumes that 70% of vehicles are transported from each destination to POL by rail and 30% by road, although in practice deliveries are distributed differently. The reasons for this are the fluctuation of production for certain markets in relation to the arrival dates of RO-RO ships and the possibility of timely organization of rail transport for each weekly RO-RO departure. The values for the transport of 5,400 vehicles in the mentioned simulation approach to POL Koper and POL Bremerhaven are presented in Table 5.

The GHG emissions and energy consumption values per ship with 1,350 cars for each POD are shown in Table 6. As defined in equation No. 5, the total values of the transport chain depend on the emission values of each transport leg and the number of cars in the transport phase. The simulation results of the total CO_2 emissions show about 4,021 tons less CO_2 emissions via Koper and at the same time about 14.85 million kWh less. According to estimates, a weekly transport chain in FVL via Koper also produces about 65 tons less NO_x and 19 tons less SO_2 emissions.

The results of the simulation case confirm the need for environmental assessment of transport chains in FVL. Their assessment in overseas chains is particularly important due to the significant share of RO-RO transport along the whole chain. According to the data in Table 2 and with the redirection of more than 100,000 additional vehicles for Asian markets to the Northern Adriatic, it will be necessary to improve the land transport infrastructure, especially the railway network and the terminal infrastructure in the port of Koper. The bottleneck and thus the higher risk is the restriction of the single-track Divača – Koper line, which, according to the construction and investment plans, should be removed in the next five years. Luka Koper Ltd. Co. accelerated investments in terminal infrastructure. An additional garage house with 6,000 parking spaces is under construction, which will provide a higher level of storage for the luxury vehicle segment. With additional storage space, the terminal's dynamic capacity will increase by more than 160,000 vehicles per year (Port of Koper, 2020). In 2020, the 6th group of tracks was built at the car terminal, which consists of 4 tracks with a length

Table 5 Estimated GHG emissions and EE of land transport by rail and road

	via POL Koper				Via POL Bremerhaven			
Orig.	**CO_2 (t)**	**NO_x (kg)**	**SO_2 (kg)**	**EE (kWh)**	**CO_2 (t)**	**NO_x (kg)**	**SO_2 (kg)**	**EE (kWh)**
MUN	44.01	91.53	44.28	271,440	81.68	166.05	68.45	384,615
STU	68.04	140.94	64.40	413,105	70.88	143.24	58.86	332,910
LIN	38.75	88.70	36.72	240,975	90.86	192.65	75.20	444,960
KEC	133.79	122.85	81.27	366,525	133.79	265.82	165.24	705,105
Total	**284.58**	**444.02**	**226.67**	**1,292,045**	**377.19**	**767.75**	**367.74**	**1,867,590**

Source: Author with ETW tool

Table 6 GHG emissions and EE of sea transport in the same share of vehicles for POD

	from POL Koper				from POL Bremerhaven			
Orig.	**CO_2 (t)**	**NO_x (t)**	**SO_2 (t)**	**EE (kWh)**	**CO_2 (t)**	**NO_x (t)**	**SO_2 (t)**	**EE (kWh)**
SHA	3,753	66.15	54.00	13,570,200	4,738	81.00	63.45	17,138,250
SIN	2,794	45.90	49.95	10,095,300	3,780	64.80	49.95	13,663,350
HKG	3,415	59.40	59.40	12,347,100	4,401	75.60	59.40	15,915,150
HIT	4,077	71.55	58.05	14,701,500	5,049	86.40	67.50	18,269,550
Total	**14,040**	**243.00**	**221.40**	**50,714,100**	**17,968**	**307.80**	**240.30**	**64,986,300**

Source: Author with ETW tool

of 700 meters. At the end of the manipulative tracks, hydraulic multi-level steel loading platforms are installed, which will enable faster and safer handling of vehicles. In 2020, the Port of Koper also built a new dedicated RO-RO berth for deep-sea RO-RO ships in the third basin. This will allow for an increase in throughput productivity, while at the same time enabling safer vehicle loading processes.

Infrastructural adjustments on the southern transport route from Europe to the Asian market enable and support environmentally friendly transport chains in the FVL, which must be included in further planning to redirect the export flows of European vehicle production via the northern Adriatic ports.

6 Conclusion

Global transportation volumes are increasing. As a result, expectations for the performance of low-carbon and energy-efficient transport chains are also rising. There is also increasing pressure on the implementation of FVLs, which must follow the principles of sustainable operations in addition to lean operations. Of particular importance are the environmental impacts of FVL operations, which are more pronounced in longer and more complex overseas transport chains. These are the export chains from Europe for Asian markets. The luxury vehicle export segment is growing and poses new challenges for all stakeholders in FVL, including terminals, RO-RO carriers, land transport providers and logistics companies.

The basic starting points for the development of sustainably operating transport chains in FVL dictate the need to study the environmental impact of the sequential operation of transport legs. The defined methodology defines a systematic approach to review the environmental impacts of FVL operation and enables more comprehensive planning processes for transport chains in FVL. The applied results of the methodological approach in the case of export flows of cars produced in Europe for Asian markets confirm the hypothesis that there are opportunities and needs for environmental assessment of existing and planning of further transport chains in FVL to ensure lower GHG footprint and higher EE. The current transportation chain of cars on the route Europe-Asia is not energy and pollutant efficient. The results of the study indicate 28% higher CO_2 emissions and 29% lower EE in the FVL via Bremerhaven compared to the transport chain via POL Koper. From the perspective of sustainable operation of FVL, it is necessary to plan the redirection of higher export flows to the southern transport route, while from the perspective of lean operation of FVL, it is necessary to remove infrastructural bottlenecks of land connections to and in the port. Infrastructure upgrading and development is underway, which will enable more efficient and environmentally friendly operation of FVL in overseas connections to Asia.

The article and research enrich the scientific basis for assessing pollution and achieving higher EE in FVL. There is a lack of such research, so the study provides the fundamental and applied basis for further approaches to assessing and planning transport chains in FVL. Further research activities will focus on the appropriate weighting of input parameters and input impacts to achieve a more comprehensive assessment of sustainably operated FVLs.

Funding: The research presented in the manuscript is partly co-funded by the Slovenian Research Agency and the Research Program Group.

Acknowledgment: The research is part of the project "Green Port" and is partly co-funded by the Slovenian Research Agency and the Research Program Group. Permission was obtained to use the ETW tool for the calculation of GHG emissions.

References

[1] Beškovnik, B., Zanne, M. (2018). Business process re-engineering of a maritime car Terminal: changing from inbound to outbound Intermodal node in finished vehicle logistics (FVL). *Polish Maritime Research*, 25(3), 54-61. doi: 10.2478/pomr-2018-0096.

[2] ETW. (2021). ETW methodology. Available at: https://www.ecotransit.org/methodology.en.html

[3] Holweg, M., Miemczyk, J. (2002). Logistics in the "three-day car" age: Assessing the responsiveness of vehicle distribution logistics in the UK. *International Journal of Physical Distribution & Logistics Management*, 32(10), 829-850. doi:10.1108/09600030210455438.

[4] Hu, Z.H.., Zhao, Y., Tao, S. (2015). Finished-vehicle transporter routing problem solved by loading pattern discovery. *Annals of Operations Research*, 234, 37–56. doi: 10.1007/s10479-014-1777-1.

[5] Iannone, R., Miranda, S., Prisco, L., Riemma, S., Sarno, D. (2016). Proposal for a flexible discrete event simulation model for assessing the daily operation decisions in a Ro–Ro terminal. S*imulation Modelling Practice and Theory*, 6, 28-46. doi: 10.1016/j.simpat.2015.11.005.

[6] Masoumi, A. M., Kazemi, N., Abdul-Rashid, S. (2019). Sustainable Supply Chain Management in the Automotive Industry: A Process-Oriented Review. *Sustainability*, 11(14), 3945. doi: 10.3390/su11143945.

[7] McKinsey (2019). McKinsey China Auto Consumer Insights 2019, McKinsey & Company.

[8] Nakamichi, K., Hanaoka, S., Kawahara, Y. (2016). Estimation of cost and CO_2 emissions with a sustainable cross-border supply chain in the automobile industry: a case study of Thailand and neighboring countries. *Transport Research Part D*, 43, 158-168. doi: 10.1016/j.trd.2015.12.018.

[9] Nieuwenhuis, P., Beresford, A., Choi, A. (2012). Shipping or local production? CO_2 impact of a strategic decision: an automotive industry case study. *International Journal of Production Economics*, 140(1), 138-148. doi: 10.1016/j.ijpe.2012.01.034.

[10] Port of Koper. (2020). Annual and sustainability report for 2019. Koper: Port of Koper.

[11] Psaraftis H.N., Kontovas C.A. (2016). Green Maritime Transportation: Speed and Route Optimization. In: Psaraftis H.

(eds) *Green Transportation Logistics. International Series in Operations Research & Management Science*, 226. Springer, Cham. doi: 10.1007/978-3-319-17175-3_9.

[12] Sim, J. and Sim J. (2017). Air emission and environmental impact assessment of Korean automotive logistics. *Journal of Cleaner Production*, 159, 130-140. doi.org/10.1016/j.jclepro.2017.05.058.

[13] Stazić, L., Radonja, R., Pelić, V., Lalić, B. (2020). The Port of Split international marine traffic emissions inventory. *Scientific Journal of Maritime Research*, 34, 32-39. doi: 10.31217/p.34.1.4.

[14] Sui, C., de Vos, P., Stapersma, D., Visser, K., Ding, Y. (2020). Fuel Consumption and Emissions of Ocean-Going Cargo Ship with Hybrid Propulsion and Different Fuels over Voyage. *Journal of Maritime Science and Engineering*, 8(8), 588. doi: 10.3390/jmse8080588.

[15] Zeng, T., Hu, D., Huang, G. (2013). The Transportation Mode Distribution of Multimodal Transportation in Automotive Logistics. *Procedia – Social and Behavioural Sciences*, 96, 405-417. doi: /10.1016/j.sbspro.2013.08.048.

[16] Tian, W. L., Cao, C. X. (2014). Research on Integrated Transportation of the Vehicle Logistics. *Advanced Materials Research*, 945–949, 3287–3290. doi: 10.4028/www.scientific.net/amr.945-949.3287.

[17] Torbianelli V. A. (2000). When the road controls the sea: a case study of ro-ro transport in the Mediterranean. *Maritime Policy Management*, 27(4), 375–389.

[18] Vilkelis, A., Jakovlev, S. (2014). Outbound supply chain collaboration modelling based on the automotive industry. *Transport,* 29(2), 223-230. doi: 10.3846/16484142.2013.789980.

[19] Zis, T.P.V., Psaraftis, H.N., Panagakos, G., Kronbak, J. (2019). Policy measures to avert possible modal shifts caused by sulphur regulation in the European Ro-Ro sector. *Transportation Research Part D: Transport and Environment*, 70, 1-17. doi: 10.1016/j.trd.2019.03.001.

[20] Werthmann, D., Brandwein, D., Ruthenbeck, C., Scholz-Reiter, B., Freitag, M. (2017). Towards a standardised information exchange within finished vehicle logistics based on RFID and EPCIS. *International Journal of Production Research*, 55(14), 4136-4152. doi: 10.1080/00207543.2016.1254354.