Carbon footprint of freight transport corridors between Norway and continental Europe

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Introduction

This short report is a deliverable of the project *Environmental assessment of transport corridors and drivers for green transport at Port of Hirtshals* describing the carbon footprint analysis of freight transport corridors between Norway and continental Europe.

The purpose of the study is to support Scandinavian decision makers in the transport industry and those involved the import/export of consumer goods with knowledge about the climate impact of different transport solutions. This work should help these decision makers in identifying multimodal transport solutions and freight transport routes that are optimal not only in terms of economy and time but also in terms of climate impact.

The transportation sector is a major contributor of greenhouse gas emissions worldwide and therefore a substantial contributor to human-induced climate change. Reducing carbon emissions related to freight transport is a priority in order to comply with current political emission reduction targets. One way to achieve this goal is reducing distances and shifting the traffic from high emission to low emission vehicles e.g. from to road to train or ship. An existing alternative to road freight transport within Scandinavia and between Scandinavia and neighboring countries is the use of vessels designed to carry wheeled cargo, such as ferries.

In this context, this study compared the environmental performance of alternative transport routes via road and ferry between Norway and continental Europe to support the decision upon which route to choose. The Life Cycle Assessment (LCA) methodology[1] was applied to calculate the carbon footprint of each transport route. LCA is a mainstream and widely applied tool for the quantitative environmental assessment of products.

More details about the study are reported in a scientific paper, currently in progress, available on request via email to the main author. The study was developed in the collaboration with the Port of Hirtshals in Denmark to support their decision making as well as those of the Port's clients. The report is for their internal use.

Geographical scope of the study

The study investigates the climate impact of the freight transport sector in Scandinavia and Northern Europe. In particular the study focuses on the freight transport between Norway and continental Europe that is based on roll-on/roll-off transport of consumer goods between production sites and final warehouses. The comparative assessment covers the freight transport between three points of departure and six destinations, for a total of eight transport corridors and 66 routes between Norway and continental Europe.

There are of course several existing routes between locations in Norway and continental Europe, due to a very large number of points of departure and destinations. To analyze the whole range of theoretically possible routes is an unrealistic task and was beyond the scope of this study. Instead, a number of relevant points of departure, destinations, and routes were selected for the comparative analysis. The points of departure, destinations, and routes were chosen in collaboration with the Port of Hirtshals to represent the most realistic and frequented routes within each corridor. These are existing routes that are deemed to be representative examples to characterize the freight markets for transport of goods at the time of the study. Analyzing these routes should allow to draw conclusions about the overall transport pattern in the geographical area under analysis, i.e. between Norway and continental Europe.

Selection of points of departure, destinations, and routes

Two points of departure for North-bound freight transport have been selected and a point of departure for South-East freight transport. Reims northeast of Paris was chosen as first point of departure for North-bound freight transport. Reims is considered a representative location in relation to transport from western and southern Europe to Norway. While Reims is not particularly interesting in itself as a point of departure for freight transport, this location has been selected to represent freight transport coming via road from Spain, France and Belgium and then heading further to Norway. Duisburg was selected as second point of departure for North-bound freight transport. Duisburg is a key transport hub in western Germany and is representative of points of departure located in western Germany and further south, such as Italy, as freight transport coming from these areas and directed to Norway will pass through or near Duisburg. Hitra located west of Trondheim was selected as point for South-East-bound freight transport. The area surrounding Hitra provides for an important share of the Norwegian salmon production, and the choice of Hitra reflects the need to better understand the impact of the increasing export of Norwegian salmon. The choice of two points of departure located in the Northern part of continental Europe and one in Norway allows to focus on the impact of transport occurring in proximity of these markets and to exclude the impact of transport occurring in Southern Europe from the comparative analysis.

Some of the largest coastal Norwegian cities were chosen as destinations for the North-bound freight transport to Norway. The largest share of Norwegian population is settled in those cities and drives the demand for transport of consumer goods. The selected coastal cities are Oslo, Bergen and Larvik. Additionally, Kongsberg was selected as an example of non-coastal Norwegian city and as representative for the transport to the region of Southern Norway. The choice of destinations for South-East bound transport was made considering the rising trade in salmon between Hitra's production area and Utska on the Polish Baltic coast, and between Hitra and Saint Laurent Blangy in Northern France. The two designated destinations are characterized by the presence of salmon processing industries.

The routes between the points of departure and the destinations were selected based on their relevance for freight transport. The selected routes are existing routes that are frequently used and are economically competitive for freight transport of the majority of consumer goods. Due to the specific geography of Northern Europe and especially the fact that continental Europe is separated from Scandinavia by water, all selected routes except for those across the Øresund bridge are characterized by transport via sea. The selected routes use the following existing ferry connections: Ystad – Scwinoujscie, Oslo – Frederikshavn, Frederikshavn – Gothenburg, Gedser – Rostock, Oslo – Kiel, Hirtshals – Larvik, and Hirtshals – Bergen.

Summing up, this study compared eight transport corridors: Duisburg (DE) – Bergen (NO), Duisburg (DE) – Larvik (NO), Duisburg (DE) – Oslo (NO), Reims (FR) – Stavanger (NO), Reims (FR) – Kongsberg (NO), Reims (FR) – Oslo (NO), Hitra (NO) – Saint Laurent Blangy (FR), and Hitra (NO) – Utska (PO). The routes within each corridor assume either a combination of transport by sea and transport by road, or they assume transport by road only, and are described in detail in Table 1.

Model description

The functional unit, which is the service under analysis, is *transporting 1-ton cargo* over each corridor*.* This is the basis for comparing alternative routes within the same transport corridor, as each route provides the same function but using a different combination of sea and road transport modes. The impact of the system is measured in terms of kg carbon dioxide equivalents (CO_2-eq) calculated using the IPCC (2013) life cycle impact assessment method with a timeframe of 100 years[2]. This corresponds to a *carbon footprint.*

Figure 1 shows the structure of the model used for the analysis. It is assumed that goods are transported via a cargo truck, that in turn can be transported via ferry depending on the chosen route. The cargo and truck characteristics are identical in all scenarios: EURO6, refrigerated, length 17 m, total weight 32 t (load 14 t, truck 9 t, trailer 9 t). Data about trucks and their emissions were taken from ecoinvent, a mainstream LCA database used worldwide[3]. These data cover entire truck transport life cycle and assumes average load factors.

Data about ferries and their emissions were taken from different primary[4] and secondary sources as well as from ecoinvent. The ferries operating in the various routes considered in this study differ in terms of size, capacity, type (*ro/ro-vessels* carrying cargo only or *ro/pax-vessels* carrying both passengers and cargo), and fuel used (LNG or diesel). Fuel consumption per ferry was determined using the SHIP-DESMO model[5,6] developed within the Danish RoRoSECA project[7]. The emissions per unit of fuel consumption were obtained from existing ecoinvent processes for diesel ships[8] and LNG ships[9] respectively. The total emissions per route were then calculated by multiplying the fuel consumption data obtained from SHIP-DESMO and the fuel consumption-specific emission factors from ecoinvent. Data referring to the construction, maintenance, and use of port facilities was quantified for each ferry by linearly scaling ecoinvent data for a transoceanic ship of 50000 t deadweight[10] according to the ferry's deadweight data reported in table 2.

It is reasonable to think that both ferries and trucks will have different emission patterns depending on e.g. meteorological or traffic conditions, and it is important to capture quantitatively both natural variability and measurement errors. A common approach to solve this problem is to use error propagation, a technique to obtain estimates of the uncertainty associated with the results that depends on the uncertainty of the model parameters. Error propagation was performed via Monte Carlo simulation, a stochastic procedure that consists in performing e.g. 1000 analysis by selecting each parameter value randomly within the distribution of its possible values. In this way, 1000 results are obtained and their distribution allows to better understand what is the variability of results, and to nuance the comparison between routes and the conclusions of the study.

Carbon footprint of transport corridors

The carbon footprint of each route is reported in Figure 2. The figure shows how much the transport via sea and via road contribute to the total carbon footprint in each route within each transport corridor, as well as the total value of carbon footprint measured in kg CO_2-eq per ton transported.

The figure shows that different routes have different impact and the routes with lowest carbon footprint are:

- The Zeebrugge−Hirtshals route in the Duisburg (DE) – Bergen (NO) corridor, the Duisburg (DE) – Larvik (NO) corridor, the Duisburg (DE) – Oslo (NO) corridor, the Reims (FR) – Stavanger (NO) corridor, the Reims (FR) – Kongsberg (NO) corridor, and the Reims (FR) – Oslo (NO) corridor
- The Hitra−Hirtshals route in the Hitra (NO) – Saint Laurent Blangy (FR) corridor
- The Oslo−Frederikshavn route in the Hitra (NO) – Utska (PO) corridor

Some general trends can be derived from the results of this study. Within the same corridor, the route with the lowest carbon footprint always includes transport via sea. However, not all the routes including a combination of transport via sea and road are preferable to a road-only route, in terms of carbon footprint. Ro/ro-vessels are a preferred option compared to ro/pax-vessels due to the higher capacity, that results in lower emissions per ton cargo transported. Ferries fueled by LNG are a preferred option over those fueled by diesel because of their lower emissions per ton cargo transported. Transport over long distances by sea in diesel-powered ferries is not preferable over road transport in the alternatives under analysis. Results show that routes via Zeebrugge-Hirtshals are the preferred alternative in several corridors because, despite the large distance covered via sea, a ro/ro-vessel is used on this route (872 km for a total of 46.99 kg CO_2-eq/ton cargo). Instead, the routes via Kiel-Oslo are the worst alternative in several corridors, because of the large distance covered via diesel ferry (689 km for a total of 124.69 kg CO_2-eq/ton cargo). Other routes with high impact are those via Scwinoujscie-Ystad-Svinesund because these routes cover either a larger distance via sea on diesel ferries or a larger distance via road, or both, compared to other alternative routes within the same corridors.

Results show that the use of ferry is not always outperforming road transport, as ferries has higher emission factors per tkm and the performance of sea routes depends heavily on the distance covered by sea. However, results show that in all the corridors under analysis the use of ro/ro-vessels ferries and the use of LNG fueled ferries allows for substantial benefits in terms of carbon emission reduction compared to road transport.

The results of the Monte Carlo simulation are visualized in Figure 3. The figure shows the distribution of results for each route over 1000 simulations. Values refer to the carbon footprint measured in kg CO_2-eq per ton transported. The general impression from the figure is that uncertainties are substantial and, in some cases, the large spread of results doesn't allow to clearly prefer one alternative over another. However, results of a statistical analysis show that 90% of the comparisons is significant with a very high level of confidence (data reported in the scientific paper).

Discussion and conclusions

The study quantified the carbon footprint of 66 routes within eight corridors for freight transport between Norway and continental Europe, differing for the combination of sea and road transport modes.

The study has focused only on a limited set of corridors and was not supposed to cover exhaustively all theoretically possible corridors between Norway and continental Europe. According to the port of Hirtshals, the alternatives selected are major existing routes of cargo traffic via ferry and are comparable in terms of feasibility, infrastructure, and costs. Besides diesel and LNG ferries, electric vessels are being introduced into Nordic fleets, such as the small electric passenger ferries already active between Helsingborg and Helsingör. Analyzing scenarios that include electric ferries was, however, beyond the scope of this analysis. The study has focused only on carbon emissions and their related impact, as they are a major concern in the transport sector, while other impacts have been disregarded. Another relevant impact to investigate is the impact of particles. Ideally, this would require to capture in detail the spatial differences in the impact due to particulate matter emitted over the sea by ferries and over urban and semi-urban areas by trucks respectively, that was beyond the scope of this study. Environmental performance is not the only factor affecting a decision on which route is preferable, and both costs and time would be important to consider. It was beyond the scope of this study to report on routes costs and time savings, or to find the optimal route based on these different variables.

The results of this study show that different routes have substantially different impact, and it is therefore possible to reduce the impact of freight transport by choosing routes with low impact. The results allow to identify the route with the lowest impact in each transport corridor, in terms of carbon footprint. Compared to a road-only alternative, a route involving transport via ferry can indeed have a lower impact. The savings of carbon emissions achievable with freight transport on ferries largely depends on the route, ferry type, and fuel used respectively. Shifting the traffic on ferries must also allow to reduce substantially the distance covered via road, in order to obtain a sensible reduction in emissions. Shifting to ro/ro-vessels and LNG fueled engines are highly preferable strategies to reduce emissions. These strategies should in particular be considered for the routes where a large distance by sea has to be covered, whereas would not allow reducing substantially the total carbon footprint in routes where the distance covered by seas is small (e.g. Rødby-Øresud).

This study is intended to support decision making for different stakeholders within the Scandinavian freight transport sector such as importers/exporters of consumer goods, ferry and port operators. The results of this study indicate that choosing routes passing through Hirtshals is an effective strategy to reduce the carbon footprint of freight transport between Scandinavia and continental Europe, at least for seven out of the eight corridors under analysis. On a larger perspective, this analysis suggests that Hirtshals could be considered an appropriate location as hub of freight transport between Scandinavia and continental Europe, from a carbon footprint perspective, because the routes with the lowest impact in several corridors pass through Hirtshals. These factors should be considered in the planning of future Scandinavian freight transport, for example when prioritizing investments in harbor and warehouse capacity in Scandinavia.

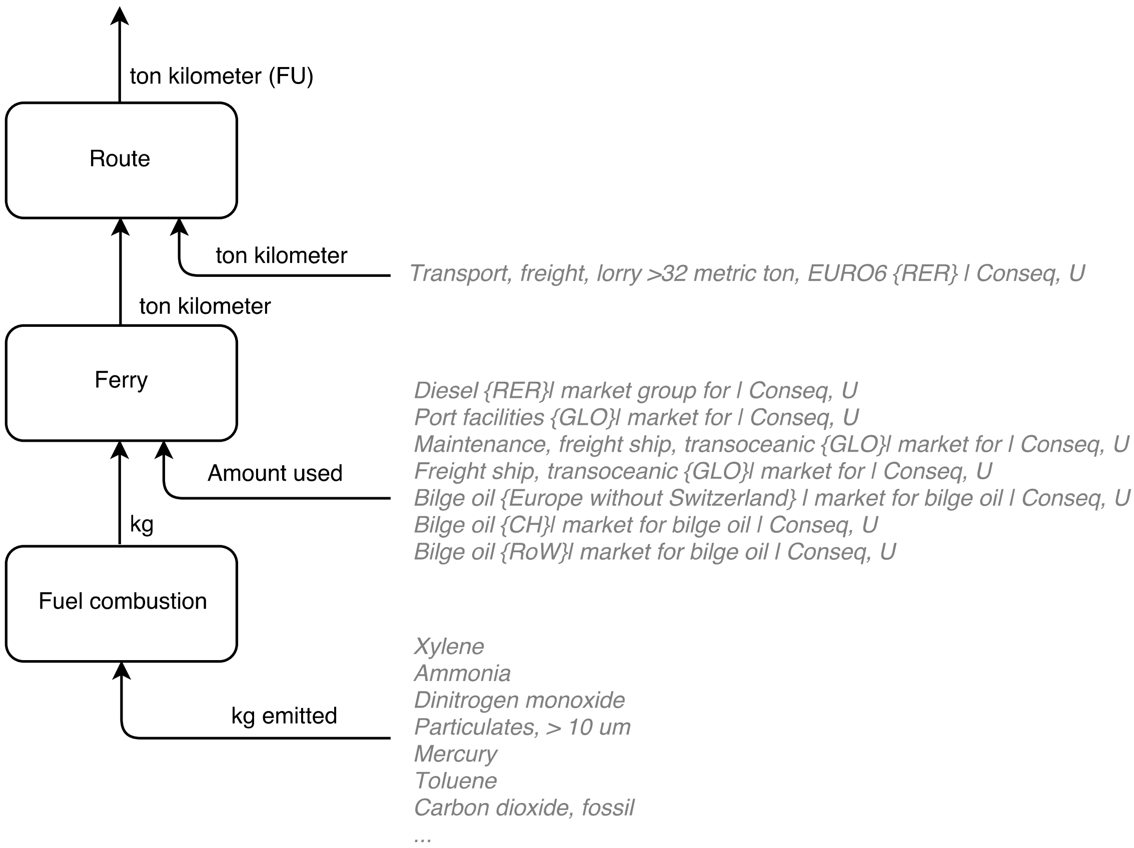


Figure 1. Structure of the LCA model. Boxes indicate activities. Arrows indicate products. Grey text in italics indicates activities or exchanges from the ecoinvent v.3.4 database, consequential Unit model. FU = functional unit.

Table 1. Routes included in the study

List of routes including departure point and destination, corridor, company who operates the ferry, name of ferry, distance covered by sea and by road, total hours and ID used in the analysis. Notes: “no Ferry” indicates that the route is only via road. Valentine s is a smaller version of Valentine that is not yet operational but it is supposed to be operating in the next years, either using diesel or LNG.

From - To	Via	By	Ferry	Sea distance (km)	Road distance (km)	Hours	ID
Duisburg - Bergen	via Rødby-Øresund	Scandlines	Deutschland	19	1740	40.5	Route01
	via Hirtshals-Larvik	Color Line	Superspeed 2	161	1321	35.7	Route02
	via Hirtshals-Bergen	Fjord Line	Stavangerfjord	533	881	42.1	Route03
	via Frederikshavn-Oslo	Stena Line	Stena Saga	289	1291	40.85	Route04
	via Kiel-Oslo	Color Line	Color Fantasy	689	926	36.35	Route05
	via Frederikshavn-Gøteborg	Stena Line	Stena Jutlandica	87	1582	49.95	Route06
	via Ystad-Scwinoujscie	POL Ferries	Mazovia	172	1785	46	Route07
	via Zeebrugge-Hirtshals-Bergen	CLdN/Fjord Line	Valentine/Stavangerfjord	1406	275	54.45	Route08
Duisburg - Larvik	via Rødby-Øresund	Scandlines	Deutschland	19	1420	35.2	Route09
	via Hirtshals-Larvik	Color Line	Superspeed 2	161	881	29.35	Route10
	via Frederikshavn-Oslo	Stena Line	Stena Saga	289	975	35.55	Route11
	via Kiel-Oslo	Color Line	Color Fantasy	689	610	31.05	Route12
	via Frederikshavn-Gøteborg	Stena Line	Stena Jutlandica	87	1266	34.65	Route13
	via Ystad-Scwinoujscie	POL Ferries	Mazovia	172	1469	40.7	Route14
	via Zeebrugge-Hirtshals-Larvik	CLdN/Color Line	Valentine/Superspeed 2	1033	275	39.7	Route15
Duisburg - Oslo	via Puttgarden-Rødby-Svinesund	Scandlines	Deutschland	19	1420	32.2	Route16
	via Hirtshals-Larvik	Color Line	Superspeed 2	161	1023	30.8	Route17

	via Frederikshavn-Oslo	Stena Line	Stena Saga	289	839	34.1	Route18
	via Kiel-Oslo	Color Line	Color Fantasy	689	474	29.6	Route19
	via Frederikshavn-Gøteborg	Stena Line	Stena Jutlandica	87	1129	32.35	Route20
	via Scwinoujscie-Ystad-Svinesund	POL Ferries	Mazovia	172	1326	38	Route21
	via Zeebrugge-Hirtshals-Larvik	CLdN/Color Line	Valentine/Superspeed 2	1033	417	41.15	Route22
	via "Storebælt" & "Øresund"	No company	No ferry	0	1442	33.25	Route23
Reims - Stavanger	via Rødby-Øresund	Scandlines	Deutschland	19	2246	68.15	Route24
	via Hirtshals-Larvik	Color Line	Superspeed 2	161	1723	41.45	Route25
	via Hirtshals-Stavanger	Fjord Line	Bergensfjord	370	1290	43.45	Route26
	via Frederikshavn-Oslo	Stena Line	Stena Saga	289	1833	48.8	Route27
	via Kiel-Oslo	Color Line	Color Fantasy	689	1424	53.7	Route28
	via Frederikshavn-Gøteborg	Stena Line	Stena Jutlandica	87	2121	57.8	Route29
	via Ystad-Scwinoujscie	POL Ferries	Mazovia	172	2291	63.55	Route30
	via Zeebrugge-Hirtshals-Stavanger	CLdN/Fjord Line	Valentine/Bergensfjord	1243	292	66.2	Route31
Reims - Kongsberg	via Rødby-Øresund	Scandlines	Deutschland	19	1805	50.65	Route32
	via Hirtshals-Larvik	Color Line	Superspeed 2	161	1398	36	Route33
	via Frederikshavn-Oslo	Stena Line	Stena Saga	289	1381	41.25	Route34
	via Kiel-Oslo	Color Line	Color Fantasy	689	972	46.15	Route35
	via Frederikshavn-Gøteborg	Stena Line	Stena Jutlandica	87	1673	40.35	Route36
	via Ystad-Scwinoujscie	POL Ferries	Mazovia	172	1840	57	Route37
	via Zeebrugge-Hirtshals-Larvik	CLdN/Color Line	Valentine/Superspeed 2	1033	400	58.75	Route38
Reims - Oslo	via Puttgarden-Rødby-Svinesund	Scandlines	Deutschland	19	1805	48.15	Route39
	via Hirtshals-Larvik	Color Line	Superspeed 2	161	1432	36.65	Route40
	via Frederikshavn-Oslo	Stena Line	Stena Saga	289	1291	40.55	Route41
	via Kiel-Oslo	Color Line	Color Fantasy	689	882	45.45	Route42
	via Frederikshavn-Gøteborg	Stena Line	Stena Jutlandica	87	1581	38.8	Route43
	via Scwinoujscie-Ystad-Svinesund	POL Ferries	Mazovia	172	1742	54.05	Route44

	via Zeebrugge-Hirtshals-Larvik	CLdN/Color Line	Valentine/Superspeed 2	1033	434	59.4	Route45
	via "Storebælt" & "Øresund"	No company	No ferry	0	1850	50.7	Route46
Hitra - Saint Laurent Blangy	via Hitra-Hirtshals (D)	Color Line	Valentine s	1002	1247	58.35	Route47
	via Hitra-Hirtshals (L)	Color Line	Valentine s LNG	1002	1247	58.35	Route48
	via Rødby-Puttgarden	Scandlines	Deutschland	19	2202	50.95	Route49
	via Larvik-Hirtshals	Color Line	Superspeed 2	161	1958	49	Route50
	via Oslo-Frederikshavn	Stena Line	Stena Saga	289	1821	46.3	Route51
	via Oslo-Kiel	Color Line	Color Fantasy	689	1413	49.1	Route52
	via Gøteborg-Frederikshavn	Stena Line	Stena Jutlandica	87	2108	51	Route53
	via Ystad-Scwinoujscie	POL Ferries	Mazovia	172	2343	57	Route54
	via Gedser-Rostock	Scandlines	Berlin	48	2233	53.65	Route55
	via Øresund-Storebælt	No company	No ferry	0	2375	51.25	Route56
Hitra - Utska	via Hitra-Hirtshals (D)	No company	Assumed as Valentine s	1002	1121	52	Route57
	via Hitra-Hirtshals (L)	No company	Assumed as Valentine s LNG	1002	1121	52	Route58
	via Rødby-Puttgarden	Scandlines	Deutschland	19	2023	38.95	Route59
	via Larvik-Hirtshals	Color Line	Superspeed 2	161	1832	42.65	Route60
	via Oslo-Frederikshavn	Stena Line	Stena Saga	289	1103	39.3	Route61
	via Oslo-Kiel	Color Line	Color Fantasy	689	1262	38.1	Route62
	via Gøteborg-Frederikshavn	Stena Line	Stena Jutlandica	87	1979	44	Route63
	via Ystad-Scwinoujscie	POL Ferries	Mazovia	172	1431	37.8	Route64
	via Gedser-Rostock	Scandlines	Berlin	48	1815	39.65	Route65
	via Øresund-Storebælt	No company	No ferry	0	2240	48.35	Route66

Table 2. Ferries included in the study

Shipping line	**From**	**To**	**Vessel name**	**Fuel**	**Distance (km)**	**Passengers capacity[1]**	**Actual passengers per trip[1]**	**Lane meters occupied by cars (%)[1]**	**Lane meters occupied by bus (%)[1]**	**Lane meters occupied by trailers (%)[1]**	**Deadweight (tons)[2]**
Color Line	Hirtshals	Larvik	Superspeed 2	Diesel	161	1928	573	41	2	36	5400
Color Line	Hirtshals	Kristiansand	Superspeed 1	Diesel	133	2315	831	41	2	36	5400
Color Line	Kiel	Oslo	Color Fantasy	Diesel	689	2770	1624	41	2	36	6133
Fjord Line	Hirtshals	Stavanger	Stavangerfjord	LNG	370	1390	526	41	2	36	3900
Fjord Line	Hirtshals	Bergen	Bergensfjord	LNG	533	1390	526	41	2	36	3900
Stena Line	Frederikshavn	Oslo	Stena Saga	Diesel	289	1700	712	41	2	36	3898
Stena Line	Frederikshavn	Gothenburg	Stena Jutlandica	Diesel	87	1006	349	41	2	36	6559
POL Ferries	Scwinoujscie	Ystad	Mazovia	Diesel	172	1000	130	41	2	36	6124
Scandlines	Puttgarden	Rødby	Deutschland	Diesel	19	1056	189	41	2	36	2904
Scandlines	Gedser	Rostock	Berlin	Diesel	48	1055	229	41	2	36	4835
CLdN	Zeebrugge	Hirtshals	Valentine	Diesel	872	0	0	0	0	80	9729
-	Hitra	Hirtshals	Valentine s*	Diesel	1002	0	0	0	0	50	7251
-	Hitra	Hirtshals	Valentine s* LNG	LNG	1002	0	0	0	0	50	7251

*[1]Shippax (2016); [2]www.marinetraffic.com (2017); * s = smaller version*

Figure 2. Global Warming Potential per route (kg CO2–eq)

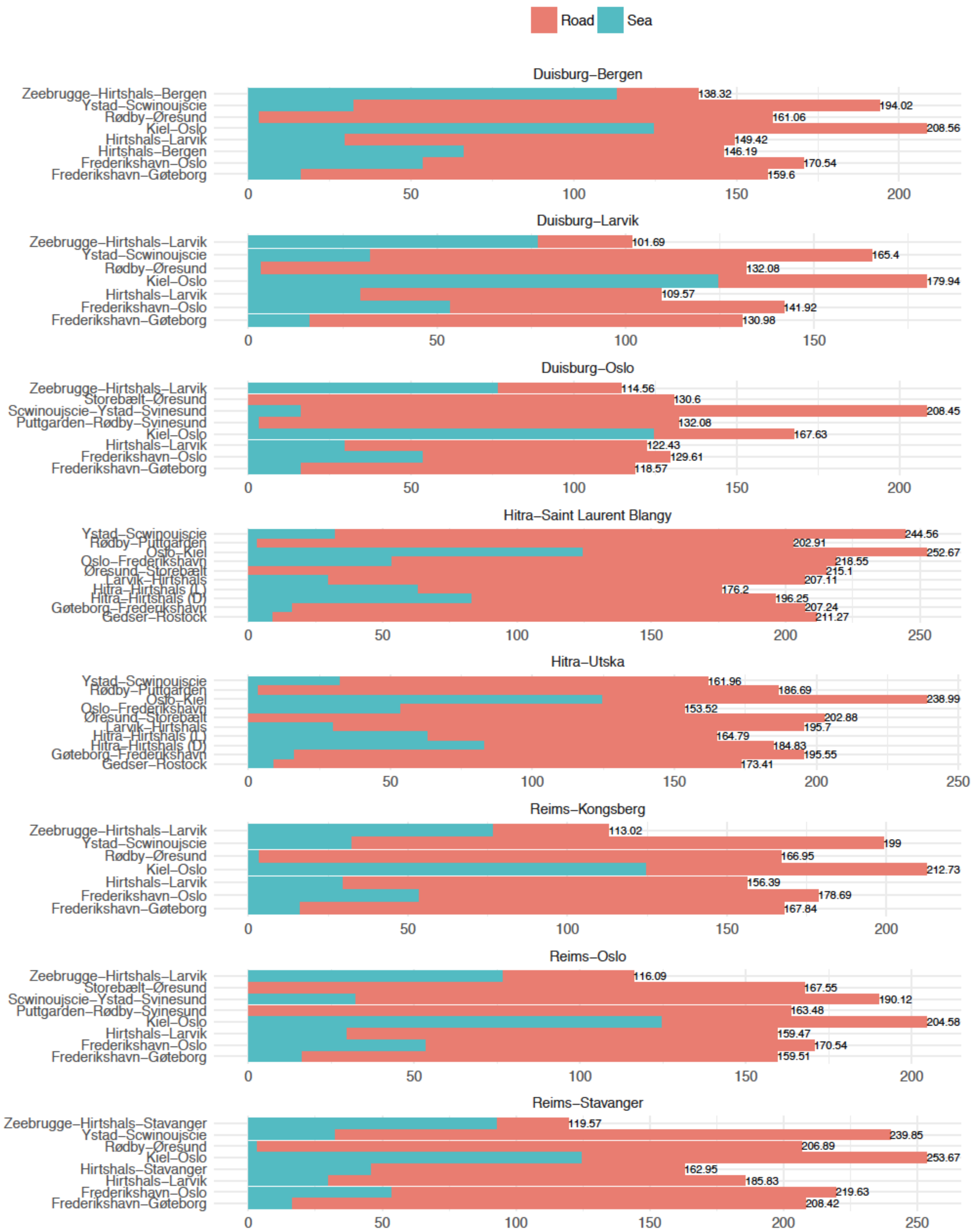
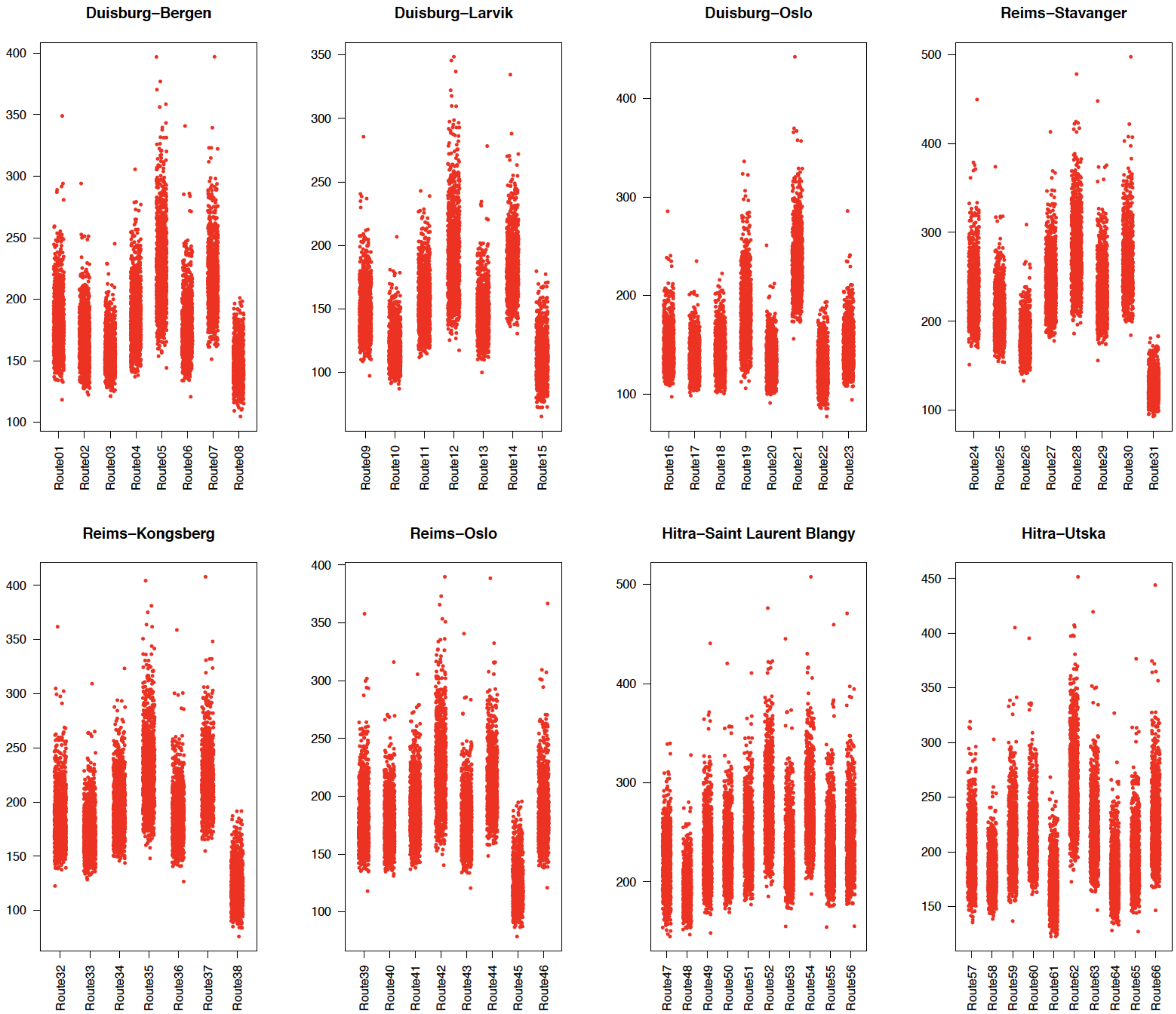


Figure 3. Carbon Footprint: results of Monte Carlo simulation (kg CO2–eq)



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