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D3.7

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Abstract

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
CO_2	Carbon dioxide
EC	European Commission
GA	Grant Agreement
KPI	Key Performance Indicator
LSP	Logistics Service Provides
NUTS	Nomenclature of territorial units for statistics
PI	Physical Internet
PO	Project officer
Ten-T	Trans-European Transport Networks
TEU	Twenty-foot Equivalent Unit
WP	Work Package

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Executive Summary

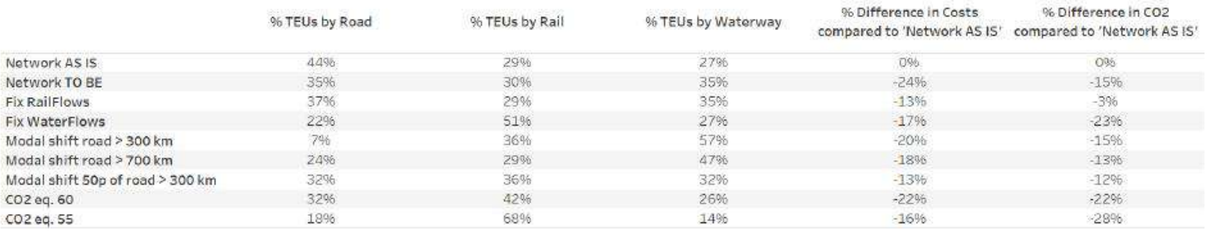
Deliverable D3.7 focuses on analysing and optimising European macro transport flows (based on Eurostat data from 2015, see Annexes). It provides insight of the cost and CO_2 savings potential of several scenarios applied to European transport flows. Moreover, it shows the potential in the European network for collaborative transport between intermodal logistics clusters, i.e. agglomerations of several types of firms and operations (logistics service providers, logistics operators, linked logistics industries and manufacturing). Furthermore, it indicates the benefits of collaborative transport with respect to increased transport efficiency and multimodality and as a result decreased costs and emissions.

Deliverable D3.7 is a result of task 3.5, in which a methodology is developed to search for the best possible combination of bundling cargo-flows and (new) multimodal transport services. Deliverable 3.6 (Network Design Model describing current European flows across clusters: as is) presented the results of an analysis of the current flows and network, in order to identify lanes for increased bundling and/or modal shift, i.e. a shift from road transport to rail or waterway transport. This report builds on these findings and further analyses the potential by modelling several scenarios to the data, analysing the outcomes and translating these into conclusions. The goal is to identify the potential savings in transport-costs and CO_2 emissions using different scenarios involving collaboration and modal shift. The outcomes can be seen as a first step towards putting it in practice in the Living Labs within the Clusters 2.0 project but also as the first step towards the Physical Internet.

Eight different scenarios have been modelled and analysed around three topics, based on the KPIs (costs, amount of TEUs per mode and CO_2 emission) that were defined in Deliverable 3.6 (Network Design Model describing current European flows across clusters: as is):

1. Cost optimisation
2. Modal shift
3. CO_2 emission minimisation

An interactive dashboard has been developed to get more insight in the scenarios and outcomes. The insight is presented in this document. Table 1 summarises the outcomes of all scenarios and a gives comparison of the KPI scores compared to the “as is” situation.



	% TEUs by Road	% TEUs by Rail	% TEUs by Waterway	% Difference in Costs compared to 'Network AS IS'	% Difference in CO2 compared to 'Network AS IS'
Network AS IS	44%	29%	27%	0%	0%
Network TO BE	35%	30%	35%	-24%	-15%
Fix RailFlows	37%	29%	35%	-13%	-3%
Fix WaterFlows	22%	51%	27%	-17%	-23%
Modal shift road > 300 km	7%	36%	57%	-20%	-15%
Modal shift road > 700 km	24%	29%	47%	-18%	-13%
Modal shift 50p of road > 300 km	32%	36%	32%	-13%	-12%
CO2 eq. 60	32%	42%	26%	-22%	-22%
CO2 eq. 55	18%	68%	14%	-16%	-28%

Table 1: KPIs overview for all scenarios

The following conclusions can be drawn based on the analysis.

- The number of TEUs per mode changes with the different scenarios. When focusing on cost minimisation, the distance to and from a waterway or rail terminal determines the preferred mode of transport. In most instances, rail is preferred over waterway when focusing on minimised CO_2 emission. Therefore, the best mode decision depends on the goal.

- The total costs of transporting all European flows are reduced by all scenarios with 13% to 24% compared to the “as is” scenario. The cost minimum is reached in the “to be” scenario (unconstrained cost optimisation) and is 24% less than the current total cost.

- The CO_2 emissions are also reduced by all scenarios with 3% to 28% compared to the "as is" scenario. The minimum amount of CO_2 emission is reached in the scenario where the maximum allowed CO_2 emission is 55 billion kgs and is 28% less that the current amount of CO_2 emission.

- The costs of the transport flows increase when applying restrictions to either the rail or the waterway terminals. The total CO_2 emission however decreases when we impose to the model that flows transported in the current situation via waterways are not allowed to switch to another mode.

- Both rail and waterway terminals require the ability to handle more flows for the network "to be" situation compared to the "as is" situation. The biggest increase in volume going through rail terminals is in the areas of Milan, Barcelona and Poznan. Waterway terminals with the biggest volume increase are situated around Basel, Stuttgart, Wels Linz and Berlin.

- The modal shift scenarios mainly show a shift to waterway transport in the BeNeLux, Germany, Austria, Switzerland area. When applying a restriction that 50% of the ton-kilometres of road are transported over a distance bigger than 300 kilometres is shifted to another mode, the increase of rail and waterway usage is comparable.

- In general, the assumption is that the minimisation of CO_2 emissions increases the cost. However, the analyses show that it is possible for both KPIs to decrease at the same time compared to the "as is" situation. Rail is the preferred mode of transport when focusing on minimum CO_2 emissions while waterway is the most cost-effective mode of transport. However, rail and waterway transport also require transport to and from the terminals. Since rail terminals are more widely spread and therefore often closer to the origin or destination, rail often turns out to be the preferred solution also from cost perspective. This means it is possible to save both on cost and CO_2 emission by choosing the right mode of transport.

- Compared to the "Network as is", the capacity of all Clusters 2.0 rail terminals is growing in the "Network to be" scenario. The exception is the rail terminal Duisburg which is decreasing due to its position in the network.

When deciding for the best scenario to put into practice, both costs and CO_2 emissions should be considered. Clusters 2.0 is focusing on combining transport between clusters and making use of other modes of transport than road for these combined shipments. Unlike the analysis in this report, it will not include all European transport flows, nor will it be a strict cost or CO_2 emission optimisation. Therefore, the most realistic expected cost and CO_2 emission savings for living labs within the Clusters 2.0 project are comparable with the savings realized in the mode shift scenario where 50% of the ton kilometres of road transport over more than 300 kilometres are shifted to either waterway or rail (13% cost savings and 12% CO_2 emission savings).

The results of this analysis can also be seen as a first step towards the concept of the Physical Internet. Several simulation studies have been carried out to investigate the potential benefits of the Physical Internet. Sarraj et al (2014) finds a reduction in total costs of 5 to 30% and decreased CO_2 emissions of 13 to 58%, depending on the different scenarios and designs of the network. The European Technology Platform ALICE (Alliance for Logistics Innovation through Collaboration in Europe) designed a roadmap to arrive at the PI in 2030 and Zero Emission in 2050. As the roadmap shows, the PI will not materialize overnight. Various steps need to be taken to move into the direction of the PI in one form or another in the near future.

Collaboration between logistic clusters by combining transport on different modes can be one of these steps. The report aims to strengthen our understanding of this possibility. This analysis of the various scenarios shows promising results.

1. Introduction

1.1 Position of this report in Clusters 2.0

The vision of Clusters 2.0 is to leverage the full potential of European Logistics Clusters for a sustainable, efficient and fully integrated transport system. Within this project an optimised network design, based on the Clusters aggregated demand data and the available services, is to be developed in Work Package 3 (Symbiotic Network of Logistics Clusters). This deliverable is reflecting work carried out in Task 3.5 (Supply Chain Match Making between the Smart Clusters Network). Due to the re-scoping (due to a lack of data from living labs) of Work Package 3 in 2018, this deliverable is now directed to analyse the potential of different options of the “to be” situation for European transport flows based on Eurostat data instead of Clusters’ data.

1.2 Purpose of this deliverable

The document is focused on analysing and optimising European macro transport flows (based on Eurostat data, see Annexes). It provides insight in the cost and CO_2 savings potential of several scenarios applied to European transport flows. Moreover, it shows the potential in the European network for collaborative transport between intermodal logistics clusters, i.e. agglomerations of several types of firms and operations (logistics service providers, logistics operators, linked logistics industries and manufacturing). Furthermore, it indicates the benefits of collaborative transport with respect to increased transport efficiency and multimodality and as a result decreased costs and emissions.

The document is a result of task 3.5 of the EC project Clusters 2.0, in which a methodology is developed to search for the best possible combination of bundling cargo-flows and (new) multimodal transport services. Deliverable 3.6 (Network Design Model describing current European flows across clusters: “as is”) presented the results of an analysis of the current flows and network, in order to identify lanes for increased bundling and/or modal shift, i.e. a shift from road transport to rail or waterway transport. This report builds on these findings and further analyses the potential by modelling several scenarios to the data, analysing the outcomes and translating these into conclusions. The goal is to identify the potential savings in transport-costs and CO_2 emissions using different scenarios involving collaboration and modal shift. The outcomes can be seen as a first step towards putting it in practice in the Living Labs within the Clusters 2.0 project but also as the first step towards the Physical Internet.

1.3 Intended audience

The document is addressed to the Clusters 2.0 project partners. In addition, it is also intended to inform policy makers, shippers looking for sustainable collaboration partners, logistics service providers, intermodal operators and terminals and other parties interested in joining the Clusters 2.0 project and/or implementing the results in daily practice.

1.4 Outline of the report

The remainder of this document is structured as follows. Chapter 2 will recap the most important findings of the analysis of the current European network. Chapters 3, 4 and 5 will present the results of different optimisation scenarios around three focus areas (see Table 2). Chapter 3 focuses on cost optimisation, chapter 4 on different modal shift scenarios and chapter 5 on CO_2 optimisation. Chapter 6 summarises the conclusions from the analysis and its implications towards practice and the future.

Chapter	**Focus area**	**Scenario name**	**Explanation**
2	Current European network	Network “as is”	
3	Cost optimisation	Network “to be”	Unconstrained
		Fixed rail flows	Fix all current rail flows and choose between waterway and road for other flows
		Fixed waterway flows	Fix all current waterway flows and choose between rail and road for other flows
4	Modal shift	Modal shift road >300 km	Modal shift for all road transport >300 km
		Modal shift road >700 km	Modal shift for all road transport >700 km
		Modal shift 50% of tonkm road >300 km	Modal shift for 50% of tonkms on road transport >300 km
5	CO_2 optimisation	Maximum 60 billion kg	CO_2 emission constrained at 60 billion kg
		Maximum 55 billion kg	CO_2 emission constrained at 55 billion kg

Table 2: Scenario summary

2. Current European network

An extensive overview of the stakeholders in the Clusters 2.0 network and the transport flows throughout Europe is provided in Deliverable 3.6 (Network Design Model describing current European flows across clusters: as is). New network data on the TEN-T network was gained, between writing this delivery and the writing time of Deliverable 3.6. The new network definition (which is thoroughly described and analysed in the following subsections) does not have any effect on the current state analysis regarding the Clusters network. However, it influences the results of the analyses carried out in the European network, i.e. including all European terminals that were used to build upon in this deliverable. Therefore, this chapter describes the changes in the network definition, the changes in the calculated Key Performance Indicators (KPIs) and the changes in the potential within the European network.

2.1 Changes to intermodal network definition

The updated intermodal network, modelled using Llamasoft Supply Chain Guru (https://www.supplychainguru.com/DataServices/GetTenTNetwork), contains additional information on the nodes and lanes in the TEN-T network. It still defines the network at a high structure level, but it extends the network especially at the ends. The network is somewhat less detailed in the Benelux, but still fulfills the level of detail required to perform this strategic study using NUTS2[1] regions as origins and destinations. Figure 1 and Figure 2 show the new network and the changes between the renewed and old rail and waterway networks.

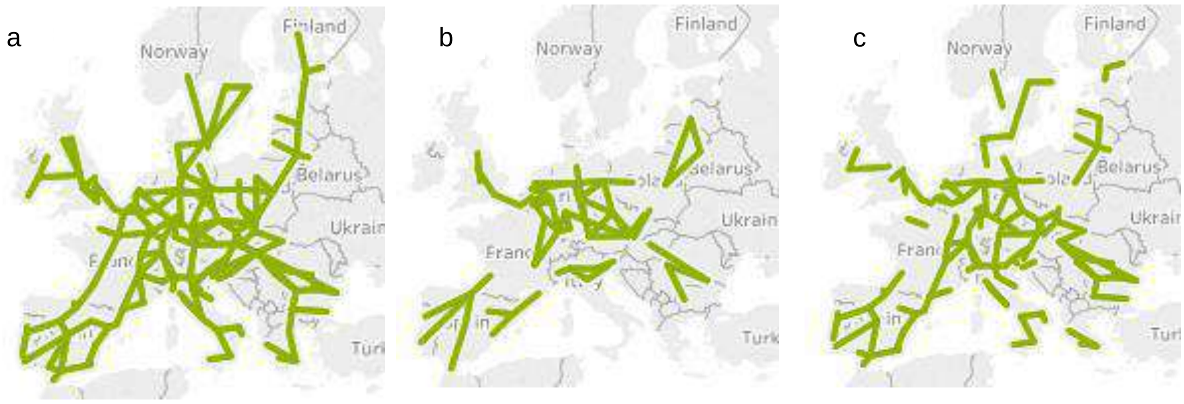


Figure 1: Changes rail network

a. Complete rail network new definition
b. Rail lanes that were in the old network definition and not in the new network definition
c. Rail lanes that are in the new network definition and not in the old network definition

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[1] The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU for the purpose of (1) The collection, development and harmonisation of European regional statistics; (2) Socio-economic analyses of the regions; (3) Framing of EU regional policies. The NUTS2 classification refers to basic regions for the application of regional policies.

Figure 2: Changes waterway network

- *a. Complete waterway network new definition*
- *b. Waterway lanes that were in the old network definition and not in the new network definition*
- *c. Waterway lanes that are in the new network definition and not in the old network definition*

2.2 Changed KPIs for European network

The KPIs that were calculated in paragraph 2.5 in Deliverable 3.6 (number of TEUs transported, transport costs and CO_2 emissions) will change somewhat for the European network, since they are based on the updated lanes and distances in the network. An overview of the KPIs and changes is given in Table 3.

	TEUs (x1,000)	**Costs (x1,000,000 euros)**	**CO2 (x1,000,000 kgs)**
Network old “as is” (D3.6)	332,731	931,930	84,449
Network new “as is” (D3.7)	332,731	862,701	76,791

Table 3: KPIs old and new “as is”

There is an additional effect for the waterway network. To determine the flows from origin to destination by waterway, the closest waterway terminal for each NUTS2 region was chosen. Hereafter, a route for an origin-destination pair was found by finding a route in the waterway network for their corresponding closest waterway terminals. As the old network was not fully connected it could be that such a route did not exist. The consequence was that this flow was routed by road instead. This happened mainly at the ends of the network, but there were also some disconnected terminals in the core of the network. With the new network definition all NUTS2 regions that have water transport according to the macro data can be reached. Therefore, more tons will be transported by waterway than with the old network definition (see Figure 3).

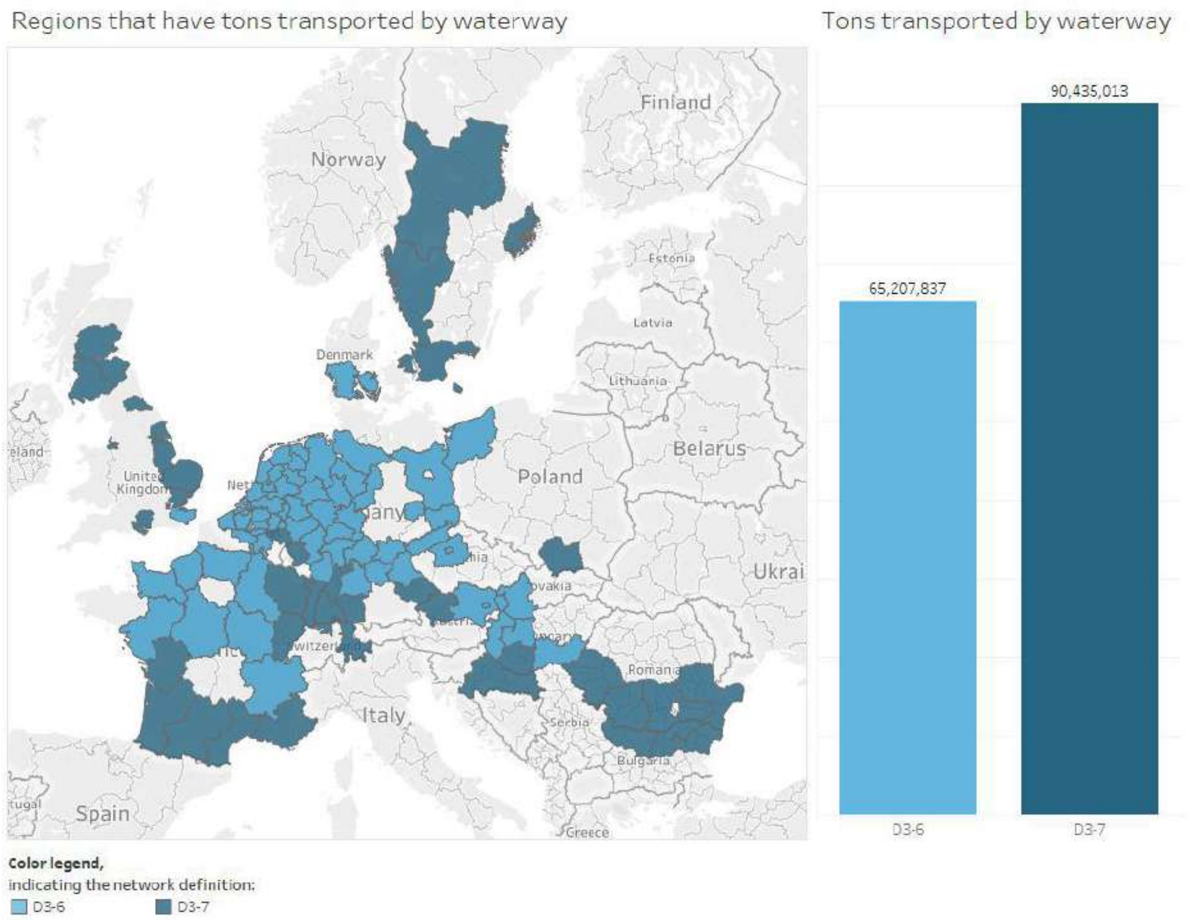


Figure 3: Changes in tons transported by waterway

2.3 Changed potential in the European network

There are more terminals in some areas and fewer terminals in other areas with the new network definition. This causes the flow between terminals to have a different spread then with the old network definition. Especially the UK, Spain and the North-East attract somewhat more potential compared to the analyses in paragraph 3.2 of Deliverable 3.6. This is a consequence of the rail and waterway network running further into these areas. The main conclusions from Deliverable 3.6 still hold, although the area of Bologna has more potential for rail than for waterway in the new network definition.

3. Cost optimisation European flows

Now that the current transport flows and their routing have been re-established, this chapter describes the results of the evaluated scenarios focusing on finding the minimum cost for transporting all European flows. For each scenario the effects on the KPIs will be presented (the number of TEUs per mode, the costs and the CO_2 emission for all flows). Maps from the developed Tableau dashboard will be provided to indicate the division of mode usage per origin and destination region and to show the network paths. Hereafter, the consequences for the terminals will be discussed.

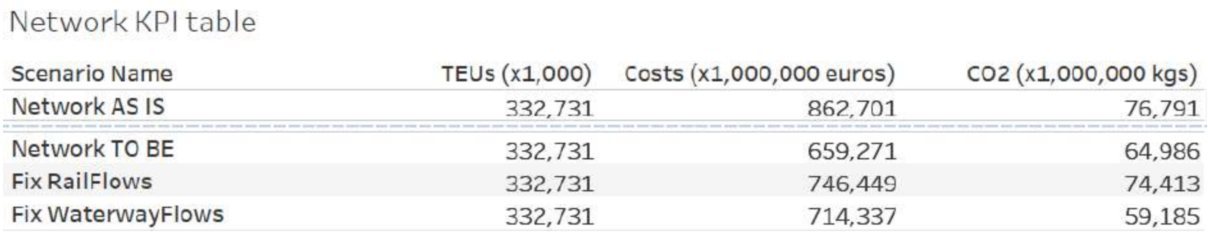
As shown in Table 2, three scenarios on cost optimisation have been analysed. These scenarios set the more theoretical boundaries. Next to an unconstrained cost optimisation, the effect of fixing either rail or waterway flows is researched to get more insight in the trade-offs in case there would be a capacity limitation.

1. The first scenario is the network “to be”, meaning there have not been given any restrictions to the network model, i.e. the model decides the optimum transport mode and route for each flow assuming unlimited capacity.
2. The first variant to the “to be” optimisation is the scenario where all rail flows are fixed, meaning the model decides on the best option for all current transport by waterway and road. This scenario considers the current rail terminal flows as maximum capacities and finds an optimum around this constraint.
3. The second variant to the “to be” optimisation is the scenario where all waterway flows are fixed, meaning the model decides on the best option for all current transport by rail and road. This scenario considers the current waterway terminal flows as maximum capacities and finds an optimum around this constraint.

3.1 Cost optimisation KPIs

The results for the three scenarios are summarized in Table 4. Figure 4,

Figure 5 and Figure 6 are snapshots from the developed interactive dashboard and show the details of the scenario for each KPI.



Network KPI table

Scenario Name	TEUs (x1,000)	Costs (x1,000,000 euros)	CO2 (x1,000,000 kgs)
Network AS IS	332,731	862,701	76,791
Network TO BE	332,731	659,271	64,986
Fix RailFlows	332,731	746,449	74,413
Fix WaterwayFlows	332,731	714,337	59,185

Table 4: KPIs per cost optimisation scenario

The number of TEUs is similar for all three scenarios. However, the division over the modes changes (see Figure 4). In the network “to be” significantly less TEUs are transported by road while significantly more TEUs are transported by waterway compared to the “as is” network. Fixing the rail flows results in a similar finding. By fixing waterway flows however, the number of TEUs transported by rail increases significantly, while the number of TEUs transported by road decreases even further. These findings indicate that waterway is the preferred option for the model over rail. However, it suddenly becomes much more interesting, when it is not possible to transport more volume by rail due to rail capacity constraints

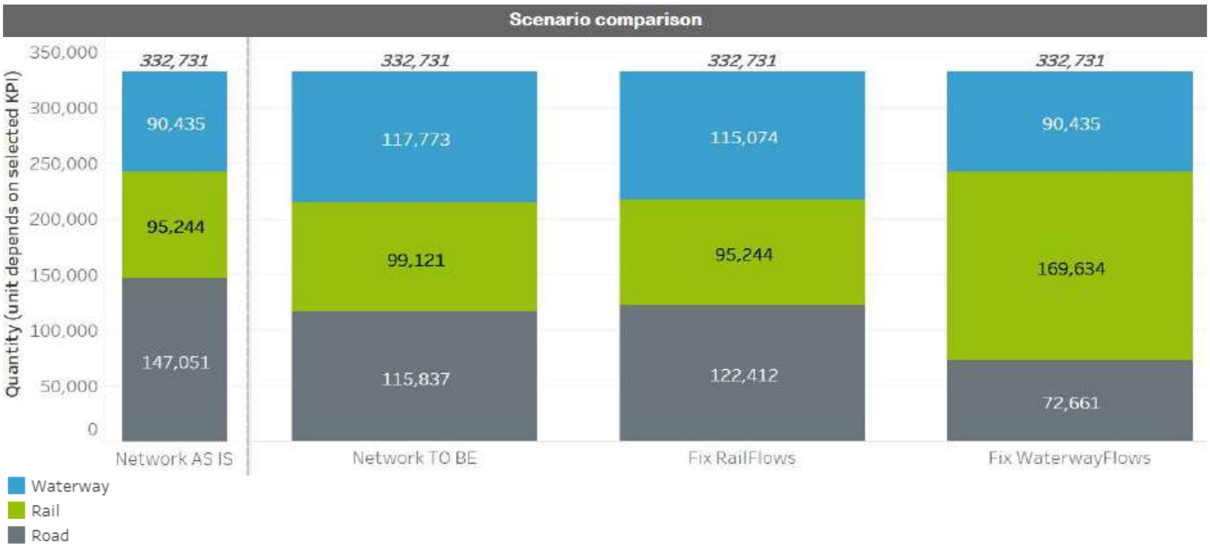


Figure 4: Number of TEUs (x1,000) per mode for each cost optimisation scenario

The costs of the transport flows are optimised in the network "to be" (see Figure 5). The costs of rail transport consist of three parts: the road transport from the origin to the rail terminal, the rail transport itself and the road transport from the rail terminal to the destination. The same goes for the costs of waterway transport. When fixing the flows of either the rail or the waterway transport, the total transport costs increase compared to the "to be" scenario. This is mainly caused because one mode is not optimised but fixed resulting in reduced flexibility in the model. However, the total transport costs are still significantly lower compared to the "as is" network.

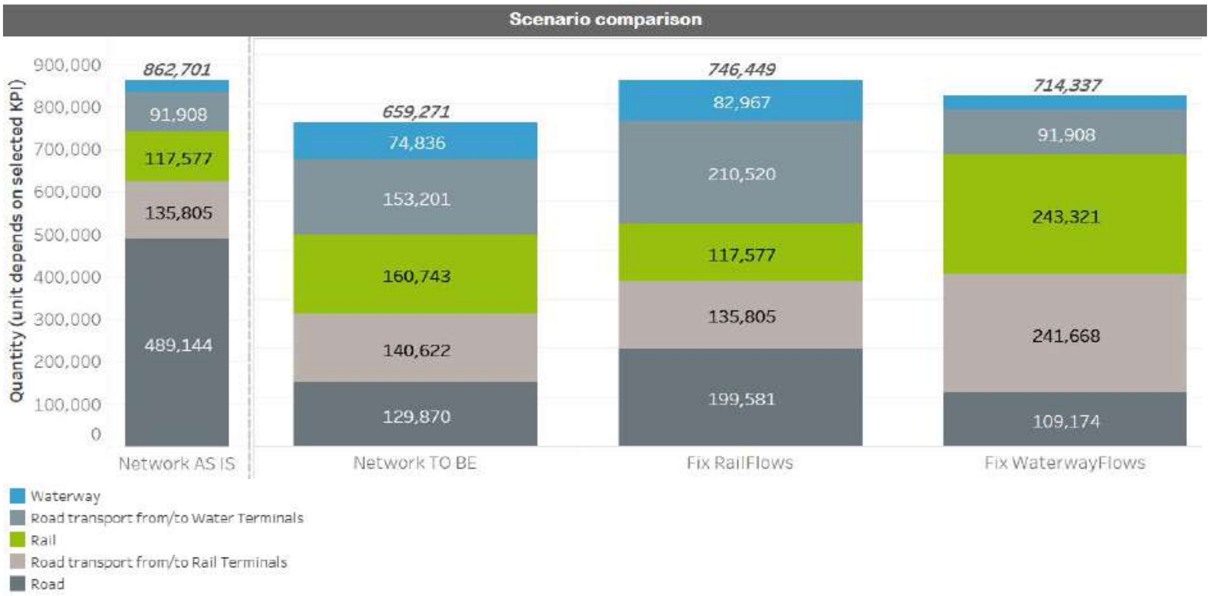


Figure 5: Cost (x1,000,000 euros) per mode for each cost optimisation scenario

A different finding arises, when looking at the CO_2 emission. For all three scenarios, the CO_2 emission decreases compared to the "as is" network situation because less volume is transported by road (including the pre- and after-transport to and from terminals). However, the CO_2 emission further decreases with 23% compared to the “as is” situation, when fixing the waterway flows (see Figure 6). This can be explained because there is a volume shift towards the less emitting rail transport in this scenario.

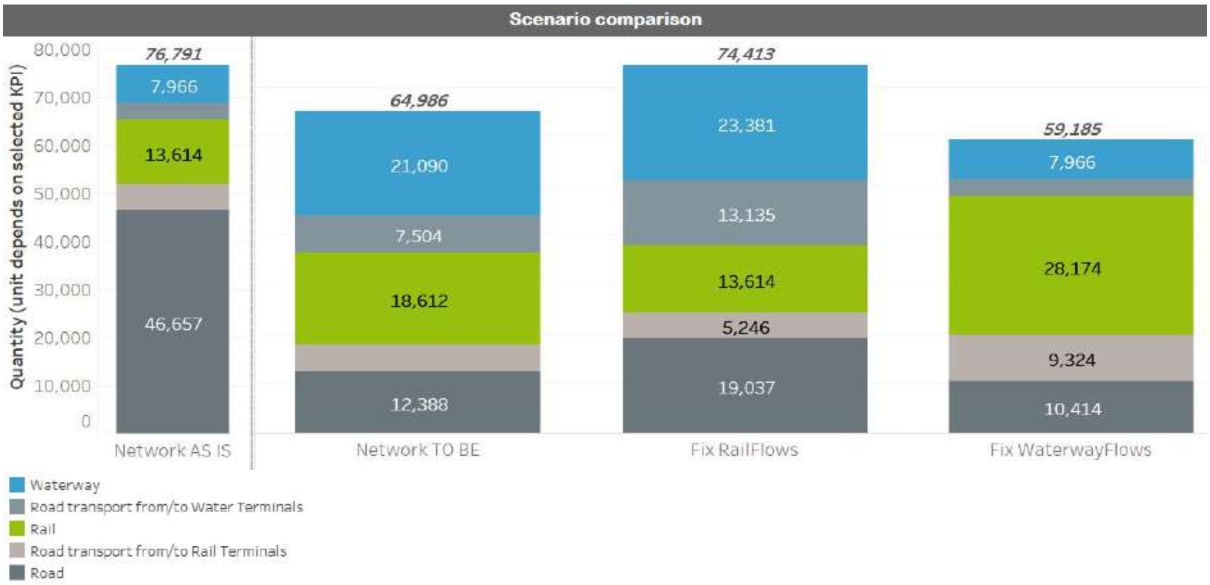


Figure 6: CO_2 emission (x1,000,000 kgs) per mode for each cost optimisation scenario

3.2 Cost optimisation maps

The underlying causes of the changes in the KPIs can be better explained by looking at the cost function. Transport by road is relatively expensive compared to transport by rail or by waterway (see Annexes for parameter setting). However, transport by rail and waterway has an additional fixed cost and requires pre and post haulage by road to get to the terminal from the origin and from the terminal to the destination. If an origin would be located on a rail- or waterway terminal, no pre-transport is required. In this case, for all transport over 200 kilometres waterway would be the preferred solution from a cost perspective (see Figure 7).

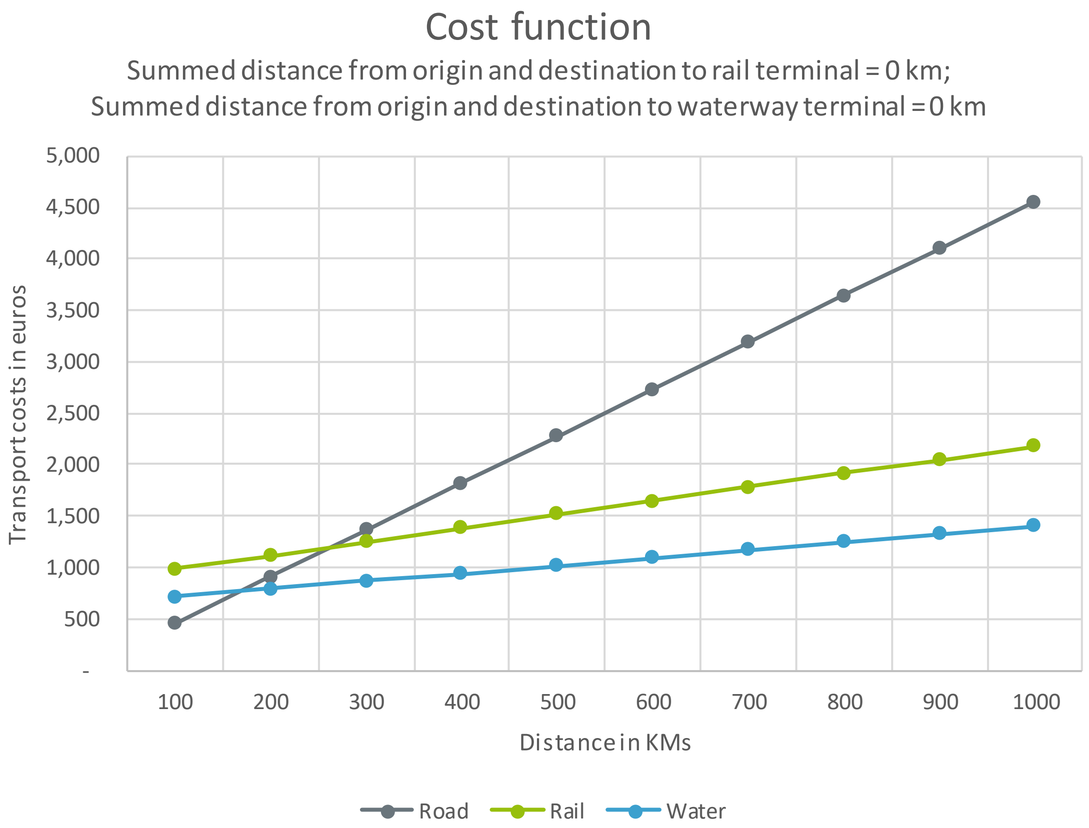


Figure 7: Transport costs per transport mode for increasing distance when summed distance from origin and destination to rail and waterway terminal is 0 km (per TEU)

However, when pre-transport is required the breakpoint for the preferred mode looks different. For example, when the summed distances from the origin and destination to the nearest rail terminals is 150 kilometres and the summed distances from the origin and destination to the nearest waterway terminals is 280 kilometres (based on the example from NUTS2 region AT11m e.g. Eisenstadt or Rust, to NUTS2 region DK03, e.g. Kolding or Odense), road is the cheapest way of transportation for all transport up to 500 kilometres. For transportation over 500 to 700 kilometres rail is the most cost-efficient way of transport. Only at distances over 700 km, waterway becomes the preferred mode of transport (see Figure 8).

Figure 8: Transport costs per transport mode for increasing distance when summed distance from origin and destination to rail terminal is 150 km and summed distance from origin and destination to waterway terminal is 280 km (per TEU)

To get a better understanding of the changes in the KPIs, maps have been developed. Figure 9 shows the division of modes per supplying or demanding region for each cost optimisation scenario (in TEUs). Again, it can be seen that the model mainly chooses to make more use of waterway transport when there are no restrictions (figure a). The waterway transport is mainly chosen in central Europe whereas Spain and Italy for example, are almost fully using rail transport in the “to be” situation. When the waterway flows are fixed, a significant increase of rail transport can be seen in central Europe (figure c).

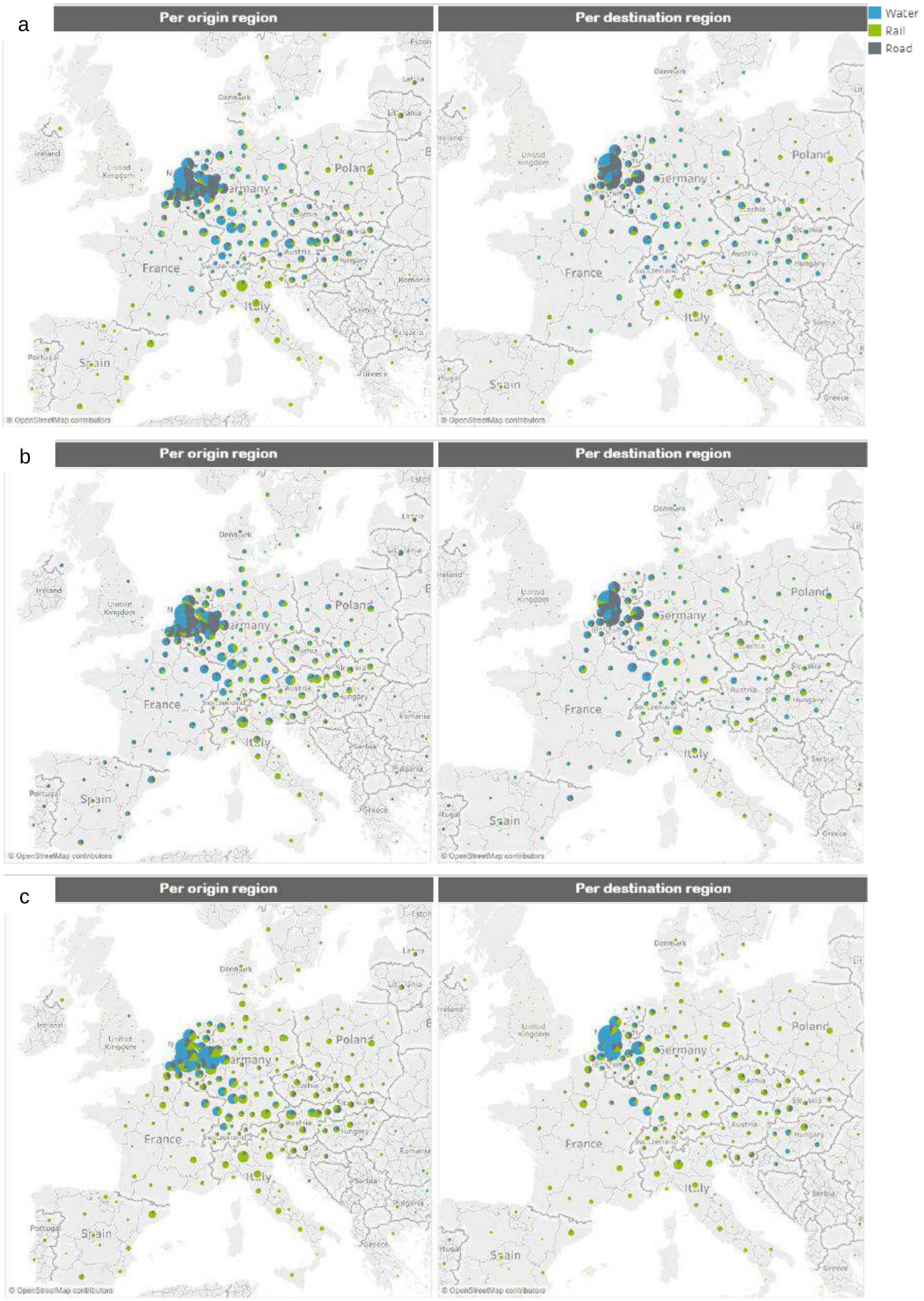


Figure 9: TEUs per mode per supplying or demanding region for each cost optimisation scenario

a. Network to be
b. Rail flows fixed
c. Waterway flows fixed

Figure 10 shows the network paths for rail and waterway in each scenario (including road transport to the terminals). This figure illustrates that the model prefers to transport over a further distance to a waterway terminal only when the rail flows are fixed (because of lower costs; figure b), e.g. in Spain, Italy and Greece. With unlimited capacity at the rail terminals (figure a), rail transport would be preferred in those areas. When fixing the waterway flows it seems that road is used for lanes with a long distance from a terminal, while other lanes are switched to rail transport (figure c).

Figure 10: Network paths per for each cost optimisation scenario

a. Network to be
b. Rail flows fixed
c. Waterway flows fixed

3.3 Terminal capacities

Optimising the European network has an influence on the required capacity of the waterway and rail terminals. In the "to be" network most additional rail volume from neighboring regions will flow through the terminals in Milan and Barcelona followed by Poznan, Warsaw and Venice (see Figure 11). Whereas Milan and Warsaw already process large volumes, especially Barcelona (plus about 200%) and Poznan (plus about 150%) would need significantly more capacity to be able to process all optimised transport flows from the neighboring regions by rail.

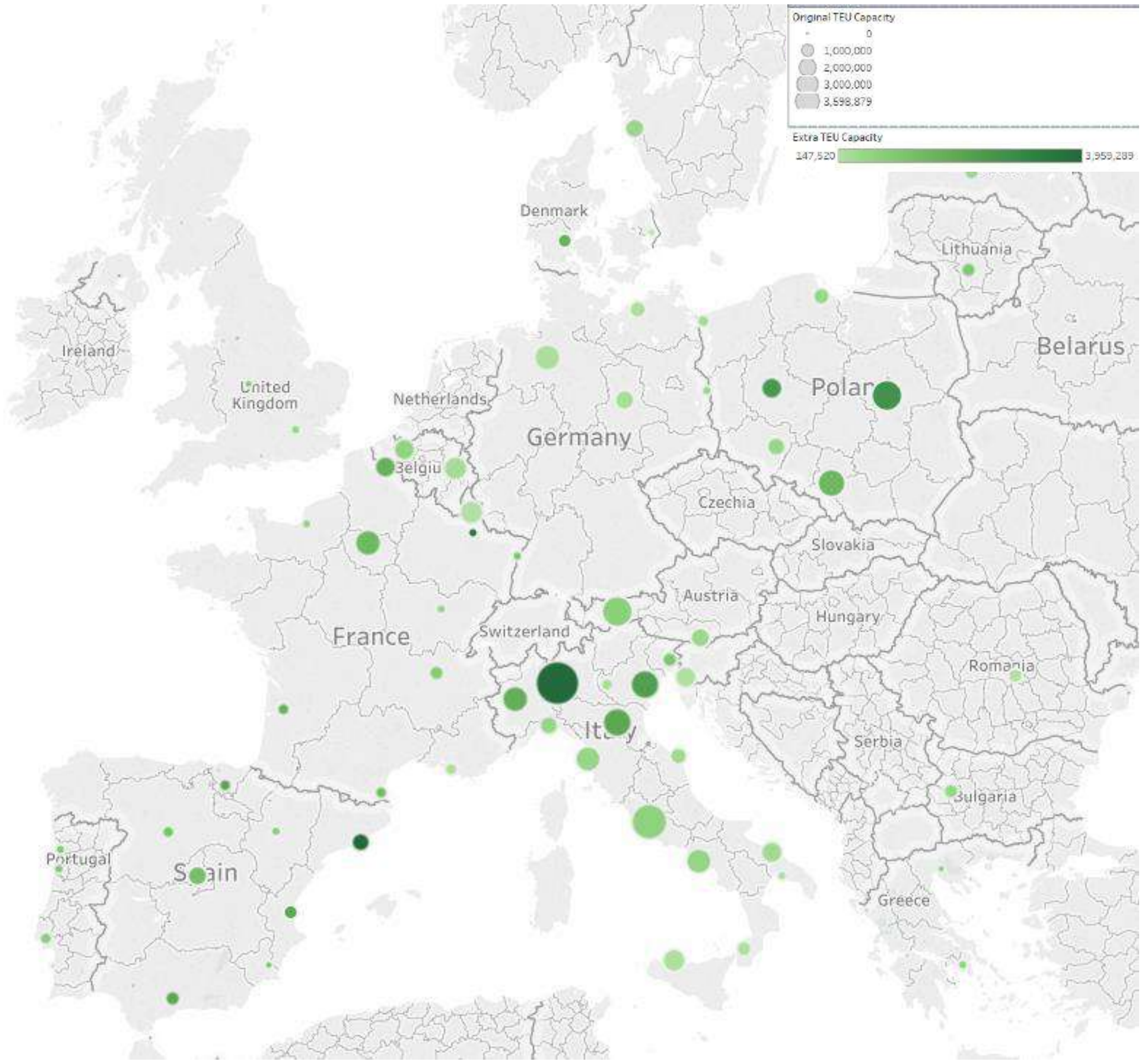


Figure 11: Overview rail terminals that require capacity increase for cost optimisation realisation

In the "to be" network most additional waterway volume will flow through the terminals in Basel followed by Stuttgart, Wels Linz and Berlin (see Figure 12). Whereas Basel and Stuttgart already process large volumes, especially Wels Linz (plus about 200%) and Berlin (plus about 150%) would need to be able to process significantly more flows by waterway.

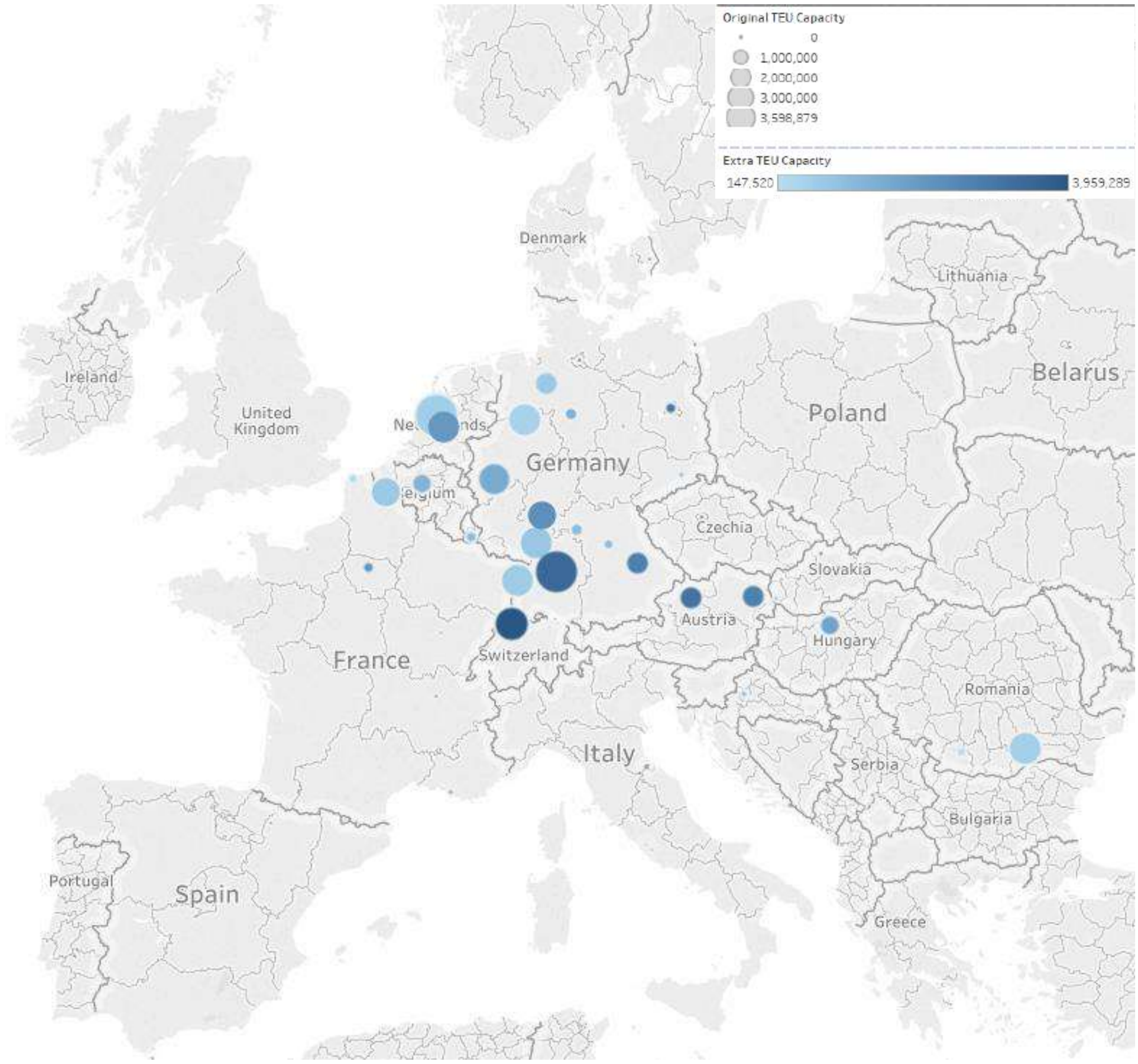


Figure 12: Overview waterway terminals that require capacity increase for cost optimisation realisation

4. Modal shift

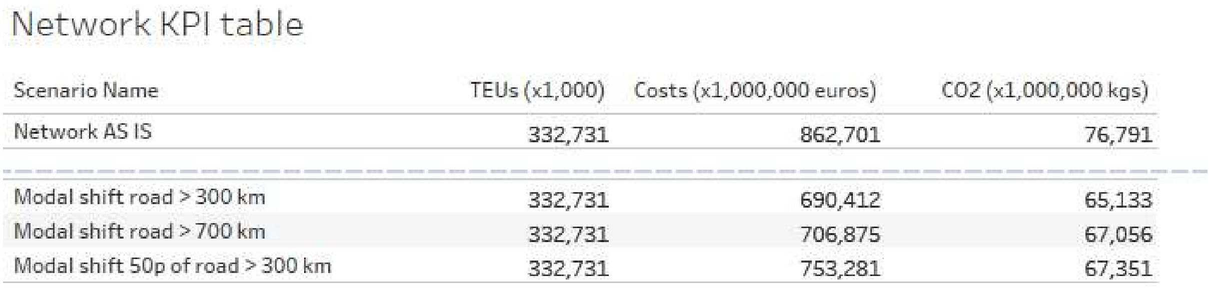
This chapter further analyses the potential of maximum modal shift within Europe; i.e. what is the effect of forcing transport flows by water or rail instead of by road. Again, the effects on the KPIs will be presented (the number of TEUs per mode, the costs and the CO_2 emission for all flows) and maps will be provided to indicate the division of mode usage per origin and destination region and to show the network paths for each scenario.

The financial break-even point for modal shift is at 300 kilometres according to the white paper of the EC DG Move (EC 2011). However, during the European High-Level Industry Board Meetings for the Clusters 2.0 project of April 10th 2019, this number was contested. Instead it was argued that the breakpoint was more at 700 kilometres in practice because of the added complexity and work. Also, the European Transformers project (Hariram et al., 2016) argued that only 50% of the ton kilometres of routes over more than 300 kilometres could be shifted to waterway or rail. Therefore, three scenarios have been analysed to gain more insight in the effects of modal shift (also see Table 2) and the trade-offs and break-even point between the various modes.

1. All road transport over less than 300 kilometres continues to be transported by road; all rail and waterway transport under 300 kilometres and all transport over more than 300 kilometres will be transported by either rail or waterway (option with lowest cost is chosen by the model).
2. All road transport over less than 700 kilometres continues to be transported by road; all rail and waterway transport under 700 kilometres and all transport over more than 700 kilometres will be transported by either rail or waterway (option with lowest cost is chosen by the model).
3. All road transport over less than 300 kilometres continues to be transported by road; 50% of the ton kilometres of road transport over more than 300 kilometres also continues with road transport while the other 50% is either transported by rail or by waterway; all rail and waterway transport under 300 kilometres and all transport over more than 300 kilometres will be transported by either rail or waterway (option with lowest cost is chosen by the model).

4.1 Modal shift KPIs

The KPIs for the three scenarios are summarized in Table 5. Figure 13, Figure 14 and Figure 15 show more details on each KPI per scenario.



Network KPI table

Scenario Name	TEUs (x1,000)	Costs (x1,000,000 euros)	CO2 (x1,000,000 kgs)
Network AS IS	332,731	862,701	76,791
Modal shift road > 300 km	332,731	690,412	65,133
Modal shift road > 700 km	332,731	706,875	67,056
Modal shift 50p of road > 300 km	332,731	753,281	67,351

Table 5: KPIs per modal shift scenario

The number of TEUs is similar for all three scenarios. However, the division over the modes changes (see Figure 13). For the scenario where all road transport over more than 300 kilometres is forced to be transported by either rail or water the number of TEUs transported by rail increases with about 25% and the number of TEUs transported by waterway is more than doubled compared to the “as is” situation. When only road flows with a length of more than 700 kilometres are shifted, the number of TEUs transported by rail stays roughly the same as in the “as is” situation. For the last scenario, 50% of road transport over 300 km is shifted, both the number of TEUs on waterway and rail increase with about 22%.

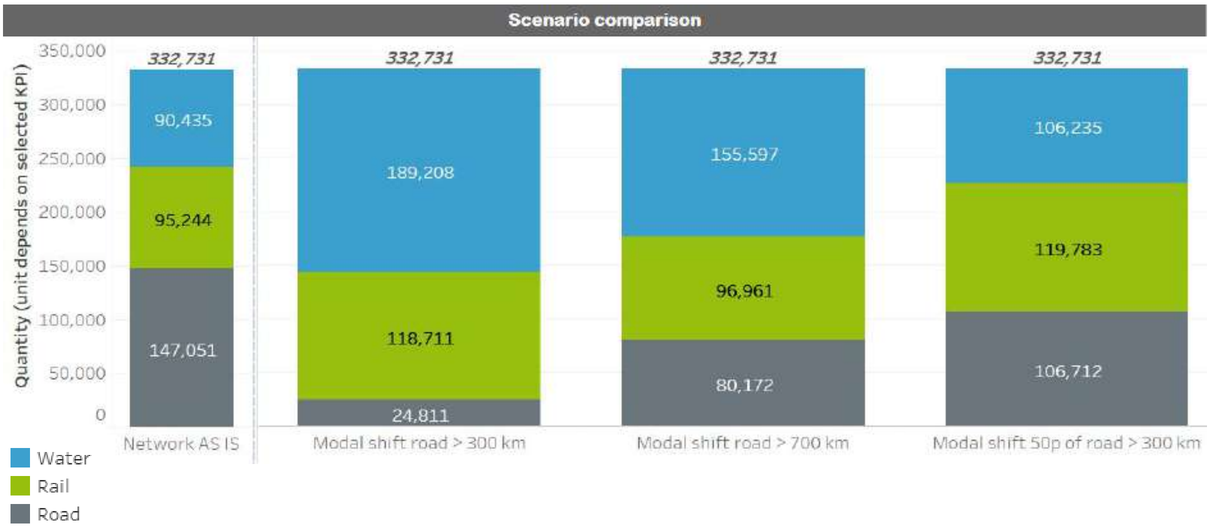


Figure 13: Number of TEUs (x1,000) per mode for each modal shift scenario

The scenario where all road transport over more than 300 kilometres is forced to be transported by either rail or waterway is the most cost efficient one (-20%, see Figure 14). The cost increases with the other two scenarios, but are still less than in the “as is” situation (-18 and -13% respectively). The savings over all scenarios derive from the decrease in road transport compared to the “as is” situation. However, the savings are partly consumed by the necessary transport to and from rail and waterway terminals. The costs for rail transport are quite constant over the three scenarios, while the costs for transport by waterway differ.

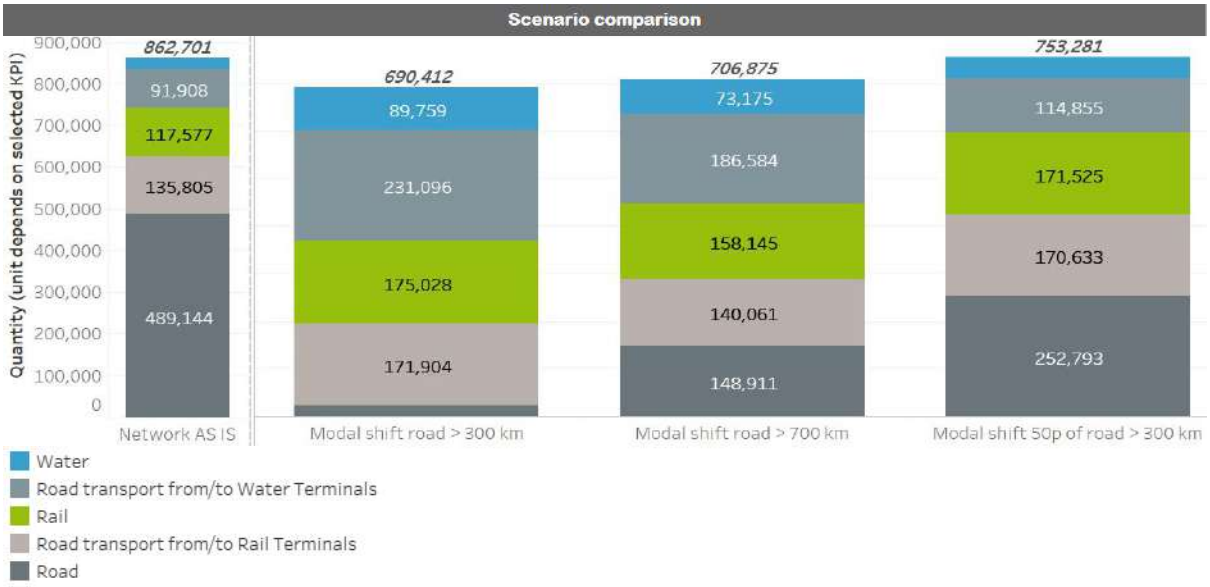


Figure 14: Cost (x1,000,000 euros) per mode for each modal shift scenario

When looking at the CO_2 emission the most favored scenario is also the one where all road transport over more than 300 kilometres is forced to be transported by either rail or waterway with a CO_2 reduction of 15% (see Figure 15). With the other two scenarios the CO_2 emission is higher than the first scenario, but it is still 12-13% lower than the CO_2 emission in the “as is” situation. The differences between the three scenarios are quite small, since the volume transported by rail is quite constant. The saved CO_2 emission by using waterway transport is mostly absorbed by the increase in transport to and from rail and waterway terminals.

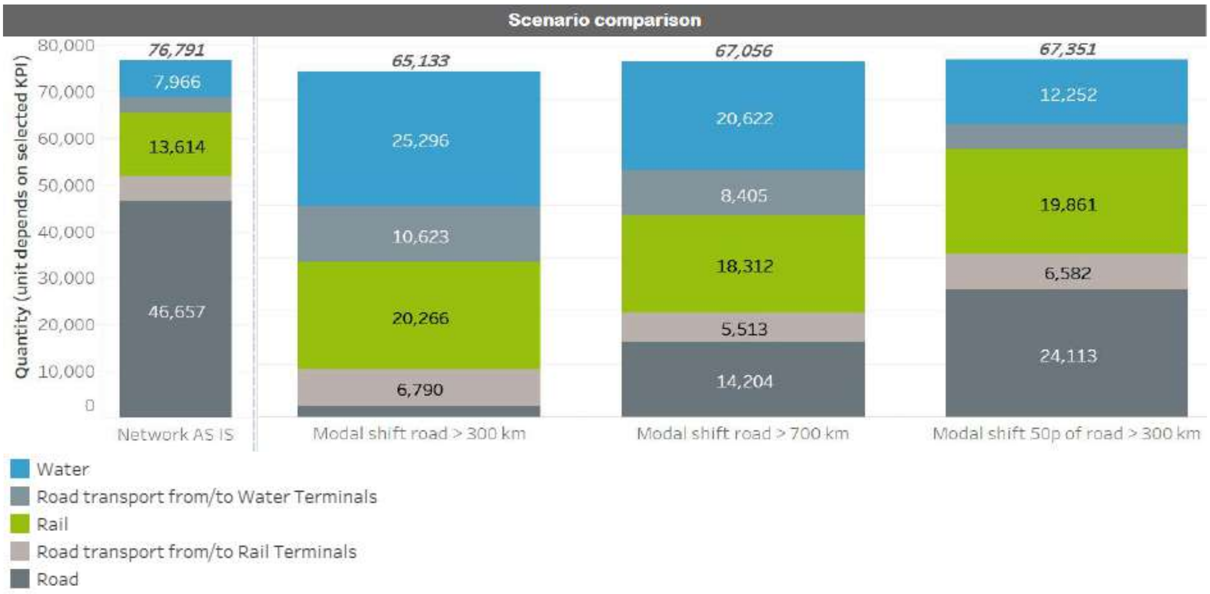


Figure 15: CO_2 emission (x1,000,000 kgs) per mode for each modal shift scenario

4.2 Modal shift maps

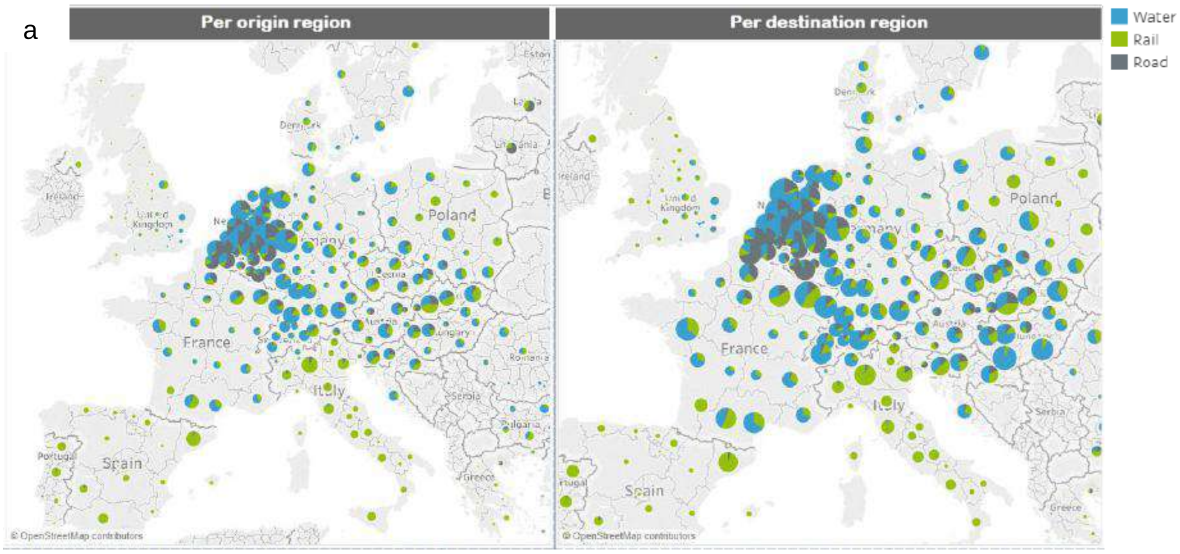
The underlying cost function as explained in paragraph 3.2 also explains what happens in these scenarios. Also in these scenarios, the most determining factor in the mode choice is the distance to the nearest rail and waterway terminal.

To get better understanding of the underlying causes of the changes in the KPIs, maps have been developed.

Figure 16 shows the division of modes per supplying or demanding region for each cost optimisation scenario (in TEUs).

When only transport over less than 300 kilometres can be transported via road, road transport is mostly used in the BeNeLux and West-Germany (figure a). Train is mostly used in Italy and Spain while the gravity point of waterway transport is in the BeNeLux. When longer distances are allowed by road, an increase in road transport is seen in Eastern-Europe (figure b). Spain and Italy only switch to road transport in the third scenario (figure c).

a



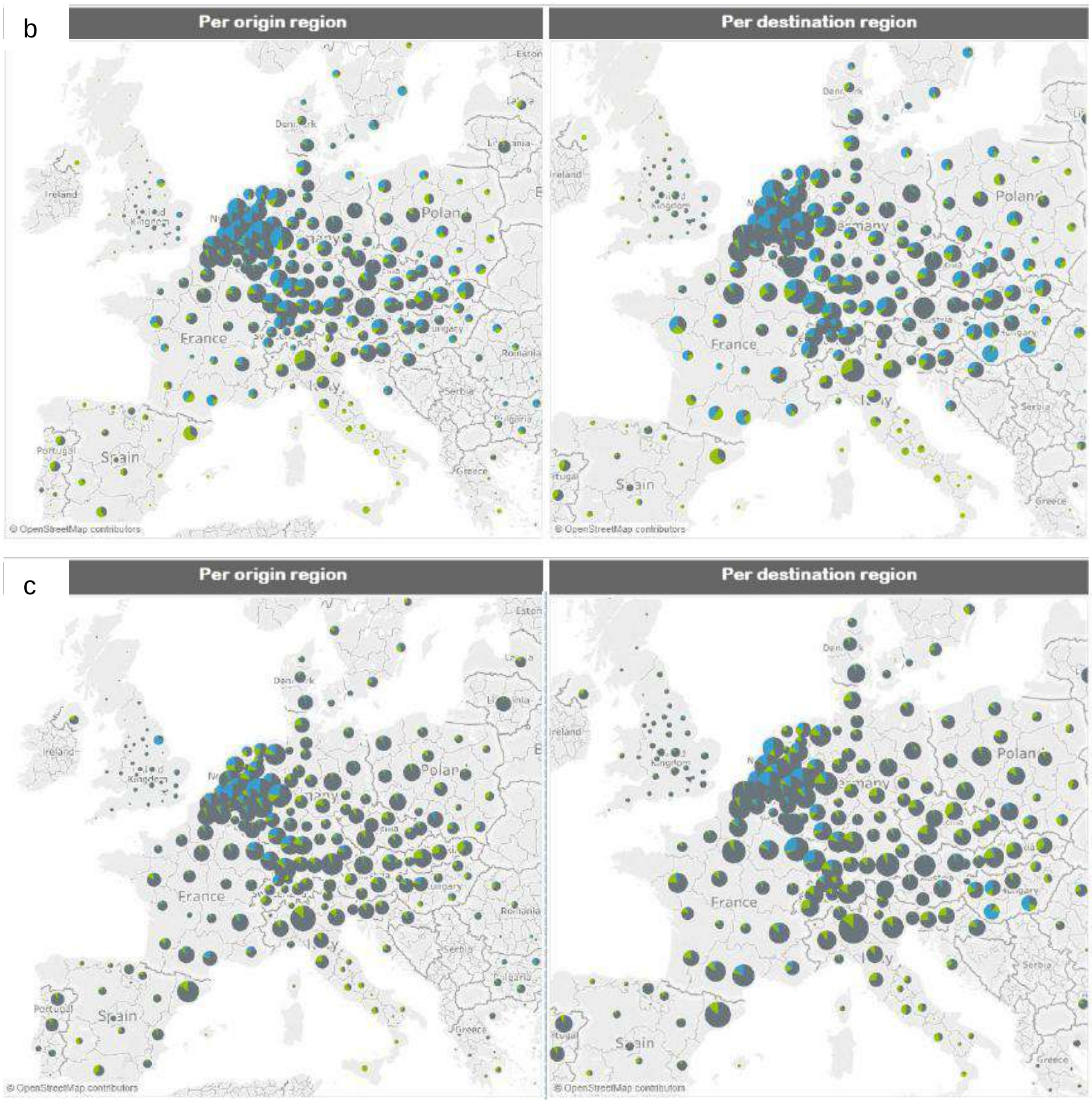


Figure 16: TEUs per mode per supplying or demanding region for each modal shift scenario

a. Modal shift of road transport >300 km
b. Modal shift of road transport >700 km
c. Modal shift of 50% of ton kilometres of road transport >300 km

Figure ***17*** shows the network paths for rail and water in each scenario (including road transport to the terminals). The changes in the network paths are minimal, which means the same routes are used throughout the scenarios (only the volumes differ).

c

*Figure 17: **Network paths per for each modal shift scenario***

a. Modal shift of road transport >300 km
b. Modal shift of road transport >700 km
c. Modal shift of 50% of ton kilometres of road transport >300 km

5. CO_2 emission minimisation

This chapter describes the results of the last set of the evaluated scenarios These scenarios are focusing on finding the minimum CO_2 emission for transporting all European flows. For each scenario the effects on the KPIs will be presented (the Number of TEUs per mode, the costs and the CO_2 emission for all flows). Maps will be provided to indicate the division of mode usage per origin and destination region and to show the network paths. Hereafter, the consequences for the terminals will be discussed.

The model used for these scenarios was constrained at a certain level of CO_2 emission. The CO_2 emission for the cost optimisation scenario (see 3.1 Cost optimisation KPIs) is about 65 billion kilograms. Therefore, the constraint started at an emission of 60 billion kilograms CO_2. For each following scenario the allowed CO_2 emission was reduced with 5 billion kilograms. The model became infeasible with the constraint of 50 billion kilograms CO_2 emission, i.e. there was no solution that could meet this requirement. This means the results of two scenarios will be presented here.

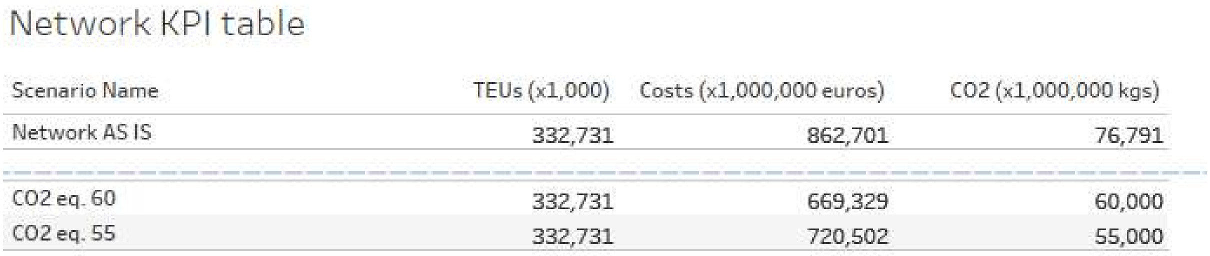
1. Cost optimisation with a maximum of 60 billion kilograms CO_2 emission (reduction of 22%)
2. Cost optimisation with a maximum of 55 billion kilograms CO_2 emission (reduction of 28%)

5.1 CO_2 emission minimisation KPIs

The KPIs for the two scenarios are summarized in Table 6. Figure 18,

Figure 19 and

Figure ***20*** show more details on each KPI per scenario.



Network KPI table

Scenario Name	TEUs (x1,000)	Costs (x1,000,000 euros)	CO2 (x1,000,000 kgs)
Network AS IS	332,731	862,701	76,791
CO2 eq. 60	332,731	669,329	60,000
CO2 eq. 55	332,731	720,502	55,000

Table 6: KPIs per CO_2 emission minimisation scenario

The number of TEUs is similar for all three scenarios. However, the division over the modes changes (see Figure 18). When the CO_2 emission constraint is set to 60 billion kilograms, the volume decrease on road is almost completely shifted to rail. When setting the constraint tighter to 55 billion kilograms, not only road but also waterway transport is shifted to rail transport.

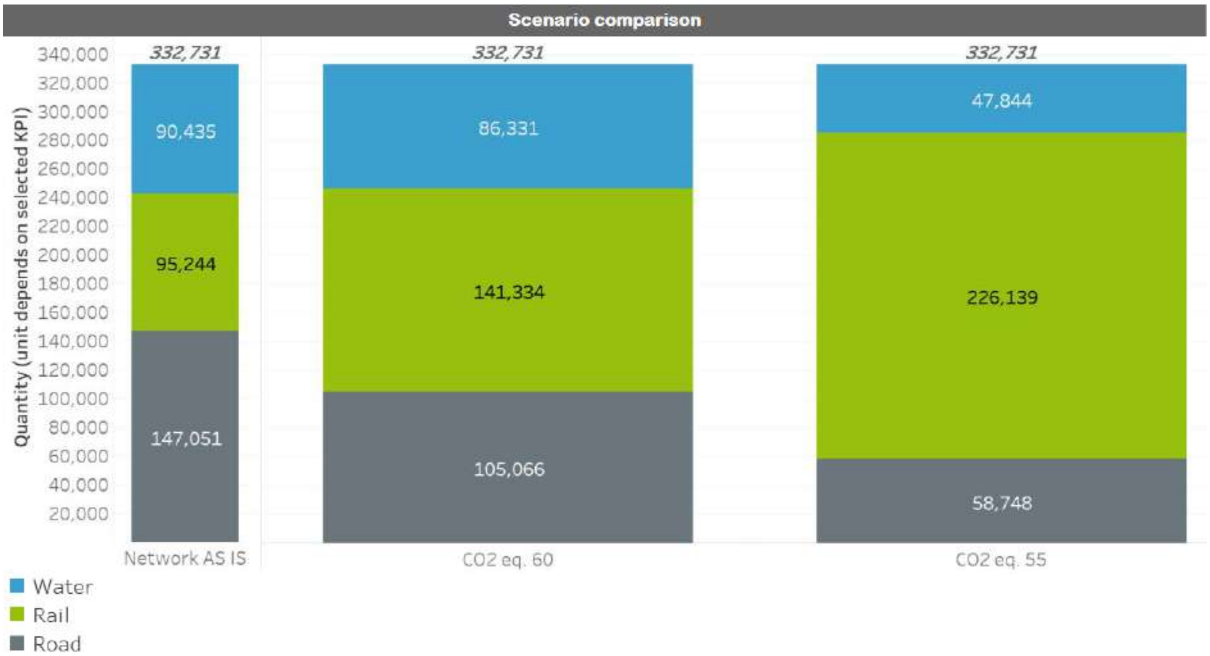


Figure 18: Number of TEUs (x1,000) per mode for each CO_2 emission minimisation scenario

The total cost increases when the CO_2 emission constraint is tightened (see Figure 19). However, the total costs are still significantly less than in the "as is" situation, because flows are optimised. This means it is possible to save both on cost and CO_2 emission by choosing the right mode of transport.

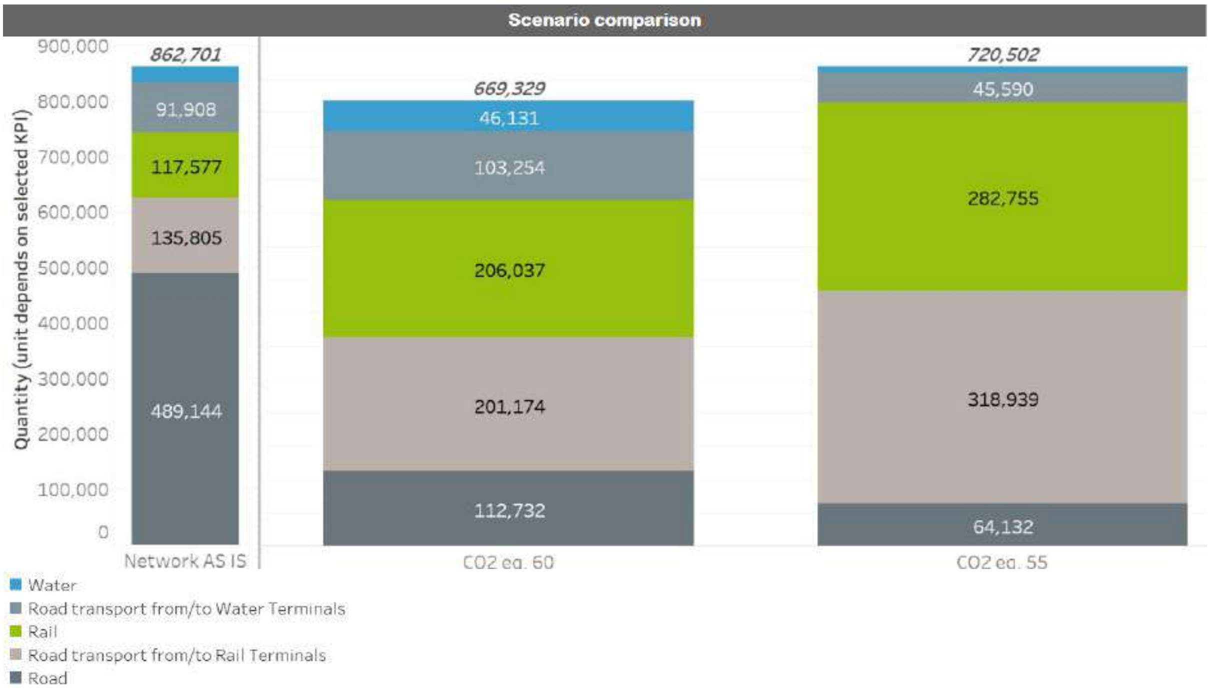


Figure 19: Cost (x1,000,000 euros) per mode for each CO_2 emission minimisation scenario

Rail is the preferred mode of transport, when focusing on minimum CO_2 emissions. The tighter the limit on CO_2 emissions, the more rail transport is used (see Figure 20).

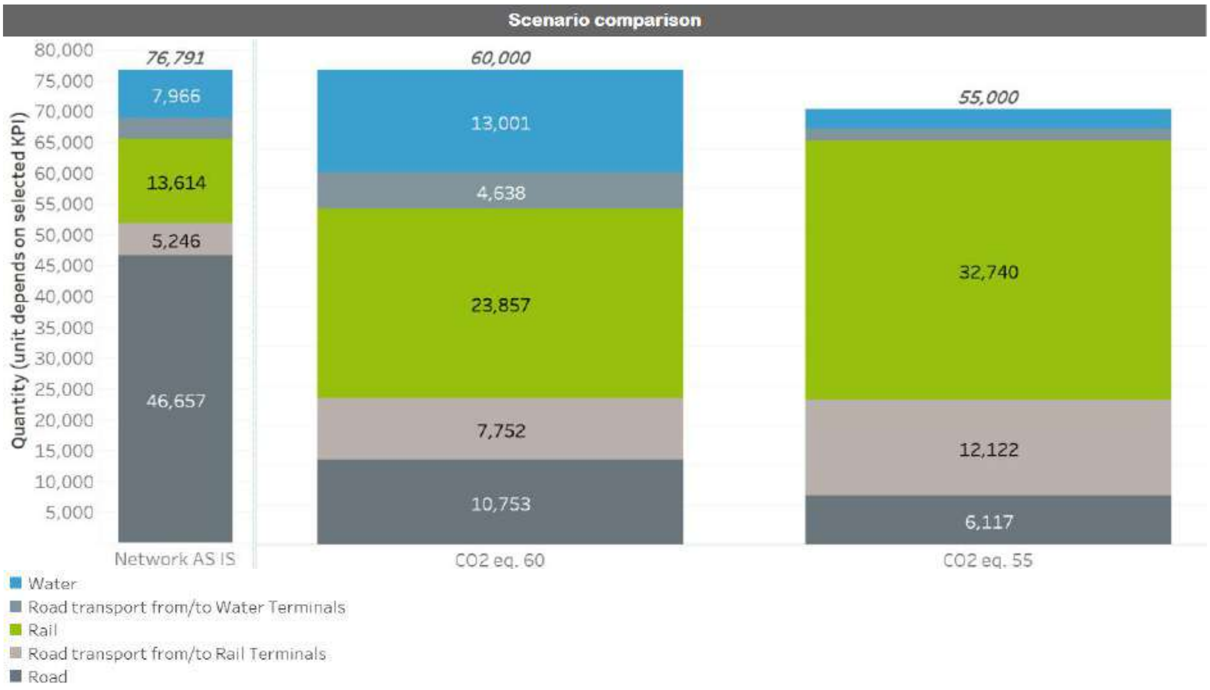


Figure 20: CO_2 emission (x1,000,000 kgs) per mode for each CO_2 emission minimisation scenario

5.2 CO_2 emission minimisation maps

The factors used to calculate CO_2 emissions can assist to understand what is happening in these scenarios. The model uses an emission of 0.062 kg / tonkm for road transport, an emission of 0.022 kg / tonkm for rail transport and an emission of 0.031 kg / tonkm for waterway transport (factors supported by McKinnon, 2011). Furthermore, the underlying cost function as explained in paragraph 3.2, also explains what happens in these scenarios. To get better understanding of the underlying causes of the changes in the KPIs maps have been developed. Figure 21 shows the division of modes per supplying or demanding region for each cost optimisation scenario (in TEUs).

Transportation by rail is selected for the longer distances, when trying to minimise CO_2 emissions. When the CO_2 constraint is set to a lower level, rail is also preferred over waterway and road on the shorter distances in Central Europe (figure b).

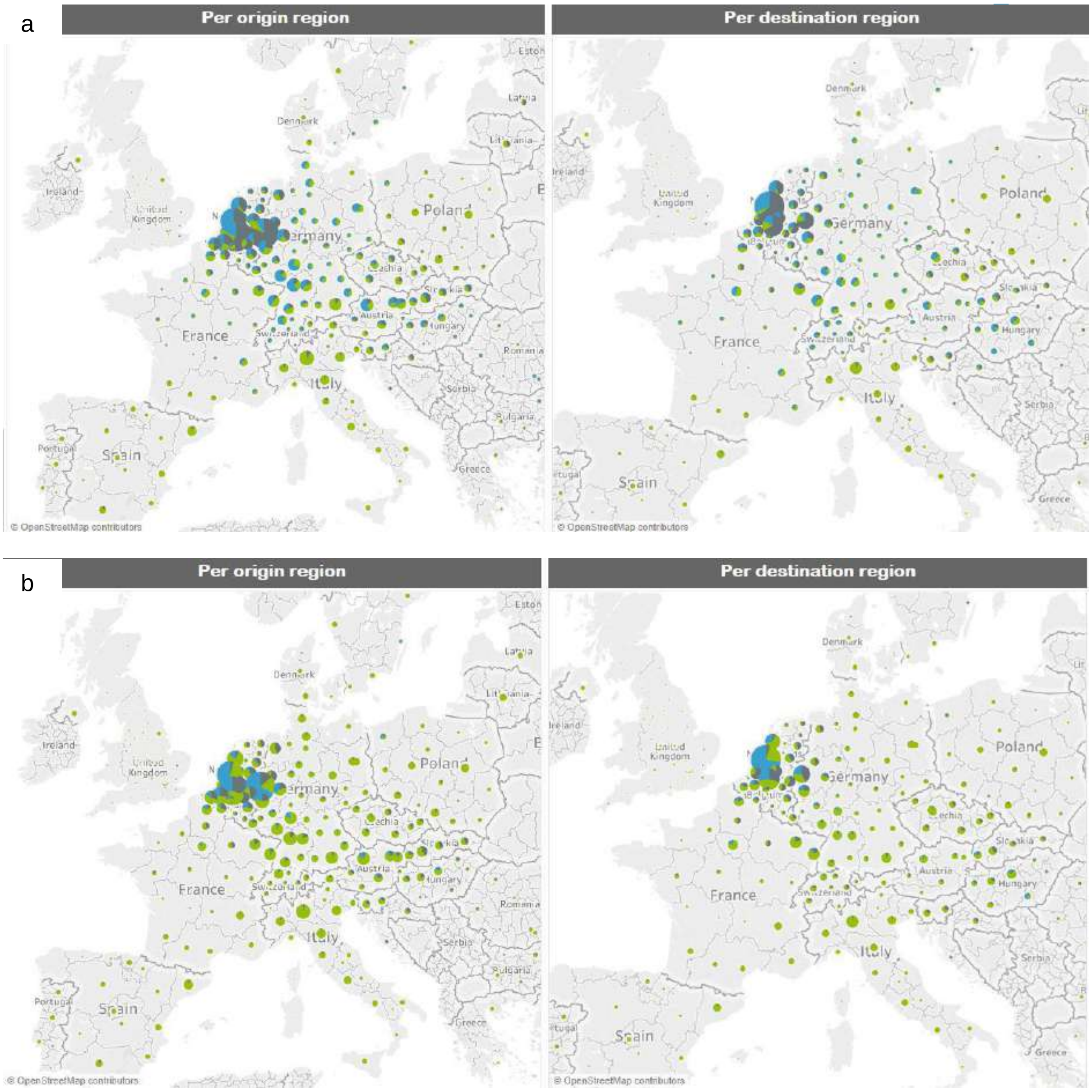


*Figure 21: **TEUs per mode per supplying or demanding region for each CO_2 emission minimisation scenario***

a. *Maximum allowed CO_2 emission is 60 billion kgs*
b. *Maximum allowed CO_2 emission is 55 billion kgs*

Figure 22 shows the network paths for rail and water in each scenario (including road transport to the terminals). Again, it can be seen that rail is preferred over waterway when tightening the CO_2 emission constraint (figure b).

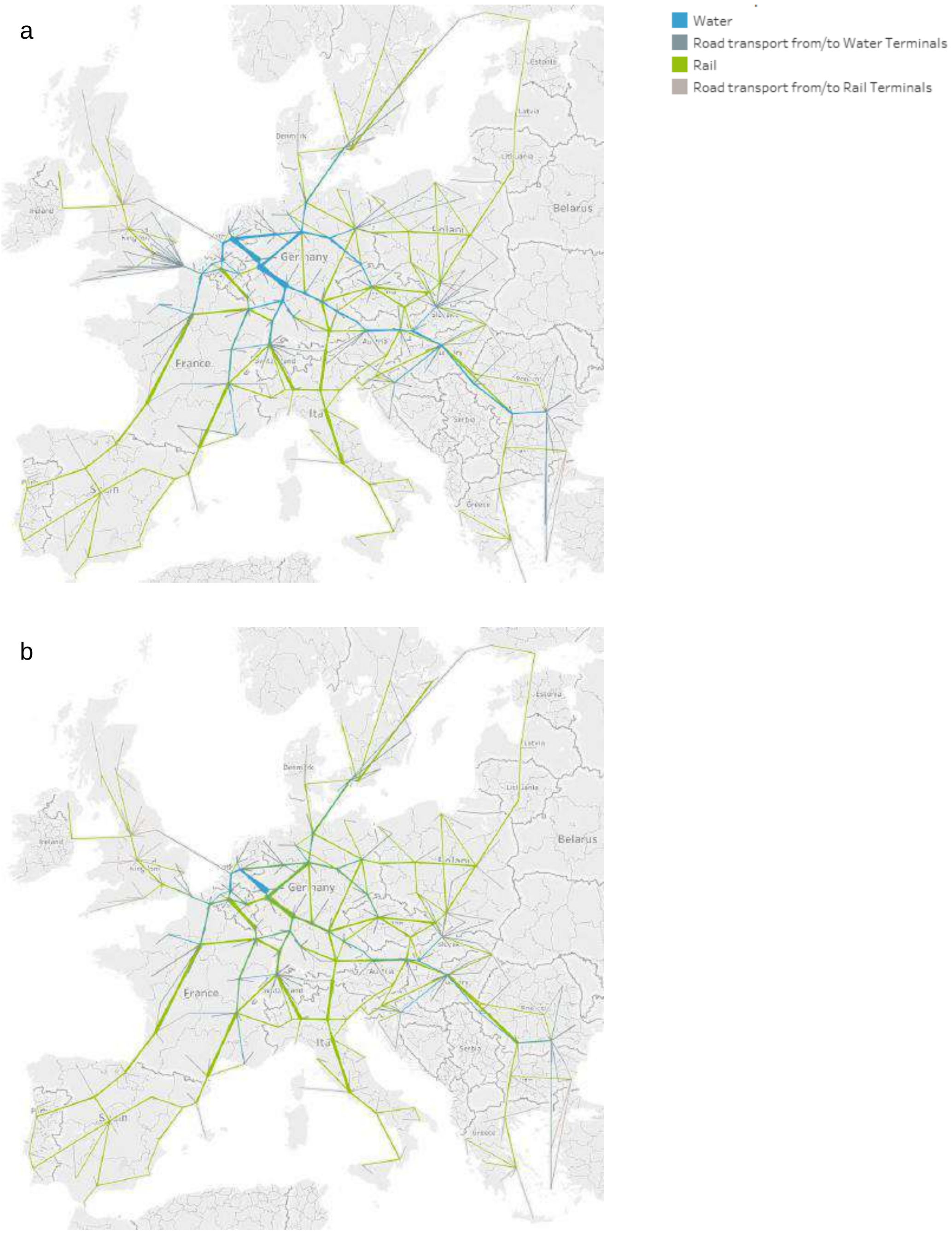


Figure 22: Network paths per for each CO$_2$ emission minimisation scenario

a. Maximum allowed CO$_2$ emission is 60 billion kgs
b. Maximum allowed CO$_2$ emission is 55 billion kgs

6. Clusters 2.0 terminals

In the previous chapters the entire European macro transport flows have been analysed in different scenarios. In this chapter we take a closer look at the impact of some scenarios for the cluster terminals involved in the Clusters 2.0 project. This chapter focuses on rail transport. Six rail terminals are in scope: Bologna, Dourges, Duisburg, Piraeus, Trieste and Zaragoza. Trelleborg is left out of the analysis in this chapter because neither of the NUTS 2 regions in the analysis has Trelleborg as its closest rail terminal. Rail terminals in Malmö, Göteborg, Stockholm, Orebro or Copenhagen are closer.

Figure 23 shows that the rail terminals of Duisburg and Bologna are the biggest of the Clusters 2.0 rail terminals in the “Network as is” in terms of TEUs handled. In the “Network to be” Bologna and Dourges have the largest capacity. All terminals, except for Duisburg, need a larger capacity in the “Network to be” than in the “Network as is”. In the remaining of this chapter we give insight in each rail terminal within the Clusters 2.0 project separately.

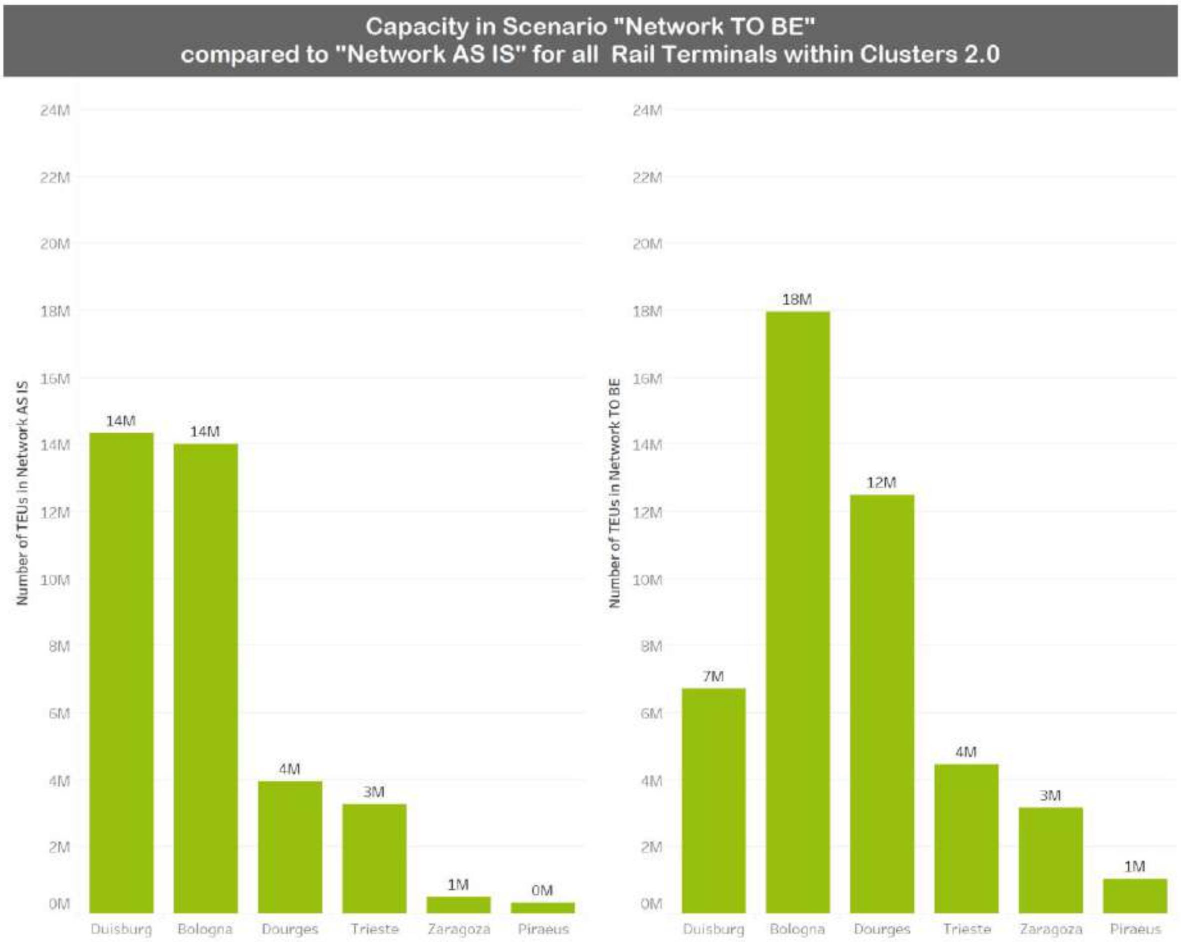


Figure 23: Capacity in “Network as is” compared to “Network to be” for all rail terminals within the Clusters 2.0 project

In Figure 24 the total capacity for rail terminal Duisburg is split in three parts.

1) The first part “Duisburg – other” consist of flows where the origin is within 2 hours drive of the rail terminal Duisburg and with a destination outside this region. The TEUs are transported by road to the rail terminal Duisburg and are sent from Duisburg to other rail terminals in Europe.
2) The second part “Other – Duisburg” are flows where the TEUs are transported from another rail terminal in Europe to rail terminal Duisburg. From this rail terminal the TEUs are transported by road into the 2 hours drive region.
3) The third part “Other – Other” consist of flows where rail terminal Duisburg acts as a transit terminal.

For all Clusters 2.0 terminals the same distinction in flows is made. See Figure 27 to Figure 30.

In Figure 24 all types of flows decrease in the “Network to be” scenario compared to the “Network as is”. The largest reduction can be seen in the transit function of the terminal.

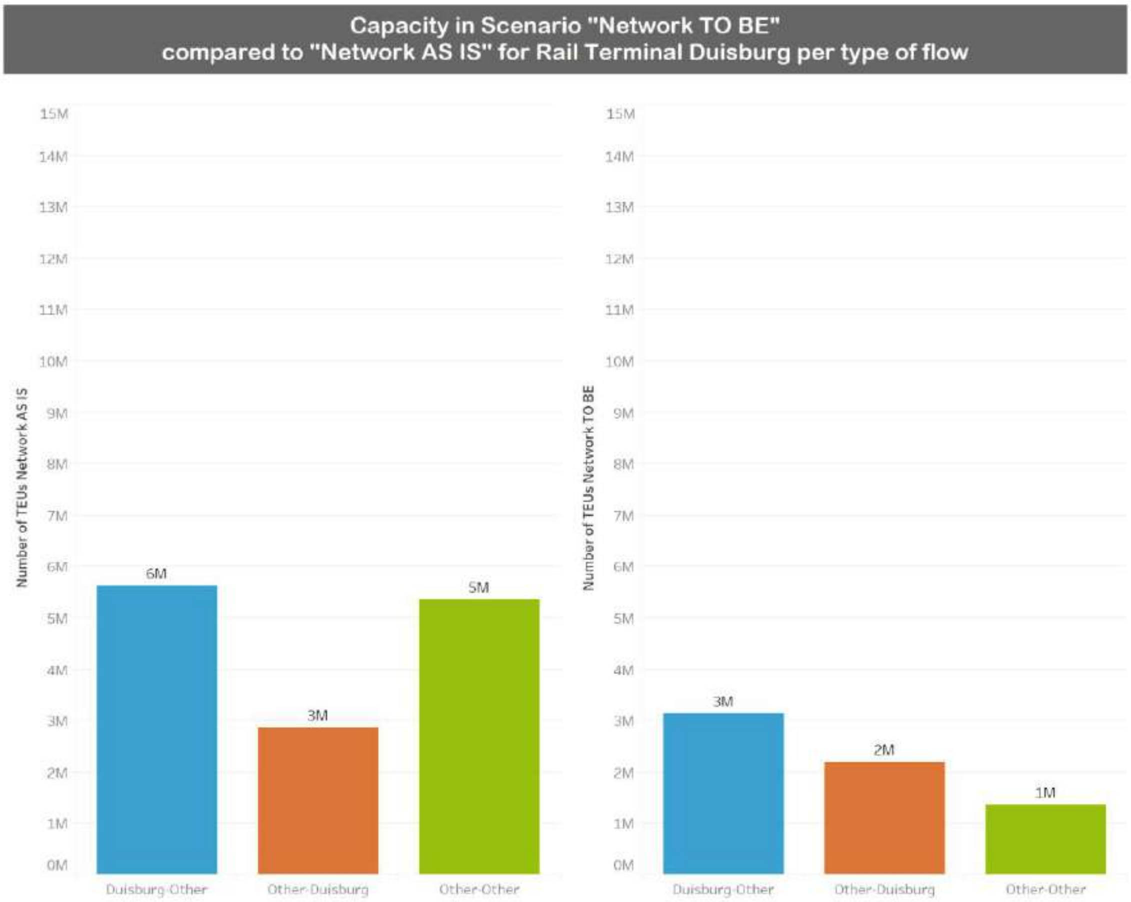


Figure 24: Capacity per flow type in “Network as is” compared to “Network to be” for rail terminal Duisburg

Looking at Figure 25 the reduction in flows for rail terminal Duisburg can be explained by the rail connections in the network. As can be seen, rail terminal Duisburg has connections to rail terminal Cologne and to rail terminal Utrecht. Both these terminals have direct connections to other parts of Europe. The model focuses on finding optimal paths through the network for each combination of origin - destination. There are simply cheaper paths in the surroundings than those going through rail terminal Duisburg.

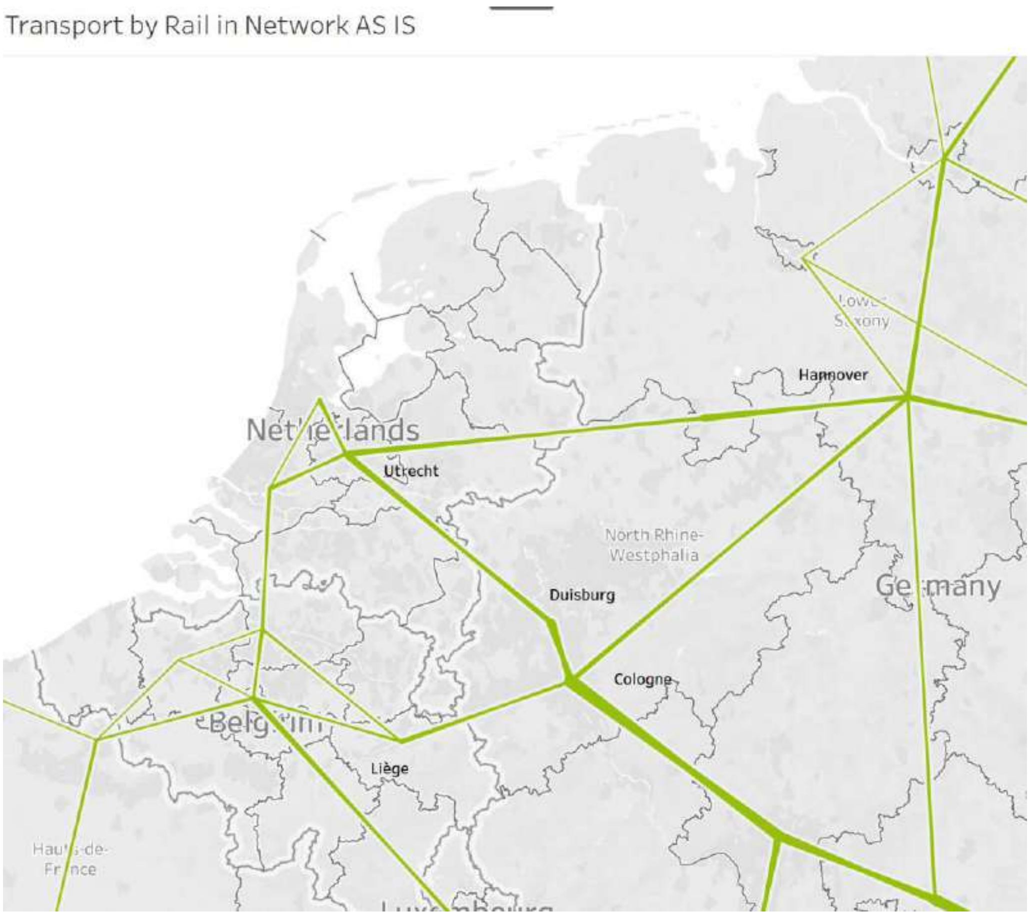


Figure 25: Rail terminal network in proximity of rail terminal Duisburg

For transport for which the origin or destination is in Italy, about 60% is done by rail in the “Network as is” situation. The rest is transported by road. In the “Network to be” scenario the use of rail transport in Italy increases to about 90% of the total transport. So 30% is transferred from road to rail. We see this effect because of longer distances, where use of rail transport is cheaper than use of road transport. This effect can also be seen for rail terminal Bologna. For all types of flows the volume increases compared to the “Network as is” (see Figure 26).

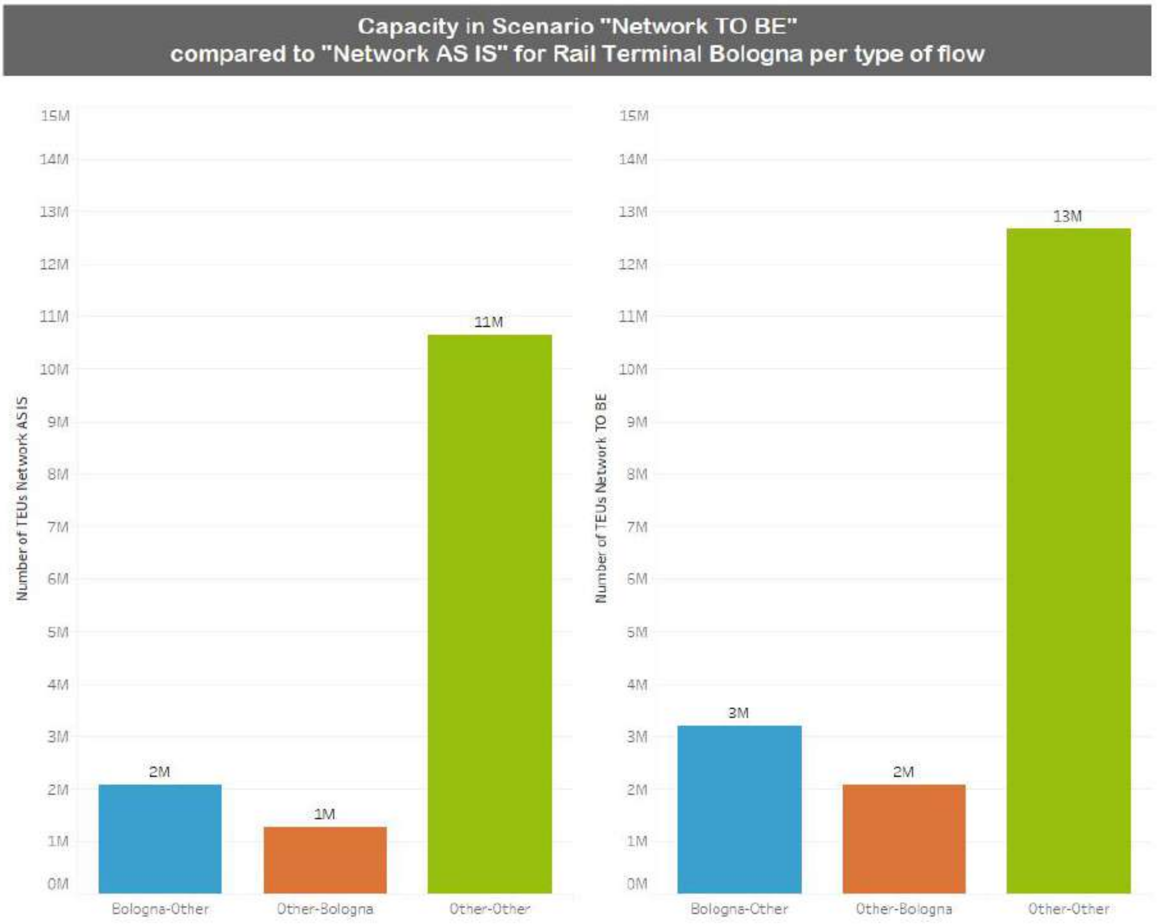


Figure 26: Capacity per flow type in “Network as is” compared to “Network to be” for rail terminal Bologna

Figure 27 shows that rail terminal Dourges is handling much more flows in the “Network to be” scenario than in the “Network as is”. The biggest growth is seen in the transit function of the terminal. Most of this growth is coming from UK, Spain and France regions. Reason for this (see also Figure 7 and Figure 8) is that for further distances transporting by train is cheaper than transporting by road. Next to that, for these regions transport by water is hardly an alternative for transport by road or rail.

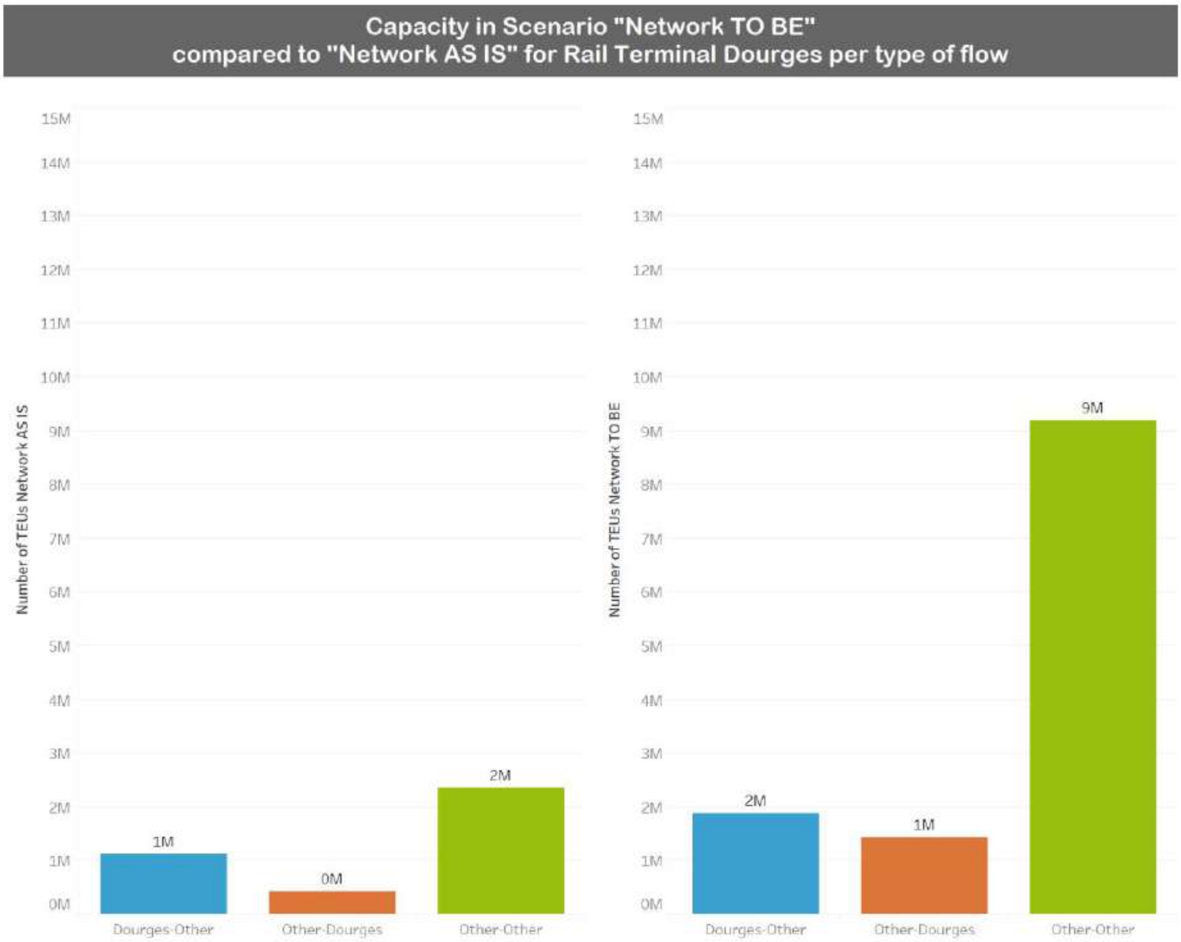


Figure 27: Capacity per flow type in “Network as is” compared to “Network to be” for rail terminal Dourges

For rail terminal Trieste the same argument as for Bologna holds (for Italy as origin or destination, the use of rail increases from 60% to 90% of total transport). The capacity for rail terminal Trieste increases (see Figure 28).

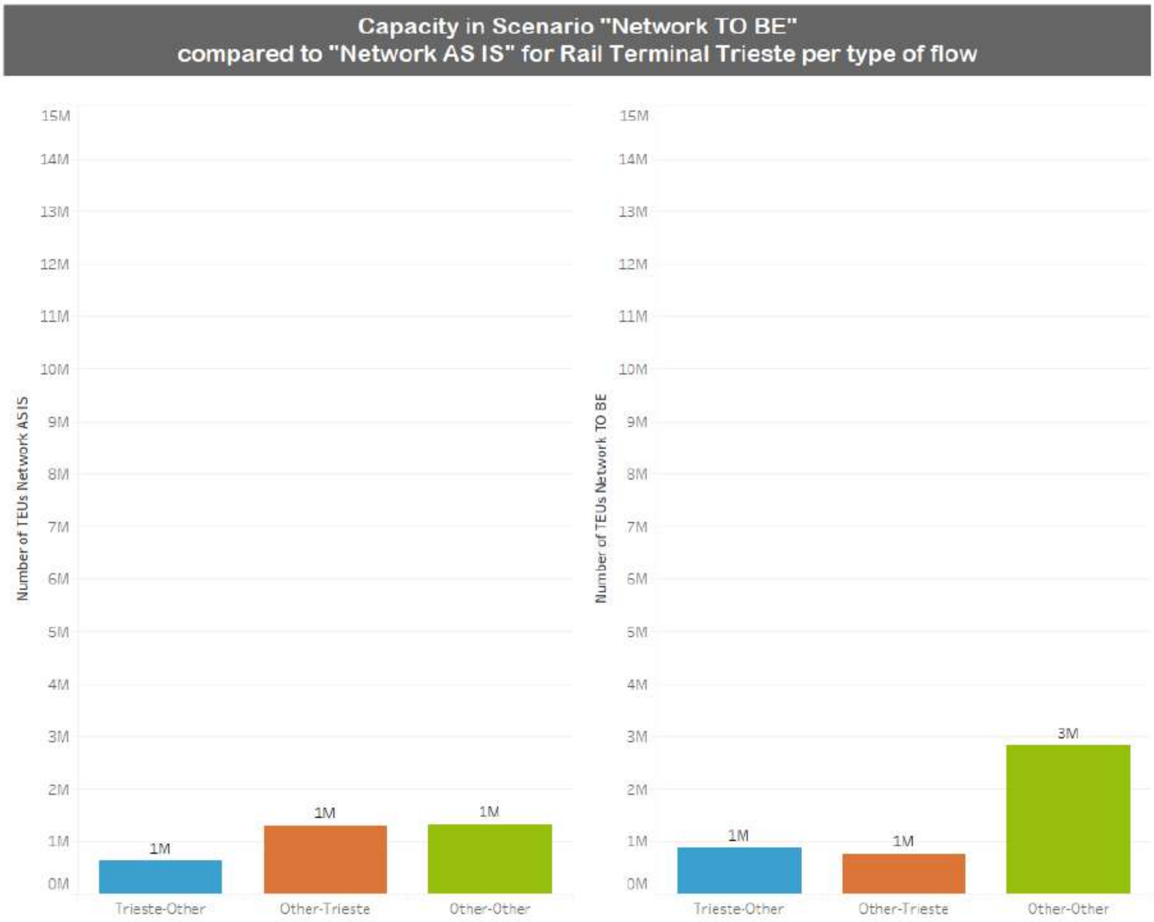


Figure 28: Capacity per flow type in "Network as is" compared to "Network to be" for rail terminal Trieste

For transport for which the origin or destination is in Spain, about 20% is done by rail in the “Network as is” situation. The remainder is transported by road. In the “Network to be” scenario the use of rail transport in Spain increases to about 90% of the total transport. So 70% is transferred from road to rail. We see this effect because of longer distances, where use of rail transport is cheaper than use of road transport. This effect can also be seen for rail terminal Zaragoza. For all types of flows the volume increases compared to the “Network as is” (see Figure 29).

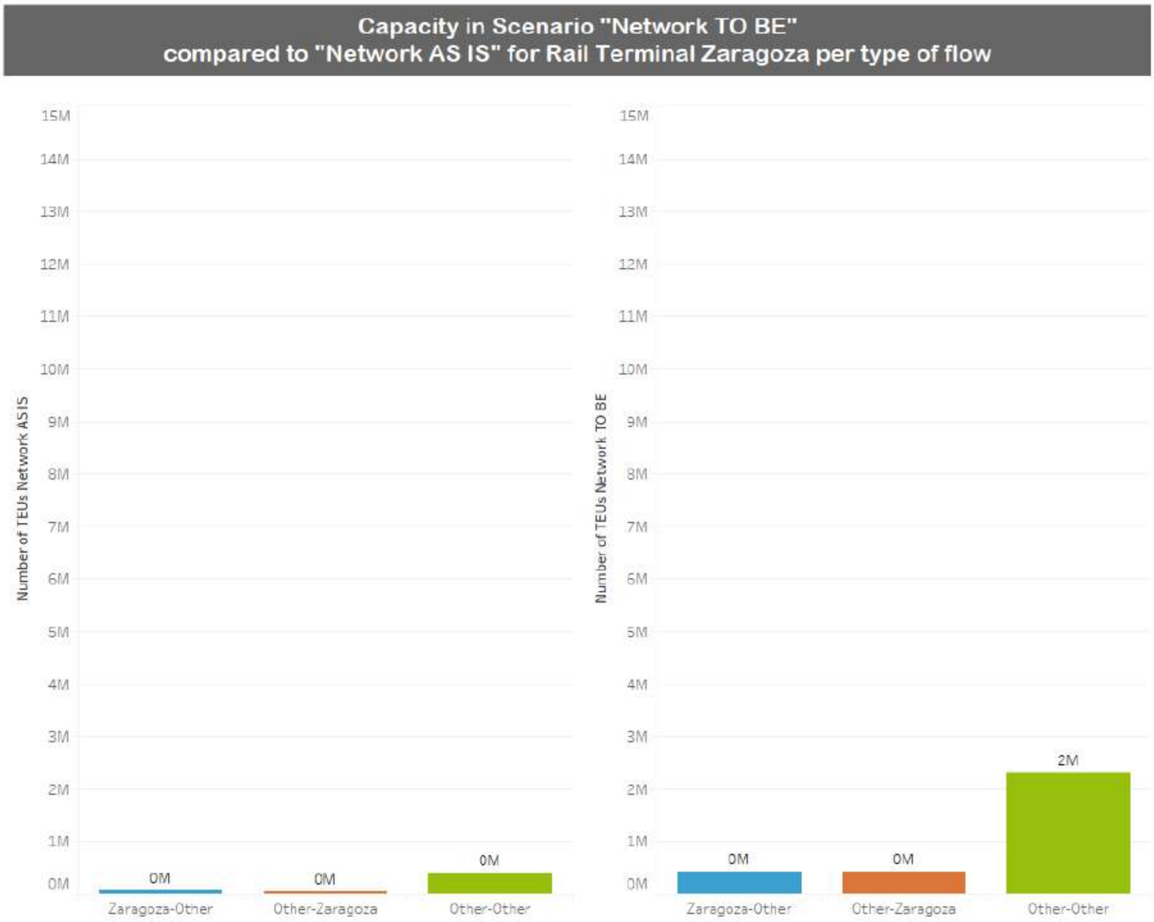


Figure 29: Capacity per flow type in “Network as is” compared to “Network to be” for rail terminal Zaragoza

The use of rail terminal Piraeus is small compared to the other Clusters 2.0 terminals. Slight growth is seen for all types of flows. The main growth is seen from products with an origin in regions in Greece that are further away than a two hours drive.

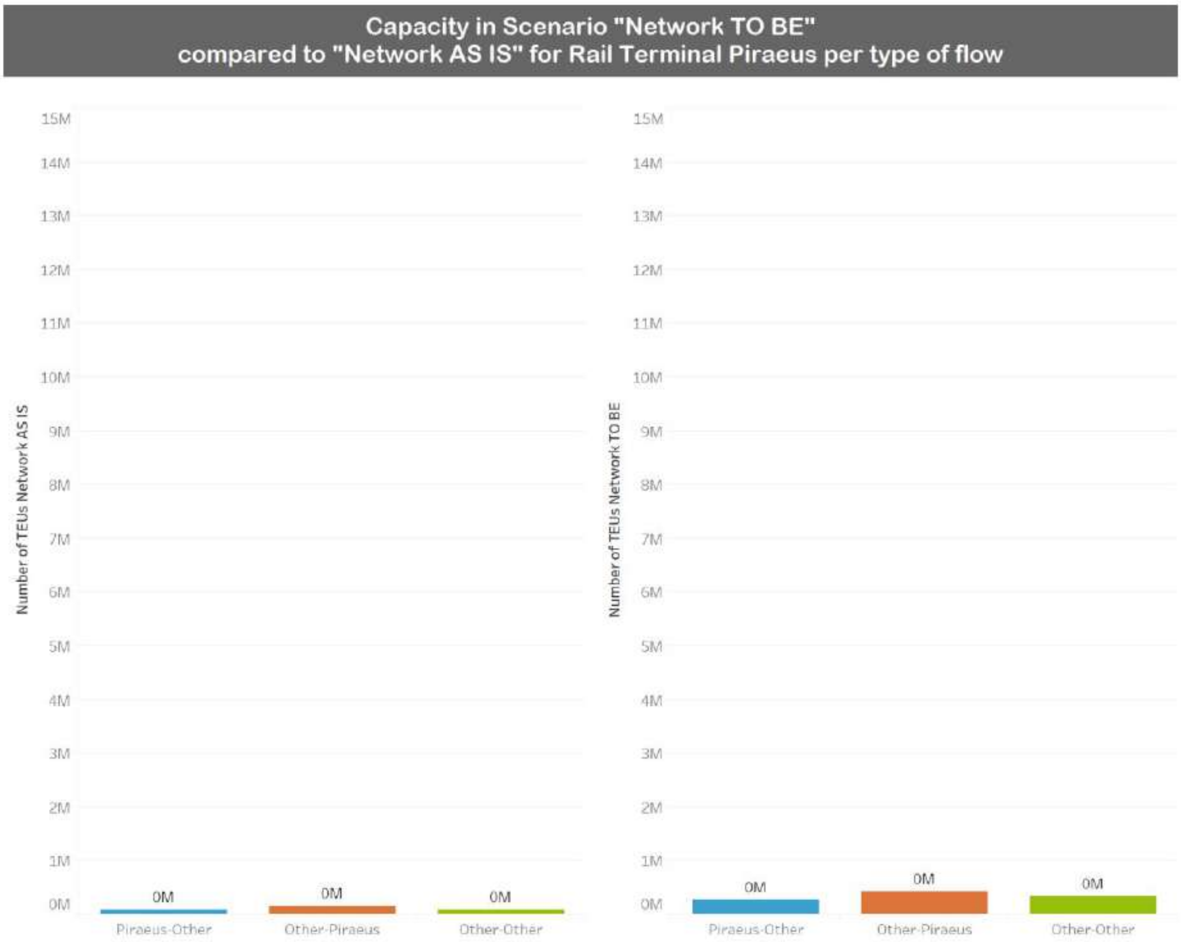


Figure 30: Capacity per flow type in "Network as is" compared to "Network to be" for rail terminal Piraeus

7. Conclusions and next steps

Eight different scenarios have been modelled and analysed using an interactive dashboard. The results have been presented using three KPIs (the number of TEUs per mode, the costs and the CO_2 emission for all flows). Maps have been developed to get a better insight in the division of modes over the supplying and demanding regions and network paths have been visualized for water and rails transport lanes. This chapter describes the conclusions that can be drawn and the next steps towards the future.

7.1 Conclusions

Table 7 provides an overview of all scenarios and a comparison of the KPIs versus the "as is" situation.

	TEUs (x1,000)	Costs (x1,000,000 euros)	% costs difference compared to Network 'As is'	CO2 (x1,000,000 kgs)	% CO2 difference compared to Network "As is"
Network AS IS	332,731	862,701	0%	76,791	0%
Network TO BE	332,731	659,271	-24%	64,986	-15%
Fix RailFlows	332,731	746,449	-13%	74,413	-3%
Fix WaterFlows	332,731	714,337	-17%	59,185	-23%
Modal shift road > 300 km	332,731	690,412	-20%	65,133	-15%
Modal shift road > 700 km	332,731	706,875	-18%	67,056	-13%
Modal shift 50p of road > 300 km	332,731	753,281	-13%	67,351	-12%
CO2 eq. 60	332,731	669,329	-22%	60,000	-22%
CO2 eq. 55	332,731	720,502	-16%	55,000	-28%

Table 7: KPIs overview for all scenarios

The following conclusions can be drawn based on Table 7 and the information in the previous chapters.

- The number of TEUs per mode changes with the different scenarios. When focusing on cost minimisation, the distance to and from a waterway or rail terminal determines the preferred mode of transport. In most instances, rail is preferred over waterway, when focusing on minimised CO_2 emission. Therefore, the best mode decision depends on the goal.

- The total costs of transporting all European flows are reduced by all scenarios with 13% to 24% compared to the "as is" scenario. The cost minimum is reached in the "to be" scenario (unconstrained cost optimisation) and is 24% less than the current total transport cost.

- The CO_2 emissions are also reduced by all scenarios with 3% to 28% compared to the "as is" scenario. The minimum amount of CO_2 emission is reached in the scenario where the maximum allowed CO_2 emission is 55 billion kgs and is 28% less that the current amount of CO_2 emission.

- The costs of the transport flows increase when applying restrictions to either the rail or the waterway terminals. The total CO_2 emission however decreases when we impose to the model that the flows that in the current situation are transported via waterways are not allowed to switch to another mode.

- Both rail and waterway terminals require the ability to handle more flows for the network "to be" situation compared to the "as is" situation. The biggest increase in volume going through rail terminals is in the areas of Milan, Barcelona and Poznan. Waterway terminals with the biggest volume increase are situated around Basel, Stuttgart, Wels Linz and Berlin.

- The modal shift scenarios mainly show a shift to waterway transport in the BeNeLux, Germany, Austria, Switzerland area. When applying a restriction that 50% of the ton-kilometres of road are transported over a distance bigger than 300 kilometres is shifted to another mode, the increase of rail and waterway usage is comparable.

- In general, the assumption is that minimisation of CO_2 emissions increases the cost. However, the analyses show that it is possible to decrease both KPIs at the same time compared to the “as is” situation. Rail is the preferred mode of transport when focusing on minimum CO_2 emissions while waterway is the most cost-effective mode of transport. However, rail and waterway transport also require transport to and from the terminals. Since rail terminals are more widely spread and therefore often closer to the origin or destination, rail often turns out to be the preferred solution also from cost perspective. This means it is possible to save both on cost and CO_2 emission by choosing the right mode of transport.

- Compared to the “Network as is”, the capacity of all Clusters 2.0 rail terminals is growing in the “Network to be” scenario. The exception is the rail terminal Duisburg which is decreasing due to its position in the network

When deciding for the best scenario to put into practice, both costs and CO_2 emissions should be considered. Clusters 2.0 is focusing on combining transport between clusters and making use of other modes of transport than road for these combined shipments. Unlike the analysis in this report, it will not include all European transport flows, nor will it be a strict cost or CO_2 emission optimisation. Therefore, the most realistic expected cost and CO_2 emission savings for living labs within the Clusters 2.0 project are comparable with the savings realized in the mode shift scenario where 50% of the ton kilometres of road transport over more than 300 kilometres are shifted to either waterway or rail (13% cost savings and 12% CO_2 emission savings). These expected savings are in line with the realized savings in collaborations realized within the CO3 project (Cruijssen et al., 2014).

The results of this analysis can also be seen as a first step towards the concept of the Physical Internet. Several simulation studies have been carried out to investigate the potential benefits of the Physical Internet. Sarraj et al (2014) finds a reduction in total costs of 5 to 30% and decreased CO_2 emissions of 13 to 58%, depending on the different scenarios and designs of the network. The European Technology Platform ALICE (Alliance for Logistics Innovation through Collaboration in Europe) designed a roadmap to arrive at the PI in 2030 and Zero Emission in 2050. As the roadmap states, the PI will not materialize overnight. Various steps need to be taken to move into the direction of the PI in one form or another in the near future. Collaboration between logistic clusters by combining transport on different modes can be one of these steps. The present deliverable aims to strengthen our understanding of this possibility. This analysis of the various scenarios shows promising results.

7.2 Next steps

Next to more practical constraints as expected transport time and flexibility, deciding on what scenario to put in practice, both costs and CO_2 emissions are important figures to be considered. These KPIs for all scenarios can be seen in one overview in Figure 31.

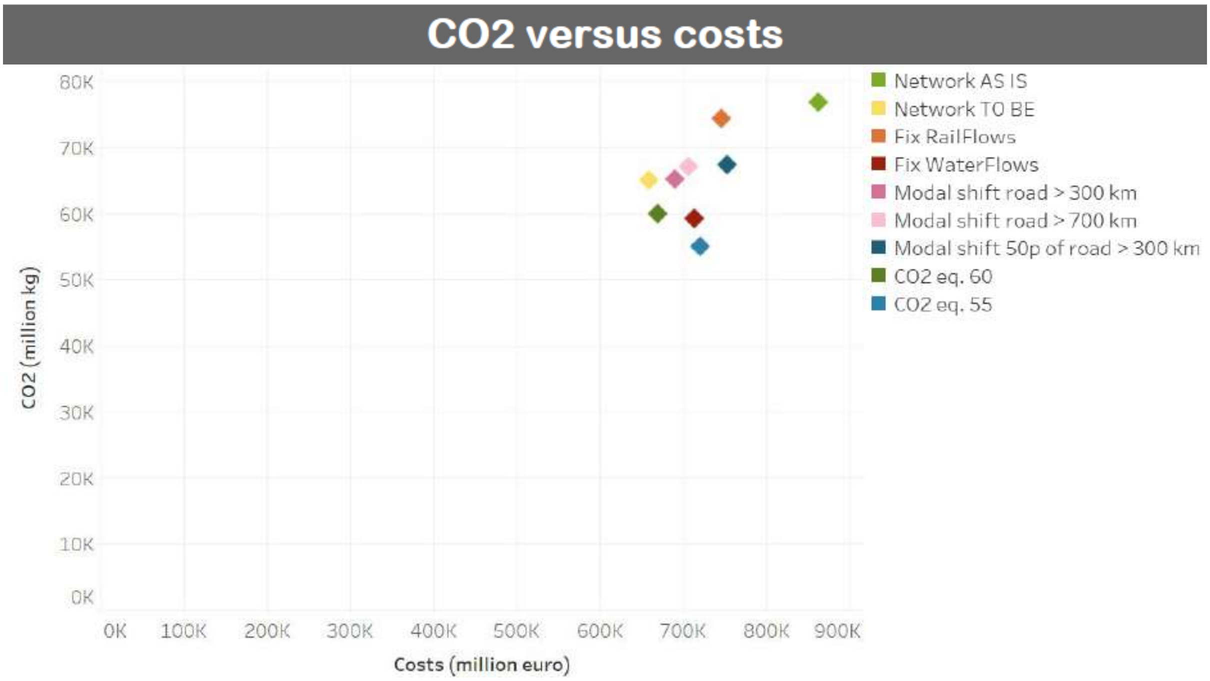


Figure 31: Overview costs versus CO_2 emissions for all scenarios

This insight can help future decision makers in e.g. general transport policies, TENT-T and the Physical Internet to balance these two factors. The results of this analysis can also be seen as a first step towards the concept of the Physical Internet. According to Cruijssen and Karakostas (2019) this was first introduced in a book by Ballot and Montreuil (2012). The Physical Internet (PI) is a logistics concept that works based on horizontal collaboration and consolidation. It is called the Physical Internet because of its similarities with the Digital Internet. In the Digital Internet, providers are responsible for links between servers, instead of the whole routes. Physical Internet applies this idea to physical flows. A supplier is connected to the PI, sends its freight to the network and the PI will get it to its destination. This is quite different from the current situation, where usually each firm has its own supply chain network, whether it is in-house or subcontracted to a Logistics Service Provider (LSP). The PI network consists of open warehouses and/or open cross-docking hubs (so-called PI-hubs). In principle, these are available for every logistic provider and every type of goods. Several simulation studies have been carried out to investigate the potential benefits of the Physical Internet. Hakimi et al (2012), show a significant decrease in the total distance driven. Another study, by Sarraj et al (2014), finds a reduction in total costs (5-30%), lower CO_2-emissions (13-58%), and a higher weight fill rate (from 59% up to 65-76%), depending on the different scenarios and designs of the network.

The European Technology Platform ALICE (Alliance for Logistics Innovation through Collaboration in Europe) designed a roadmap to arrive at the PI in 2050. This roadmap is shown in Figure 32). ALICE, funded by both the industry and the European Commission, strives to make horizontal collaboration and the PI possible. Its members include various types of organisations, like research institutes (including TU/Delft, TNO, TU/e), ports (including Port of Rotterdam, DuisPort), Manufacturers (including Volvo, Ford), consultancy agencies, and many more.

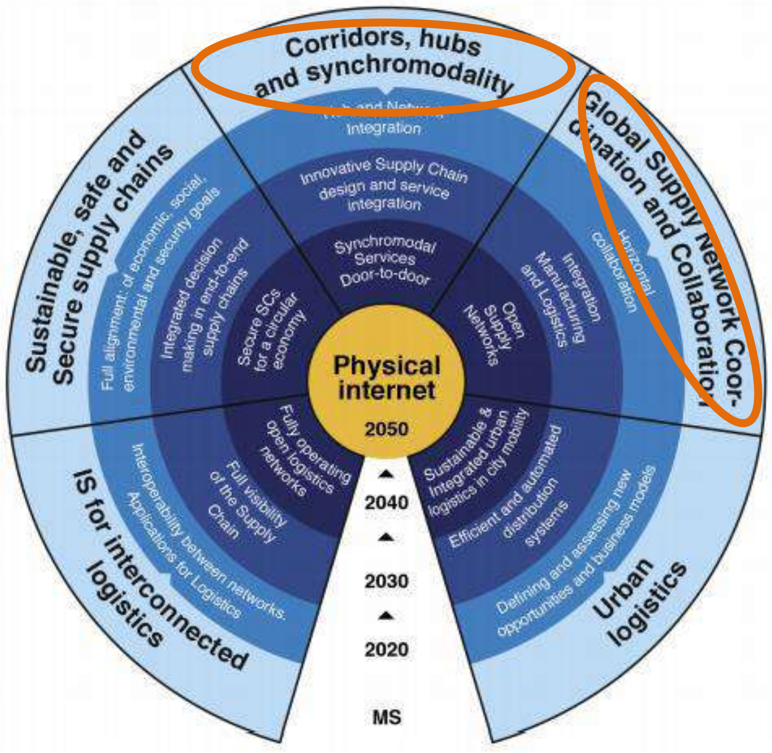


Figure 32: ALICE roadmap

As the ALICE roadmap shows (Figure 32), the PI will not happen overnight. Various steps need to be taken to move into the direction of the PI in one form or another in the future. This analysis showed that the expected results in savings are promising. Clusters 2.0 is aiming at the development of corridors and network coordination. Collaboration between logistic clusters by combining transport on different modes can be one of these steps. This report is a step in the direction of realizing this by providing insight in the possibilities and handholds to make decisions.

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Annexes

Parameter settings

a) Cost for road transport: €4.55 per TEU per km (PLANCO Consulting GmbH. Economical and ecological comparison of transport modes: Road, railways, inland waterways, 2007; URL www.ebu-uenf.org/fileupload/ SummaryStudy engl.pdf)
b) Cost for rail transport: €848.40 per TEU plus €1.33 per TEU per km (PLANCO Consulting GmbH. Economical and ecological comparison of transport modes: Road, railways, inland waterways, 2007; URL www.ebu-uenf.org/fileupload/ SummaryStudy engl.pdf)
c) Cost for waterway transport: €632.80 per TEU plus €0.77 per TEU per km (PLANCO Consulting GmbH. Economical and ecological comparison of transport modes: Road, railways, inland waterways, 2007; URL www.ebu-uenf.org/fileupload/ SummaryStudy engl.pdf)
d) CO_2 emissions for road transport: 0.062 kg / tonkm (McKinnon; https://www.ecta.com/resources/Documents/Best%20Practices%20Guidelines/guideline_for_measuring_and_managing_co2.pdf)
e) CO_2 emissions for rail transport: 0.022 kg / tonkm (McKinnon; https://www.ecta.com/resources/Documents/Best%20Practices%20Guidelines/guideline_for_measuring_and_managing_co2.pdf)
f) CO_2 emissions for water transport: 0.031 kg / tonkm (McKinnon; https://www.ecta.com/resources/Documents/Best%20Practices%20Guidelines/guideline_for_measuring_and_managing_co2.pdf)

EuroStat data processing

Road transport

Sources used

a) road_go_cta_gtt: Annual cross-trade road freight transport by link, group of goods and type of transport (1 000 t), from 2008 onwards
b) road_go_ia_rc: International annual road freight transport by country of loading and unloading with breakdown by reporting country (1 000 t, million tkm)
c) road_go_ta_rl: Annual road freight transport by region of loading (1 000 t, million tkm, 1 000 jrnys)
d) road_go_ta_ru:Annual road freight transport by region of unloading (1 000 t, million tkm, 1 000 jrnys)
e) road_go_na_rl3g: National annual road freight transport by regions of loading (NUTS3) and by group of goods (1 000 t), from 2008 onwards
f) road_go_na_ru3g: National annual road freight transport by regions of unloading (NUTS3) and by group of goods (1 000 t), from 2008 onwards

Data processing

1) Sources (c) and (e) are used to calculate the tons loaded per NUTS2 region, split in national and international transport.
2) Sources (d) and (f) are used to calculate the tons unloaded per NUTS2 region, split in national and international transport.
3) Then for each loading NUTS2 region, the national loaded tons are spread over the unloading NUTS2 regions in proportion of the national unloaded tons.
4) To calculate the national ton-kms, the tons are multiplied by the distances between the corresponding NUTS2 centers calculated over a road network. As these distances are too large on average, the numbers are corrected with a factor based on country totals.

We know the total ton-kms for national road transport per country, we divide this by the national tons per country from step 3 to get the average kms per country. Then the correction factor equals these average kms divided by the average distance from the road network.

5) Sources (a) and (b) are used to calculate the tons loaded from origin countries to destination countries.
6) Then the tons transported between the countries are spread over NUTS2 regions in those countries in proportion of the international tons for the loading and unloading regions.
7) To calculate the international ton-kms, the tons are multiplied by the distances between the corresponding NUTS2 centers calculated over a road network. Also, these distances are too large on average, and the numbers corrected with a factor based on country totals similar to step 4.

Rail transport

Sources used

a) rail_go_trsorde: Annual railway transit transport by loading and unloading countries (1 000 t, million tkm)
b) rail_go_intcmgn: International annual railway transport from the loading country to the reporting country (1 000 t, million tkm)
c) rail_go_intgong: International annual railway transport from the reporting country to the unloading country (1 000 t, million tkm)
d) rail_go_typeall: Railway transport - goods transported, by type of transport (1 000 t, million tkm)
e) rail_go_contwgt: Annual railway transport of goods in intermodal transport units

Data processing

1) Source (a), (b) and (c) are used to calculate the tons and ton-kms transported between countries.
2) Source (d) is used to get the tons and ton-kms transported nationally.
3) Then a correction is made to add the transport by intermodal transport units, based on source (d) and (e). The tons for a loading country are increased by the fraction of the intermodal transport tons compared to the total railway tons for the loading country.
4) Then the tons and ton-kms between the countries are spread over NUTS2 regions in those countries in proportion of the GDP for the loading and unloading regions (population for Switzerland).

Waterway transport

Sources used

a) iww_go_atygofl: National and international inland waterways goods transport by loading/unloading region

Data processing

1) Source (a) is used to calculate the tons and ton-kms transported between NUTS2 regions and between countries.
2) As the tons and ton-kms between NUTS2 regions are missing some data, a correction is made based on the tons and ton-kms between the countries. The tons between regions are multiplied by the proportion of the tons transported between the corresponding countries based on country totals and the tons transported between the corresponding countries based on region totals. The same is done for the ton-kms.

All data is from 2015 and filtered on EU28 countries plus Switzerland.
All numbers are compared with the statistical pocketbook 2016, chapter on freight transport.