Influence of the performance of hinterland transportation in port choice decision making

Application on the balance between the seaports of the North Sea and those of the Mediterranean Sea

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MASTER THESIS
INFLUENCE OF THE PERFORMANCE OF HINTERLAND TRANSPORTATION IN PORT CHOICE DECISION MAKING

APPLICATION ON THE BALANCE BETWEEN THE SEAPORTS OF THE NORTH SEA AND THOSE OF THE MEDITERRANEAN SEA

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Preface

This thesis is the result of my graduation project realized to obtain the degree of Master of Science in the field of Transport, Infrastructures and Logistics at the Delft University of Technology. This thesis has been realized at BG Consulting Engineers, in Paris in France.

The choice of a thesis subject on port choice and freight transportation was not obvious for me. When arriving at the TU Delft and during my study there my focus was mainly on passengers and urban transportation. Thank to the diversity of the TIL master I got the opportunity to discover the freight transportation field and the process of operating a port, due to the high importance of the port of Rotterdam in the Dutch economy.

My wish was to realize my thesis in a company to gain working experience, as my Dutch was not good enough to realize it in a Dutch company; I decided to come back in France to graduate. After having contacted BG Consulting Engineers for a thesis, the opportunity was offered to me to work on this subject. I found the subject really interesting, as the corridor studied in this thesis goes through both France and the Netherlands. Carrying out my thesis in an field that was maybe not my specialization allowed me to developed my knowledge in that field and open me the opportunity to work in that field in my future carrier.

During this thesis many people have supported me to fulfill my goal. I would like to thanks them. First, the people from BG Consulting Engineers: Mr. Guillaume De Tilière, head of the transport department of BG Consulting Engineers, that offered me the possibility to realize this Master Thesis in its department, Mr. Reynaud for its interesting remarks about my research and paper and a huge thanks to Mr. Buguellou that really helped me with the modeling in this thesis and was always there to answer my questions. I would like to thanks all my colleagues at BG Consulting Engineers for the great working environment and atmosphere that they provided to me during this thesis.

Next to that, I am thankful to my graduation committee: Prof. Dr. Lori Tavasszy, Dr. Hans van Ham and Dr. Jaap Vleugel, for their valuable comments about my graduation work, especially about the theoretical aspects of the model.

Célénie PICCOT
Paris, August 2014

Summary

Over the last decades, world seaborne container trade explodes. This significant increase was mainly due to the rise of worldwide trade thanks to the liberalization of the markets, and to the significant economies of scale realized by the increasing capacity of the containerships, that has made the maritime chain more efficient.

Nevertheless, the efficiency of the global maritime chain cannot only be measured on the efficiency of its maritime segment; other components also need to be taken into account. Indeed, usually the maritime chain is divided into three components, one being the maritime carriage and the two others, the transit of the containers in the port and the hinterland transportation of containers. Lately two of those three components have seen a considerable increase of their efficiency, the maritime carriage and port transit. Thus nowadays, the hinterland transportation is the component of the maritime chain that lag behind, and that is responsible of the main bottlenecks in the maritime chain.

In Europe, where lots of countries are concentrated in a small surface area, the problematic of hinterland transportation is even more important for port competition, because if good hinterland connections exist between a port and the hinterland, its hinterland can increase significantly and this port can become more competitive. The improvement of the performance of the inland transportation thus leads to a reduction of the captive hinterland of the European ports, and create fiercer competition between ports.

In Europe this competition is mainly observed between two port ranges: the Hamburg-Le Havre (HLH) port range, that gather the three main European ports and the Mediterranean range. The HLH range is currently the indisputable leader for container handling in Europe with a market share of 45 %[1], whereas the Mediterranean range has a market share of 25 %. The supremacy of the HLH range can be explained by several reasons: the repartition of the economic activities and of the population in Europe that are principally concentrated in northern Europe; the geographical characteristics of Europe, with the presence of navigable inland waterways in the north and of mountains in the south; but above all because the northern ports benefits from better hinterland connections, due to denser infrastructure networks.

The European Union is nowadays aware that efficient hinterland transport infrastructures, as efficient and well organized transport services are necessary to facilitate the exchanges of goods within Europe. They have thus decided to implement a new policy of Trans-European Transport Network (TEN-T) in 2013, based on the development of 9 main transport corridors in Europe. One of those is the North Sea-Mediterranean corridor that, as is name indicate, link the North Sea to the Mediterranean Sea, by passing through the Netherlands, Belgium, Luxembourg and France. This corridor thus connects the HLH range to the Mediterranean range. One of the main projects that might be developed through the implementation of this corridor is the construction of the Saone-Mosel Saone-Rhine (SMSR) canal, which aimed at creating the two missing inland waterway links of this corridor, by linking the Saone to the Mosel and to the Rhine, with two different branches. The SMSR canal is not the only project that will be developed by the implementation of the North Sea-Mediterranean corridor, numerous railway projects are also planned.

[1] Compute for 314 ports in Europe, according to the Eurostat data

The question that rises from the preceding statements is: Will the development of this corridor, and the projects that go along with it, affect the supremacy of the HLH range in Europe and allow the ports of the Mediterranean range to gain market share on those of to the HLH range. Thus, the aim of is to answer the following research question:

To what extent the improvement of the hinterland transportation of maritime containers on the Corridor North Sea-Mediterranean Sea of the TEN-T network, can lead to:

- **shifts of container flows between the ports of the HLH range and those of the Mediterranean range,**
- **modifications of the modal shares of the different hinterland transport solutions,**

at the horizon 2030 under different future scenarios?

To answer this question two steps have been undertook. First, future scenarios at the time horizon 2030 have been defined; and then a port choice model has been developed at the scale of Europe in order to can quantify the impacts of the North Sea-Mediterranean on the ports.

As express above one of the main projects that will be developed with the construction of the North Sea-Mediterranean corridor is the Saone-Mosel Saone-Rhine canal. This canal will thus be used as a basement for the construction of the infrastructure scenarios of this research. The scenarios that will be analyzed in this research are composed of two types of sub scenarios: an infrastructure sub scenario and an economic and organizational sub scenario.

Two infrastructure sub scenarios will be studied; the first one the reference scenario focuses on the infrastructure improvements that have already been planed by the public authorities for 2030, and includes mainly rail projects. The second one also takes into account the infrastructure scenarios that have been planned for 2030, but also considers the construction of the SMSR canal. In addition, three economic and organizational sub scenarios will be developed: a basic scenario that will consider the evolution of the container traffics and the evolution of the hinterland transportation costs at this time horizon 2030. A second one, based on the first one, but in which a reduction of the border effects in Europe will be considered. Finally, the third scenario will consider that changes in the maritime organization will lead to the implementation of shipments' price that will be proportional to the distance for the Asia-Europe trade. By combining the infrastructure and economic and organizational sub scenarios, a total of 6 scenarios will be analyzed.

		Economic and organisational scenarios		
		2030Basic	Reduction of the border effects	Sensitivity to the maritime cost
Infrastructure scenarios	Reference scenario	X	X	X
	SMSR scenario	X	X	X

In order to be able to evaluate the impacts of those scenarios a port choice model has been developed and used. As already stated before port choice is usually realized based on factors that are related to the three components of the maritime chain that are the maritime carriage, the port transit and the hinterland transportation. In this thesis the focus is on the consequences of the improvement of the hinterland transport infrastructures and services, on port choice. For this reason, it has been decided to develop the model principally on the hinterland segment of the maritime chain, and to leave aside the two others components of the maritime chains.

The model consists of a four step models, in which the generation of traffic is realized by the disaggregation of the Country-Country exchanges obtained from Eurostat to the regional and node levels. The step of distribution is then realized thanks to a gravity model in which the port attractiveness corresponds to the port throughput, the node attractiveness to the tons of container import and export by this node. Finally, the impedance function is a power function, in which the power is differentiated for national or international exchanges between the port and the hinterland, in order to take into account the border effects. The impedance taken into account in this model is the generalized transport costs of the solutions that minimized the transport cost between the port j and the hinterland i. The two latest steps consist of the determination of the modal shares of the different transport solutions for each couple port-hinterland, and of the affectation on the network. The first one is realized by using the Abraham's law and the affectation that is realized by an all-or-nothing assignment for all the transport chains.

The specificity of this model allows a precise description of the generalized transport costs of each of the transport solution. It is thus really useful for the evaluation of new hinterland transport infrastructures and services.

By calibrating this model with regard to the data for 2007, one main difficulty is faced: it is the lack of actual data regarding the containers flows between the European ports and the hinterlands regions. It is thus not possible to calibrate the model on this type of data. That is why it has been decided to calibrate the model more on the containers throughput of the ports; on the market shares of the European ports in the French regions; and on the modal share at the level of the ports. Thanks to this step of calibration the parameters of the model have been determined. For the value of time, a value of 2€/TEU/hour has been found; the powers of the gravity model, that take into account the border effects, vary depending of the category of the port, and finally the Abraham parameter takes a value of β=11.

By applying this model to the scenarios of interest that have been described above the following results are observed. First, for the basic economic scenario in the situation of reference in 2030 it is observed that the HLH range will win market share on the Mediterranean range, with regard to 2007.This is partly explained, by the fact that the generation of containers for 2030 is based on the GDP and population forecasts at this time horizon, and that the forecast are more important for northern Europe than southern Europe. For this basic economic and reference infrastructure scenario it can also be observed that the modal share of the road decreases significantly, due to the large increase of its road costs between 2007 and 2030.

Then, the model allows to demonstrate that the implementation of the SMSR canal within all the economic scenarios, will not lead to a significant shift of containers between the two ranges of interest that is to say the HLH and the Mediterranean ranges, as the respective market shares of those two ranges in Europe almost do not vary between the reference and SMSR scenario. This is mainly due to the fact that the construction of the SMSR canal only leads to modifications on the North Sea-Mediterranean corridor, so on small areas of the two ranges. Nevertheless, the small impacts observed with the creation of the canal, are in favor of the Mediterranean range which is winning market share on the HLH range. This is due to the fact that thanks to this canal the

Mediterranean range, and more specifically the port of Marseille, obtain access to the large containers market of northern Europe (Benelux and Germany), whereas the opening to the market to the South of France is less of interest for the ports of the HLH range. As a result the contestable hinterland line, the line representing the area where the biggest competition between the ports of the HLH range and those of the Mediterranean range occurred; slightly shifts to the North on the corridor of interest

In addition, the two ports that benefit the most from the opening of the canal are the port of Marseille and Rotterdam that are directly connected to the Rhine-Rhone canal. Indeed, they are both extending their hinterland, the first one to the South, and the second one to the North.

By now focusing on the modal shares, it can be observed that with the implementation of the SMSR canal, the inland waterway (IWW) transport solution and IWW+Rail are winning market shares on the study area. Those gains are mainly observed between the regions situated north of the canal and the port of Marseille, and the regions situated south of the canal and the Benelux ports. Those gains of market share from the IWW are mainly taken from the rail.

Regarding the two divergent economic and organizational sub scenarios, the model first highlights that the reduction of the border effects leads to a gain of market shares of the major European ports on the smaller ports, in the contestable hinterland. Indeed, the ports of Rotterdam and Antwerp see their hinterland extend considerably in this scenario. In addition, it is the scenario that leads to the smallest benefit, with regard to creation of the canal, for the port of the Mediterranean range. This phenomenon leads to a shift of the contestable hinterland line toward the south, and to a gain of the market shares for the rail, due to the increase of the shipment distances that are more favorable to this mode.

In turn the integration in the model of the maritime segment, by assuming that the maritime cost is proportional to the sea distance, leads to a large shift of the contestable hinterland line toward the North of the Region Rhône-Alpes for the corridor of interest. This highlights that with such an hypothesis the ports of the Mediterranean ranges are becoming more competitive and are thus taking market share back to the port of the Northern range. In addition, it is under this economic scenario that the SMSR project is the most beneficial for the ports of the Mediterranean range and thus for the port of Marseille.

Nevertheless, for this scenario it seems that the model reduces the effects of the hypotheses taken, with regard with what would have been observed in realty. This can be explained by the structure of the model that does not considered the maritime segment, but just try to incorporate it in the hinterland port choice model by a system of bonus/penalty. The model thus faces its limits with this scenario.

Conclusion

It can be concluded that the creation of the North Sea-Mediterranean corridor, will not lead to significant changes in the market shares of the HLH and Mediterranean ranges in Europe, with the standard economic and organizational forecasts for 2030. Nevertheless, this corridor will have consequences on the local market shares of the ports that are directly linked to this specific corridor, for regions situated along the Rhine-Rhone axe. Indeed, two ports, Marseille and Rotterdam, will mainly benefit from the creation of the SMSR canal, at the expense of the ports of Le Havre in

France, and Antwerp. In addition, the creation of the canal will also have influences on the modal shares on the corridor in favor of the IWW solutions, and at the expense mainly of the rail mode.

Finally, it can also be concluded that the model used in this thesis is a good tool, for the modeling of the impacts of changes of the hinterland transport infrastructure and services, in port choice decision making in Europe. Nevertheless, it seems that this model should restrain to this specific purpose, as the results for the maritime scenario were not really plausible. If policies regarding the maritime segment, want to be evaluated, it seems then necessary to incorporate the maritime segment into the model since the calibration of this one.

Recommendations for future model improvements will be first to try to calibrate the model by replacing the current impedance that corresponds to the minimum costs of all the transport alternatives between i and j, by the logsum of the costs of all the alternatives that will lead to more accurate results. The current model can also be expand or combined with other model in order to take into account the other segments of the maritime chain. Finally, a huge improvement of the model will be possible when data will become available, for the exchanges of containers between the ports and their hinterland. Because it will then be possible to determine the impedance function in a scientific manner thanks to the Poisson estimator method, and to calibrate the model by using regression analysis. It is thus recommend to the European Union think about a way to collect the data related to the trade of container between the ports and the hinterland.

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1. Introduction

Nowadays, the ports' hinterlands are not limited to the local vicinity of the port, but they extend more and more in the interior of the country. Moreover, a specific region is not allocated anymore to one port, but can be served by several ports. This leads to the development of contestable hinterland. If this phenomenon of contestable hinterland was already observed for ports belonging to the same gateway (Ducruet et al., 2009), it is also now observed for ports belonging to different gateways and even different ranges.

For instance, in the region Rhône-Alpes in France the foreign ports are competing with the French ports. They have a market share of 40 % against 60 % for the French ports (Cour des comptes, 2006). It can thus be wondered, what are the factors that influence the port's choice made by the shippers and the shipping companies? That is to say, why one shippers of the region Rhône-Alpes will make its containers transit by Rotterdam, whereas another one will make it transit by Marseille. To answer this question literature usually states that port choice is influenced by three factors: the characteristics of the maritime segment, the characteristics of the port transit and the characteristics of the hinterland connections from and to the port.

In this thesis, special focus will be given to the characteristics of the hinterland connections because nowadays, it is the segment of the maritime chain that lags behind, principally because of congestion on the network, and lack of interoperability between the national networks. To improve the quality of the intermodal network in Europe the European Union, has implemented a new policy, the TEN-T network, which is based on the Core Network Corridors that corresponds to the multimodal backbone of the TEN-T network. One of these corridors links the North Sea to the Mediterranean by passing through the Netherlands, Belgium, Luxembourg and France. With the development of this corridor new infrastructures will be built and new services developed.

One of the possible projects that could be developed is the Canal Saone Mosel Saone Rhine (SMSR) , whose goal is to create a high gauge canal between the Saone and the Mosel and the Saone and the Rhine. With the development of such a canal the port of Marseille expects to gain market share on the region situated north to the Canal and to become a major port in Europe, by competing with the port of the Hamburg-Le Havre range. Indeed, nowadays the Hamburg-Le Havre (HLH) range is the dominant range in Europe, it three main ports (Rotterdam, Antwerp and Hamburg) handle 20 % of the European container traffic (European Commission, 2013d).

The goal of this thesis is thus to determine if the improvement of the ports' hinterland connections on the Corridor North Sea-Mediterranean Sea of the TEN-T network, can lead to a shift of containers flows between the ports of the HLH range and those of the Mediterranean range at the horizon 2030 under different future scenarios, and can also lead to modifications of the market share. The main network improvement that will be studied in this thesis is the construction of the SMSR Canal.

To give more insight about this thesis the chapter 2 will describe the research field. After having defined the research plan, it seems important to analyse the maritime transport chain and the maritime market in chapter 3. Then, in chapter 4 an analysis of the port competition for container market in Europe will be provided, as the future infrastructure developments planned by the TEN-T network. In order to can quantify the possible shift of container flows between the two ranges, a model will be used. This model will be described in chapter 5 and calibrate in chapter 6. Chapter 7 will present the different scenarios that will be analysed in the thesis and the results of those scenarios will be presented in chapter 8. Finally, this study will be closed with a conclusion and recommendations.

2. Project Presentation and Approach

This chapter will define the research field and scope of this study. First background information about containers market in Europe and port competition will be given. Then the problem statement, research questions and objectives of this research will be described. Finally the research delimitation and scientific contribution will be exposed.

A more in depth analysis of the problem will be realized in the next chapter.

2.1. Context: Globalization and performance of the maritime chain

Since the end of the Second World War, globalization developed considerably. With globalization, companies started to spread their production activities all over the world leading to an increase of trade, and thus an increased need of transportation among continents. One of the means to transport goods on the international market, when the origin and the destination are separated by ocean or sea, is to transport them by ship.

Nowadays, in the European Union 74 % of the goods entering or leaving Europe do it by Sea (European Commission, 2014). The main entrance and exit gates for the international trade in Europe are thus ports.

In Europe several ports are involved in international trade. They are competing to attract a bigger trade share than their opponents. Those ports that shine on the international scale in Europe can be mainly divided into two ranges: the North Sea range also called Hamburg-Le Havre (HLH) range and the Mediterranean range. Those ranges compete partly for the same hinterland, meaning that some regions in Europe are accessible via hinterland transport by both ranges.

Currently the balance between these two ranges is largely in favor of the HLH range. Indeed, this range collect around 45 % of the container market in Europe (cf. § 4.2.2), against 27% for the Mediterranean range in 2010.

Several factors can influence the port competitiveness, among which three are determinant: port performance, maritime performance and the hinterland performance (Posthuma, 2011). By hinterland performance, Posthuma means the performance of the inland transportation access modes. De Langen (2007) notices that the hinterland development as a competitive factor is really relevant in Europe, because the hinterland distance in Europe are short and because most of the hinterlands on the main continent are accessible by both ranges. There is thus a large part of the hinterland that is contestable.

2.2. Research Objectives

2.2.1. Problem statement

Gouvernal et al. (2012) affirmed that currently ports of the HLH range have an advantage on those of the Mediterranean range, regarding container throughput. Nevertheless, they wonder if the HLH hinterland advantage will be permanent, and if new ports strategies in the future might lead to a significant shift.

Ports strategies are not the only policies that might lead to a significant shift in containers balance between the two ranges, the development of the Trans European Transport Network (TEN-T network) could also have an impact on the balance between both ranges. The latest version of the TEN-T network is based on the concept of Core network Corridors that corresponds to the multimodal backbone of the TEN-T network (cf. Chap 4). With this new concept major new infrastructures will be built and new services will be developed on the North Sea-Mediterranean Corridors.

Thus, the question that is asked by several stakeholders is if the construction of those infrastructures will lead to a shift of containers from the North to the South in the future. This question of a potential shift in the balance between the ports of the HLH range and those of the Mediterranean range is of importance because ports base their future development on future forecast.

2.2.2. Research Questions

To determine if impacts from the development of those infrastructures and services will occur it is necessary to determine if the performance of the hinterland transport of containers can influence the balance between the ports of the HLH range and those of the Mediterranean range. This will allow highlighting if the maritime battle is really played on ground? Therefore the main research question of this thesis will be:

To what extent the improvement of the hinterland transportation of maritime containers on the Corridor North Sea-Mediterranean Sea of the TEN-T network, can lead to shifts of container flows between the ports of the HLH range and those of the Mediterranean range, and to modifications of the modal shares of the different hinterland transport solutions at the horizon 2030 under different future scenarios?

This problematic is of importance because nowadays the maritime flows and the choice of the call ports have influence on the whole logistics distribution network of Europe. In this problematic the shifts of containers between the two port ranges, consists of the transfer of container throughputs from one range to another.

2.2.3. Research sub questions

This research question is still really broad, in order to give more insight into the details of this thesis, several sub questions will be treated in this thesis:

1. What are the factors influencing port competition?

2. What are the characteristics of the hinterland transport between the ports and their hinterland?

3. What is the current situation regarding the balance between the ports of the HLH range and those of the Mediterranean range? How this balance can be explained?

4. What are the main future transport infrastructures and services developments on the North Sea-Mediterranean Sea that will occur by 2030?

5. What are the main future plausible economic and organizational changes that might influence considerably port choice decision making in Europe by 2030?

6. How can port competition between the European ports be modeled, by focusing on the hinterland segment of the global maritime chain?

7. What will be the impacts of the creation of new hinterland transport infrastructures and services, under different economic and organizational scenarios, on the ports throughput, the ports hinterlands and the modal share of the different transport solutions on the North Sea-Mediterranean corridor in 2030?

2.3. Research perimeter

First it should be specify that this graduation project was conducted in France at the company BG Consulting Engineers. This explains why the focus of this research is on the TEN-T corridor that goes through France. This research was realized in parallel of a study for VNF (Voie Navigable de France), on the socio-economic impacts of the project Saone-Mosel Saone-Rhine (SMSR), explaining some decision of the research delimitation.

The main research question quote above is really broad, it is thus necessary to delimitate the research field due to the limited time of this graduation thesis:

- **Segment market**: Containers

This research will only focus on the container market in Europe, because "the biggest competitive battle between the ports takes place in the container sector" (CRA, 2004). Due to the time frame of this study, that does not allow to take all the types of goods, into account, and the fact that port competition is more intense for container market, this study will only consider containers, in port competition.

- **Time Frame**: 2007 and 2030

The modelling of the port competition between the two ranges will be realized at two time horizon. First, in 2007 for the calibration of the model, because most of the required data are available for this year, but also because it seems important that the socio-economic model of the SMSR model is consistent with the hypothesis of the project Seine-North Europe Canal, this latest being based on data of 2007. Then for the future scenarios the year 2030 is considered because the Core Network is prioritised for 2030.

- **Geographical scope**

The goal of this research is to study the hinterland connections improvements on the North Sea-Mediterranean Corridor. Nevertheless, the study area will not be limited to this corridor. Indeed, all the countries of the EU 27, except Croatia and Malta, will be part of the study area, in order to have a global picture of the hinterland of the main ports in Europe. Switzerland has been added to this area, because it is an important hinterland for the competition between the North range and the Mediterranean range.

All the ports belonging to those countries and having a container throughput of above 87 000 tons in 2007 will be part of the model, leading to a total amount of 130 ports.

2.4. Research method

- **Focus on the hinterland connections**

As mentioned before port competition depends on three main factors: port performance, maritime performance and the hinterland performance. Nevertheless, in this research, the choice has been made to focus principally on the inland haulage of maritime containers to access the hinterland from the port, due to the specific problematic of this research.

- **Modelling at the node level**

The particularity of the model used in this research is that the assignment of traffic is done at the node level, and not at a regional scale. This is possible due to the precise description of the transport network.

- **Definition and evaluation of the scenarios**

Due to the specificity of the model, the scenarios will mainly be built on the differentiation of the services and infrastructures in the future, and they will allow evaluating the performance of the hinterland transport chain.

2.5. Scientific contribution

The model that has been developed and used in this research is in continuity with the former models on container port competition. Nevertheless, it has its own particularity as it describes at a really detailed level the hinterland transport connections between the port and the hinterland. To do so, its focuses on the network of each mode, on the intermodal transport chains, on the inland terminal and hubs where transshipment occurs. This level of detail of the hinterland connections from the port to the hinterland is not common container port competition models[2].

This research also allowed to model port competition on a high numbers of ports in Europe,130, thus avoiding to overestimate the ports' throughput and ports' hinterland of the main European ports.

2.6. Research plan and reading guide

After having defined the research question it was necessary to define a research plan, in order to know how to proceed in this research. The main steps of this research were the following:

- Literature review on port competition and port choice;
- Literature review on the TEN-T network;
- Literature review on the modelling of port competition ;

[2] The specificities of this model with regards to the other port competition model will be detailed in § 5.2

- Construction of the scenario ;
- Compilation of the input data;
- Development and calibration of the model ;
- Modelling of the scenarios;
- Analysis of the results of the scenarios.

Some of those steps have been realized in parallel and other independently. In the figure below the structured of the report is displayed by notably specifying for each chapter, which research question will be answered.

Chap.2	Introduction Problem Statement Research Objectives Research Question Methodology	Definition of the research questions (q)
Chap.3	Background information on the organization of the maritime chain and on port competition	q.1&2
Chap.4	Trans European Transport Network (TEN-T) development in the context of port competition in Europe	q.3&4
Chap.5/6	Model description and calibration	q.6
Chap.7	Construction of the scenarios	q.4&5
Chap.8	Model outcomes for the scenarios	q.7
Chap.9	Conclusion & recommandations	All

Figure 1: Report's structure

3. Background information on the organization of the maritime chain and on port competition

This chapter will describe the development of the maritime transport chains in the last decades. It will answer the following sub-questions:

1. What are the factors influencing port competition?

2. What are the characteristics of the hinterland transport between the ports and their hinterland?

First, section 3.1 gives insights on the explosion of the world merchandise and container trade. Then in section 3.2 the problematic of port competition is exposed, by describing the three components of the maritime chain: maritime carriage, port transit and hinterland transportation, and by explaining why nowadays hinterland connections are predominant in port choice. Finally, in section 3.3 the intermodal contribution in hinterland connections will be highlighted.

3.1. Explosion of the World seaborne container trade

3.1.1. World trade of merchandise

Since the end of the Second World War, globalisation developed considerably, as can be observed on Figure 2 , globalisation corresponds to a modification of the world economy that results in free and high increase of trade and high degree of specialization of the regions regarding production activities. It is difficult to evaluate what is the trigger of globalization, but for sure improvement of transport network helped this evolution. Globalization can be explained by a better integration of national economies, a decrease of trade barriers and the development of better technologies for trade and telecommunications.

During the last decade the phenomenon of globalisation slowed down. This was due to the global crisis that made the global trade collapse by 20 % in volume between fall 2008 and spring 2009 (UNCTAD, 2012).

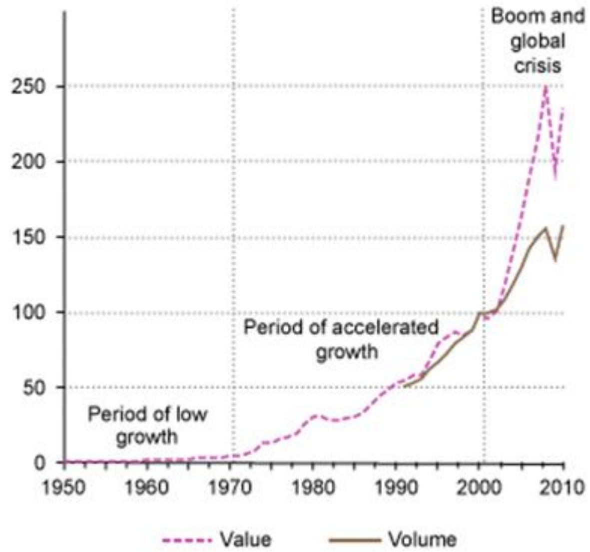


Figure 2: Long-term trends in value and volume of merchandise exports,, 1950-2010 (Index numbers, 2000= 100; Source: UNCTAD)

The worldwide trade of merchandises is mainly realized between three groups of countries: the European Union, Asia and North America. Thus, the flows are mainly east/west, exceeding considerably the north/south traffic. Indeed, in 2012 71.5 % of international trade was realized on those east/west relations between those three major economic powers. In addition, to the previous statement it can also be state that on the east/west trade there is an imbalance between the two directions. Indeed, Asia export massively towards Europe and North America, and the opposite directions concern fewer goods.

3.1.2. World seaborne trade of merchandise

It has been seen in the previous section that globalisation went along with an increase of international trade. A major part of international trade, between countries that does not have a common border, is transported via Ocean (Hummels, 2007). Indeed, nowadays in the European Union 74 % of the good entering or leaving Europe do it by Sea (European Commission, 2014). On figure 3 the strong growth (179 % since 1985) of seaborne trade that occurred in the last decade can be observed. This was due to the increase of transport's capacity, the industrialisation of the maritime mode and the constant decrease of the transport costs.

Figure 3: International Seaborne Trade (Millions of tons) (Source: UNCTAD, 2012)

For the transportation of goods, usually the distinction is made between:

- Liquid Bulk
- Solid Bulk
- General cargo

It can be observed on Figure 4 that the share of general cargo increase considerably since 2000, to be nowadays the main category transported by ship. This is due to the increase of manufactured goods' trade that is more and more transported by containers.

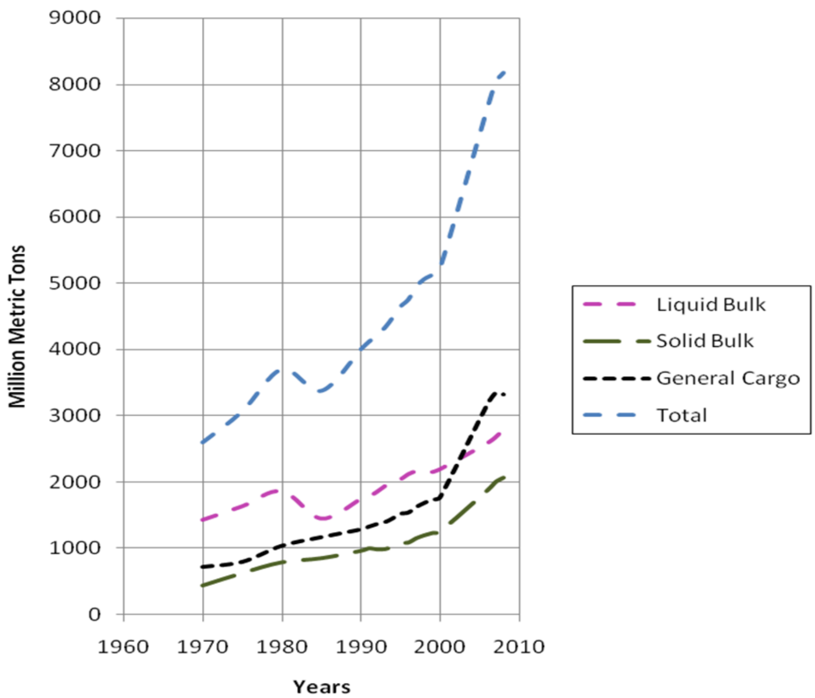


Figure 4: International World Trade repartition among the category of goods (Tobar Vega, 2010)

3.1.3. World container trade

In addition to the development of the international trade, globalisation also implied the development of new techniques of traffic flow management. Among those techniques, containerisation rapidly becomes a major tool for trade. In 2012 around 17 % of the volume of world seaborne trade corresponds to container trade. If this average seems rather low, it is compensated by the fact that it represents 52 % of the world trade by value (UNCTAD, 2012),and more than 60% of the general cargo trade in 2007. For the trade between two highly industrialized countries the share can even reach 90 % (The World Bank, 2007).

Nevertheless, even if transportation by containers developed considerably in the 70s and 80s its creation dated from 1956. It was the initiative of an American entrepreneur Malcom MacLean's that adapted fours of its vessels to transport 58 trailer of trucks by maritime path between New York and Houston. Ten years later the first transoceanic connections started, between Port Elizabeth in the USA and Rotterdam. Since then the concept emerged in Europe. By using a packaging that can be used by different modes of transport without intermediary manipulation, MacLean's invented the multimodal concept that spread around the world later due to the normalisation of containers (Noel, 2003). This was a real revolution on the way to transport manufactured goods.

The development of containerization had some influence on port competition. Before the implementation of containers ports were rather specialized, but since the introduction of containers ports understand that they can not rely anymore on their former specialization to be competitive. Thus, port have to generalized, leading to the fact that port of the same range could become easy substitute from each other, increasing port competition.

The spread of containers was linked to a continual increase in both number and capacity of containerships. Indeed, the capacity of containerships was of 1000 TEU in the 60's, and reach today a capacity of 18 000 TEU with the Maersk Triple-E (cf. Figure 5 for evolution). The increase of capacity allows considerable economies of scale: the larger the ship, the cheaper the transportation of TEU per km. Today the capacity is principally limited by the draft of the boat and the number of cranes available to unload containers. Nevertheless, the ship capacities are still expected to grow in the future.

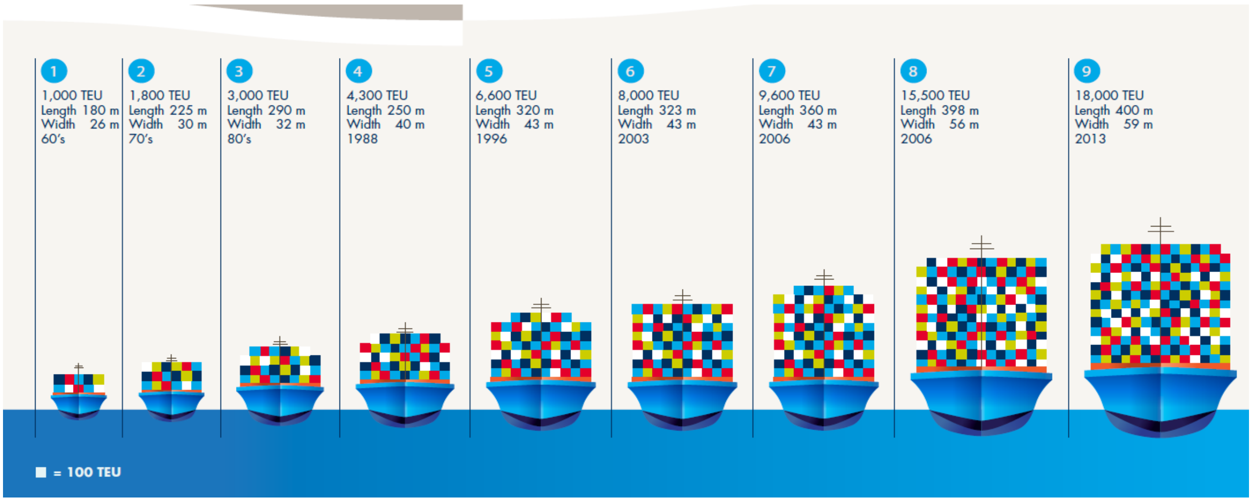
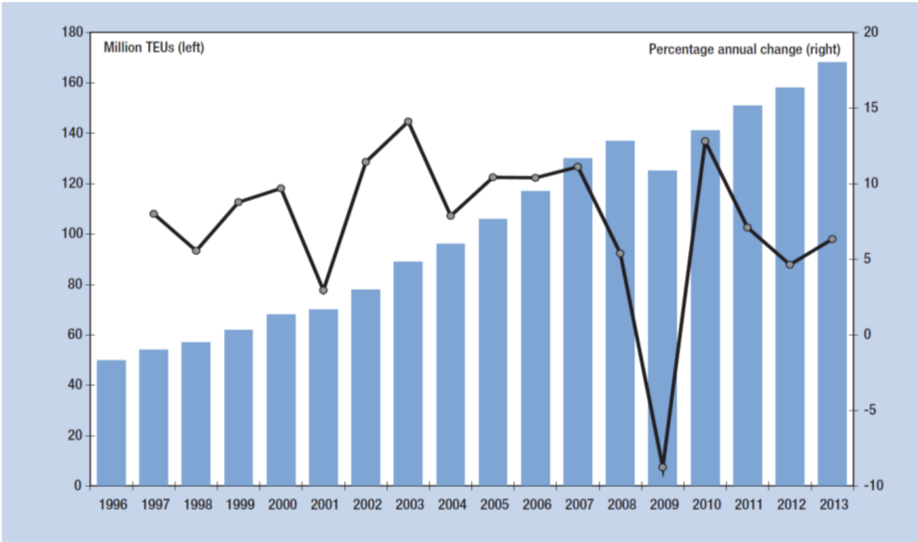


Figure 5: The evolution of the capacity of the containership (Source: Port of Rotterdam, 2011

The implementation of larger ships had consequences on their routing and call. First, the routes have been modified because the post-Panamax vessels were unable for instance to pass the Panama Canal. In addition due to the high capacity of the ships, that created economies of scales, less and less calls are realized on the long haul routes (Notteboom, 2008). For instance, the number of port calls has decreased considerably from 4.9 calls in 1989 to 3.35 in December 2009 in the European ports on the Far East-North Europe Route (Ducruet & Notteboom, 2012). There is thus a concentration of the large vessels on the main ports, increasing the competition between those ports to host the large ships. The smaller ports see their traffic stagnate or even decrease until they disappear. A port that wants to be competitive nowadays should be able to host those large deep sea vessels.

The increase of the capacity of the ships goes along with a continuous increase of the number of containers transported as can be observed in Figure 6 (exception of 2009 due to the crisis). This increase of containers flows is not only explained by the increase of trade but also by the increase use of containers to send goods that were before transported by others means.



Source: UNCTAD based on Drewry Shipping Consultants, *Container Market Review and Forecast 2008/2009*; and Clarks Research Services, *Container Intelligence Monthly*, various issues.

Figure 6: Global maritime container trade, 1996-2013 (Millions of TEUs and annual percentage change)

As for general sea trade, it can be highlighted that seaborne containers are mainly transported between three main nodes: Asia, North America and Europe. Before 1990, the transatlantic corridor corresponded to the major share of the international flow, but since the second half of the 90's a shift occurred and most of the flows are now generated from Asia. Lately in 2011, the container exchanges between Asia and Europe have overtook container exchanges between Asia and North America, and both exchanges came back to the same rate in 2012. The exchanges on those corridors during the last year are presented in Figure 7:

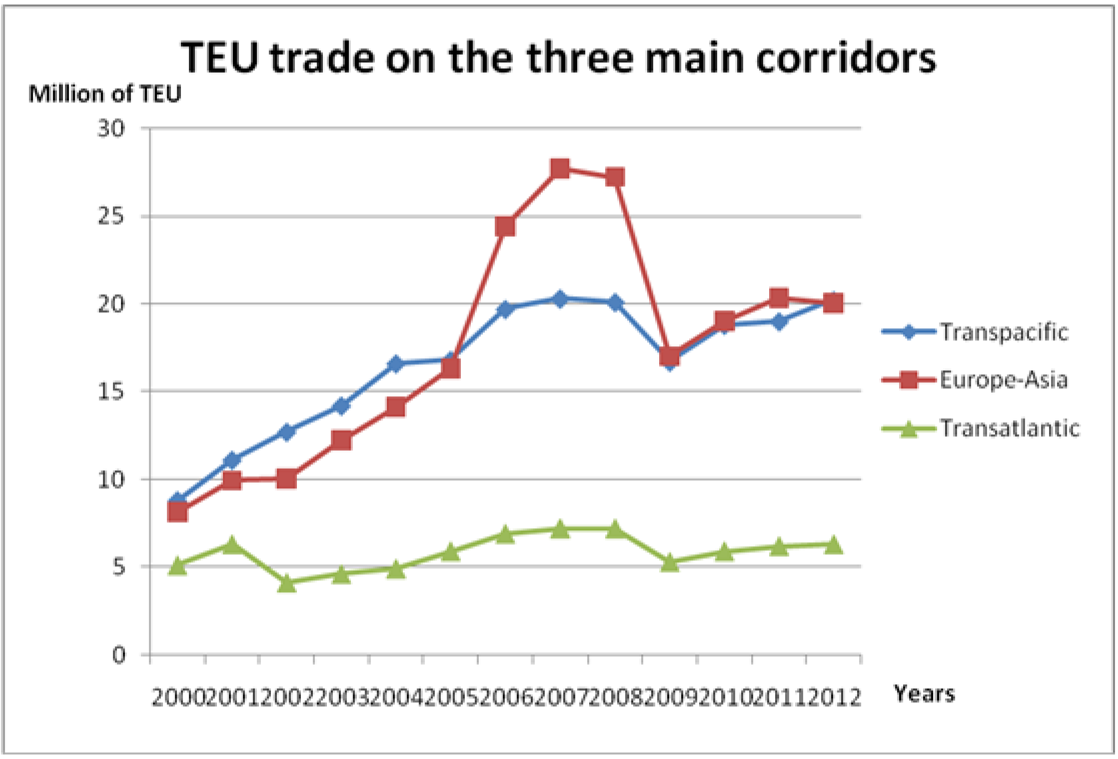


Figure 7: TEU trade on the three main worldwide corridors 2000-2012 (Source: UNCTAD, Review of maritime transport 2007, 2008 and 2013)

It should also be notices that as for general trade, there is an imbalance on the main O/D pairs depending on the direction. Indeed, Asia export massively towards Europe and North America, and the opposite directions affect less goods, leading to a high number of empty containers on the return journey. Empty containers are thus a challenge for maritime and inland transportation that need to be considered to improve the efficiency of the maritime trade. This, specificities is out of the scope of this study.

3.2. Predominance of the hinterland in port competition

3.2.1. Definition of port competition

The development of containerization had also some effects on port competition. Indeed, it had first for consequences to expand considerably the hinterland of ports. The hinterland of a port can be defined as “the area inland from the port to which imports are distributed and from which export are collected” (UNECE, 2009). Notteboom (2008) even say that hinterland of a port “is the area over which ports draws the majority of its business”. The goal of each port is to increase its hinterland in order to increase its market.

Haralambides (2002) highlights the fact that the primary hinterlands have decreased for most of the ports. The captive (primary) hinterland refers to the direct area around the port where the port is well established whereas the contestable (secondary) hinterland refers to hinterland where there is rivalry between several ports (Morgan, 1951; De Lagen, 2007). The statement of Haralambides is confirmed by the fact that over the last years hinterland did not restricted anymore to the local vicinity of the port, but that ports serve geographical area situated further away, exceeding the borders of countries. The European Commission (2013) states that one out of every two tons of goods handled in a port come or have for final destination an EU Member State different than the one in which the port is situated.

Thus, if before ports had captive hinterlands, changes in the maritime market have lead to the development of contestable hinterlands, leading to more competition between ports, (Nottemboom, 2008). This competition between ports has made the ports less dominant in the total transport chain, leading to a shift of power from the port to the shipping lines. Ports’ authorities have thus realized that they need to be more efficient to attract customers, and that ports are not fixed elements in the transport chain anymore, but that they are interchangeable.

Thus, now ports have to share their market and compete for the same hinterland. It is well-known that ports of the same range, for instance HLH range, compete for the same hinterland, but ports from different ranges also compete with each other’s. It is the case for the Mediterranean and the HLH ranges that compete for the following hinterlands: France, Germany, Switzerland and Italy. It can thus be concluded that several types of port competition exist. Verhoef (1977) made the distinction between four types of competition between ports:

> "1. Competition between port companies or intra-port competition,
>
> 2. Competition between ports or inter-port competition, such as the competition between Rotterdam and Antwerp,

3. Competition between port clusters belonging to the same range such as the Rhine Scheldt Delta Cluster and the Seine Estuary cluster (Notteboom, 2008),

4. Competition between port ranges with a range defined as a number of ports sharing the same coastline and having a more or less common hinterland. " (Posthuma, 2011).

Even if definition 1, 2 and 3 are not the main focus of this study they can influence competition between port ranges. Indeed, competition at a lower scale can lead to more competitive tariff or efficiency, making thus the port also more attractive at a larger scale. Indeed, this is highlighted by the port of Rotterdam authority that stated in its port vision Compass 2030 that "competition within the port lead not only to better results, but also to innovation, which is important if the port is to remain successful in the long term".

In this research, the **focus will be on the competition between port ranges**, the port ranges of this study being: the North Sea and the Mediterranean Sea.

3.2.2. Factors influencing port choice decision making

In the previous paragraph, the principle and development of port competition has been explained. It is now necessary to understand what the main factors making one port more competitive than another are.

First, it should be acknowledged that port choice is not only made on the intrinsic characteristics of the ports, or on their location or on the maritime elements: "Shippers take into account the quality and cost of the complete supply chain, not just the maritime element" (Port of Rotterdam Authority, 2011). External factors are thus also taken into account, because ports are not isolated elements, they instead act as gateway for European Union trade. The whole performance of the logistic chain, in which the port is just one element, should be taken into account in order to improve the supply chain. The Port of Rotterdam Authority states that ports will compete "on the basis of their position in the supply chain as a whole" (Port of Rotterdam Authority, 2011). Nowadays, it is the door-to-door routing of goods that need to be taken into account (De Langen, 2007). What matters for shippers are the total transport costs, time and reliability of the door-to-door goods routing. This is confirmed by Notteboom (2008) that stated that port choice is a function of network costs that include port characteristics, inland transportation and maritime carriage. Ports are just nodes, transfer points in this network and they are chosen such as to minimize the total costs (sea, port and inland costs) (Notteboom, 2008). Their geographical location advantage is not sufficient to attract traffic.

It should also be considered that more and more shippers want to improve the carbon footprint of their products, to do so they choose cleaner port and inland transport modes, leading to the increase of the use of inland waterways (IWW) and rail transport. But this also leads the shippers to choose port that are closer to their final destination (Port of Rotterdam Authority, 2011a).

From what precede it is clear that the port choice is a complex process that depends on a long list of factors, among them: geographical location of the port, cost of transport of the global transport chain, preference of the shippers, characteristics of the goods, port infrastructure, port accessibility by land and sea, port connectivity, port efficiency, reliability of the transport chain, capacity, frequency and costs of the hinterlands connections, ports due and fees, port management, institutional and labour environment, location of the warehousing, network of the shipping lines (Tavasszy et al., 2011).

The preceding factors are usually divided into three main categories by the literature (Nottebom, 2008):

- Maritime carriage
- Port transit
- Hinterland transportation

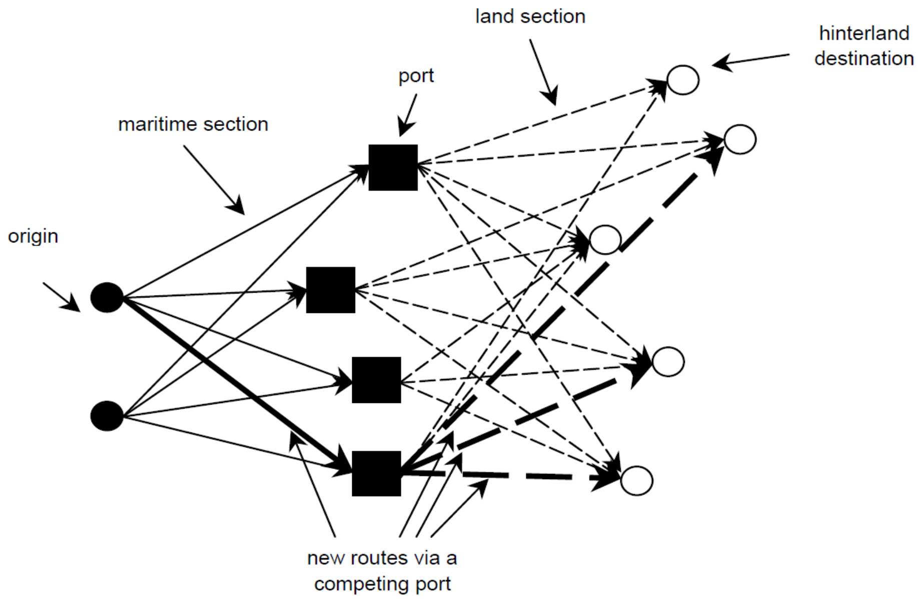


Figure 8: The concept of maritime transport chain (Source:Dekker, 2005)

This is confirmed by the model of Posthuma (2011) that considered that three factors have influences on port competitiveness: maritime performance; port performance (linked to port development) and hinterland performance (linked to hinterland development and modal spilt). A short description of those three elements that composed the transport chain will be given in the next paragraphs.

3.2.2.1. Maritime carriage

Maritime carriage is the part of the transport chain related to the transport of containers on sea. The origin and destination of this part of the chain are ports, with possible intermediate stops in other ports. The boundaries between the maritime carriage and the port transit consist of containers handling. The maritime carriage is ensured by shipping lines, whose number offering international services has quite reduced in the late years.

The network of shipping companies can be characterized by three major criteria (Notteboom, 2004, 2006):

- Frequency of service

- Fleet and vessel size
- Number of port calls (related to the network structure of the shipping lines)

Nowadays two main network structures can be adapted by the shipping lines: direct call or hub-and-spoke model. The direct strategy means that the ships of the company will realize direct calls at most of the ports (independent of their size or their importance). This lead to a high number of port calls for larger ships. The hub-and-spoke strategy emerged later with the increase of the vessels' size. In this configuration larger ships will only stop at the main hubs, where containers will be transhipped to short sea ships or feeder to serve smaller ports. This structure is applied when the density of demand is low. But in some cases this structure is also applied because smaller ports are unable to host the larger ships, due to draft limitation of the port.

Regarding maritime carriage substantial improvements have been realized. Indeed, the size of the ship increased considerably and the handling of goods becomes more efficient. Thus, the maritime performance reaches a quite high level. New optimisation are now orientated toward an improvement of the vessels' emission. It can also be assumed that the maximal capacity of the ship has not been reach yet and that some improvements will be developed in the future.

3.2.2.2. Port Transit

Port transit corresponds to the storage of the containers at the port in the port yard. As explained above the boundary between the maritime carriage and the port transit corresponds to container handling, the boundary between the port transit and hinterland connections is also container handling. Port charges only constitute about 10% of the total freight rate (UNCTAD, 2012). They correspond to one node of the infrastructure and are the gateways for the good on the "land" part of the transport chain.

Port performance relates mainly to the equipment available at the ports to load and unload containers but also to the space available in the port to stock containers. That is why the main components of the port taken into account in port choice (Chang et al., 2008) are:

- Port capacity,
- THC (Terminal Handling costs),
- Reliability,
- Port location,
- Berth availability,
- Water draft ,
- Port due.

The performance within the port will not be described in depth in this research, as it is not the main focus of this study. More information can be found in other researches.

3.2.2.3. Hinterland connections

In order to serve the hinterland, the ports need to have connection with it. The connections can be realized by different modes of transport: road, rail, short sea shipping and inland waterways. It is considered that short sea shipping will be removed of hinterland connections in this research because this transportation mode is on Sea, and not on land.

The provision of efficient inland transportation services from the port is of high importance in the decision of shipping lines, as it allowed attracting more market to the port. Indeed, hinterland corridors are the arteries of the ports that connect them to their regional markets, without those corridors the port would not be able to attract any market.

The hinterland transport connections of the ports are considered in port choice decision making by taking into consideration the "generalized transport cost" of each solution. This costs is not only influenced by the distance to the hinterland but by others factors, such as costs, quality of the infrastructures, frequency of the services and natural or political barriers (Vigarie, 2004).

3.2.3. The importance of the hinterland connections' performances

In the previous paragraph it has been seen that three main components are taken into account in port choice decision making. Most of the time the choice of the port is made such as to minimize the costs between the origin and the destination of the shipment on the whole transport chain. Nevertheless, in this total cost function all the components of the transport chain do not have the same share. Indeed, "in most door-to-door transport chains, the costs of hinterland transport are higher than maritime transport costs and port costs combined" (de Langen, 2008). Notteboom (2008) stated that hinterland transportation costs contribute between 40 to 80 % of the total transport costs of the maritime transport chain. Thus, they are of high importance, and outweigh considerably the maritime costs. This can be explained by the economies of scale that occurred for the maritime transport part, that reduce the cost of transportation of containers on the sea and increasing the share of the hinterland transportation in the total door-to-door transport. This difference of costs is also due to the fact that the energy intensity of the hinterland transport is significantly higher than the one of the deep-sea shipping. The cost per kilogram per km on the hinterland is 5 to 30 times as high as the maritime shipping cost (Notteboom, 2008).

That is why decision makers give a high importance to the hinterland transport in the global transport chain. The Joint Transport Research Center (2008), even state that among the various factors that influence port competition, the quality of the hinterland transport infrastructure is one of the most critical. Wiegmans et al. (2008) also considered that one of the main criteria that shipping lines, shippers and logistics service providers take into account in port decision making is the **quality of the hinterland connections**, that is most of the time access by the capacity, congestion and reliability of the network and services (Acciaro et al., 2013).

This implies that whether the European mainland is approach via the Mediterranean range or the North range will mainly depend on the geographical location of the origin/destination on the hinterland with regard to the ports and above all on the **quality of the inland road, rail and inland waterway transport services of the port**. This confirms the high share of the performance of the hinterland transportation in port choice decision making. That is why some transport professionals say that "**the sea battle is played out on land"** (Reynaud, 2009).

This statement can be explained by the fact that maritime segment of the whole maritime chain has already made considerable progress, from the technical, organisational and commercial point of views. Such progress can be represented for instance by the creation of containers ships with a capacity of more than 18 000 TEU, more flexible regulation with operator than for inland transportation and more openness to change in global economy. Maritime transportation can be seen as an industrialized process (Reynaud, 2009) whereas it is not yet the case for inland transportation.

Furthermore, the increase in the size of the containership implied that all containers now arrive at the same time in ports creating bottlenecks in the port itself but also in the hinterland that suffers from congestion. The congestion on the hinterland network is moreover reinforced by the fact that the transportation of goods on the European network is mainly realized on a limited amount of corridors.

Thus, the huge productivity gains in maritime transportation have not been realized yet by inland transportation and ports suffer from problem of inland accessibility or lack of capacity on the inland infrastructure. That is why it is important to focus now on inland transportation. Through this study it will be possible to determine if improvements in inland transportation will have consequences on port choice decision making.

3.3. Mode and intermodal contributions in hinterland connections

3.3.1. Hinterland Transport Modes

As mentioned above ports cannot anymore look only within their physical boundaries to be competitive they have to ensure that they have good relations with other maritime destinations and with their hinterland. Regarding hinterland relations it seems important for the ports to have several modes available. Indeed, this give more flexibility to the clients meaning that if a failure occurs on one mode, there is still possibility to shift containers on another mode.

Three modes are usually available at ports: road transport and two massified modes rail and barge transport. In the next paragraph a description of the advantages and disadvantages of each mode will be given, with a description of the concept of the massified mode and the situation in which they can be used will be given

3.3.1.1 Road transport

Road transport is nowadays still the dominant mode used to serve the hinterland. This can be explained by the fact that road transport provide some advantages for the transport of containers. The main advantages of trucking are the high density of the network that lead to flexibility and the fact that all the destinations can be reached without any transhipment, leading most of the time to faster delivery. Another advantage is that the number of actors involved in the carriage of containers is limited when considering this option.

The major drawback is that inland haulage by road creates lots of congestion at the port. Indeed, when a ship calls at a port all the trucks arrive during the same time period to pick up containers, creating congestion at the port gate. Congestion is also observed on the road network like on the A15 for the port of Rotterdam, and this can impact the reliability of this mode. External effects such as pollution and noise are also created by road transport. If internal and external costs are taken into account it is the most expensive mode per kilometre.

3.3.1.2 Special features of the massified modes

It can be stated that in general massified modes are more able to transport large volume of good than road transport. That is why as "container throughput decreases the share of road increases, reflecting the limited opportunities to consolidate the larger volumes on particular corridors that are normally required to allow economically viable rail or barge movement to/from a port's hinterland" (UNECE, 2009). Thus, ports having larger containers throughput can realize economies of scale because they can use the cheapest hinterland modes as will be outlined later. In addition massified modes allow reducing pollution and GES emission. They also allow to increase the hinterland of the port, and were partly responsible of the overlap of the hinterlands, and thus of the strengthening of competition between ports.

There is a kind of cycle with hinterland development. This cycle correspond to the fact that to can build hinterland connections with massified modes a sufficient demand of cargo is necessary. Then, the cargo demand will even more increase when such connections exist. But on the other side, if a port does not have enough cargo to develop such mode, it cannot attract new cargo and will never have the demand to implement such services. This cycle can thus impede seriously the development of intermodal corridors.

To summarize the use of massified modes requires that:

- **A high volume of goods should be transported on a same segment, and preferably with a high density**
- **Containers should be transport on a segment on a regular basis to ensure the development of a service, and it is preferable if there is a balance between the two directions**
- **Goods must be transported on long distances to be competitive with road**
- **Goods do not have a high value of time, and thus do not require fast shipment**
- **The extremities of the logistics chains should be located near the terminals**

The intermodal transportation is complex because it involves lots of actors, both from public and private sectors that have to work together. It thus requires additional organizational transport constraints, like coordination. The problem is that companies that are normally concurrent have to cooperate to provide a unique service, but each company want to optimize its own transport segment making the whole optimization of the chain difficult (Fries et al, 2007). It would be easier if only one company will be responsible of the whole itinerary.

3.3.1.3 Rail transport

Rail transport has a relatively low share in Europe. The capacity of the train varies between 40 to 95 TEU (Notteboom, 2008). This mode is mainly used for long distances (above 250 km), due to the high share of transhipment costs in the total transportation costs and its lower frequency with respect to the road. It also requires more equipment than road haulage, due to the fact that additional storage facilities are necessary at the transhipment point. In addition this mode is not really relevant for the shipment of small quantity but rather use for large shipment.

The main constraints of the rail network are the limitation of the network (due to a lower density of the network if compared with road network), and the fact that pre/end road haulage is necessary, as the door-to-door journey cannot be realised entirely by train. This adds additional transhipment costs and time. Nevertheless, in the case of maritime containers it should be considered that only one pre/end haulage is required as one extremity of the transport chain is the port, where additional road haulage is not necessary.

Another constraint is the lack of interoperability of both personnel and infrastructure on the networks between European countries. It refers first to the incapability of drivers to drive a train on two different countries due to the necessity to have the two qualifications. Then, it also refers to the differences in gauge, in signalling system, administrative burden and power supply. It has for consequence that rail transport is quite slow with regard to road transport, because additional waiting time is created at the border.

Another drawback is the fact that most of the time the freight trains do not have priority with regard to passenger trains, meaning that the number of train paths available is limited, as the departure times. For the same reasons the flexibility is limited, because if a train path is missed it cannot be used later due to the high use of the network. Finally, costs differ a lot on the rail infrastructure and there is no transparency about the price.

By focusing more specially on the port it can be highlighted that access to the rail network in the port is of high importance. Indeed, the organisation of the rail transport within the port is essential for the whole competitiveness of the rail link. To improve this organisation it seems really important that port authority control the rail network within the boundaries of the port, and that this latest was not left to the national railway authorities.

3.3.1.4 Barge transport

Barges are navigating on the inland waterway network. Thus, they cannot be used as inland transportation mode by all ports, due to the fact that some ports are not connected to navigable inland waterways network. This leads to a limited flexibility of the services and explains the fact that Rotterdam and Antwerp handle around 95 % of the total container transport by barge in Europe, as they are really well connected to the Rhine basin and because 20 000 km of inland waterway is concentrated in Germany, Belgium, France, Austria, and the Netherlands. In addition, even if some waterways exist they cannot all be used for navigation or can only be used on a limited extend due to several limited factors such as insufficient water depths or bridges clearance, locks and local current state.

Another restriction of the barge transport mode is due to the fact that barge transportation was often limited to some products (bulk) and only opens recently to other market such as container market. In addition the fleet is mainly composed of old engines and barge leading to air pollution.

Barge transport is also characterized by its reliability, because of the high capacity of its infrastructure and the fact that there is no congestion on it. Currently, the capacity of this mode has not reached its limits, and can thus be developed to host more freight transport. In addition, a barge is the vehicle from the three previous modes that has the highest capacity (60 to 200 TEU). It is also the cheapest mode of transportation.

The main disadvantage is the speed of inland waterway that is really low, thus this mode can only be used for goods that does not have a high value of time. Nevertheless, the speed of IWW is not a big disadvantage when taking into account the total travel time of the containers on the maritime door-to-door transport chain. Indeed, travelling from China to Europe require 3 to 4 weeks so the additional travel time by barge with regard to road is judged really small. In another hand it is a really ecological mode of transport.

One of the main issues limiting the use of IWW in France is that the handling costs from and to the barge are not including in the Terminal Handling Charge (THC), whereas the handling cots from rail and road are taken into account in the THC. This does not lead to a fair competition between all the modes.

3.3.2. Terminals

The three modes used for hinterland connections have been described in the previous sections. Nevertheless, there are not the only components of the hinterland connections. Indeed, in the transport chains, containers can be directly transport to their final destination or they can be transhipped at intermediate nodes usually inland terminals. Those transhipments are advantageous only if the distance on which the goods are transported is long enough, because it is only in that case that the cost of transhipment are counterbalanced by the lower costs of transportation. Usually, the transhipments at an inland terminal are realized for massified modes, but is not required for road shipment.

Indeed, an important part of the competitiveness of the road mode with respect to the alternatives modes is linked in its simplicity of utilisation and it flexibility. Against a road door-to-door service (without transhipment), the IWW and rail modes required an effort of organisation and coordination of the different steps that depends often of different operators.

3.3.3. Intermodal transport chains

3.3.3.1. Introduction to intermodal transport

In the two previous subparagraphs it has been observed that containers can be transported by massified modes. This often requires associating several hinterland modes in the global transport chain, as the density of rail and barge networks is not as sharp as the one of the road network. Pre and end haulage are thus necessary, which implies that containers need to tranship in inland terminals.

In this paragraph the different possibilities of intermodal chains will be described. First a definition of intermodality should be given. Intermodal transport corresponds to "the movement of cargo from shipper to consignee using two or more different modes under a single rate, with through billing and through liability" (Hayuth, 1987).

Intermodality is thus related to the integration of several modes at three levels (Communication from the Commission to the European Parliament and the Council, No Date):

- Integrated infrastructure and transport means,
- Interoperable and interconnected operations (especially at the terminals),
- Integrated services and regulation.

According to Reynaud (2009), “inland transport by rail of maritime containers appears to be competitive for distances of over 300/400 km, always assuming that the cost of rail transhipment within the port precinct is not higher than the cost of road transhipment or lower”. On figure 14 this phenomenon is highlighted by representing the costs on the y axis and the distance on the x axis. The point of intersection between the line B and the line C, corresponds to the distance at which rail or barge become cheaper than truck haulage.

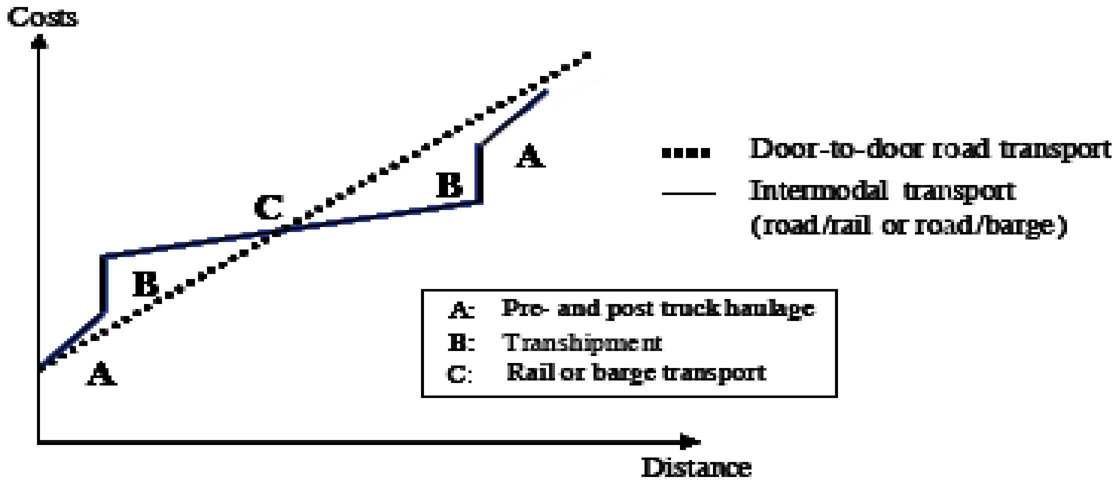


Figure 9: Breakeven distance of intermodal services with regard to trucking: single-road mode transport.

Intermodal transport is particularly adapted for the transport of maritime containers, because these latest only require one road haulage, instead of two for shipment that does not have for final destination one port.

When looking at hinterland connections it is important to not focus only on the intrinsic characteristics of the infrastructure. It is also necessary to look at the services that are provided on those infrastructures. Indeed, you can have really efficient infrastructures but with no services provided on it. The efficiency of those services is thus important, such as the reliability on the travel time, even if it can be assumed that on such long distances the reliability is of less importance.

3.3.3.2. The different kind of intermodal transport chains

As explained above intermodal transport chain consists of the successively use of two or more modes of transportation. Several possibilities thus exist depending on the modes used and of their order.

- **Combined transport rail-road**

The combined transport rail-route can be represented by the transport of containers from the port to a platform rail-road by train, and then an end haulage by truck.

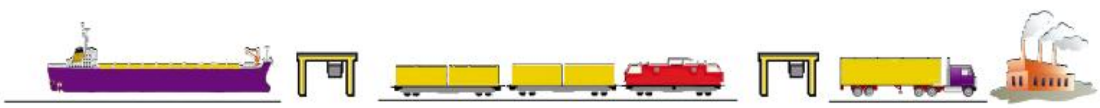


Figure 10: Representation of the combined transport rail-road (ADEME, 2006)

- **Inland Waterway-Road**

In this intermodal transport chain, the transport by barge is realized between a seaport and an inland waterway port. The pre/post carriage is then realized by road.

Figure 11: Representation of the combined transport Waterway-Road (ADEME, 2006)

- **Inland waterway-Rail**

This intermodal transport chain is rare but still exists and will be taken into account in the model used in this thesis. It is mainly for itinerary having for final destination an ITE (Installations terminals embranchés), as for instance an industry directly connected to the rail network.

- **Inland waterway-Rail-Road**

This kind of intermodal transport is not commonly developed yet, due to the high number of transhipment. The only known cases are on the Rhine at Duisburg or Basel. But these two locations benefits of specific conditions with large catchment area and strong link with the national rail operators (Beyer, Verhaeghe, 2014). If such solution is not widespread yet, it can be highlighted that currently itineraries with three transhipments are already realized, when containers used successively two train shuttles by transhipment in a rail hub such as Ludwigshafen. Thus, why the same could not be developed with a transhipment rail-inland waterway? It should be admitted that this kind of haulage can only be realized on long distances, in order to justify the two transhipments.

These four types of intermodal chains will be taken into account in this study, to the hinterland relations between a port and its hinterland.

3.4. Conclusion

In this chapter the main characteristics of the maritime transport chains have been described. First, it has been demonstrated that container trade had exploded during the last decades, and that it has enabled to realize significant economies of scale on the maritime chain. It has also been highlighted that the maritime transport chain is usually divided into three components: maritime carriage, port transit and hinterland transportation; and that the latest component has an important share in port choice. Finally, the different types of hinterland transport solutions have been detailed, with their main characteristics.

This chapter has thus focused on the worldwide container trade and on the general organization of the maritime chain, but to can answer the research question more focus should be given to the situation in Europe, this will be done in the next chapter.

4. Trans European Transport Network (TEN-T) development in the context of port competition in Europe

In the previous chapter the principles of port competition have been exposed. This chapter will describe what the current situation with regard to port competition in Europe is. Thus the following research sub question will be answered:

3. What is the current situation regarding the balance of containers between the ports of the HLH range and those of the Mediterranean range? How this balance can be explained?

4. What are the main future transport infrastructures and services developments on the North Sea-Mediterranean Sea that will occur by 2030?

In this chapter, first the analysis of the port competition in Europe for container market will be provided. Then in section 4.2 the reasons for the current state of the balance of containers between the ports of the HLH range and those of the Mediterranean range will be provided. In section 4.3 the European policy with regard to the transport infrastructures will be detailed, and in section 4.4 the conclusion of this chapter will lead to the problematic of this thesis.

4.1. Container port competition in Europe

As mentioned in chapter 2, the goal of this research is to determine if the setting up of the corridor North Sea-Mediterranean, under different scenarios, will have influences on the balance of containers between the ports of the North Sea and those of the Mediterranean. To can answer this question it is first necessary, to define the ports' ranges in Europe and to determine what the current balance between those ranges is.

4.1.1. The port network structure in Europe

Europe is currently one of the continents that gathers the highest number of ports. In 2007, there were 130 European ports capable of handling containers, among which 40 were ensuring international trade liaisons (ESPO/ITMMA, 2007). By comparison, in the USA/Canada only 35 ports seaports were able to handle containers, among which only 17 were ensuring deep sea liaisons (ESPO/ITMMA, 2009).

Usually, the ports in Europe are divided into groups called ranges. In this study the following six ranges that are represented in Figure 12 (Notteboom, 2008):

- Hamburg-Le Havre range (HLH),
- Mediterranean range ,
- UK and Irland range,
- Atlantic Range,
- Baltic,
- Others: Black Sea +Turkey +Greece.

This research will principally focus on the HLH and the Mediterranean ranges, as its aims is to study the evolution of the balance of containers between those two ranges.

Figure 12: Port Ranges in Europe

4.1.2. Container traffic in the European Ports

After having define the ports' ranges in Europe, it is necessary to study the repartition of traffic between those port ranges. First, the container throughput of the 14 major European ports between 2000 and 2010 will be studied. In Figure 13, it can be observed that three ports are dominating the European market. Those ports are Antwerp, Rotterdam and Hamburg. Indeed, 20 % of the goods coming to Europe transit by these three ports (European Commission, 2013b), that all belong to the HLH range. Thus, from those results it seems that the HLH is predominant for the handling of containers in Europe.

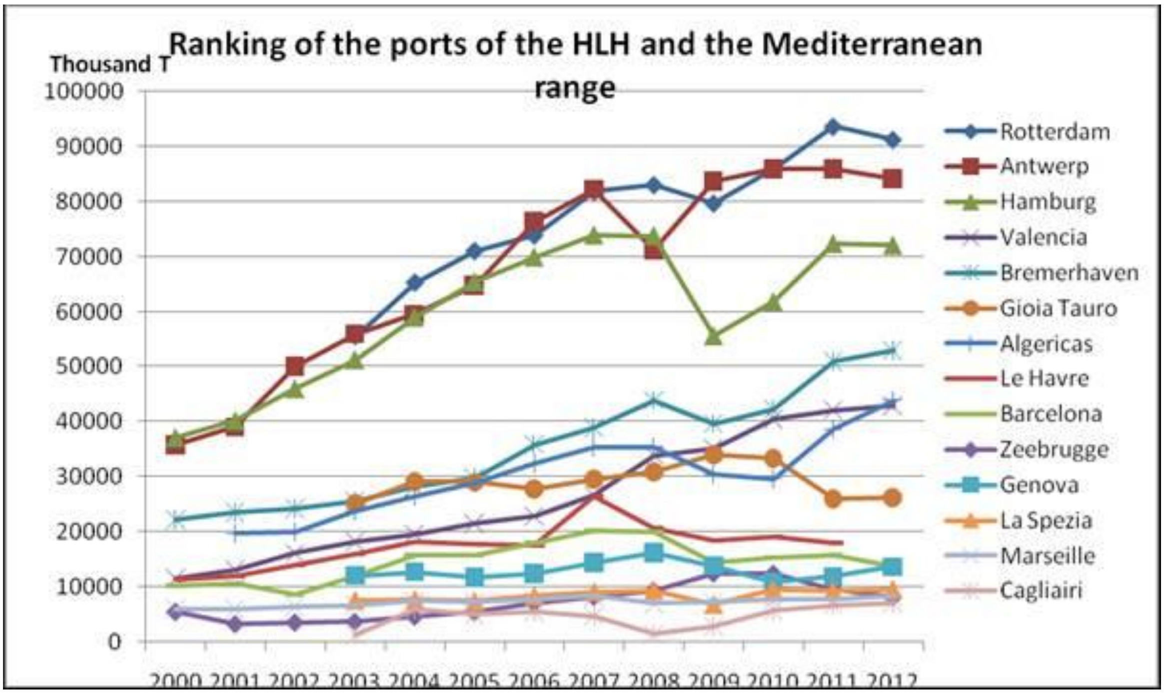


Figure 13: Ranking of the ports of the HLH and Mediterranean ranges (Eurostat, 2014)

In the previous graph only the containers throughputs of the 14 first European ports have been taken into account. To have a view at the level of the ranges, the repartition of container throughput between those ranges have been studied and represented in Figure 14.

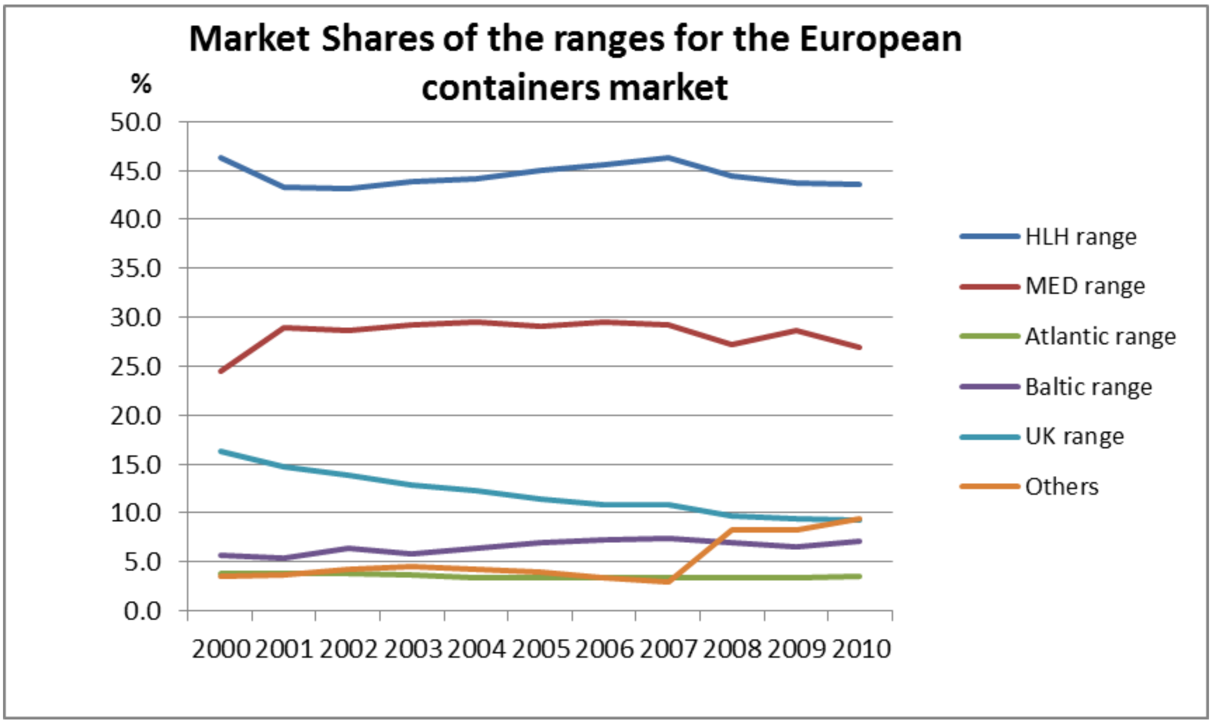


Figure 14: Market Shares of the European ranges for containers market between 2000 and 2010 (Eurostat, 2014)

This graph highlights the fact that the HLH range is the dominating range for the handling of containers in Europe, with around 45 % the market share. The Mediterranean range comes at the second place, with a little more than 25 %, and the four other ranges being far behind with market share below 10 %.

If focus is now given on the history of the competition between the Mediterranean and the HLH range, it should be noticed that between 1990 and 2000 the Mediterranean ports developed significantly (no data available), winning market shares on the HLH range (ESPO/ITMMA, 2009). Between 2000 and 2006 difference in market shares between the two ranges continue to decrease, due to the development of the transhipment hubs (Algericas and Gioia Tauro) (Gouvernal et al., 2012). Nevertheless, since 2006 the gap increases, due to the fact that the ports of the HLH range better opened their hinterlands toward the East of Europe than the ports of the Mediterranean range.

From what precedes it is obvious that there is an unbalance between the ports of the HLH range and those of the Mediterranean range, in favour of the HLH range that gathers the main part of the European market. Some authors even called it the "unhealthy" balance (Notteboom, 2008). In order to determine if such an unbalance will persist in the future, the reasons for this specific balance will be detailed in the next section.

4.2. Motives of the balance between the ports of the Hamburg-Le Havre and Mediterranean range

If a quick look is given to the geographical position of each port, it can be observed that the ports of the Mediterranean have one main advantage with respects to the ports of the HLH range. For all the routes that pass through the Mediterranean Sea, so notably the Asia-Europe route, they reduce the travel distance of the deep sea vessels of around 3300 km. Nevertheless, as it has been highlighted in the previous paragraph, containers are mainly directed toward the ports of the Northern Europe. This section will thus try to find out why.

One of the reasons might be that most of the containers have for final hinterland destination Northern Europe instead of Southern Europe. Shippers thus try to transport their containers by Sea the closest to their final destination, because sea transport of container per kilometre is cheaper than hinterland transport of container per kilometre. Knowing that the worldwide flows of goods are mainly explained by the Gross Domestic Product (GDP) and the population in the vicinity of the ports (Tavasszy et al., 2009), the repartition of GDP and population in Europe should be study to see if the previous hypothesis is true.

From Figure 15 (left), that represents the density of population in Europe it can be highlighted that the density of population is actually higher in northern Europe, than in the south of Europe, with a density of more than 1 000 inhabitants per km² on the coast line from Le Havre to Amsterdam, so in the really vicinity of the ports of the HLH range. The repartition of the GDP (Figure 15, right) seems to be more balanced, even if Benelux and Germany, gather a high share, but the location of this GDP generating points are located further away from the coast. If Europe is divided into two parts, by taking a virtual line that is equidistant from the HLH range to the Mediterranean range, it can be seen that the northern part of Europe gather 59.5 % of the population and 65 % of the GDP, whereas the South part gather 40.5% of the population and 35% of the GDP.

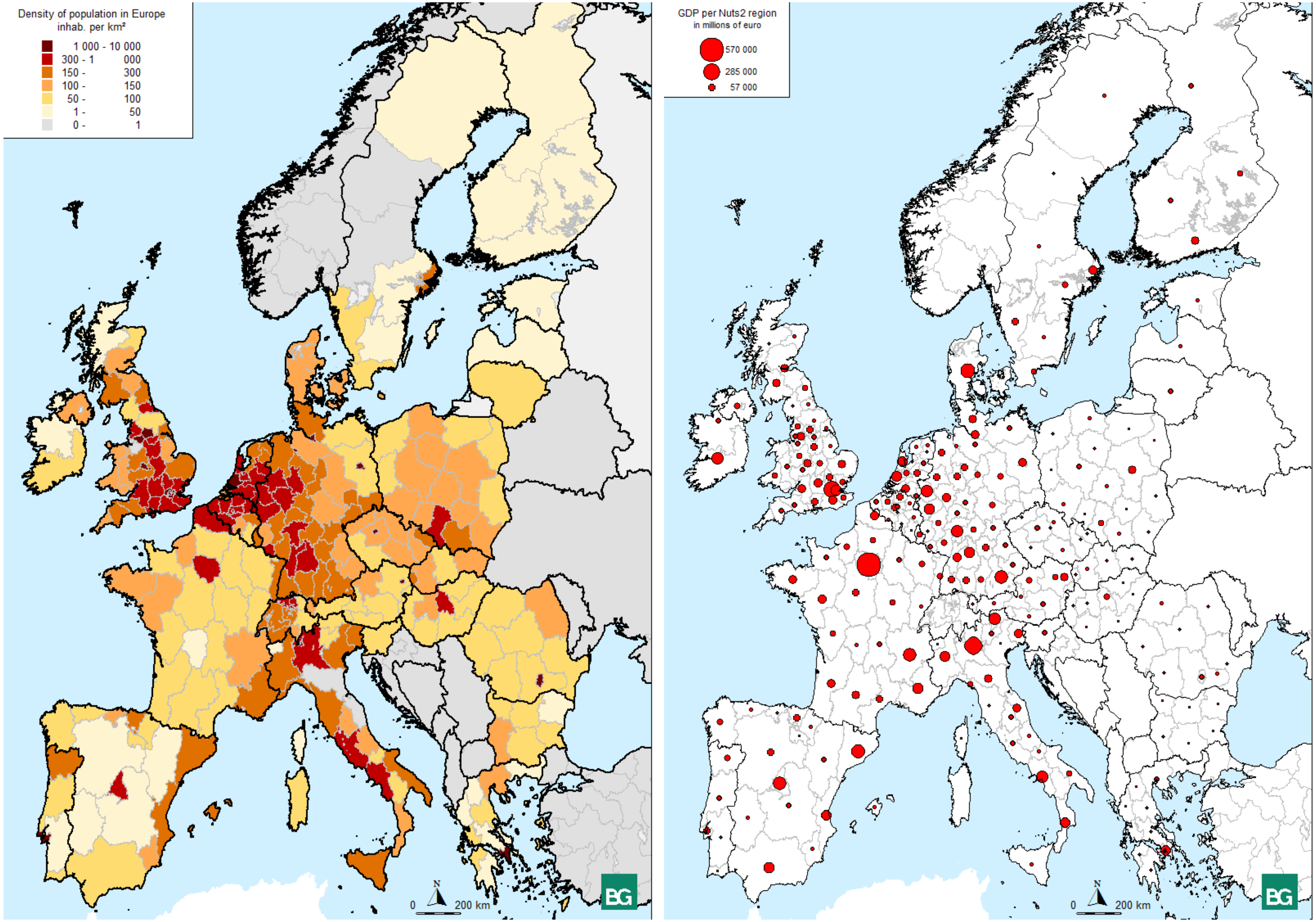


Figure 15 : Density of population (left) in Europe in 2007 and GDP per capita (right) (Source: Eurostat, 2014)

By doing the same with the container throughput, it can be observed that the northern part (HLH range, UK and the Baltic) gathers 60 % of the container throughput of Europe whereas the southern part (Mediterranean, Adriatic, Black Sea, Greece and Turkey) gathers 36.44 % of the containers throughput, and the last 3.5 % are affected to the Atlantic range that is divided between both the North part and the Southern part. From what precede, it seems that the **distribution of containers among the European ports, only transcribes the repartition of population and GDP in Europe, and that there is no “unhealthy” unbalance.**

The **geographical characteristics** of the region are also of importance for the port choice decision making because they have consequences on the ease of implementation of the hinterland transport. Regarding this criteria the ports of the Northern range have a far more favourable situation than the Southern ports. Indeed, the Alps creates a barrier really close to the coast line for the ports of the Mediterranean range to extend their hinterland up to the North, whereas the ports of the Northern range benefits from a flat relief up to the Alps. In addition, the Northern ports benefit from a vast inland waterway thank to the Rhine, Mosel and Scheldt basins. Figure 16 represents the current situation, regarding the geographical and economical characteristics of Europe.

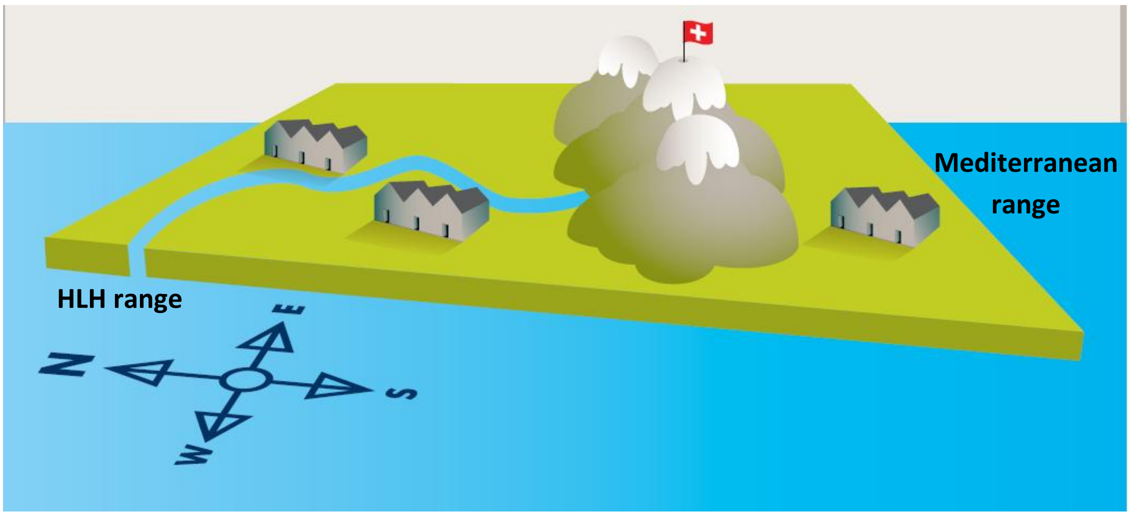


Figure 16: Geographical situation of the European ports (Source: Port of Rotterdam Authority, 2011)

Finally, the ports of the HLH range have higher capacities than the ports of the Mediterranean range, this has for consequences that they can attract bigger ships and can thus benefits from **scale effects**. Southern ports are unable to attract the bigger ships (nowadays) due to too scarce demand/volume of container.

Ports of the Northern range are also located quite close from each other in term of distance if you compared with those of the Mediterranean range. Ducruet et al. (2009) groups them into multi-port gateway regions. The vicinity of those ports has for consequences that those ports can take advantage of mutual inland transport infrastructures, increasing the utility of those infrastructures, making the infrastructure projects more viable, and easier to implement.

Another factor that can influence this balance is the **quality of the hinterland connections**, as it has been highlighted in chapter 2 quality of hinterland connections is the prevailing factor in port choice decision making, it is thus highly possible that the quality of the hinterland connections is responsible for that balance. Let's take the example of the port of Marseille; it can be observed that it has pretty bad hinterland connections. Indeed, most of the containers are shipped in the hinterland by road creating congestion on the road network of the region and of the Rhone Valley. This is due to the fact that the alternative modes that are IWW and rail do not offer efficient transport solutions. The rail network is already at saturation at the level of Lyon, and the hinterland waterway network only go up to Pagny, so not that far in the hinterland, and are even more restricted to two layers barges from Lyon. By comparison the ports of the Northern range use far more massified modes (Capellari and Libourel, 2012).

Those statements are confirmed by Gouvernal et al. (2005) that stated that the predominance of the ports of the HLH range is due to the efficiency of those ports but also to the well-functioning hinterland connections. The report of OCDE/ITF (2008) stated that "The North-South imbalance among ports in Europe is growing larger, and this is largely because of more favourable hinterland transport conditions in the North".

4.3. The Trans European Transport Network (TEN-T)

The previous section has highlighted that the efficiency of the transport infrastructures and services is not equal among all the European countries, and that the overall quality of the transport network in Europe could be increased. Indeed, nowadays links are missing in the European intermodal transport network, preventing the development of efficient intermodal chains at the European scale. To overtake this problem the European Union came with a policy based on the TEN-T network. In this chapter the principle of the TEN-T network will be explained, and then focus will be given to the details of this policy instrument for the corridor of interest in this research.

4.3.1. The Core Network Corridors of the TEN-T

The TEN-T network is not a new policy instrument of the European Union. Indeed, its development started in 1990 when the Commission adopted its first action plan regarding TEN (transport, energy and telecommunications) (European Commission, 2005). The initial goal of the TEN-T was to link the main cities and economics centres in Europe (within and outside the EU), in order to concentrate the main traffic on those links.

In 2013, a revision of the TEN-T Guidelines was realized (Official Journal of the European Union, 2013). This revision highlights several points, with regard to the transport issues in Europe:

- the current European Infrastructure network is fragmented between the different modes,
- multi-modal transport could be better exploited,
- multi-modal nodes have a high role to play to connect the different modes.

In order to resolve the problems quoted above the Regulation 1315/2013 of the European Parliament states that the new main objectives of the Trans-European transport network are to ensure:

- the cohesion of the European Union's regions, by improving their accessibility and connectivity;

- the efficiency of the transportation network, by the removal of the bottlenecks and the construction of the missing links, and by improving interconnections and interoperability;
- the sustainability of the transportation sector;
- safe, secure and high quality services for both passengers and freight transport.

Those objectives will be reached, by the implementation of the new EU infrastructure policy that is based on a dual layer approach:

- a **Comprehensive Network** in charge of ensuring connections with all the regions in Europe that will be developed by 2050;
- a **Core Network** that gathers all the most important part of the Comprehensive Network, and that can be seen as a multi-modal backbone of the mobility network. The core network is prioritised for 2030.

According to the paragraph 13 of the Preamble of the Regulation 1315/2013, the main objectives of the core network are to remove the bottlenecks and to build the missing links, to provide interoperability of the different modes and to reinforce the multimodal liaisons. To do so the European Core network is divided into nine corridors (cf.

Figure 17) that should concentrate at least three modes, and should be implemented at the horizon 2030:

- The Scandinavian-Mediterranean Corridor
- The North Sea-Baltic Corridor
- The North Sea-Mediterranean Corridor
- The Baltic-Adriatic Corridor
- The Orient/East-Med Corridor
- The Rhine-Alpine Corridor
- The Atlantic corridor
- The Rhine Danube Corridor
- The Mediterranean Corridor

The main improvement of this new version of the TEN-T network is that the corridors are for the first time multimodal corridors including the different transport modes and also the intermodal platforms. The different modes are thus bringing closer in order to favour their association. The following modes are included: air, inland waterway, rail, road and sea. This new version is also the first one that really includes freight transportation. The Core Network Corridors will thus provide transportation both for passengers and freight at high efficiency and low emissions, by “making extensive use of more efficient transport modes in multimodal combinations” (European Commission, 2013c).

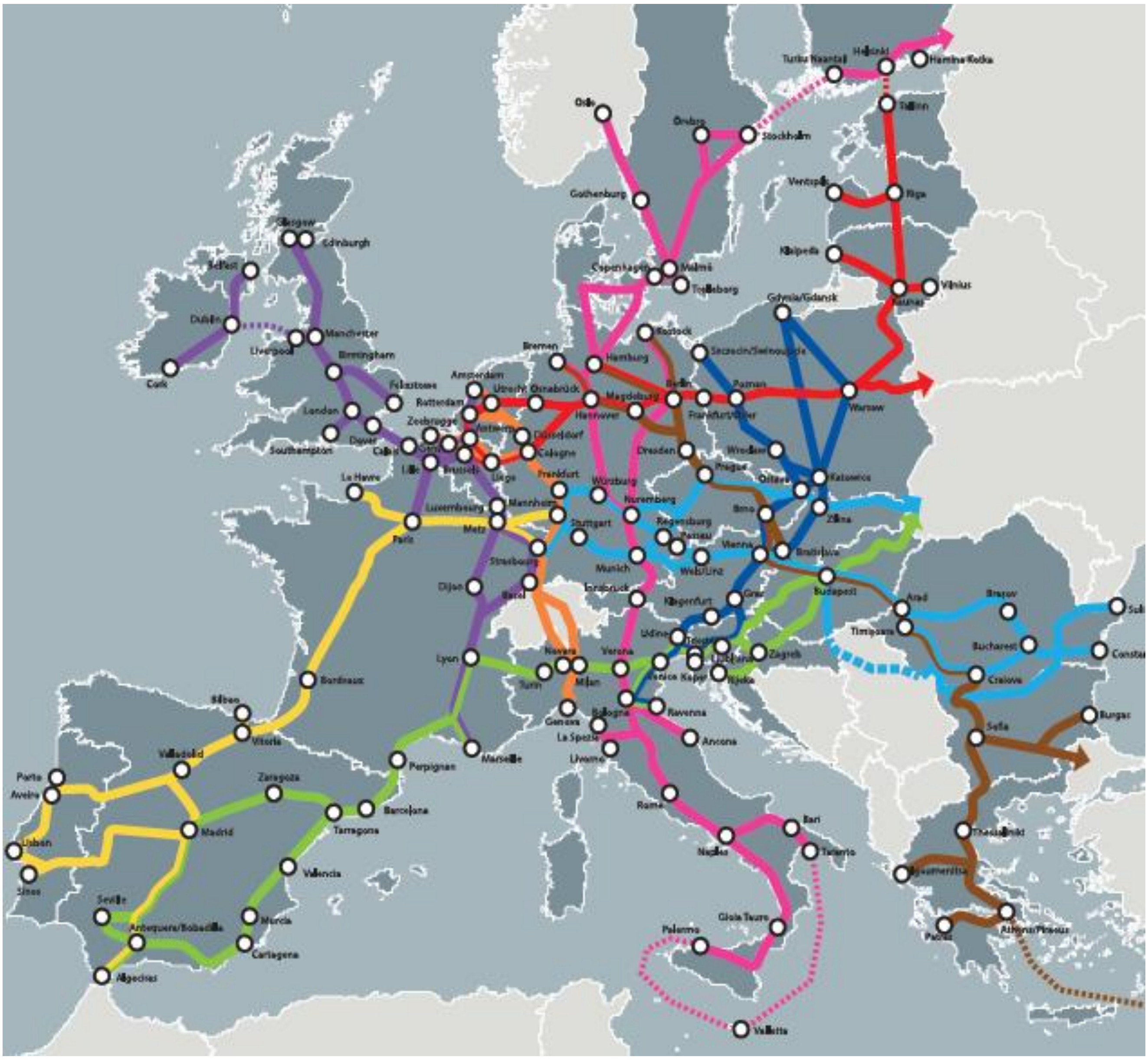


Figure 17: TEN-T Core Network Corridors (Source: European Commission)

In this core network Corridor, ports have a specific role. Indeed, due to their location at the extremities of those corridors they act as gateways for merchandises that arrive in Europe. In addition, as most of the European ports are located at the extremities of those corridors they are expected to be well connected to the rest of Europe by multimodal links.

Finally, it should be acknowledged that this approach of core network corridors goes beyond the infrastructure of transport, as its also gives insights to the global organisation of the system of transport.

4.3.2. The North Sea-Mediterranean Corridor

The interest of this study is on the balance of containers between the HLH and the Mediterranean ranges, with special focus on the ports of Rotterdam, Antwerp and Marseille. That is why the Core Network Corridor of interest in this study is the North Sea-Mediterranean Corridor (purple corridor on Figure 17). Nevertheless, the corridors Rhine-Alpine and Scandinavian-Mediterranean will also be considered to some extent as they also linked ports of Northern Europe with ports of the Mediterranean Sea.

The corridor North Sea-Mediterranean "stretches from Ireland and the north of UK through the Netherlands, Belgium and Luxembourg to the Mediterranean Sea in the south of France" (European Commission, 2013). This corridor goes through six member states: Ireland, UK, the Netherlands, Belgium, Luxembourg and France. It also reaches the borders of Switzerland. The alignment of the core network on the map is just there for indication. As explained above what matters is the functional objectives of the corridor.

This multimodal corridor aims at: offering better intermodal services on the main continent between the North Sea ports, the Mass, Rhine, Scheldt, Seine, Saone and Rhone river basins and the ports of Fos-sur-Mer and Marseille. It has also for goal to improve connections between Ireland and UK and the main European continents, but this goal is not of interest in this study, as only the mainland Europe part of this corridor will be considered. It includes the freight priority project 30 of the TEN-T programme of 2005, that is to say the Inland Waterways Seine-Scheldt.

The main missing links (on the main continent, not in UK) for this corridor are the IWW missing connections, mainly between the Seine and Scheldt (canal Seine-Escaut) and between the Rhine and the Rhone. The rail connections between Brussels,-Luxembourg and Lyon need also to be upgraded to can compete with the road mode.

On the countries of interest for this research the NS-MED corridor can be defined as follow:

In France

The corridor, which includes the Rail Freight Corridor 2, can be divided into two branches. The first one starts between the French-Luxembourg border at the North and end at Marseille at the South. This corridor goes through the main industrial regions of France that are: Nord-Pas-de-Calais, Ile-de-France, Lorraine, Alsace, Rhône-Alpes and Provence Alpes Côte d'Azur[3]. This corridor includes the "magistrale ecofret" the rail corridor that attracts most of the freight traffic in France.

It includes major hinterland ports, such as Mulhouse, Metz and Lyon, and one of the major waterway projects currently under study: **the Canal Saone-Mosel Saone-Rhine**. This project will allow linking the Mediterranean Sea to the Rhine River, by connecting the Saone at Saint-Jean-de-Losne (nearby Pagny) to the Mosel at Neuves-Maisons near Nancy and to the Rhine at Mulhouse[4]. It

[3] A map with the description of the French regions can be found in Appendix 4.
[4] A map explaining this project can be found in 7.1.2.

is planned to be put in service at the horizon 2025-2030. This project will be look closely in this thesis.

The second branch starts at Calais (link with UK) goes to Lille and Valenciennes to finally reach Paris. It includes two French ports that are Calais and Dunkirk, such as inland ports of Paris and Lille. Regarding freight the main infrastructure project of this branch is the construction of the Seine-North Europe Canal (CEMT class Vb), whose goals is to link the basin of the Seine to the Belgium waterway network. The Canal Seine-Nord Europe is planned for 2022.

In Belgium and Luxembourg

The main nodes that generate freight are the seaports of Antwerp, Zeebrugge, Gent and Oostende, such as the urban nodes of Brussels and Antwerp and the inland terminals and Rail-Road terminals. The corridor starts in Zeebrugge and Antwerp to go down to Gent and Brussels. At those locations, the corridor is dividing into two branches, one going to Paris and the other one to Luxembourg and Mulhouse.

In the Netherland

The corridor starts at Amsterdam, goes through the port of Rotterdam and is then link to Antwerp. Important road projects are under work construction and studies, those projects are the extension of the A4 between Delft and Schiedam, the bypass between A13/A16, and project of upgrading the Rotterdam-Antwerp freight line in the future (or even to build the ROBEL, a specific Rotterdam-Belgie freight line that will add cross-border capacity).

The Netherland faces also several bottlenecks (or future bottlenecks) on its IWW network at the following locations: Volkeraklock, Kreekaklock, Krammerlock, Lock Hansweert, Terneuzen Sea lock and the first part of the Terneuzen-Gent Canal.

The implementation of this corridor and of the projects attached to it will lead to significant changes in the inland transportation network but also in the services provided. It will be interesting to determine, after the implementation of the measures incorporated in the TEN-T vision, if significant changes occurred with regard to the repartition of traffic among ports.

4.4. Definition of the research question

In the previous paragraphs, it has been highlighted that the quality of the hinterland connections might be one of the reasons why the balance of containers between the ports of the North range and those of the Mediterranean range is such in favour of the North range, even if it is true that the North has some socio-economic advantages for the attraction of containers. On the other hand it has been highlighted that with the implementation of the Core Network Corridors of the TEN-T network, improvements of the transport infrastructures will occur on the corridor linking the North Sea to the Mediterranean Sea.

The question that thus arises is**: To what extent the improvement of the hinterland transportation of maritime containers on the Corridor North Sea-Mediterranean Sea of the TEN-T network, can lead to shifts of container flows between the ports of the HLH range and those of the Mediterranean range, and to modifications of the modal shares of the different hinterland transport solutions at the horizon 2030 under different future scenarios?**

This chapter has thus allowed defining the problematic of this research; the next chapters will present the method that will be used to answer it. First, in chapter 5, the tool that will be used to answer this question will be described, this tool will then be calibrated in chapter 6, and finally chapter 7 will present the hypothesis that will be taken to answer the research question.

5. The Portprint model for efficient assessment of the transport logistic chains

This chapter will start by explaining why it is necessary to use modelling to answer the research question. Then the specificities of this model with regard to other models will be displayed, as its perimeter. Finally, in section 5.4 the structure of the model will be presented, as the data required to use this model. In this chapter the following research question will be answered:

6. How can port competition between the European ports be modeled, by focusing on the hinterland segment of the global maritime chain?

5.1. Model purpose

The objective of this research is to determine if the improvements of the hinterland connections will allow inducing containers shift in the balance between the ports of the HLH range and those of the Mediterranean range. One of the sub goals is to determine if a shift of the modal share (road, rail and inland waterways) will occur due to those improvements. Thus, the goal is to quantify the impact of the changes in the hinterland transportation networks in term of market share between the ports.

To quantify the impact it is necessary to model the process of port choice decision making, in order to determine the market share of each port on each hinterland region for a relation with a partner maritime zone and the modal share of each mode between a port and a hinterland. To do so the PortPrint model will be used, by modeling different changes in the hinterland connections by the provision of new services.

The goal of the PortPrint model is thus to distribute the container flows among the European ports and to model the repartition of those containers on the hinterland, by specifying by which mode the inland shipment haulage of containers between ports and hinterlands will be realized.

In a more general way it allows to answer policy questions related to port competition, that is why it will be used in this thesis.

5.2. Model specificities in comparison with other port choice models

In the literature several models have been used to represent port choice decision making. For instance, the model of Posthuma (2011) took into account port competition between fours ports, as it focuses on inter-port competition within the HLH range. The smaller amount of ports considered (four), with comparison to the PortPrint model, allowed him to take two out of the three components of the maritime transport chain directly into account in the model (port transit and hinterland connection), as the input data necessary to consider those two elements of the transport chain can be obtained for those four ports.

In the Portprint model all the important ports handling containers in Europe, have been considered (throughput above 87 000 tons in 2007), thus 130 ports. This high number of ports is due to the fact that the goal of the model is to study the balance between two port ranges. To do so all the possible influences on this port ranges have to be taken into consideration that is why it is necessary to take the smaller ports into account as they can have consequences on the throughput of the major European ports. Nevertheless, it is not possible to obtain all the characteristics of these 130 ports (ports due, congestion, capacity, and utilization) in a homogeneous way. Indeed, the commercial secret and the special agreements between terminal operators and major shipping lines, make the procurement of those data really difficult. That is why the PortPrint model focuses on the hinterland transport characteristics only, by describing them in a really precise way. Indeed, the description of the hinterland costs, allow to take into account the inland transfer, and to make change in the costs structure of each mode, allowing testing different scenarios.

Tavasszy et al. (2011) took 437 containers ports around the world into account in their model. In this model the maritime liaisons are taken into account in a precise way by integrating the liner services of the different shipping lines into the model as the shippers' preferences. Nevertheless there is no differentiation of the tariff on the kilometre price of the whole maritime network. Furthermore, the description of the hinterland connections between the ports and their hinterland is not as precise as the description of the model Portprint, but this is due to the fact that it is a worldwide model. Thus the description of worldwide inland transport network is a really difficult, even impossible, task. This model focuses more on the maritime component of the whole maritime chain, and tries to integrate the hinterland transportation. Whereas the Portprint model focus mainly on the hinterland connections and try to integrate the maritime component, and is not at the same scale as it focus principally on Europe.

The description of the traffic repartition in the Porptrint model is quite precise because it is distributed at the node level. Usually, port competition models distributes the traffic at the regional level NUTS 3 for the model of Newton (2008) and at the level NUTS 2 for the one of Posthuma (2011).

5.3. Perimeter of modelling

5.3.1. The area of modelling

The goal of this research is to study the hinterland connections improvements on the North Sea-Mediterranean Corridor. Thus, all the countries cross by this corridor and that belong to the main continent should be part of the study area: France, Luxembourg, Belgium and The Netherlands. In addition, the two ranges that are considered for the balance of containers are the Northern range that included Germany, and the Mediterranean range including Spain and Italy. Thus, those countries are also part of the study area.

The port of Hamburg has a hinterland quite extend toward Eastern Europe that is why it has been decided to take all the countries of the EU 27, except Croatia and Malta, in consideration in the study area, in order to have a global picture of the main ports' hinterland in Europe. Switzerland has been added to this area, because it is an important hinterland for the competition between the North range and the Mediterranean range, and because it is surrounding by EU Members States.

The ports that are taken into account in this model are the ports belonging to the countries of the study area[5] and having an annual container throughput, in 2007, above 87 000 tons. It is necessary to take the smaller ports in consideration in this model because, if they were not taken into account the market share and hinterland of the main ports will be overestimated, and thus making the model not really accurate.

On Figure 18 the study area and ports belonging to this study area are represented:

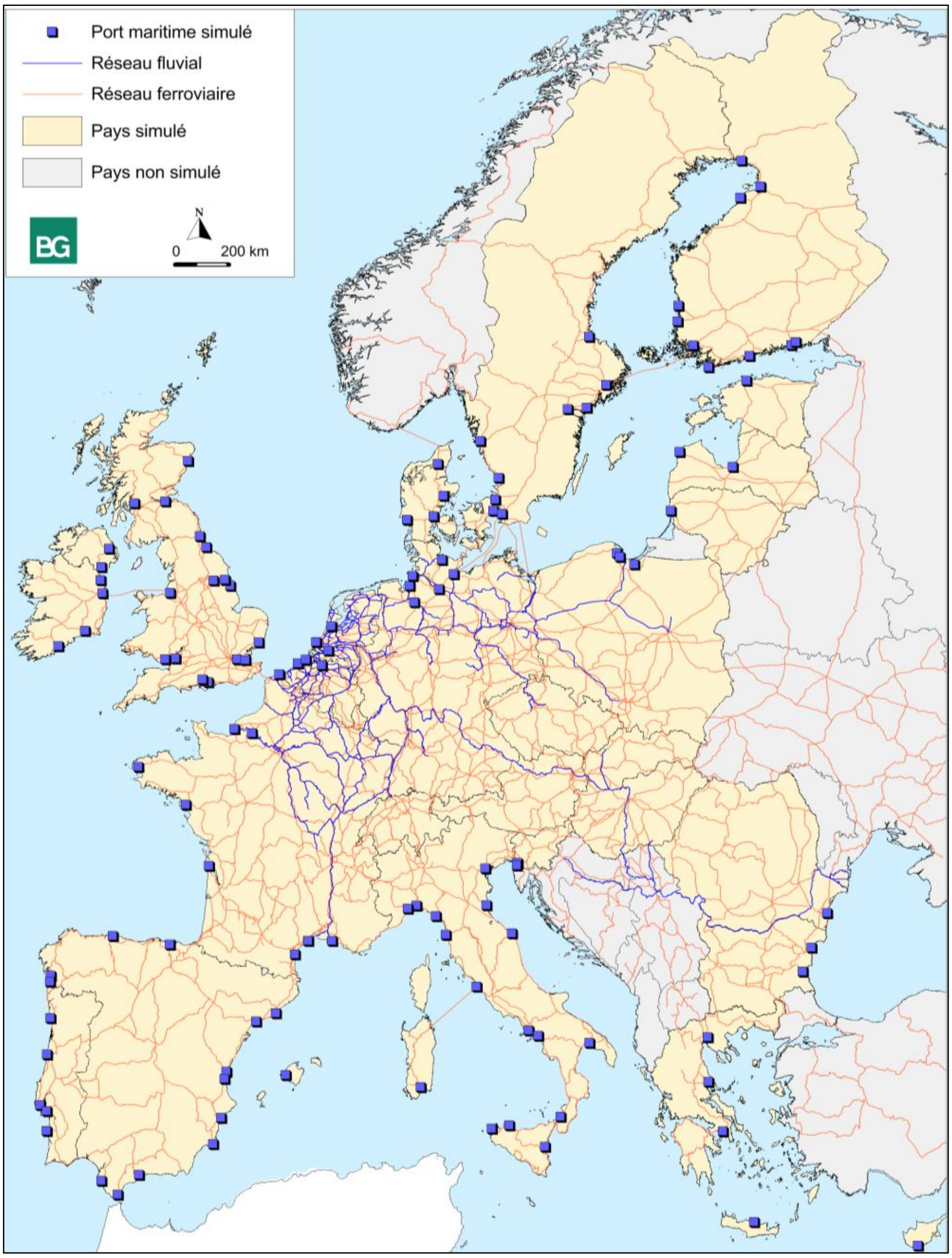


Figure 18: Study area of the model PortPrint

[5] The list of the countries and ports belonging to the study area can be found in Annex.

5.3.2. The considered transport mode

The model PortPrint only modeled "directly" the hinterland transportation of containers. Indeed, as will be explained later the maritime carriage is not directly taken into account in the model. This is due to the fact that currently there is no difference of price for transporting one container from Asia to Mediterranean than to transport one from Asia to the HLH range.

In addition, the pre/post hinterland carriage and the port transfer in the partner maritime zones (other extremity of the transport chain, outside of Europe), are not considered in this model, because the aim of this research is to determine what occur for port choice in Europe and not on those countries.

Only the hinterland transport chains are considered. Those transport chains can be monomodal or intermodal. The chains taken into account by the model PortPrint are:

- Road,
- IWW + Road (that will be refer as IWW in the rest of the report),
- Rail + Road (that will be refer as Rail in the rest of the report),
- IWW + Rail + Road[6] (‘that will be refer as IWW+Rail in the rest of the report).

The description of the transportation chains is really precise in the PortPrint Model because the intermodal terminals and the hubs are taken into account in the building of the transport chains. The transport chains are then built by juxtaposition of monomodal segments.

5.3.3. The traffic of maritime containers

The traffics of containers considered are those that are realised between the countries and ports of the study area and the partners’ maritime zones. The partners’ maritime zones have been classified according to the following pattern: Asia, North America, South America, Africa, Mediterranean and Intra-Europe (that take into account the feedering).

It is important to notice that the model PortPrint does not make the distinction between imports and exports, as the total traffics are considered. The inland shipment haulage from the port of the study area towards the Commonwealth of Independent States (CIS) is not considered.

[6] Possibilities of transshipment IWW-Rail are only introduced at the terminals of Antwerp, Rotterdam, Duisburg and Basel for the base year.

5.4. The model PortPrint

The model PortPrint is a modeling tool of the hinterland container traffic flows on the transport network. As explained above, the goal of this model is to simulate the hinterland shipment haulage of containers in order to evaluate how the traffic of containers generated/attracted by a point of the territory is distributed among the ports. This model is thus able to simulate the supply and demand of transport and to estimate the effects of potential modification.

The door-to-door problematic is at the center of the freight traffic flow modeling in this model. It requires having a really precise description of the source of traffic, of the components of the transport network (segment, inland terminal) and of the supply of transport, including the intermodal services, irrespective of the combination of the modes and the technique used.

5.4.1. The Structure of the model

The model PortPrint is made of five modules that can be observed in Figure 23:

- Module of Generation
- Module of Exploitation
- Module of Distribution
- Transport solution share module
- Assignment module

The model used in this thesis was not created from scratch for this thesis. Indeed, some materials were already available and provided by BG. BG had already developed the module of exploitation, with the description of all the costs of the three modes road, rail and IWW for 2007 but also fro 2030. Those exploitation costs were developed in previous studies that have been realized for VNF and RFF, and are thus reliable. BG also already adds develop the method for the module of generation. My work was thus mainly to develop the distribution and transport solution share modules and to apply them in practice.

It should also be specify that, for the development of this model it was necessary to realize some computer programming, as my knowledge in that domain was quite limited, the computer coding was realized an employee of BG .

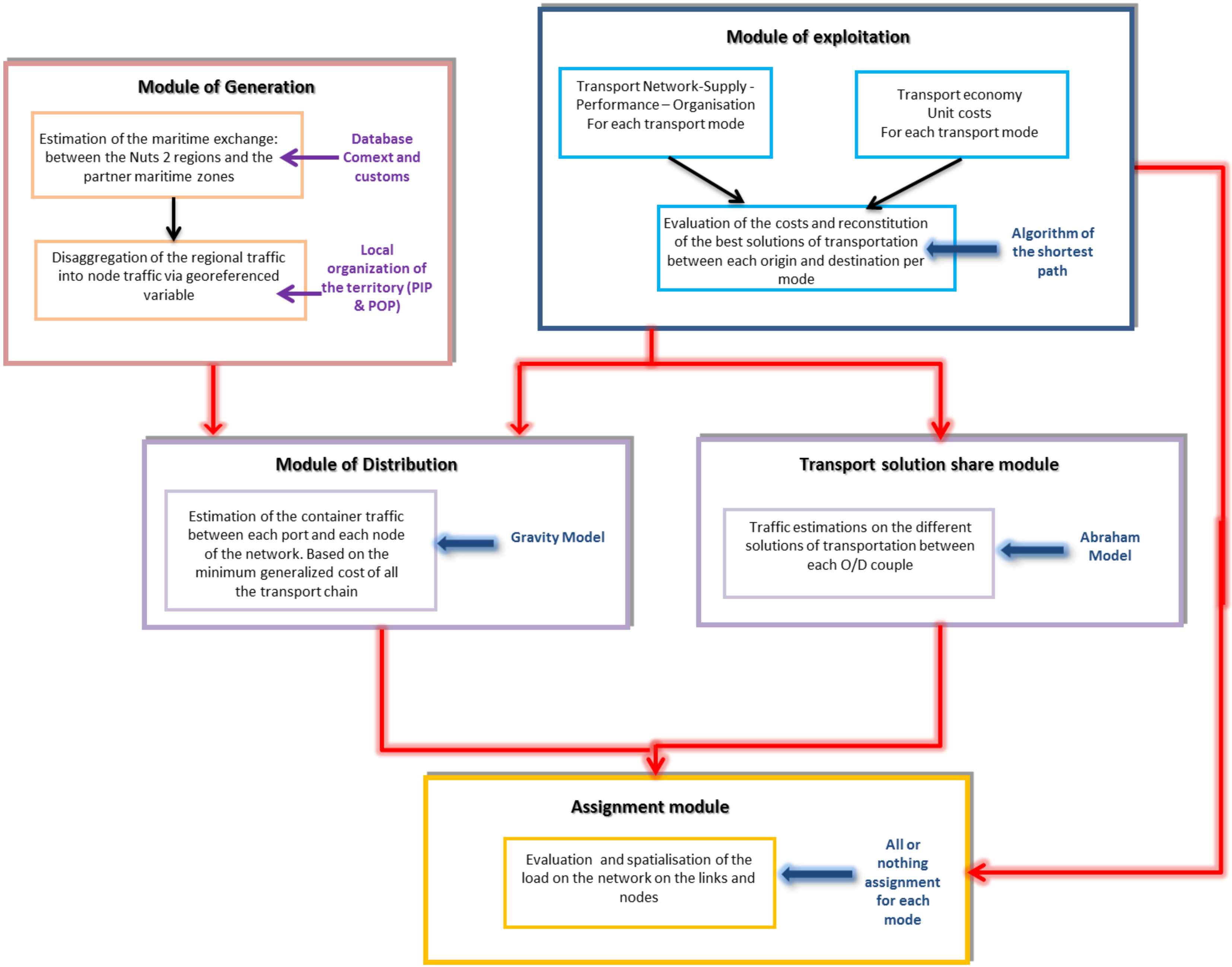


Figure 19 : Structure of the PortPrint model

5.4.2. Module of generation

The goal of this module is to determine the production and attraction of containers for each region (NUTS 2) and each node of the network (8004) of the European road network. The distinction between import and export in this module is not made as the total traffic is taken into account.

This module is divided into three steps:

Step 1: Determination of the extra EU container maritime traffic (in tons)

The goal of this first step is to determine, the origin-destination matrix of exchanges of containers between each country of the study are and each partner's maritime zones. To do so, the trade database Country-Country of Comext (Eurostat) that provides the tons per type of products exchanged between a country A and a country B has been used.

The first step to be taken was to determine which products are containerisable in order to obtain the container maritime traffic between a country A and partners' maritime zone B. Comext gives the number of tons per type of products under several classifications of products (NST/R, HS). But what is of interest in this study are the containers or tons of products transport in containers. It is thus necessary to define what the containerisable products are. In order to do so, the types of product of the nomenclature NST/R have been combined into 16 product's groups (cf. Appendix 1).

Then, among those 16 groups, the products that are containerisable have been determined. After that the tons of products that are transported by containers have been computed for each origin-destination by multiplying the tons of containerisable products on this OD by the rate of containerization in the European ports, as explained in the flowing equation.

$$Container = Tons.of.\Pr oducts.containerisable * Rate.of.Containerisation.in.the.ports$$

The output of this step is an origin-destination matrix with the tons of products import and export in containers from partner's maritime zone by European country[7].

Step 2: The regional traffic: Estimation of the maritime exchange (maritime zone-NUTS region)

From the first step of this module the tons of products exchanged by containers, between each partner maritime zone and each country of the study area is obtained. It is then necessary to determine the tons of containers exchanged per each region NUTS 2 with all the partner maritime zones, by disaggregating the data of the country level to the regional dimension.

The containers traffics between the regional level NUTS 2 and the main partners' maritime zone are determined using to different techniques depending of the countries:

- Using the data from the customs, that gives the exchanges of good between each region and the partner's maritime zone. Nevertheless, those data are only available for France (Sitram) and Germany.
- By distributing the national imports and exports between the regions in function of the repartition of the population (for the import) and the GDP (for the export) among all the regions of one country.

[7] **Details about the methodology apply can be found in Appendix 1.**

The output of this step is an exchange matrices between NUTS 2 regions and partners' maritime zones.

Step 3: Disaggregation of the regional matrix at the node level
The inputs of this latest step are the containers maritime exchange between each NUTS 2 region and the partners' maritime zones. The goal is to obtain the exchange between each node of the road network (8004 nodes) and the partner's maritime zones. The disaggregation is realized at the node level in function of the average of the relative weights of each node of the region considering the population and the industrial and commercial zones.

For instance, let's consider that in one region NUTS 2, there are three nodes, three cities and three commercial or industrial surfaces. The population and the commercial zones of the regions are linked to the nearest nodes, thus the city A and the industrial center a are attached to the node 1, city B and industrial or commercial surface b are attached to the node 2 and finally the city C and the industrial or commercial surface c are attached to the node 3.

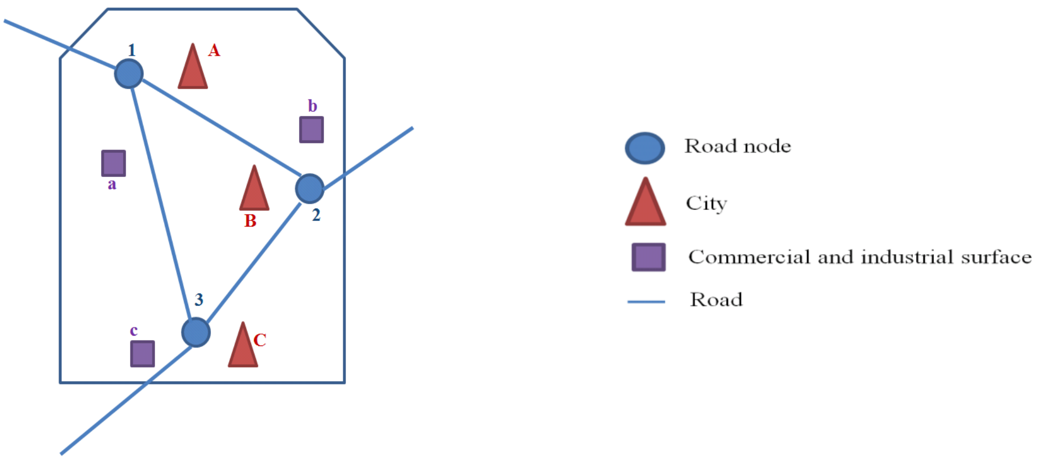


Figure 20: A NUTS 2 region and its main elements

With the distribution of industrial and commercial surfaces and of the population observed in table 2, the weights are those observed in Table 3. Thus, the total container traffic having for final destination this region is distributed according to those percentages of the table 3 among the nodes.

Table 1: Characteristics of the region NUTS 2 and weights of the nodes

Population		Industrial or commercial zones		Weight of each node in the region	
A	75 %	a	50 %	1	62,50 %
B	20 %	b	25 %	2	22.5 %
C	5 %	c	25 %	3	15 %

This process is realized for all the regions NUTS 2 in Europe. At the end of this step the exchange matrices between each node of the road network and the partners' maritime zones are obtained.

To sum up the process of the module of generation viewed as follow:

Table 2:Process of the module of generation

Step 1

Tons	Africa	Asia	Med	NA	SA	EU
Countries						
Austria (1)						
...						
UK (26)						

Step 2

Tons	Africa	Asia	Med	NA	SA	EU
Nuts 2						
1						
....						
275						

Step 3

Tons	Africa	Asia	Med	NA	SA	EU
Nodes						
1						
....						
8004						

5.4.3. Module of exploitation

For the modelling of intermodal transport of goods, modellers used more and more "Virtual network" or "super-network" (Jourquin & Limbourg, 2007). Those networks allow representing the transhipment operations between two modes in the network thanks to the creation of a transfer link in the network. In this thesis such a virtual network will not be used, due to the complexity to apply it in practice. Nevertheless, the method used in this thesis is based on the same approach, as it allows assigning flows on different transport chain, by splitting up all the operations of the transport chain. But in this case the decomposition is realized on the specification of the generalized costs and not within the network.

5.4.3.1. Structure of the module of exploitation

The goal of this module is to find the best solutions for each transport chain between a port and a given node, the best solution being defined as the one leading to the cheaper generalized cost. To reach this goal it is first necessary to determine the generalized costs of all the possible solutions, by using as input data the characteristics of the transport networks (supply, performance, organization of the transport mode), and the unit costs for each mode (road, rail and IWW).

To can determine the generalized costs of the transport solution, first the costs on each section of the network for each mode need to be determine[8]. Then the different sections are juxtaposed to

[8] The description of the cost of each segment per mode is given in Appendix 2.

create the multimodal transport chain, and the cost of the transport chain is calculated. The description of the costs is quite precise because it is based on the unit costs of each mode. Below the method of determination of the generalized cost of the transport chain is given.

5.4.3.2. Computation of the costs of the road chain and of the segments of the multimodal transport chains

5.4.3.2.1. Evaluation of the road cost

The road mode can be used as the main and unique transport mode or as pre or end haulage for multimodal transport solutions. The costs of those two alternatives will be determined in this thesis.

a) Trucking: Single mode road transport

The road cost is determined by summing the cost of driving on the road network, the cost of the loading and unloading containers at the extremity of the hinterland chain and the driving cycles' cost. Those three components will be detailed in the next section.

Determination of the cost of driving on the road network between i and j

This cost of driving on the road network is made up of three components:

- the fixed kilometer costs,
- the variable kilometer costs that are function of the characteristics of the section:
  - Toll
  - Energy costs (function of the speed of the vehicle)
- the hourly costs linked to the driver salaries and the usage of the vehicles.

Thus the cost of driving through a section a can be computed as follow:

$$\mathbf{Cost_a = C\_Fkm_a + C\_Time_a + C\_Toll_a + C\_Energy_a} \quad (1)$$

With

C_Fkm$_{(a)}$: Fixed kilometer costs
C_Time$_{(a)}$: Hourly cost
C_Toll$_{(a)}$: Toll of the section a
C_Energy$_{(a)}$: Energy cost of driving through section a[9]

The costs of all the section are computed and then the algorithm of the shortest path searches the itinerary between i and j that minimized the sum of the costs of the sections to linked those two nodes. Thus the costs between an origin i and a destination j without any transshipment or intermediary stop of the vehicle is:

$$\mathbf{Cost\_Road\_Line_{ij} = MIN \sum Cost_a} \quad (2)$$

Inclusion of the loading/unloading and of the driving cycles

The total cost on the whole OD is then modulated in function of two parameters:

- the costs of loading and unloading goods,
- the driving cycles that are dependent of the driving time of the road itinerary from the shortest path algorithm. The principle of driving cycle is explained in Appendix 2.

The loading and unloading of goods is expressed as follow:

[9] Precision about the composition of those costs can be found in Appendix 2.

$$\mathbf{Cost\_Const} = (\mathbf{Time\_Load} + \mathbf{Time\_Unload}) * (\mathbf{C\_salary} + \mathbf{C\_day}) + \mathbf{C\_Load} + \mathbf{C\_Unload} \quad (3)$$

With *Cost_Const: The constant cost related to the loading and unloading operation*
Time_Load: Time of the load operation
Time_Unload: Time of the unload operation
C_Load: Cost of the load operation
C_Unload: Cost of the unload operation
C_salary: Salary cost of the driver
C_day: Daily cost (Amortization of the vehicle and structural costs)

And the driving cycles are taken into account as follow:

$$\mathbf{C\_Cycle_{ij}} = \mathbf{C\_Rest_{ij}} + \mathbf{C\_Break_{ij}} \quad (4)$$

With

$$\mathbf{C\_Rest_{ij}} = \mathbf{Nb\_Rest_{ij}} * \mathbf{Time\_Rest} * \mathbf{C\_day} \quad (5)$$

$$\mathbf{C\_Break_{ij}} = \mathbf{Nb\_Break_{ij}} * \mathbf{Time\_Break} * \mathbf{C\_day} \quad (6)$$

With *$C\_Cycle_{(i,j)}$: The cost related to the driving cycles to realize an itinerary between i and j*
Time_Rest: Rest time (9 h)
Time_Break: Break time (45 minutes)
$C\_Rest_{(i,j)}$: The rest's costs for an itinerary between i and j
$C\_Break_{(i,j)}$: The break 's cost for an itinerary between i and j
$Nb\_Rest_{(i,j)}$: Number of rest between i and j
$Nb\_Break_{(i,j)}$: Number of break between i and j, that is dependent of the travel time according to the regulatin.

Final road costs ('without intermediary stops for loading or unloading)
The total road cost between an origin and a destination thus corresponds to the sum of the costs of the equations (2), (3) and (4) without any intermediary transshipment operation or stops.

$$\mathbf{Cost\_Road\_TOTAL_{ij}} = \mathbf{Cost\_Road\_Ligne_{ij}} + \mathbf{C\_Cycle_{ij}} + \mathbf{Cost\_Const} \quad (7)$$

With *Cost_Road_TOTAL(i,j) : The total road cost between an origin i and a destination j*

b) The pre/end road haulage

The cost of a pre/end road haulage takes into account the value defined above in the equation (7) to which additional costs due to the empty return journey of the truck, the integration of problematic of rotation notably for the driving cycle and specific constant are added

The cost of pre/end haulage is decomposed as follow:

$$\mathbf{Pre\_Haulage_{(i,x)}} = \alpha(\mathbf{Cost\_Road\_Line_{(i,x)}} + \mathbf{Cost\_cycle\_AR_{(i,x)}}) + \mathbf{Const\_Pre\_Haulage} \quad (8)$$

With
$Pre\_Haulage_{(i,x)}$: The pre haulage's cost between the node i and the transshipment point x.

Const_Pre_Haulage: Constant for the pre-haulage grouping the loading, waiting and transshipment costs on the extremities of the haulage segment. [10]
Cost_Road_Line$_{(i,x)}$: The costs between an road origin i and the transshipment point x, without intermediary stops.
Cost_cycle_AR$_{(i,x)}$: Cost related to the rest, if the driving time induced an additional cycle on the whole return journey between the origin i and the point of transshipment x. The rest cost is divided by two considering that it is distributed between both single and return journeys.
α : Rate of empty return

The end-haulage is evaluated in a similar way, the value of Time_Load and C_Load being replaced by Time_Unload et C_Unload. All the values of the units costs at the time horizon 2007 and 2030 can be found in Appendix 2.

5.4.3.2.2. Evaluation of the Rail costs

In this paragraph the method of determination of the rail costs will be detailed. This method is similar to the one of the road costs as it consists of an algorithm of shortest path.

a) Evaluation of the rail costs between two nodes in direct relation

Cost of driving through a rail section

First the cost of driving through a rail section is expressed as:

$$\mathbf{Cost\_rail_a} = (\mathbf{Crail\_km_a} * \mathbf{Lg_a}) + (\mathbf{Crail\_Time_a} * \mathbf{Time_a}) + (\mathbf{Crail\_fee_a} * \mathbf{Lg_a}) + \mathbf{Crail\_Punct_a}$$
(9)

With *Cost_rail$_{(a)}$: Cost of driving through the section a*
Lg$_{(a)}$: Length of the section
Time$_{(a)}$: Driving time on section a
Crail_km$_{(a)}$: Kilometer costs
Crail_Time$_{(a)}$: Hourly costs
Crail_Punct$_{(a)}$: The rail costs specific to the section such as transshipment related to a difference in gauge between Spain and France
Crail_fee$_{a)}$: The infrastructures fee, on section a [11]

The rail cost between i and j is then estimated from an algorithm of shortest path that search the path minimizing the sum of the sections' costs between two nodes of the graph:

---

[10] $$\mathbf{Const\_Pre\_Haulage} = (\mathbf{Time\_Load} + \mathbf{Time\_Wait}) * (\mathbf{C\_salary} + \mathbf{C\_day}) + \mathbf{Cost\_Transbo} + \mathbf{C\_Load}$$
With *Time_Wait: Waiting time on the intermodal point i and Cost_Transbo: Transshipment cost between two modes of transport*

[11] $$\mathbf{Crail\_fee_a} = \mathbf{Crail\_fee\_Prest_a} + \mathbf{Crail\_fee\_RCE_a} + \mathbf{Crail\_fee\_Punct_a}$$

With Crail_fee_Prest$_{(a)}$: The minimal service's rail fees/ Crail_fee_RCE$_{(a)}$: The rail fees related to the transportation of electricity/ Crail_fee_Ponct$_{(a)}$: The rail fees specific to some sections (Perthus, Tunnel sous la Manche…)
Those rail fess are detailed in Appendix 2

$$\mathbf{Cost\_Rail\_Line_{ij}} = \mathbf{MIN} \sum \mathbf{Cost\_rail_a} \tag{10}$$

With *Cost_Rail_Line*$_{(i,j)}$ *: The total rail cost on the whole itinerary i and j*

Rail Constant

To the costs of driving the train on the itinerary (i,j), it is then necessary to add the constant costs, that can be divided into three components:

- a fixed cost of exploitation related to the type of train used,
- a cost related to the setting up of train and the immobilization of the wagons,
- a cost related to the operation of loading and unloading.

So finally the constant cost is expressed as follow

$$\mathbf{Const\_TOTAL\_rail} = \mathbf{Const\_Rail} + \mathbf{Crail\_Form\_train} + \mathbf{Crail\_Load} + \mathbf{Crail\_Unload} \tag{11}$$

Const_TOTAL_rail: The constant rail cost
Const_Rail: Fixed cost of exploitation of the train
Crail_Form_train: The cost of the setting up of the train[12]
Crail_Load: The cost related to the load of the train
Crail_Unload: The cost related to the unload of the train

Total rail cost

Finally, the total rail cost between an origin i and a destination j correspond to the sum of the cost of driving the train on the rail network (10), the rail constant (11), the cost of immobilization of the wagons waiting between two services and the costs related to the frequency of the rail services.

$$\mathbf{Cost\_Rail\_TOTAL_{ij}} = \mathbf{Cost\_Rail\_Line_{ij}} + \mathbf{Const_{TOTAL_{rail}}} + \mathbf{Freq_{(a)}} + \mathbf{Const\_wagon}$$
(12)

With *Cost_Rail_TOTAL*$_{(i,j)}$ *: The total rail cost between a rail node i and a rail node j*
Const_wagon: Cost related to the average waiting time of the wagon (6 h)
Freq$_{(a)}$*: The cost related to the frequency of the direct service between the inland terminals k and z. This cost is estimated in function of the weekly frequency of the service on a basis of 5 days per week and a value of time of 0.5 € per ton and per hour.*

5.4.3.2.3. Evaluation of the inland waterway costs

Finally, in this model the IWW cost function is expressed as a duo with[13]:

- a hourly cost including : Amortization of the material, staff expenditures, maintenance, Insurance, and structural costs,
- a kilometer cost including: fuel and inland waterway toll.

[12] $\mathbf{Crail\_Form\_train} = \mathbf{Time\_Form\_train} * \mathbf{Crail\_Wagon}$
With *Time_Form_train: The time of the setting up of the train and Crail_wagon: The cost of immobilization of the wagon*

[13] More information about the unit cost of the IWW can be found in Appedix 6.

In addition the cost function is differentiated depending of the type of barge used from a point i to a point j, the number of layers that can be transported on the barge (2, 3 or 4), the draught, the air draft and the navigation basin. The cost of transport per barge on each section is computed by taking the hypothesis that the barge used to realize this journey is the one having the lowest cost. The type of barge used in the model can thus be different than the one used by the shipper in realty, because the model does not take into account the size of the shipment that influence the logistics solution taken by the shipper. For this study, the following barges have been selected for the transport of containers[14]:

Table 3: Characteristics of the barge

Class of IWW	Type of barge	Enfoncement max	Length	Width	Capacity
IV	RHK[15]	2 - 2,5	80-85	9,5	60 TEU
Va	Large Rhine vessel 110m	3,0 m	95-110	11,4	200 TEU

The exploitation time is of 15 hours for the RHK and 18 hours for the large Rhine. Thus, for a day of 24 hours a break of 9 or 6 hours exists during which the hourly costs are account for but not the salary.

The cost of navigation from the origin port to the destination port by inland waterway is:

$$\mathbf{Cost\_IWW\_Total} = \frac{\mathbf{Cl+distance*Ck+time*Ch+int\left(\frac{Time}{18}\right)*6*(Ch-Cs)+Cu}}{\mathbf{Number\ of\ containers_{layers}}}$$

(13)

With:

Distance: Distance between two ports
Time: travel time between two ports by taking into account the process time at the locks (30 minutes by lock) and the speed on the inland waterways.
Ch: Hourly inland waterway cost
Cs: Salary costs
Cl: Loading cost[16]
Ck: Kilometer costs
Cu: Unloading costs[17]
$int(\frac{Time}{18})$*: Number of cycle of navigation of 18 hours (for the Large Rhine and 16 hours for the RHK).*
6: number of rest hours per cycle of 24 hours
$Number\ of\ containers_{layers}$ *: Number of containers depending of the number of layers*

[14] The pushed convoys have not been selected for the modeling because this type of barge has a unit cost really similar from the one of the Large Rhine vessel.

[15] Rhein-Herne-Kanal (Johan Welker pour l'ONU)

[16] $$\mathrm{Cl} = \frac{\mathrm{Time\ W*Ch+\frac{Number\ of\ containers_{layers}}{Cal}*Ch+P*Number\ of\ containers_{layers}}}{\mathrm{Number\ of\ containers_{layers}}}$$

With *Time W: Waiting time/CaL: Capacity of load in containers/h /P: Price of the load (€/ containers)*

[17] The unloading cost has the same form by replacing the capacity of loading by the capacity of unloading.

Finally, for each origin/ destination pair and for each number of layers/type of barge pair, the unit cost per container is determined. And according to this cost the best solutions is selected for the next module, according to the minimum path algorithm.

5.4.3.2.4. Conclusion

In this section the costs of the monomodal road transport chain have been determined, such as the cost of each segment of the multimodal transport chain. In the following section the cost of the multimodal transport solution will be determined.

5.4.3.3. Computation of the cost of the multimodal transport chain cost

In this section, the door-to-door transport chains of the multimodal solutions will be constructed by juxtaposition of the segments of the alternative and pre/end road haulage of the previous paragraph, and by adding the transshipment's costs between the modes. Then the best multimodal itinerary will be found by minimizing the sum of the cost of the different segment building this chain.

Thus for a multimodal transport chain, with main transport mode being the rail, the cost of the transport chain is expressed as follow:

$$\mathbf{Cost\_chaine_{(i,j,t)}} = \mathbf{MIN} \sum \left(\mathbf{Pre\_Haulage_{(i,x)}} + \mathbf{Cost\_Rail\_Total_{(x,y,t)}} + \mathbf{Post\_Haulage_{(y,j)}}\right)$$
(14)

With

$Cost\_chaine_{(i,j,t)}$: Cost of the chain between the origin i and the destination j by type of transport chain t
$Pre\_Haulage_{(ix)}$: Cost of the haulage between an origin i and a intermodal point x
$Post\_Haulage_{(yj)}$: Cost of the haulage between the intermodal point y and the destination j
$Cost\_Interchantier_{(x,y,t)}$: Cost of the segment between the intermodal points x and y for a given transport mode

For a multimodal transport chain with a main transport being IWW, the equation (24) is used by replacing Cost_Rail_Total by Cost_ IWW_Total. When a trimodal chain is used those two components are added to obtained the cost of the chain.

5.4.3.4. Computation of the generalized costs of the best solutions

Finally, the cost of the transport chain is transformed into a global generalized cost by taking into account:

- The difficulty of organization of the intermodal transport, by introducing an additional cost for the intermodal solution. This additional cost is differentiated depending of the geographical direction[18].
- The value of time that is going to be determined through calibration.

Thus, the generalized costs taken into account in the rest of the model have the following form:

$$\mathbf{Cost.Gen.Solution_{(i,j,t)}} = \mathbf{Cost.chaine_{(i,j,t)}} * \Delta_{(\mathbf{t,s})} + \mathbf{Val.Time} * \mathbf{Time.chaine_{(i,j,t)}} \qquad (15)$$

[18] The levels of additional costs are presented in Appendix 2.

With
Cost.Gen.Solution$_{(i,j,t)}$: The generalized costs of the solution between the origin i and the destination j for the transport chain t
Cost.chaine$_{(i,j,t)}$: The cost of the transport chain between the origin i and the destination j for the transport chain t[19]
Δ$_{(t,s)}$: The additional cost due to the difficulty of organization of the transport chain and the geographical orientation of the relation between the origin i and the destination j. When this chain is only road this parameter is fixed to 1.(=
Time_chaine$_{(i,j,t)}$: The time to travel from the origin i to the destination j by this transport chain.
Val_Time: The unit value of time taken into account

The output of this module is thus the generalized costs of the best solutions of each type of transport chains for each port/hinterland couples.

5.4.4. The module of Distribution

The goal of this module is to determine what the market shares of each port on each hinterland are, and thus to evaluate the traffic between each port and each hinterland. This module thus allows determining the spatial interaction between the port and their hinterland.

5.4.4.1. Distribution's model theory

Usually in the freight distribution models, the trade flow between an origin and a destination are determined based on production and attraction of the origin and the destination and on a measure of the transport resistance, that is most of the time represented by a transport costs or a generalized transport cost (De Jong et al. , 2004). The port choice concept is more complex as it consists of determining by which port the traffic for a given origin-destination will pass through.

Two main types of spatial interaction model are usually used to model port choice, the standard multimonial logit function and the gravity model. A short description of the two models will first be given before to specify which one is going to be used in this thesis.

- **Logit model**

This model consists of determining the port j, by which the exchange between an origin i and a destination m, will be shipped. To do so the following formula is applied:

$$\boldsymbol{P}_{(\boldsymbol{i},\boldsymbol{j},\boldsymbol{m})} = \frac{e^{U_{ijm}}}{\sum_j e^{U_{ijm}}} \qquad (16)$$

Where P $_{(i,j,m)}$ correspond to the probability of choosing port j for the exchange between an origin i and a destination m

U_{ijm} is the utility of choosing the port j for the exchange between an origin i and a destination m
Thus, with the logit function, a port j is chosen by comparing the utility of its chain with regard to the other chain (that include another port). Usually, the utility of the port j for the exchange between an origin i and a destination m, are determine by the generalized costs of the whole transport chain.

[19] In the case of a road transport chain, Cost.chaine=Cost_Road_Total$_{ij}$

- **Gravity model**

The gravity model expresses the number of trips between an origin and a destination zone, and is proportional to: a factor that characterized the origin zone; a factor that characterized the destination zone and a factor expressing the travel costs between an origins i and a destination j.

The equation of the gravity model can be express as follow:

$$\boldsymbol{T_{ijm} = \mu Q_{im} X_{jm} F(c_{ij})} \tag{17}$$

With
T_{ij} = traffic flow from origin i to destination m passing through port j
Q_i = production ability of origin i for exchange with destination m
X_j= Attraction ability of port j for exchange with destination m
F_{ij}=Accessibility of port j from hinterland i
μ= measure of average trip intensity in area

This gravity model owes is name from the analogy with the Newton's law, but this model can also be explained as a derivation from the micro-economic utility theory (Bovy et al., 2006). According to this theory, decision makers try to maximize their utilities, that they derived from their activities.

5.4.4.2. Choice of the model and description of its attributes

In this thesis it has been chosen to use the gravity model, for the distribution module, due to its ease of implementation, and the data available for modeling. The gravity model will determine the attractiveness of one port j for the shipment of containers between a node i of the European hinterland and a partner maritime zone m. The distribution is done based on the next three data:

- $M_{node\ (i,m)}$: tons of containers import and export by port j (factor for the destination zone) to the partner maritime zone m (without the transshipped containers),
- $M_{port\ (j,m)}$: tons of containers import and export by node i (factor for the origin zone) to the partner maritime zone m,
- c_{ij} : hinterland transportation generalized cost between the port j and the European node i.

Thus, after the precision of those attributes the gravity function has the following form:

$$\boldsymbol{Attrac_{(i,j,m)} = \frac{M_{node\ (i,m)} * M_{port(j,m)}}{F(c_{ij})}} \tag{18}$$

Where F(cij) is the distribution function that "represents the relative willingness to make a trip as a function of the generalized travel costs cij" (Bovy et al, 2006).

Two of the three attributes of the gravity model have been determined in the previous paragraph. It is now necessary to determine the form of the distribution function. If survey data would have been available, regarding the hinterland of the port in Europe, at the node level and for each maritime zone m, it would have been possible to determine this function thanks to the Poisson estimator method[20]. Nevertheless, in this case no sample data are available. It is thus not possible to apply this

[20] The method can be found in appendix 3.

method it, but if future reliable data about data hinterland become available such a method should be applied.

Due to the non availability of the data it has been assumed that the form of the distribution function will be as follow:

$$\mathbf{F(cij)} = \frac{1}{c_{ij}^{\Delta_{ij}}} \quad (19)$$

With c_{ij} the generalized transport cost between the hinterland i and the port j
Δ_{ij} the power parameter of the distribution function.

The power parameter of the distribution function Δ_{ij} will be determined by calibration and is differentiated in function of the national or international relation between the port and the hinterland. Indeed, this differentiation allows taking into account the border effects, that applied for the exchange of goods between different countries due to the difficulty of organization of the freight transport between different countries that are partly due to cultural and technological differences between the national networks. Nevertheless, it should be acknowledged that nowadays, there is no clear description of what the border effects really included, that is why they are going to be determined by calibration. In addition, they will be differentiated by category of ports[21], as it has been observed that the major ports are less impacted by this border effect than the smaller ports. Contrary to the model of Tavasszy (1996), it should be noticed that the border effects in this model are not distinguished by modes. This is due to the fact that in this thesis the distribution and modal spilt are realized in two different steps, in opposition to the model of Tavasszy, where those two steps are realized in just one. Nevertheless, the difficulty of organisation specific to each mode and origin-destination, have been taken into account in this thesis in equation (15) with $\Delta_{(\mathbf{t},\mathbf{s})}$.

Another question that arise, is what cost value should be used for c_{ij}. Indeed in the previous paragraph it has been seen that several transport solutions exists between a node of the hinterland i and the port j, and that those transport solutions have different value of generalized transport costs. Thus the question is which impedance should be used? Rodrigue et al. (2013) stated that “often the minimal travel time over all modes is used. Alternatively, the so called logsum of the impedances of the different modes is used.” It thus seems that currently there is not real stated of the art about the form of the impedance.

In this research, three possibilities have been considered and even modelled, the two stated by Rodrigue et al. (2013), and the weighted average cost of the best solutions of all the transport chain, for which the weight corresponds to the market share of each alternatives. The following table give the form of those impedances as their advantages and drawbacks.

[21] Those categories can be found in Appendix 4.

Table 4: The advantages and drawbacks of the different type of impedance

Type of impedance	Advantages	Drawbacks
Minimal costs $\min_k \mathrm{Cost.Gen.Solution}_{(i,j,k)}$	- Ease of implementation in practice. - Consider that the choice of the users is pragmatic and that they choose the solution with the lower costs.	- Does not allow taking into account the change in the hinterland if the minimal cost does not change. - With this cost the concept that when more mode are available a port is more attractive is not verified - The model has then little influence on port choice decision making, but only allow taking into account the main trends.
Weighted average costs[22] $\sum_k \mathrm{MS_k} * \mathrm{Cost.Gen.Solution}_{(i,j,k)}$	- Allow to take all the types of transport chain solutions in consideration for the determination of the hinterland	- This cost does not represent the price of any real solution in practice - Some inconsistent results might appear in practice as will be explained in the example below
Logsum $log(\sum_k e^{\mathrm{Cost.Gen.Solution}_{(i,j,k)}})$	- Best theoretical impedance when there is several alternatives possible	- Difficulty to calibrate in practice

Below an example is given in which the three alternative impedance are tested. In this example two infrastructure scenarios are compared, the reference scenario and the SMSR scenario that consists of the creation of a missing link in the IWW network, thus the generalized costs for this transport solution decreases, as observed in table 6.

It can be seen that when the minimal cost is used, the construction of the new SMSR canal and the significant decrease of the IWW costs has no effect on the value of the impedance function, because the IWW is not the cheapest mode after the construction of the canal. This is a limitation of the minimal cost solution, because it can be seen that the cost of the IWW solution is now really close from the one of the Rail solution, so the accessibility of the area increase in realty, and shippers might used both of the alternatives.

[22] Where MS_k represent the market share of the transport solution k, that is determined in the transport solution modal share module, so a loop of retroaction between this distribution and transport solution share module were necessary.

Table 5: Application of the impedance functions (This specific example has been taken from the model between the port of Antwerp and a point of the network situated below Lyon in France along the Rhone)

		Road	Rail	IWW	IWW+Rail	Minimal cost	Average weighted cost	Logsum[23]
Reference scenario	Cost	726	537	848	790	537	549	36.83
	Modal Share	3.40%	94.50%	0.60%	1.35%			
SMSR scenario	Cost	726	537	598	790	537	560	34.31
	Modal Share	2.60%	72.90%	22.00%	1.90%			

By using the average weighted cost as impedance function in this specific case, it can be observed that the result is worse than expected. Indeed with the used of the weighted average cost it can be observed that the impedance between the two scenarios increase, making this port less attractive for this node whereas the contrary will occurred in reality. It should nevertheless, be mentioned that this results occurs in this specific case but not for all port-hinterland relations.

Finally, the logsum seems to translate in an accurate way the opening of this new liaison, as it makes the total impedance decrease when only the IWW cost decrease.

Thus, by referring to this specific example it seems that the logsum is the best impedance cost function, to apply in this model, this is in accord with what the literature has highlighted in the last years. Thus, for this thesis the logsum has first been applied in the gravity model. By doing, a correct calibration of the model could not be found due to the lack of data available for the calibration step.

It has thus finally been decided to implement the minimal costs as impedance value, instead of the logsum. With the minimal cost of all the transport solution as impedance an acceptable calibration of the model has been found, as will be observed in the next chapter.

Thus, the final form of the gravity model is as follow:

$$\boldsymbol{Attrac}_{(i,j,m)} = \frac{\boldsymbol{M}_{\boldsymbol{node}\ (i,m)} * \boldsymbol{M}_{\boldsymbol{port}(j,m)}}{(\boldsymbol{Min.Cost}_{(i,j)})^{\Delta ij}} \qquad (20)$$

With *$Attrac_{ijm}$: Attraction of the port j on the node i for the exchange with the maritime zone m*

$M\_node_{i,k}$: The weight of the node i (tons generated by the node) for the partner maritime zone k

$M\_port_{j,k}$: The weight of the port j (tons of the port) for the partner maritime zone k

$Min.Cost_{(I,j)}$: The minimal cost of all the transport chains available between a port I and an hinterland node j.

Δ_{ij} : Parameter

From the previous equation, the market share of the port j for the traffic flows between i and m can be determined thanks to:

$$\boldsymbol{Market\ Share}_{(i,j,m)} = \frac{\boldsymbol{Attract}_{(i,j,m)}}{\sum_{k=1}^{n} \boldsymbol{Attrac}_{(i,k,m)}} \qquad (21)$$

[23] The cost have been divided by 10 to compute the logsum

With *Market Share (i,j,m) : The market share of the port j on the node i for the partner maritime zone m. This market share is expressed in* %.

Finally, the traffic flow between each port and a given hinterland node for a specific maritime zone can be expressed as:

$$\mathbf{Flow}_{(\mathbf{i,j,m})} = \mathbf{Market\ Share}_{(\mathbf{i,j,m})} * \boldsymbol{M}_{\boldsymbol{node}\ (\boldsymbol{i,m})} \quad (22)$$

With *Flow $_{(I,j,m)}$:The flow of containers between the port j and the node i for the partner maritime zone m*
At the end of this module it is know by which ports transit the containers flows of each couple (i,m) and with which market share.

5.4.5. Transport solution share module

After having determine the market share of each port for the exchange flows between i and m. It is now time to determine the repartition of the traffic between (i, j) among the different transport chains, in function of the generalized costs of each transport's chain. The distribution of traffic between the different solutions is based on a probabilistic distribution of the Abraham's type.

Theoretical determination of the model:
The model of Abraham assumes that the relation between the traffic T_{ij} on the itinerary k, and the traffic T_{ij} on the itinerary i can be expressed as follow:

$$\frac{T_{ij}^{m}}{T_{ij}^{l}} = (\frac{GC_{ij}^{m}}{GC_{ij}^{l}})^{-\beta} \quad (23)$$

With *GC_{ij}^{m}= Generalized cost of the transport solution m for the traffic between the hinterland i and the port j*

B= It is a parameter that will be determined during the calibration of the model

And then as $\sum_{k=1}^{n} T_{ij}^{k} = T_{ij}$, the Abraham's law can be generalized to more than two itineraries, by applying the following equation (SETRA, 2013):

$$\frac{T_{ij}^{l}}{\sum_{k=1}^{n} T_{ij}^{k}} = (\frac{GC_{ij}^{l}}{\sum_{j=1}^{n} GC_{ij}^{k}})^{-\beta} \quad (24)$$

It should be noticed that with the Abraham method each transport solution is assigned traffic, meaning that none of the transport chain type has a traffic nil between a origin and a destination. In addition, when the factor β became close to 0, the containers tends to distribute on a uniform manners on the different itineraries.

Practical determination of the model:
The repartition of traffic between the different transports chains between a node i and a port j, is determined by only taking into account the best solution (minimal cost) of each transport chain. The mathematical formulation is thus expressed as follow:

$$\alpha_{(i,j,1)}\mathrm{Cost.Gen.Solution}_{(i,j,1)}^{\beta} = \alpha_{(i,j,2)}\mathrm{Cost.Gen.Solution}_{(i,j,2)}^{\beta} = \alpha_{(i,j,n)}\mathrm{Cost.Gen.Solution}_{(i,j,n)}^{\beta}$$
(25)

With *$\alpha_{(i,j,1)}$, $\alpha_{(i,j,2)}$, $\alpha_{(i,j,n)}$: The repartition of traffic on the different transport solutions from 1 to n*

$\text{Cost. Gen. Solution}$ *(i,j,n) : Cost of the transport chain solution between a location i and the port j by the transport solution n. The costs included additional costs for alternative modes.*
β is the parameter to adjust during the calibration

At the end of this module, the market share of each transport solution on each itinerary hinterland-port is known. The last step of the model consists of assigning traffic on the network.

5.4.6. The assignment module

The assignment module consists of affecting the flow of traffic on each segment and node of the network. This affectation is realized thanks to an all-or-nothing assignment for each transport chain type. Even if this affectation is really simplify and pragmatic, it can be justified by the fact that the level of aggregation of the demand matrix used is also in favor of this approach, because the demand data are obtained from node to node and not from firm to firm (Jourquin & Limbourg, 2007). The affectation of traffic is thus totally deterministic and based on the output of the two last modules are used as input data.

At the end of this module the traffic is assigned on the sections of the network.

5.5. Data requirements

To can use the model described in the above sections it is necessary to have several input data. In this paragraph those data will be specified such as their source.

5.5.1. The containers demand

In this model it is necessary to have as input the containers import and export per region NUTS 2. As observed above those data are not directly available. To compute the containers demand per region NUTS 2 in Europe, the Eurostat Comext trade data have been used. Those data give the volume of products exchanged between two countries per group of products. Then the disaggregation to the region is done using the population and GDP of each region[24]. And finally, the disaggregation is realized at the node level.

5.5.2. The port traffic

The port traffics are used in the gravity model of the distribution module. They represent the attraction/production ability of the ports. The ports' container traffics are directly extracted from the Eurostat database.

5.5.3. Hinterland input data

The model is based on the description of the hinterland connections, by the computation of their generalized costs. To can compute the hinterland generalized costs several data are needed.

5.5.3.1. Characteristics of the network

First a really precise description of the network is necessary for the three modes used in the transport chain. The description is realised through a GIS interface, by dividing the network into links

[24] The population and GDP per NUTS are extracted from the Eurostat database.

and nodes. For instance the road network is composed of 8004 nodes and 26872 links, whereas the rail network is composed of 2793 nodes and 7022 links.

Then specific characteristics on the section of the network are necessary to can determine the generalized costs. For the rail network the characteristics of the links are as follow:

- The average speed (obtained from the train operators, train path, exploitation data from train operators. For the road network the speed is also adjusted according to the topography of the land you go through)
- The fee category to which the section belong
- The gauge of the section
- Which type of traffic can circulate on the section: only passenger traffic or mixed circulation
- Length of the train that can be admit on the network
- Number of locomotive necessary due to the slope of the rail

In addition, the **distance** between the ports and the nodes is computed directly in the GIS[25] interface. The distance is used in the computation of the generalized costs. Detailed about **the nodes** of the network are also necessary to can build the transport chain. For instance, it should be known which modes can access the inland and port terminals, and where the transfers between modes can occur.

Finally, for the alternatives modes the **services** are also of importance to determine the frequency at which the containers can be shipped to their final destinations. The services are extracted from the database CESAR and from the website of the operators[26].

[26] An example of the service available on the IWW network

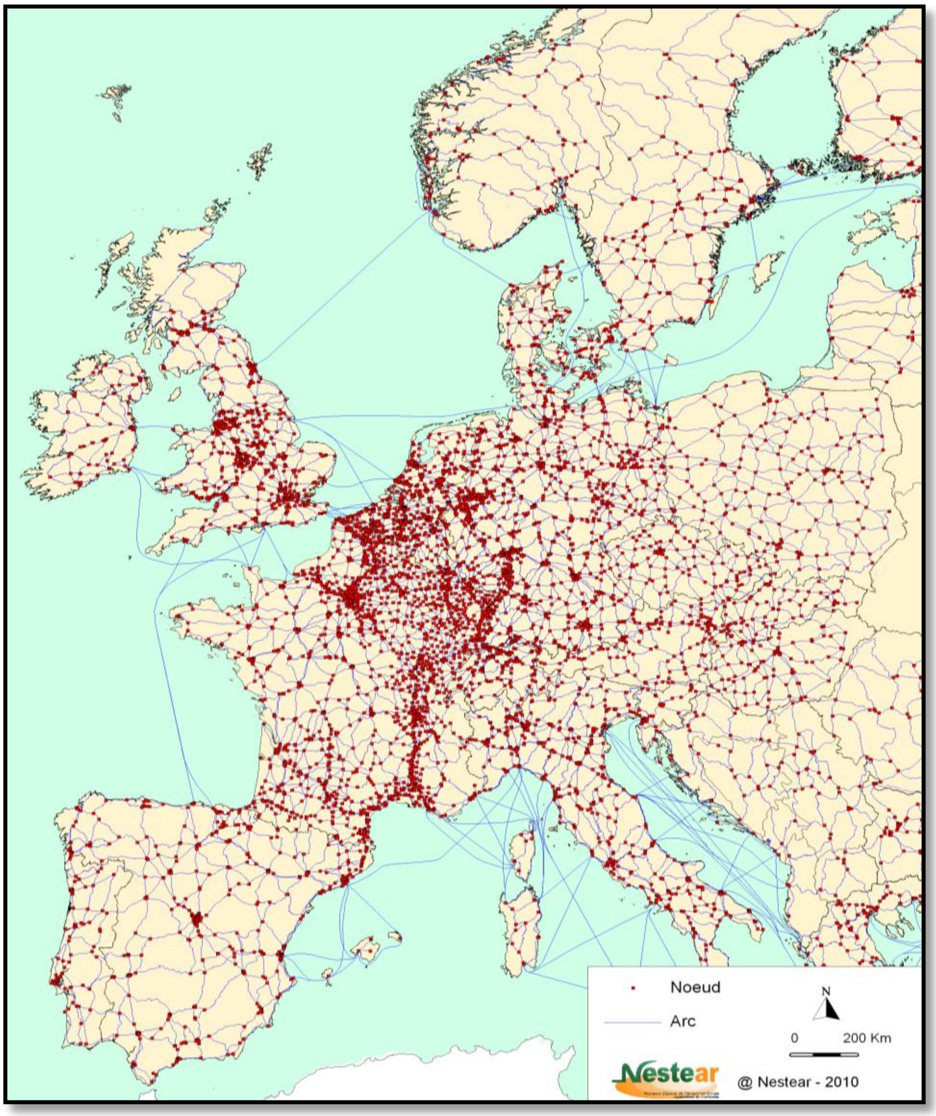


Figure 21 : Road network

5.6. Conclusion

In this chapter, the model that will be used in this thesis has been presented, as the data that are used as input. It consists of a four step model, whose distribution step rests on a gravity model. Nevertheless, the PortPrint model cannot be used yet to model the scenario of 2030. First the calibration of the model should be done.

6. Calibration of the model and modeling of the base year 2007

In the previous chapter, the model has been described. Nevertheless, it cannot be used straight away. First, it is necessary to calibrate the model that is to say to determine the parameters that have not been assigned any value in the preceding section. Those parameters are:

- the power of the impedance function Δ_{ij} that expresses the border effects in the gravity model;
- the value of time Val.Time used in equation (15);
- the Abraham parameter β, that is used for the determination of the modal shares.

Those parameters will be determined by adjusting them in order to fit the results of the model with the observed data for the base year 2007. In a first part of this paragraph the parameters of this model will be calibrated, then the sensitivity of the model to the value of time will be analyzed, before to analyse the results of the model for 2007, in order to can compare them in a later phase to those of the future scenario.

6.1. Calibration of the model

In order to simulate the repartition of the maritime containers in Europe in 2030, it is first necessary to calibrate the model. This calibration step is time consuming, and is really important in the construction of the model as it determine the quality of the model. Usually, the calibration is realized by comparing the simulated data with the observed data for the base year, by using statistical tools. Nevertheless, as it has already been expressed above the calibration of this specific model is made difficult because:

- the input data used for the model are already estimated data and not real observed data (use of the SITRAM and customs database, such as GDP and POP repartition);
- the lack of data regarding the specification of the hinterland of each port, thus of the traffic between the port and the hinterland;
- of the non homogeneity of the data on the large study area between the different sources (Comext, port authorities, customs, …).

For all these reasons the calibration phase is a really difficult, as it is not possible to compare the results of the model with observed data as they did not exist for the whole study area. That is why the model will not be calibrated with usual statistical tools, but the calibration will instead be based on an iterative process aiming at determining the parameters of the model. The calibration thus rests on realism with the available literature, and is really focus on the validation of the model rather than the calibration[27]. Those verifications being realized by hand simulation.

[27] The calibration and validation terms in this sentence refers to the definition of Institute of Transport Engineers (1992), where calibration consists of "estimating the values of various constants and parameters in the model structure", whereas the validation refers to the step in which "the models must be checked to assure they adequately perform the functions for which they are intended, that is, to accurately estimate traffic volumes".

The calibration of the value of those parameters can be realized thanks to three type of data:

- validation using data related to the hinterland of the ports and the market shares of each port on each hinterland region,
- validation on the throughput of the ports,
- validation based on the modal share of each transport solution for each port .

6.1.1. Calibration on the hinterland of the ports and the ports throughputs: results for 2007

The calibration of the model requires an evaluation of the results with regard to the data known for the base year. The available data are presented in Appendix 6, and are mainly related to the hinterland of the French ports.

The hinterlands of the ports are dependent of two out of the three parameters that need to be calibrated.

- the hinterland transport costs that include the value of time,
- the national and international parameters Δ_{ij} that vary depending of the category of the port.

Nevertheless, at the end of this step of the validation of the hinterland of the port only the parameter Δ_{ij} could be determined, the determination of the value of time required a back and force process between the calibration on the modal share.

6.1.1.1. Calibration on the hinterland of the ports

As already stated before, no database provides the OD matrices between the ports and their hinterland for all the European ports. Some ports authority precise their ports hinterland, but most of the time the data that they provide are not consistent between each other. In this model, the focus is on the creation of the Saone Mosel Saone Rhine canal that will be located in France; it has thus been decided to focus on the French hinterland for the calibration. The data relative to the French hinterland are available in Appendix 6 for the years 2004 and 2005. In addition, it should be specified that the hinterland of the ports are not given at the scale of each port, but are aggregated at the level of the French ports and the foreign ports. Thus, it was not possible to apply the statistical tools (such as the R^2) that are usually applied for the verification of the calibration, as they were no observed data related to the simulated data.

The consistency of the ports hinterland was also mainly checked for the ports that will be of interest in this study that is to say: Hamburg, Rotterdam, Antwerp, Le Havre, Marseille, Genoa and Barcelona. The detailed of the ports' hinterland in the French region can be found in Appendix 7.

During this step of the calibration it was thus only checked that the order of magnitude of the hinterland of the European ports in France were in accordance with the observed data. A more precise calibration was realized on the ports' throughputs as it is explained in the following paragraph.

6.1.1.2. *Calibration on the ports' throughputs*

The only accurate data that is available to realize the calibration of the port choice model, are the ports throughputs for 2007 obtained from Eurostat. It has thus been decided to calibrate the model based on those data. To do so an adjustment step by step of the values of the parameters Δ_{ij} has been realized in order to obtain simulated ports' throughputs as close as possible from the Eurostat data, but to obtain also consistent ports hinterland. The value of the Δ_{ij} parameters that have been found thanks to this validation are presented in Table 6 : Parameter in function of the category of the port.

Table 6 : Parameter in function of the category of the port[28]

<table>
<tr><th>Range Port</th><th>National</th><th>International</th></tr>
<tr><td>World</td><td>Adjusting</td><td>Adjusting</td></tr>
<tr><td>Range</td><td rowspan="5">2.4275</td><td>2.745</td></tr>
<tr><td>National</td><td>2.895</td></tr>
<tr><td>Intermediary</td><td>3.195</td></tr>
<tr><td>Regional</td><td></td></tr>
<tr><td>Local</td><td></td></tr>
</table>

As specified in the previous table, for the world port category, the parameters have been adjusted for each of the ports belonging to this category. In addition, it should be noticed that Belgium and the Netherlands have been considered as "one country" within this model, meaning that no international border effects have been considered between these two countries, the national power applying instead. This seems consistent with the results of Tavasszy (1996), that found that the barriers between the Netherlands and Belgium (especially for road and IWW) is smaller than the barriers between others countries. This can be explained by the vicinity of both countries and the lower cultural differences. But also by the history between those two countries, with notably the Benelux Union, in which the Benelux "countries exempted their mutual trade from customs duty" since 1948 (Benelux Parliament, 2014).

In order to determine if the value taken for those parameters were accurate, comparison has been made between the observed and simulated data by applying the GEH indicators (SETRA, 2010). This indicator is mainly used for the calibration of the traffic models. It is an indicator that is usually applied to all counting points of the road enquiries and that is tolerant for the large errors for the small flows of traffics. This indicator is expressed as follow and will be applied there to the ports' throughouts:

$$GEH = (\sqrt{\frac{2 * (s - o)^2}{(s + o)}}$$

Where s corresponds to the simulated traffic and o to the observed traffic.

The results of the ports throughputs comparisons between the observed and simulated data for each port of the study area can be found in Appendix 7. In this Appendix it can be observed that the values of the GEH are below 4 for all the ports, the value of 4 being the threshold found in literature

[28] World ports: Antwerp/Hamburg/Rotterdam
Range ports: Zeebrugge/Bremerhaven/Barcelona/Valencia/Le Havre/Genova/Feliwtowe
National: Marseille/Dublin/La Spezia/Livorno/Trieste/Venezia/Goteborg/Koper/London/Southampton

for this indicator. The implementation of this indicator thus gives a positive feedback on the calibration of the model at the level of the port throughputs.

After having analysing the results at the port scale, the figure below will highlight the comparison between the observed and simulated data at the scale of the ports' throughput of the countries.

Table 7: Traffic observed and simulated by group of ports

	Observation with transhipment (millions)	Observation without transhipment (millions)	Simulation without transhipment (millions)	Différence	Variation
Baltic	38.8	37.7	29.3	-8.4	-22%
UK & Irlande	66.7	63.1	54.4	-8.7	-14%
Germany	104.0	63.5	61.4	-2.1	-3%
Netherlands	79.6	59.4	58.2	-1.2	-2%
Belgium	82.4	61.9	62.9	1.0	2%
France	34.1	27.1	27.1	0.0	0%
Iberia	104.5	51.5	52.5	1.0	2%
Italy	82.3	45.1	49.8	4.6	10%
Other Med pc	19.2	11.5	11.2	-0.3	-3%
Black Sea	13.7	4.4	8.1	3.6	82%
TOTAL	**625.4**	**425.4**	**415.0**	**-10.5**	**-2%**

By and large the port traffics are estimated in an accurate way, as indicated in the previous table. It can indeed be observed that the simulated ports' throughputs are really good for all the ports belonging to the corridor North Sea-Mediterranean that is to say for the ports of Benelux and France, but also to their neighbours Germany and Spain for which the variation are below 5%. Nevertheless, divergences between the observed and simulated data for ports' throughputs occur in:

- two closed maritime area: the Baltic (variation of 22 %) and the Black Sea (variation of 82 %);
- UK and Ireland with a variation of 14 %;
- and Italy with a variation of 10 %.

Those divergences can be explained by several factors. For instance, the Italian divergence is due to a problem of generation of traffic in this area, as will be explained later. Indeed, the disaggregation of the traffic at the regional level in function of the population and the GDP, in the generation phase, can lead to a **bad localization of the generation of containers** and thus influence in a negative way the choice of the port. The region of Naples highly populated, generates in the model too many containers in comparison with realty, implying an overestimation of the throughputs of the ports situated next to Naples.

The divergences in Baltic and UK are due to the incompatibility between the geographic nature of the Comext's OD data and the data provided by the ports. Indeed, the Comext data take into account the origin and destination of the goods. For instance, for a container shipped from Finland to North America, Comext will register a trip between Finland and North America thus an extra EU trip, whereas ports data in Finland will register the same trip as a trip between Finland and Hamburg. Thus as an intra EU trip, because to go from Finland to North America, a transhipment in Europe (there in Hamburg) is necessary.

Nevertheless, those problems of calibration do not affect considerably the corridor of interest in this research. Indeed, UK, Ireland, the countries of the Baltic and the Black Sea are not part of the corridor of interest. Only the gap of 10 % in Italy is of relevance for this research, as the ports of Italy have influence in the market share of the Mediterranean ports.

It can be concluded that the model allows reproducing in a quite satisfactory way the port **throughputs by countries**, even if differences between observation and simulation appear at a non aggregated level, with for instance the port of Hamburg that crushes the port of Lubeck, or the cluster of the port of Hamburg, Rotterdam and Antwerp that limit the attractiveness of the port of Bremerhaven. It is thus now interesting to look if the model also lead to satisfactory results regarding the modal share of the port.

6.1.2. Calibration on the modal shares of the different transport's chains

In the previous paragraph the value of the parameters Δ_{ij} for each couple port-hinterland have been determined. In this paragraph thank to the validation of the modal share at the scale of the ports the two others parameters are going to be determined:

- the value of time of the containers, also called value of immobilization of the container;
- the parameter β of the Abraham model.

The value of time is determined thanks to a back and forth process between the validation on the port hinterland and the port modal share.

To determine those parameters in an accurate way, the validation of the modal share of the different chains of transport is based on two dimensions:

- the respective parts of the different transport mode at the port level ;
- the evaluation of the level of containers traffic on some sections of the different networks (that are known for the base year).

The evaluation calibration of the modal share of the ports highlights several difficulties. First, the availability of the data for the hinterland shipment of containers, indeed most of the time ports give their modal shares for all cargo goods, but do not provide the data related to the shipment of containers only. The second difficulty is related to the specific characteristics of each port regarding modal shares that are difficult to translate in the model. Among the specificities of the ports, the case of Antwerp and Rotterdam that shipped 1 million of empty TEU per year by IWW, or the port of La Spezia that evacuated its containers on small distances by train towards hinterland terminals due to saturation on the ports, cannot be taken into account in the generalized costs of the transport solutions.

First, the Abraham parameter has been determined. To do so, the value of the Abraham parameter used in previous simulation realized by BG Ingénieurs Conseils has been used. Indeed, those previous simulations have shown that the simulated traffic converged to the observed traffic for a value of β=11. Thus this value has been taken as input for the calibration of the model. Then some test have been realized with value close to β=11, but it was finally observed that this data was the best for this study case.

The next, step was to determine the value of time of the containers, an iterative process was thus applied whose aim was:

- to ensure the best fit between the observed and simulated modal share at the level of each port;
- to ensure the best fit between the simulated and observed traffics of some sections of the European IWW network;
- to ensure the best fit between the observed and the simulated port throughputs.

It was found that the value of time that allow to best calibrate the model, was a value of 2€/TEU/hour. The tables below sum up the process of calibration of the value of time with regard to the modal share of the main ports of the study area and to the traffic on some IWW sections.

Table 8 : Comparison of the observed and simulated market share (Source: Data respective port authorities and Schiffahrt Hafen, Bahn und Technik (2/2007) extracted from Notteboom (2009))

			Observed data			Simulated data			
	Countries	Year observed data	Road	Rail	IWW	Road	Rail	IWW	IWW + Rai
Rotterdam	Netherlands	2007	60,0%	9,0%	31,0%	57,9%	12,3%	26,1%	3,7%
Amsterdam	Netherlands	2005	60,0%	5,0%	35,0%	89,5%	0,0%	8,2%	2,3%
Le Havre	France	2006	86,8%	5,1%	8,1%	85,7%	9,8%	4,4%	0,2%
Marseille-Fos	France	2006	81,9%	12,1%	6,0%	80,9%	12,6%	6,5%	0,0%
Antwerp	Belgium	2007	59,8%	8,0%	32,2%	71,9%	12,7%	12,3%	3,1%
Zeebrugge	Belgium	2006	61,2%	37,6%	1,2%	87,3%	12,6%	0,0%	0,1%
Hamburg	Germany	2007	68,9%	29,0%	2,1%	59,0%	36,8%	4,1%	0,2%
Bremerhaven	Germany	2006	39,6%	56,3%	4,1%	52,3%	45,3%	2,4%	0,0%

It can be observed that the modal shares simulated are not really closed from the observed results. The choice has been made in this thesis, to calibrate the modal shares preferentially by focusing on the ports of Marseille and Rotterdam, as it is expected that those ports will be the one that will benefit the most from the opening of the SMSR canal that will be the study case. Indeed, for the port of Marseille the results are almost similar between the observed and simulated data. For the port, of Rotterdam the same can be observed if the IWW and IWW+Rail simulated modal shares are grouped together. The results for the port of Le Havre are consistent also with the observed data.

For the port of Antwerp it can be observed that the IWW modal share is underestimated. This is due to the fact that the port of Antwerp is using the IWW mode for exchange of empty containers with the port of Rotterdam that cannot be simulated by the model, as it has difficulty to simulate the short distances shipment via the IWW. With regard to the port of Hamburg, it can be observed that it suffers from an overestimation of its rail modal share that can be explained by the fact that the feedering is not included in the model and that containers that are normally shipped by feedering toward the Baltic, are instead affected to the rail solutions.

If now, the modal share is observed at the scale of the ports grouped by countries, the following results are observed:

Table 9: Modal share by port of transit grouped by countries

	Trafic in millions of tons per port (Export + Import all the maritime zones)					Modal Share in %			
Port	TOTAL without	Road	Rail	IWW	IWW+Rail	Road	Rail	IWW	IWW+Rail
TOTAL	**414.95**	**328.85**	**56.45**	**25.51**	**4.14**	**79.3%**	**13.6%**	**6.1%**	**1.0%**
Baltic	29.3	28.8	0.6	0.0	0.0	98.1%	1.9%	0.0%	0.0%
UK & Irland	54.4	48.6	5.8	0.0	0.0	89.3%	10.7%	0.0%	0.0%
Germany	61.4	35.4	23.7	2.2	0.1	57.7%	38.5%	3.6%	0.2%
NL	58.2	34.4	6.9	14.8	2.1	59.0%	11.8%	25.5%	3.7%
Belgium	62.9	45.8	8.0	7.2	1.9	72.8%	12.7%	11.5%	2.9%
France	27.1	23.4	2.5	1.2	0.0	86.2%	9.4%	4.4%	0.1%
Le Havre	15.8	13.5	1.5	0.7	0.0	85.7%	9.8%	4.4%	0.2%
Marseille-Fos	7.5	6.1	0.9	0.5	0.0	80.9%	12.6%	6.5%	0.0%
Other Fr	3.8	3.8	0.1	0.0	0.0	98.5%	1.3%	0.2%	0.0%
Iberia	52.5	48.3	4.2	0.0	0.0	91.9%	8.1%	0.0%	0.0%
Italy	49.8	45.2	4.6	0.0	0.0	90.8%	9.2%	0.0%	0.0%
Other Med	11.2	11.0	0.1	0.0	0.0	98.9%	1.1%	0.0%	0.0%
Black Sea	8.1	8.1	0.0	0.0	0.0	100.0%	0.0%	0.0%	0.0%

From this table, it can be seen that the road mode is the more used mode for the inland shipment of maritime containers with a market share of 79.3 % on the whole study area. The rail comes second with a modal share of 13.6 and the inland waterways come third with a market share of 6.1 %. The transport chain combining rail and inland waterways are pretty rare, with a modal share of 1 %. This latest type of transport chains is mainly concentrated on the Rhine axe, notably on the port of Duisburg and marginally on Basel.

If we compare those results, with the observed data it can be seen that the model allows representing the principal tendencies observed at the European level in quite satisfactory way. Those tendencies are sum up in the following paragraph:

- The German ports are essentially oriented toward the rail mode. The model give a modal share of 38.5 % for all the German ports whereas the port statistics indicated a rail modal share of 37 % for Hamburg and 45 % on Bremerhaven in 2007. The simulated shares of the IWW are low of 3 or 4 % that is in accordance with the port data.
- The modal shares of the Dutch ports are principally oriented toward the IWW. The model represents a modal share of 25.5 % for the IWW and 4 % for the solutions IWW-Rail[29]. The share of the rail is probably over estimated, principally due to the absence of the representation of the feeder from the Baltic.
- The simulation highlights a quite balance profile for the port of Belgium. The modal share of rail is of 12.7 %, it is over estimated for the port of Antwerp (13 % instead of 8 % observed) and under estimated for the port of Zeebrugge (13 % instead of 37 %). The IWW is estimated to around 11.5 %, thus a level clearly below the observations. Finally, the relations IWW-rail represent 3 % of the modal share.
- For the other countries, the road is largely dominant, with a rate above 85 %. In France, rail simulated represent around 9.4 % of the inland shipment and the IWW around 4.4 %. In UK, Italy and the Iberian Peninsula the rail represent respectively 10.7 %, 9.2 % and 8.1 % of the modal share.

[29] Most of those solutions are represented by IWW itinerary between Rotterdam and Duisburg, and then rail route between Duisburg and centre of Europe.

After having analyzed the modal share at the scale of the ports or groups of ports, a look will now be given to the IWW traffic on specific sections. The following table presents the traffic simulated on specific sections in function of the value of immobilization of the TEU during the transport for a value of β=11 of the Abraham parameter.

Table 10: Traffic simulated and observed by section of IWW

Traffic in millions of tons	SIMULATION - Value of time in € per hour per TEU					Value observed (VNF base Port to Port 2007)
	1.0 €	1.5 €	2.0 €	2.5 €	3.0 €	
Section between le Havre and Tancarville	2.01	1.19	**0.69**	0.42	0.26	**1.14**
Section between Hte-Normandie and Ile de France	1.72	0.99	**0.55**	0.32	0.18	**0.71**
Section between Fos and Avignon	1.09	0.77	**0.49**	0.29	0.19	**0.49**
Border section Bâle - Huningue	2.58	2.06	**1.53**	1.01	0.66	**1.58**
Section between Orsoy and Emmerich	25.69	21.44	**17.33**	13.24	9.82	**1 876 188 TEU between Orsoy et Emmerich**

Value observed: base on the database of VNF quay to quay in 2007

It can thus be observed that, at the scale of the IWW sections, the value of time of 2€/TEU/hour is the one leading to the most consistent results.
At the end of the calibration the model is almost ready to be used, for the modelling of future scenarios. Nevertheless, before to can do so, it is necessary to validate the model that is to say to observe how the model reacts to changes in input data.

6.2. Sensitivity of the model to the value of time

Has already mentioned above the value of time is a sensitive subject in transport modelling. Researchers do not really agree on that subject. One of the best ways to determine the value of time of the goods is to realize a state preference survey to the clients to determine what their real value of time is. But in the case of containers, due to the diversity of the product transported in it, it is really difficult to determine an average value.

The following table illustrates the effects of changes of the value of time on the respective usage of the different modes of transport. If the value of time is set to 1 €/TEU/h it can be observed that the gap between the modal share of IWW and rail decrease (with respect to a value of 2 €/h) with a modal share of 11.1 % for the rail and 11% for the IWW. This is normal because, with a lower value of time the slower modes become more attractive for hinterland transportation. The road is nevertheless, still largely dominant with a modal share above 75 % and the services rail-IWW is relatively rare.

When the value of time increase, the modal share of IWW and IWW + Rail decrease to reach a value of -6.1 % and 1 % for 2 €/h and 3.1 and 0.7 % for a value of time of 3 € TEU/h. Whereas the modal share of Rail increase to reach a value of 15.8 %.

Table 11: Effect of the value of time on the market share of the different transport chains

Trafic in millions de tons		Traffic				Modal Share				Elasticity with respect to 2€/TEU/hour			
		Road	Rail	IWW	IWW-Rail	Road	Rail	IWW	IWW-Rail	Road	Rail	IWW	IWW-Rail
SIMULATION - Value of time-in €/TEU/hour	1,00 €	316,6	46,2	45,9	6,3	76.3%	11.1%	11.0%	1.5%	0,07	0,36	-1,60	-1,07
	1,50 €	324,3	51,3	34,2	5,1	78.2%	12.4%	8.2%	1.2%	0,06	0,37	-1,36	-0,98
	2,00 €	328,9	56,5	25,5	4,1	79.3%	13.6%	6.1%	1.0%				
	2,50 €	331,7	61,5	18,4	3,4	79.9%	14.8%	4.4%	0.8%	0,03	0,35	-1,11	-0,68
	3,00 €	333,5	65,7	13	2,8	80.4%	15.8%	3.1%	0.7%	0,03	0,33	-0,98	-0,63

On this study area, it can be observed that the modal share changes between the different modes of transport are concentrated principally between the rail and IWW. Thus, when moving from a value of time of 2 € TEU/h to 1 € TEU/h there is a decrease of around 11 millions of tons both for road and rail traffic (corresponding to a high variation for the rail) and an increase of 19.5 millions of tons on the IWW and of 2.1 millions of tons on the Rail + IWW chain. On the reverse scenario the increase to 3 € TEU/h is characterized by an increased of the road to 4.0 millions of tons and of the rail to 9.3 millions of tons, and a decrease of 12 millions of tons on the IWW and of 1.3 millions of tons on the complex chain.

Thus, most of the tons are switched from rail to IWW or vice-versa depending of the value time, meaning that those modes are competing together, rather than competing in a group against the road mode, and that the road modal share is less sensitive to the value of time than the two other modes.

6.3. Analysis of the results in 2007

After having calibrating the model with the available data for 2007, it is now time to analyse the general results of the model in 2007, with regard to the problematic of this thesis, so with special focus on the corridor North Sea-Mediterranean.

6.3.1. Analysis of the market shares at the level of the countries

In order to determine if the implementation of the TEN-T network will have impacts on the flows of containers in Europe, it is first necessary to determine what the current situation is. The implementation of the TEN-T is expected to have consequences on the hinterland of the European ports that is to say on the market shares of the European ports on the different regions in Europe. Table 12 represents the market share of the ports grouped by countries, in the different countries of the study area. From this table it seems that the European ports can be divided into two main classes. The ports that made their market share principally in the country in which they are located, such as the British ports that represent 92 % of the UK exchange (this can be understand by the fact that UK is an island), the Iberian ports and the Italian ports and the ports that can extend their hinterland further away from their borders, such as the Benelux and German ports.

It seems also that the countries, in which there is the closest competition between ports, are the countries that do not have a maritime façade or a containers port, such as Switzerland where the

Dutch and Belgian ports gather respectively 25 % of the inland container shipment of this country, Italian ports 18% and German ports 17 %. But also Austria where 33% of the exchange transit in the German ports, 21 % in the Netherlands, 17 % in the Belgian ports and 15 % in the Italian ports, and in another hand Luxembourg.

Table 12: Traffic by country (horizontal) in function of the port of transit (vertical)

	In %										
Country	TOTAL	Baltic	UK & Irlande	Germany	Netherlands	Belgium	France	Iberia	Italy	Other Med ports	Black Sea
TOTAL	100%	7%	13%	15%	14%	15%	7%	13%	12%	3%	2%
Germany	100%	0%	0%	66%	16%	17%	0%	0%	0%	0%	0%
UK	100%	0%	91%	1%	3%	3%	0%	0%	0%	0%	0%
Italy	100%	0%	0%	2%	3%	3%	0%	0%	91%	0%	0%
Spain	100%	0%	0%	1%	2%	2%	0%	95%	0%	0%	0%
France	100%	0%	1%	3%	13%	24%	57%	1%	2%	0%	0%
NL	100%	0%	0%	3%	65%	32%	0%	0%	0%	0%	0%
Belgium	100%	0%	0%	1%	34%	64%	0%	0%	0%	0%	0%
Sweden	100%	67%	1%	15%	7%	9%	0%	0%	0%	0%	0%
Finland	100%	53%	1%	19%	11%	15%	0%	1%	1%	0%	0%
Greece	100%	0%	0%	2%	3%	9%	0%	1%	2%	82%	0%
Poland	100%	21%	1%	38%	19%	19%	1%	0%	1%	0%	0%
Romania	100%	0%	1%	10%	9%	10%	1%	1%	2%	0%	66%
Portugal	100%	0%	0%	2%	3%	2%	0%	92%	0%	0%	0%
Denmark	100%	51%	0%	38%	5%	5%	0%	0%	0%	0%	0%
Irland	100%	0%	74%	6%	10%	9%	1%	0%	0%	0%	0%
Austria	100%	1%	3%	33%	21%	17%	4%	2%	15%	3%	0%
Bulgaria	100%	0%	1%	13%	12%	12%	1%	1%	3%	2%	56%
Czech Republic	100%	5%	5%	45%	19%	13%	3%	2%	6%	1%	0%
Switzerland	100%	1%	3%	17%	25%	25%	6%	3%	18%	1%	0%
Lithuania	100%	48%	1%	18%	13%	18%	1%	1%	1%	0%	0%
Latvia	100%	76%	1%	9%	6%	7%	0%	0%	0%	0%	0%
Hungary	100%	6%	5%	31%	20%	9%	4%	2%	17%	6%	1%
Slovakia	100%	9%	5%	33%	20%	11%	3%	2%	12%	4%	1%
Slovenia	100%	0%	0%	12%	11%	9%	1%	1%	11%	56%	0%
Cyprus	100%	0%	0%	1%	1%	1%	0%	0%	0%	97%	0%
Estonia	100%	56%	1%	19%	12%	11%	0%	0%	1%	0%	0%
Luxembourg	100%	0%	2%	4%	41%	51%	2%	0%	1%	0%	0%

By now focusing on the corridor of interest, North Sea-Mediterranean, it can be seen that only one country, see the competition of three groups of ports in its country, its France. Indeed, the French ports gather 57 % of the French inland container shipment, the Belgium ports 24 % and the Dutch ports 13 %.

On Table 13 that represent the market share of each port in each of the French region, it can be observed that the two major French ports for containers' handling: Le Havre and Marseille; have a high market share in France, especially in the region situated next to those ports. The northern region being served by the port of Le Havre, and the Southern one by the port of Marseille. But Belgium and Netherlands ports are also really present with respective modal shares of 24% and 13 %, the Belgian ports are even the port with the second market share in France, thut outpassing Marseille. Due to the specificty of France, being a country with maritime border and major ports on its territory, that has one of the highest hinterland competition within its coutry, the thesis will mainly focus on its hinterland that is part of the North Sea-Mediterranean corridor.

Table 13: Market share of the ports in France

		Germany	NL	Belgium	Other Europe	Le Havre	Marseille	Other FR
	TOTAL	3%	13%	24%	4%	32%	16%	8%
FR10	Île de France	2%	14%	26%	2%	48%	2%	7%
FR21	Champagne-Ardenne	5%	25%	39%	2%	22%	2%	5%
FR22	Picardie	2%	19%	34%	1%	33%	1%	8%
FR23	Haute-Normandie	1%	4%	8%	1%	74%	0%	12%
FR24	Centre	4%	14%	18%	2%	50%	3%	8%
FR25	Basse-Normandie	1%	4%	8%	1%	74%	1%	10%
FR26	Bourgogne	6%	16%	26%	4%	32%	12%	4%
FR30	Nord - Pas-de-Calais	2%	20%	55%	1%	12%	0%	9%
FR41	Lorraine	6%	26%	50%	2%	11%	2%	3%
FR42	Alsace	11%	37%	35%	2%	9%	3%	2%
FR43	Franche-Comté	11%	25%	30%	4%	17%	10%	3%
FR51	Pays de la Loire	3%	8%	14%	3%	50%	3%	18%
FR52	Bretagne	3%	8%	11%	3%	54%	3%	18%
FR53	Poitou-Charentes	3%	9%	17%	4%	39%	8%	19%
FR61	Aquitaine	4%	11%	21%	9%	20%	17%	18%
FR62	Midi-Pyrénées	4%	10%	16%	13%	13%	40%	4%
FR63	Limousin	5%	15%	15%	6%	35%	11%	12%
FR71	Rhône-Alpes	6%	11%	17%	8%	17%	37%	3%
FR72	Auvergne	5%	13%	15%	6%	29%	26%	6%
FR81	Languedoc-Roussillon	1%	2%	7%	14%	4%	70%	2%
FR82	ovence-Alpes-Côte d'Az	1%	2%	4%	9%	3%	80%	1%
FR83	Corse	6%	10%	9%	23%	11%	38%	3%

6.3.2. Analysis of the market shares of the major ports of the North Sea-Mediterranean axes

After having determined the market shares at the scale of the country, and the French regions, it is now interesting to focus on the corridor of interest, the North Sea-Mediterranean corridor. To do so, the market shares of the main container ports that belong to this corridor will be studied. Three ports having an annual container throughput above 5 millions of tons are directly connected to this corridor; there are the ports of Rotterdam, Antwerp and Marseille. Those three ports will be the main ports of interest in this research, with the port of Le Havre. Indeed, the port of Le Havre is the first French container port, and is thus important in the analysis of a corridor that passes through France. The port of Le Havre will be of interest in this research with regard to its competition with the port of Marseille, for the French hinterland.

On the following figures the hinterlands of the four ports quoted above are represented for the year 2007. The market shares have been represented at the node level, by translating the node network into a voronoi diagram. The voronoi diagram consists of "partitioning a plane with n points into convex polygons such that each polygon contains exactly one generating point and every point in a given polygon is closer to its generating point than to any other" (WolframMathWord, 2014). On those figures the following results can be observed.

- For most of the ports there are strong border effects, between the country of origin of the port and the others countries. This is partly due to the structure of the model that includes a border effect in the gravity model, in order to can fit with what is nowadays observed for the shipment of containers. Nevertheless, it can be observed that the border is less a barrier for the "world" ports that are Rotterdam, Antwerp and Hamburg, than for the others ports.

- On the port of Rotterdam's figure the importance of the inland waterway shipment along the Rhine can be seen, due to high market share of this port next to the Rhine (for instance in Alsace in France).

- The French ports of Le Havre and Marseille seems to be real “French” ports as their hinterland extend only in France. Whereas the port of Antwerp, Rotterdam and Hamburg are international ports, as their market share in the hinterland is still quite high even far away from their borders.

- Finally, it can be observed that the model faces some limits for the determination of the market share of the port on the small islands. This is due to the specificities of the data structure and can specifically be seen for Corsica and Ireland.

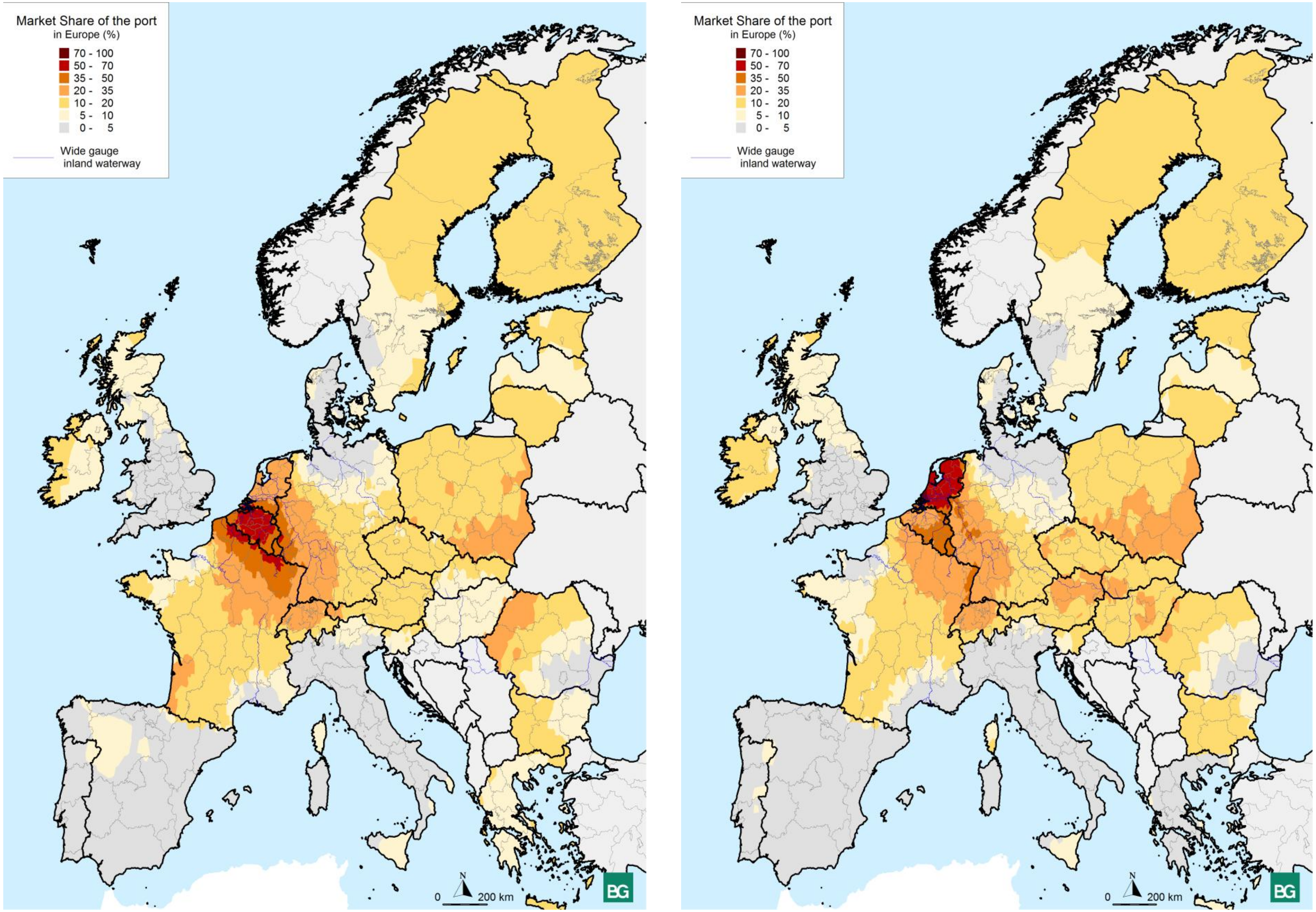


Figure 22: Market Share of the port of Antwerp (left) and Rotterdam (right) on the hinterland in 2007

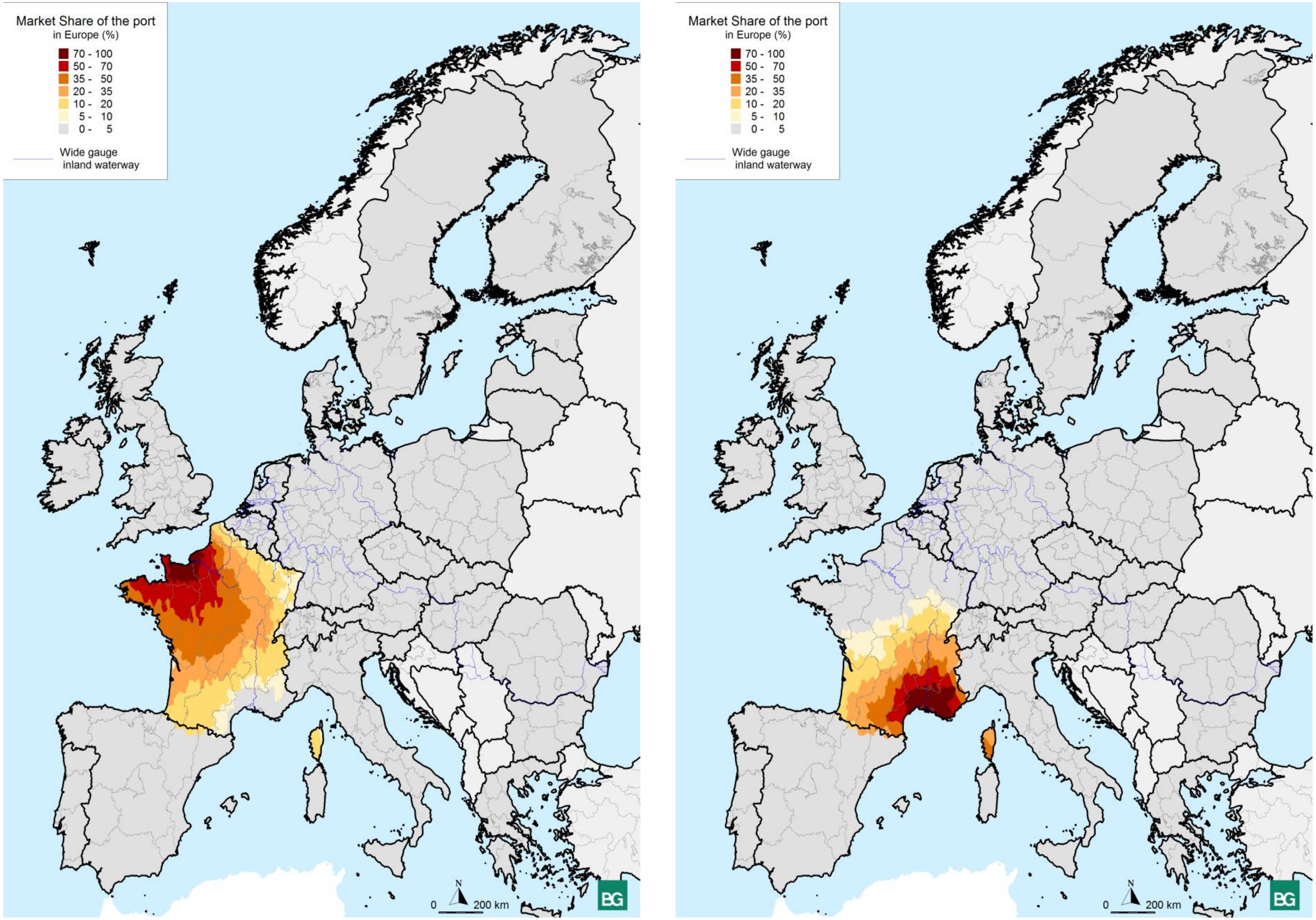


Figure 23: Market Share of the port of Le Havre (left) and Marseille (right) on the hinterland in 2007

6.3.3. Determination of the contestable hinterland

The goal of this research is to analyse if the construction of new transport infrastructures in the hinterland will lead to a shift of containers from the North to the South. To study the potential impact it is first necessary to determine what the hinterland of each port is. This has been done in the previous section. But it is also important to determine where the ports of both ranges are actually competing; this consists of determining the contestable hinterland.

To determine this contestable hinterland first Figure 24a highlights for all the hinterland voronoi zones, what is the range, among the six European ranges defined previously, having the highest share. The limit between the purple and red zones corresponds to the limit where there is a shift of predominance between the HLH and the Mediterranean ranges.

In order to have a clearer view of the contestable hinterland, the difference of market shares between the first and second ranges for each voronoi zone is highlighted in Figure 24b. This representation will allow having a clearer view of what are the zones where there is high competition between the different ranges. The HLH and Baltic ranges, such as the Mediterranean and Black Sea ranges have been combined in this figure for ease of visualisation on the contestable hinterland between the North ranges and the Southern ranges. Thus, the four following ranges are represented in that map:

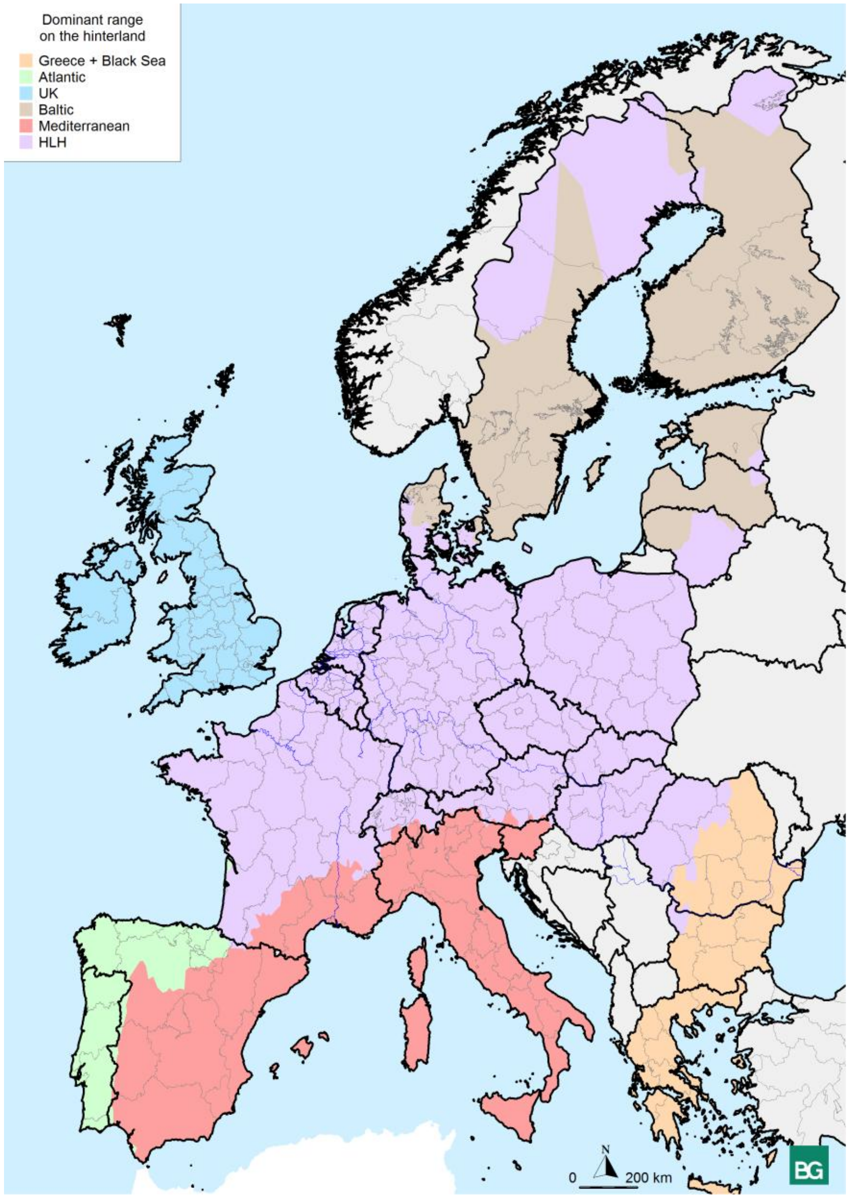
- HLH and Baltic ranges (from Rouen to Kotka),
- Mediterranean and Black Sea Range (from Algeciras to the port of the Black Sea),
- Atlantic Range (from Cadiz to Brest),
- UK range.

It can be seen that the HLH range is the dominant range in Europe. Indeed, this range takes market share on the sea coast of the Atlantic range in France and the Baltic range in Poland and Germany. In addition, the limit between the predominance of the two ranges of interest (HLH and Mediterranean ranges) is located in Midi-Pyrenees, at the border Auvergne-Languedoc Roussillon, at the middle of the region Rhone-Alpes (at the level of Grenoble), at the south borders of Switzerland and in Austria. This limit is thus located really nearby to the Mediterranean coast, meaning that the HLH range put a lot of pressure on the Mediterranean range. Those results are consistent with the custom's data and external commerce data of 2005 (Samarcande, 2007), that can be found in Appendix 6.

To conclude it can be said that the contestable line is situated quite to the South of the European continent, as already highlight in the paragraph about the market share of the range, meaning that the ports of the HLH range have an hinterland that extends quite far to the South.

6.4. Conclusion

In this chapter, the model has been calibrated and validated with regard to the observed data of 2007. It can thus be used now to model the outcomes of future scenarios. To do so, it is first necessary to define those scenarios. This will be realized in the next chapter.



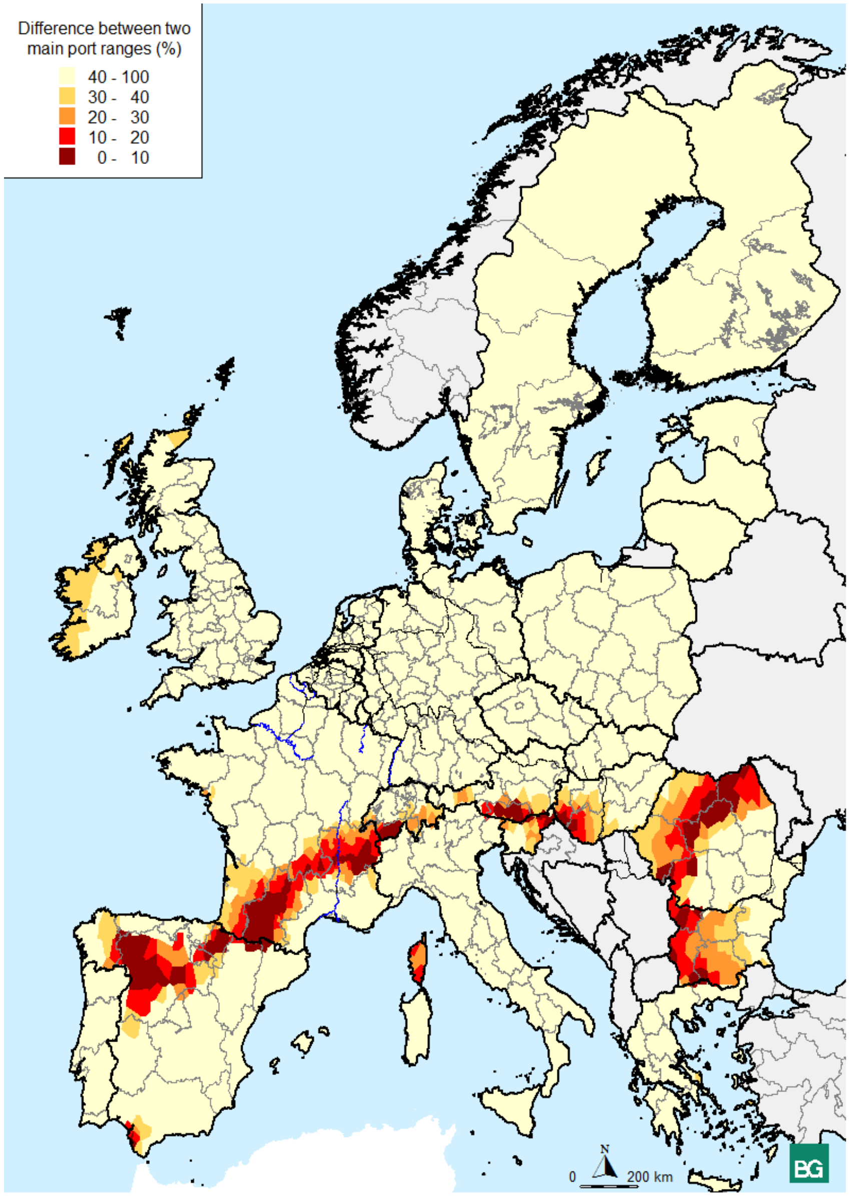


Figure 24: Market Share of the port ranges on the hinterland in 2007 (a) and Market share differences of the two main ranges (b)

7. Construction of the scenarios

The goal of this research is to determine what will be the consequences of the development of new transportation infrastructures and services in Europe, on the balance of container flows between the ports of the HLH ranges and those of the Mediterranean range. To can determine the effects of such infrastructures and services, it is first necessary to implement the improvements of the infrastructures in the georeferenced network used by the model, and to describe the new services.

Then, the economic conditions under which those infrastructures and services will be developed should also be detailed. The scenarios that will be studied in this research will thus be based mainly on two basements: infrastructures scenarios, and economic and organizational scenarios.

Thus this chapter will answer the two following research sub questions:

4. What are the main future transport infrastructures and services developments on the North Sea-Mediterranean Sea that will occur by 2030?

5. What are the main future plausible economic and organizational changes that might influence considerably port choice decision making in Europe by 2030?

Two infrastructural sub-scenarios will be developed in this thesis:

- the reference scenario;
- the Saone-Mosel Saone-Rhine (SMSR) scenario.

They will be studied under three different economic and organizational sub-scenarios:

- the basic economical and organizational scenario of 2030;
- the reduction of the border effect scenario;
- the sensitivity to the maritime costs scenario.

To end up with those sub-scenarios a literature study has been realized to determine what the current situation is and what scenarios have already been developed in the literature. Then a brainstorming has been done to decide which scenarios will be the most interesting for this research with regard to the corridor of interest.

By combining the infrastructure and the economic and organizational sub-scenarios, a total of six scenarios are developed, as can be observed in the following table. They will be analyzed at the time horizon 2030, due to the opening planning date of the SMSR project by VNF.

Table 14: Presentation of the six scenarios of the research

		Economic and organisational scenarios		
		2030Basic	Reduction of the border effects	Sensitivity to the maritime cost
Infrastructure scenarios	nce scenarioRefere	X	X	X
	SMSR scenario	X	X	X

Those six scenarios are going to be described in this chapter by first describing the infrastructural sub-scenarios, before to detail the economic and organizational scenarios.

7.1. Infrastructures sub-scenarios

In this research an important focus is given to the development of new infrastructures, but above all on the development of new multimodal transport services, as the development of infrastructures without any services is totally useless.

It should be acknowledged that the scenarios of this thesis are mainly oriented toward the possible construction of the high gauge IWW canal Saone-Mosel Saone-Rhine in France; this is due to the fact that the socio-economic evaluation of this project has been realized in parallel of this research. The description of this project will be provided in the paragraph related to the SMSR scenario.

7.1.1. The reference scenario

The reference scenario is the scenario that includes the current state of the network in 2014 with in addition the future projects that have currently been planned by the public transport authorities for an opening by 2030. First, a description of the new infrastructures will be provided before to list the new IWW, Rail and bimodal (IWW+Rail) services that will be developed.

7.1.1.1. Infrastructure improvements

The main infrastructure modifications on the corridor of interest (and the neighboring corridors) for this reference scenario are the development of the following infrastructures:

- **Canal Seine North Europe (aslo named Seine-Scheldt):** it consists of the construction of a canal of CEMT's class Vb that will link the basin of the Seine to the Belgium waterway network. The Canal Seine-Nord Europe is planned for 2022.

- **CFAL: "Contournement Ferroviaire de l'Agglomération Lyonnaise":** This is a rail project that consists of creating a bypass (70 km) around the city of Lyon that is currently one of the most congested points of the French rail network. It will allow creating new train paths both for passengers and freight.

- **GPSO: "Grand Projet Ferroviaire du Sud Ouest" :** It is also a rail project that consists of:
  - building a new line between Bordeaux and Toulouse;
  - building a new line between Bordeaux and the border with Spain with a common segment between those two lines;
  - the improvements of the current infrastructures.

- **CNM: "Contournement de Nîmes et Montpellier":** This project consists of creating a bypass for the train line around the cities of Nîmes and Montpellier. The goals of this project are notably to give a high impulsion to the development of freight transport by rail, to create more train paths, and in the future to create an HGV line for passengers. In the context of this thesis it will allow improving the freight rail connections between Spain and the rest of Europe.

- **Upgrade of the rail gauge in Spain to the UIC recommendations:** Currently, the Spanish rail network does not have the same gauge as the rest of Europe (1000 mm instead of 1435 mm). In order to come with interoperability it is necessary to make the different system compatible, via the construction of new rail lines or the implementation of a third rail. This will remove the transhipment operations at the border that are seen as burdens in the total transport chain.

- **The Gotthard Base Tunnel:** This project consists of the construction of a railway tunnel of 57 km, in the Swiss Alps. The goal is to build a new high speed rail line through the Alps that will be used both by passengers and freight. From the freight point of view this project will allow transferring a large amount of merchandises from the road to the rail, thanks to the Swiss policy with regard to heavy good vehicles. The opening of the Gotthard tunnel is planned for 2016.

- **Lyon Turin Ferroviaire (LTF):** This project consists of the construction of a rail link between Lyon (in France) and Turin (in Italy), with the construction of a railway tunnel between Saint-Jean-de-Maurienne in France and Suse in Italy.

- **Brenner Base Tunnel:** This consists of the construction of a rail tunnel between Italy and Switzerland. The opening date is planned for 2025.

- **Basque Y high speed rail network (Bilbao-Irun):** It is a 172 km long high speed network that is currently under construction in Spain, aiming at connecting the three cities of Bilbao, Vitoria and San Sebastian. This line aims at transporting both goods and passengers. The expected opening data of this new line is 2017.

7.1.1.2. New IWW services

With the development of the previous infrastructure projects, new transportation services will be created. Indeed, at the horizon 2030, changes will occur due for instance to the construction of the Seine North Europe (SNE) Canal that will lead to the development of new services between the Seine and Scheldt basins, from the ports of:

- Le Havre and Rouen on the Seine Bassin;
- Rotterdam Antwerp, Zeebrugge and Dunkerque and the Scheldt basin;

and trough the four new intermodal platforms that will be built thanks to the creation of the SNE Canal: Noyon, Nesle, Péronne and Marquion.

As no information has been provided by the IWW authorities and barges operators about the future development of services it has been decided to develop one service per day/ six day per week on the following links:

Table 15 : Connections between the maritime ports of the Seine and Scheldt basins

Origin	Destination
Le Havre & Rouen	Rotterdam
	Antwerp
	Zeebrugge
	Dunkerque

Table 16 : Connections between the maritime ports of the Seine and the intermodal platforms

Origin	Destination
Le Havre & Rouen	Noyon
	Nesle
	Péronne
	Marquion
	Dourges
	Lille
	Béthune
	Prouvy
	Bruxelles

- Connections between the ports of the North and the intermodal platforms

Table 17: Connections between the ports of the north and the intermodal platforms

IWW services between the port of the North Sea and the SNE platforms		IWW services between the port of the North Sea and the Seine platforms	
Origin	**Destination**	**Origin**	**Destination**
Rotterdam & Antwerp & Zeebrugge & Dunkerque	Noyon	Rotterdam & Antwerp & Zeebrugge & Dunkerque	Gennevilliers
	Nesle		Evry
	Péronne		Bonneuil sur Marne
	Marquion		

For the reference scenario there will also be some developments on the Rhine and Rhone basins even if they will not be connected yet, for the navigation of barge. Those new services are the consequences of the development of new containers' terminals along the Rhine and the Rhone. Those services will be oriented to Fos-Sur Mer for the basins of the Rhone and the Saone, and to Rotterdam and Antwerp for the basins of the Mosel and the Rhine. The new services are presented below:

Table 18 : Development of new container terminals and intermodal services in the reference scenario

	Intermodal platform	Maritime port
Rhone and Saone basins	Sète	Fos-sur-Mer
	Avignon	
	Salaize	
	Villefranche	
Rhine and Mosel basin	Nancy	Rotterdam-Antwerp
	Metz	
	Thionville	
	Lauterbourg	

7.1.1.3. New rail services

In the reference scenario the main changes regarding rail services are:

- The development of new rail services between Spain and the rest of Europe. Indeed, new direct services are going to be proposed between the main Spanish platforms (Barcelona, Tarragona, Valencia, Vitoria, Bilbao and Madrid) to the North of France (Paris, Lille and Lyon), Germany (Saarbrucken, Ludwigshafen, and Koln), Benelux (Antwerp, Moerdijk) and

Italy (Turin, Busto). The servicing toward the south and west of Spain and Portugal will be realized with a stop on the platform of Vitor ia, Valence and Madrid.

- The creation of the Lyon Turin Ferroviaire Tunnel will also allow creating services between France and the North of Italy.

7.1.1.4. Development of interconnections rail –IWW

This thesis put emphasis on the hinterland transportation of maritime containers, and thus gives a close look to the intermodal transportation solutions. Rail and IWW solutions are already intermodal solutions as they required transshipment of containers between the train or the barge and the truck, for the pre/post truck haulage. This thesis will also take into account the trimodal transportation solutions that is to say: IWW+ Rail+ Road. For this kind of intermodal solution transshipment is necessary between train and barge.

To come with efficient trimodal solutions several state of the art rules need to be implemented in the network:

- the number of articulation points between the two alternatives modes should be limited and well located in order to benefit from the mass phenomenon.
- this new offer should be articulated to the actual network in order to avoid redundancy, so principally on the location of the platforms of Ludwigshafen and Duisburg.

In the reference scenario the Rhine and the Rhone basins are not interconnected, it is thus possible to articulate the IWW and rail services in order to compensate the IWW missing link. The best locations to do so are the intermodal platforms located South of the Rhone (Avigon) and those at the level of Lyon.

Nowadays, the rail services and IWW services along the Rhone seems to be more concurrent than complementary. In order to develop complementarities between the IWW and the rail, radial rail relations in the direction of Toulouse-Bordeaux and in the direction of Spain, where the inland waterway are absent, will be developed. A rail liaison in direction of Nice does not seem possible due to congestion on the rail network in this region and to the low demand for transportation of goods on this axis. The following services have been considered for the reference scenario, in order to favor trimodal solutions:

Table 19: New rail services on the Rhone

	Origin	Destination
France	Perpignan	Avignon (Sète or Arles)
	Toulouse	
Spain	Barcelona	
	Tarragone	
	Saragosse	
	Valencia	
	Madrid	

In the reference scenario, it seems also interesting to develop rail services at the level of Lyon. A trimodal platform already exits in Lyon with the port Eduard Herriot, nevertheless there is no possibility of extension of this port that suffers from saturation. That is why two other platforms have been considered:

- Salaise, located south of Lyon that has for main advantages to avoid the problem of air draft in Lyon. Nevertheless, the distance between Fos-sur-Mer and the platform is quite short (around 250 km) which is not optimal for the development of economies of scale.
- Villefranche sur Saone situated north of Lyon. There the problem of air draft of the bridges of Lyon appears.

The hypothesis has been made that the following services will be developed.

Table 20: Rail Services from the trimodal platform in Lyon

	Origin	Destination
Actual services from Lyon	Marseille	Villefranche and/or Salaise and or Lyon Herriot
	Fos	
	Avignon	
	Le Mans	
	Rennes	
	Le Havre	
	Dourges	
	Strasbourg	
	Antwerp	
	ruggeZeeb	
	Duisburg	
	Ludwigshafen	
Services due to the creation of the LTF	Turin	
	Novare	
	Busto	
	Genova	
	Verone	
Service related to the future creation of the SMSR Canal	Valenton	
	Noyon or Nesle	
	Basel	
	Rotterdam	

7.1.2. The Saone-Mosel Saone-Rhine scenario

The Saone-Mosel Saone-Rhine scenario consists of linking the Rhine to the Mediterranean by the construction of a high gauge Canal of 220 km between the Saone and the Mosel and the Saone and the Rhine (cf. Figure 25). The project will connect the Saone at the level of Saint-Jean-de-Losne to the Mosel until Neuves-Maisons and the Rhine at the level of Mulhouse (VNF, n.d), and will be navigable for barges with three layers (assuming that the problem of air draught of the Lyon's bridge swill be resolved).

This project has several objectives (VNF, 2012):

1. “Develop the north-south traffic between the Mediterranean Sea (Spain, Italy, France) and the rest of Europe”;
2. “Improve the connection between the maritime and inland ports” in order to strengthen the links between those two entities”;
3. “Broaden the ports’ hinterland;
4. Increase the number of markets that can be reached by IWW and rail transport” ;
5. Improve the connection between the Rhone basin and the countries of Northern Europe were inland transportation is really developed;
6. Creating sustainable transportation solutions in order to improve the overall transport chain.

Eight French regions are concerned by this canal:

- The five regions that are crossed by this canal: Alsace, Lorraine, Bourgogne, Champagne-Ardennes and Franche-Comté[30].

- The three regions that will mainly profit from the economic benefices of this project: Rhône-Alpes, Provence-Alpes-Côté-d’Azur and Languedoc-Rousillon.

Moreover, this canal will also have influences on the countries that are crossed by the Rhine and the Mosel, that is to say: Germany, Belgium, Luxembourg and the Netherlands. The focus of this thesis being on maritime containers, the influences of this canal on these latest countries will only concerns the hinterlands of the ports that are connected to the Rhine or the Mosel, so mainly the Belgium and Dutch ports. Finally, some influences for Spain are also expected, as Spain will benefit from the relative vicinity of a high gauge IWW network linking the Mediterranean to the North of Europe.

The figure below highlights in yellow the zone that will be impact the most by the development of this project.

The starting point of the development of the SMSR scenario will be the reference scenario. Only additional services related to the creation of the SMSR canal will be considered, they are going to be presented in the following paragraph.

[30] A map with the French region can be found in Appendix 8.

Figure 25 : Context of the connection Saone-Mosel Saone-Rhine (Source: VNF, n.d)

7.1.2.1. New IWW services of the SMSR scenario

The construction of the canal SMSR, will allow developing additional intermodal services and platforms, with respect to the reference scenario. The construction of new services is realized with the same method as in the reference scenario, and thus with a frequency of six services per week.

Table 21: Connections between the port of the Rhine and those of the Rhone

Origin	Destination
Fos sur Mer	Rotterdam
Fos sur Mer	Antwerp

With the construction of the canal new intermodal platforms will be built on the two segments of the canals in: Vesoul, Epinal (in direction of the Mosel) & Giromagny-Belfort (in direction of the Rhine).The new services are thus:

Table 22: Connections between the maritime ports and the SMSR platforms

	Origin	Destination
IWW services between the port of the Rhone and the SMSR platforms	Fos sur Mer	Vesoul
		Epinal
		Giromagny-Belfort
IWW services between the ports of the Rhine and the SMSR platforms	Rotterdam & Antwerp	Vesoul
		Epinal
		Giromagny-Belfort

Table 23 : Connections between the ports of the Rhine and the platform located south of the SMSR canal

Origin	Destination
Pagny	Antwerp, Rotterdam & Vesoul
Chalon sur Saone	
Mâcon	
Villefranche	
Lyon	
Salaize	
Valence	
Avignon	
Arles	
Sète	

Table 24: Connections between the port of the Rhone and the platform located north of the canal SMSR

Origin	Destination
Nancy	Fos-sur-Mer & Avignon
Metz	
Thionville	
Mulhouse-Ottmarshekm	
Huninge	
Basel	
Colmar Neuf-Brisach	
Strasbourg	
Lauterbourg	
Karlsruhe	
Ludwigshafen	
Mainz	
Koblenz	
Kôln	
Duisburg	
Nijmegen	

7.1.2.2. New rail services

In the SMSR scenario it is assumed that the same rail services as those proposed in the reference scenario will be developed.

7.2. Economic and organisational sub-scenarios

In this thesis the economic conditions that will be used at the horizon 2030 will be the same for all the scenarios, implying that the focus is mainly on the development of infrastructures and services, and in modification of the organisational aspects of the transportation of the maritime containers. The basic economic scenario that will be used in this research is going to be described below. The method describe below is frequently used by BG Ingénieurs Conseils in the modelling of European and French projects. Then the specific aspects related to the reduction of the border effects and sensitivity to the maritime costs will be considered.

7.2.1. The Basic economic scenario for 2030

7.2.1.1. Forecasting of the extra EU containers traffic between each NUTS 2 regions and the partner maritime zones

To can model the flows of maritime containers at the time horizon 2030 several additional inputs data from the base case of 2007 are necessary. Those input data (distinct from the infrastructure improvements) are:

- the projection of GDP and POP at the horizon 2030;
- the traffics of container between a node i and a partner maritime zone m in 2030.

It should also be noticed that the projection of the port traffic data at the horizon 2030 are not required, because in the gravity model the port traffic of 2007 are going to be used. Indeed, this value is the more accurate one that can be obtained at the horizon 2030. This implies that only the hinterland improvements are taken into account at the horizon 2030. Port infrastructure developments are thus omitted.

- **Projection of the GDP and POP at the horizon 2030**

The socio-economic variable that are used as input for the model are derived from scenarios that are often updated by the European Union, regarding the evolution of each EU's country, in the context of the interdependency of their economy and their insertion in the international market (European Commission, 2011). For instance, the population projections at the level NUTS2 are extracted from the study Europop2008 (Convergence scenario, Eurostat) that are also used in the European Scenarios. The evolution of both Population and GDP can be observed in Appendix 9: GDP and Population forecasts take as input in 2030.

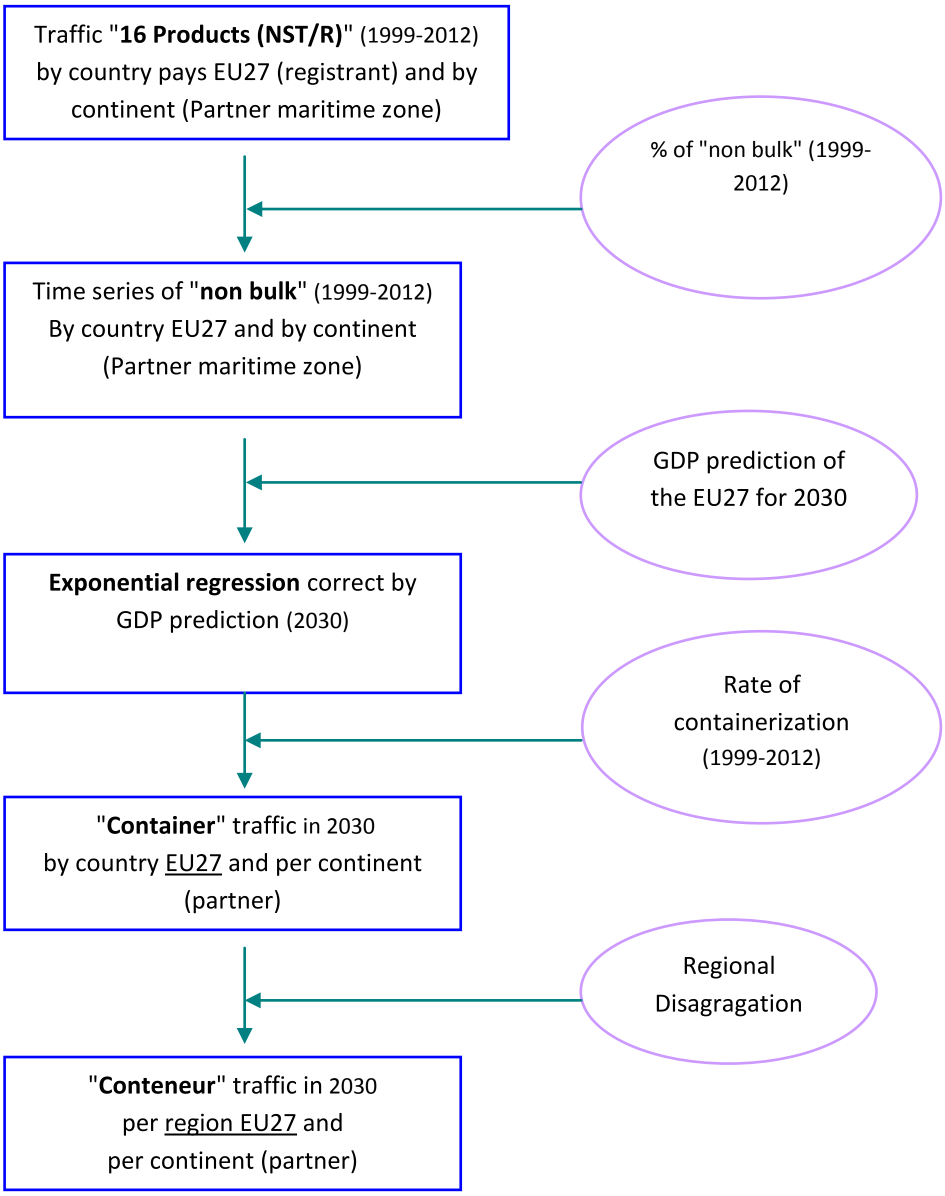
- **Projection of the container traffic between a NUTS 2 region and a partner maritime zone**

After having determined the socio-economic data (GDP and population) it is necessary to determine the traffic of container between the countries of the study area and the partner's maritime zones for 2030. To do so an economic adjustment is made on the chronological series (1999-2012) of the containers traffic between the European countries and the partner maritime zones.

The methodology is based on several steps:

1. Estimation of the non-bulk traffic by EU countries and by continent for the year 1999-2012 (source: Comext, Eurostat Ports), by applying the same methodology as for the base year 2007.
2. Exponential projection of the time series (1999-2012) of the traffic "non bulk" per country and per continent
3. Compound annual growth rate of the traffic "non bulk" in 2030 corrected by the GDP prediction
4. Estimation of the traffic of container per country and per continent in 2030.
5. Regional distribution of the container traffic per country and per continent.

Figure 26: Projection of extra EU container traffic per continent (Source: Comext, Eurostat Ports, DG ECFIN (scénario décennie perdue))



The table below sum up then the tons of containers traffic import and export by each country of the study area with each partner maritime zones, at both horizon 2007 and 2030.

Table 25: Generation of traffic at the horizon 2007 and 2030 in millions of tons

TOTAL - 2007								TOTAL-2030							
Countries	Africa	Asia	MED	NA	SA	extraEU	intraEU	Countries	Africa	Asia	MED	NA	SA	extraEU	intraEU
AT	0.26	1.89	0.71	1.23	0.24	4.33	0.78	AT	0.85	5.55	4.73	1.83	2.95	15.91	0.96
BE	2.20	10.07	2.65	3.76	2.26	20.94	5.15	BE	3.94	18.40	8.97	4.19	6.11	41.62	6.70
DE	2.52	22.32	4.92	11.24	3.19	44.18	10.92	DE	4.49	73.21	18.23	10.80	10.26	116.99	12.94
DK	0.10	2.18	0.23	0.84	0.25	3.60	4.34	DK	0.14	3.99	0.50	0.76	0.63	6.02	5.24
ES	1.96	19.04	8.32	5.34	3.60	38.26	9.38	ES	8.53	17.94	22.31	3.73	8.53	61.04	14.15
FI	0.18	2.74	1.53	1.34	0.61	6.39	7.32	FI	0.22	4.25	2.39	0.77	1.00	8.62	8.82
FR	3.97	14.57	6.55	6.49	2.77	34.36	10.51	FR	3.51	36.10	11.52	4.95	3.23	59.30	14.91
GR	0.97	2.07	1.56	1.10	0.30	6.01	3.82	GR	3.71	4.08	14.17	0.48	0.33	22.77	3.82
IE	0.18	1.51	0.49	0.50	0.11	2.80	4.78	IE	0.26	1.76	0.34	0.54	0.20	3.09	5.62
IT	2.52	17.26	11.11	8.35	3.33	42.58	7.81	IT	2.21	40.88	17.13	5.89	5.35	71.46	10.49
LU	0.02	0.22	0.09	0.31	0.03	0.67	0.24	LU	0.02	0.23	0.36	0.28	0.06	0.96	0.30
NL	1.79	11.48	2.48	4.45	1.70	21.91	7.55	NL	3.56	30.62	4.86	9.17	13.38	61.59	11.21
PT	1.81	1.31	1.19	0.84	0.67	5.80	3.16	PT	10.04	1.72	5.41	0.85	3.23	21.25	3.99
SE	0.40	3.85	1.50	2.10	0.60	8.44	9.40	SE	3.22	11.60	7.15	1.21	1.49	24.67	12.94
UK	2.47	18.65	4.41	6.49	1.61	33.63	17.59	UK	1.98	49.64	6.90	5.63	3.71	67.86	21.64
15EU	21.35	129.16	47.73	54.38	21.27	**273.89**	**102.73**	15EU	46.67	299.98	124.97	51.07	60.45	**583.14**	**133.74**
BG	0.05	0.61	1.55	0.20	0.34	2.75	1.02	BG	0.07	2.19	2.02	0.16	0.17	4.61	1.15
CY	0.01	0.36	0.21	0.02	0.02	0.63	0.90	CY	0.01	1.08	0.61	0.03	0.03	1.77	1.27
CZ	0.05	1.47	0.06	0.48	0.08	2.14	1.15	CZ	0.07	6.78	0.18	0.50	0.13	7.66	1.72
EE	0.01	0.30	0.05	0.11	0.01	0.47	0.65	EE	0.01	0.73	0.12	0.04	0.01	0.91	1.06
HU	0.02	0.83	0.00	0.14	0.05	1.04	0.82	HU	0.03	2.55	0.01	0.13	0.05	2.77	0.88
LT	0.14	0.46	0.11	0.54	0.04	1.29	1.29	LT	0.03	1.73	0.21	0.27	0.14	2.39	1.73
LV	0.01	0.25	0.10	0.09	0.03	0.48	1.62	LV	0.02	0.70	0.87	0.05	0.01	1.64	2.83
MT	0.01	0.08	0.07	0.02	0.01	0.19	0.23	MT	0.01	0.35	0.22	0.01	0.02	0.62	0.37
PL	0.55	3.35	0.62	1.43	0.62	6.57	3.04	PL	0.35	11.93	1.85	0.87	1.03	16.03	4.59
RO	0.29	2.43	3.29	0.90	0.46	7.37	1.56	RO	0.27	8.12	7.73	0.70	0.24	17.06	2.17
SI	0.03	0.47	0.66	0.10	0.10	1.36	0.34	SI	0.07	2.50	2.12	0.10	0.24	5.03	0.39
SK	0.02	0.64	0.03	0.21	0.02	0.91	0.90	SK	0.02	2.94	0.10	0.12	0.05	3.23	1.10
12EU	1.17	11.24	6.77	4.25	1.78	**25.21**	**13.51**	12EU	0.96	41.60	16.04	2.99	2.12	**63.72**	**19.25**
CH	0.18	0.98	0.32	0.43	0.19	2.10	0.56	CH	0.50	2.90	0.85	0.53	0.81	5.58	0.36
Total	22.70	141.39	54.82	59.06	23.24	**301.21**	**116.80**	Total	48.13	344.48	141.87	54.59	63.38	**652.44**	**153.35**

7.2.1.2. Evolution of the unit costs

In 2030, not only the generation of containers will change but also the unit transportation costs. The evolution of the unit costs is based on the costs provided by VNF for the socio-economic evaluation of the Canal Saone-Mosel Saone-Rhine at this time horizon. The detailed of those costs can be found in Appendix 2.

It is very difficult to give a general evolution of those costs, because different inflators are used, and the costs are unique for all the origin-destination couples. Nevertheless, it can be stated that the costs of the three modes increase between 2007 and 2030, the larger increase being observed for the road.

Indeed, the road costs increase with an annual growth rate of 0.38 % between 2007 and 2030 for shipments of distance included in the interval 300-1500km. This is due to an increase of almost all the road unit costs: fuel costs and tolls, fixed kilometer costs, hourly costs, average load of the truck and to the implementation of the carbon fuel tax. The only indicator that decreases is the consumption of the vehicles.

The rail costs also increase between 2007 and 2030; because of the high rise of the rail fees, despite a reduction of the hourly and kilometer costs. The IWW unit costs only slightly increase between 2007 and the 2030 reference scenario, but what is important is that the creation of the SMSR canal allows homogenizing the costs between all the basins.

7.2.2. The reduction of the border effects scenario

Since the implementation of the TEN-T network, the European Union has put emphasis to improve the connections between the different European Countries. If at the beginning of the implementation of this policy, the focus was more on passengers, nowadays the movements of goods is also of high importance in this policy instrument.

One of the goals of the TEN-T network is to improve the connections between the different countries. To do so, the construction of infrastructures is necessary but not only. Indeed, factors such as organisational aspects, actor's perceptions are also of importance. Such factors can be considered as qualitative factors, and when they are relative to cross-border transport, they can be grouped into borders effects. Those border effects include (Tavasszy, 1996):

- technical differences between countries (as for instance electrification or signalling system);
- cultural and language differences between countries;
- actors perceptions;
- political and socio-economic aspects;
- organisational difficulties that include for instance the change of train drivers at the border due to lack of qualification to can drive on both territory.

From the previous list, it seems that the border effects are difficult to quantify (Tavasszy, 1996), as there is no consensus on their content.

In this thesis the problem of organisation of cross-border transport in Europe, has been translated by the implementation of border effects. It should be acknowledged that those border effects have already decreased considerably since the opening of the borders and the markets in Europe and since the implementation of the TEN-T network. Nevertheless with the implementation of the new regulation relative to the comprehensive and core networks of the TEN-T, it is expected that those border effects will continue to decrease mainly because of the improvement of the interoperability of the networks, but also due to a better organisation of the transport chain and a better knowledge of all the alternatives by the actors.

That is why this scenario will consist of reducing the border effects that are taken into account in the gravity model, in order to determine the consequences of a further reduction of those border effects on port competition in Europe.

It is expected that this decrease of the border effects will have consequences on port competition, as ports would be able to reach hinterland further away in other countries, due to the improvement of the hinterland transportation networks and services.

The border effects of the base year scenario have been determined by calibration of the model, by differentiating the power of the impedance function for the international port-hinterland relations and in function of the class of the port.

The reduction of the border effects in this scenario will be realized by considering that the international parameter Δ_{ij} of the gravity model is equal to the average of the national and international parameters of the reference scenario, corresponding to the division by two of the difference between the national and international Δ_{ij} parameters of the reference scenario.

The following values for this parameter are thus obtained and used in the model:

Table 26 : Adjustment of the parameter Δ_{ij} in order to reduce the border effects

<table>
<tr><th>Range Port</th><th>National</th><th>International</th></tr>
<tr><td>World</td><td>Adjusting</td><td>Adjusting</td></tr>
<tr><td>Range</td><td rowspan="5">2.4275</td><td>2.58625</td></tr>
<tr><td>National</td><td>2.66125</td></tr>
<tr><td>Intermediary</td><td>2.81125</td></tr>
<tr><td>Regional</td><td></td></tr>
<tr><td>Local</td><td></td></tr>
</table>

7.2.3. The sensitivity to the maritime costs scenario

Finally, the latest scenario will try to determine what the sensitivity of the model to the maritime segment is, by only taking into account the trade between Asia and Europe. Indeed, as already explained before, the model that has been calibrated in this thesis does not include the maritime segment, but only the hinterland transportation segment of the whole maritime chain. Such a simplification has been taken by considering that the maritime costs to reach all the ports in Europe are equal, even if it is known that those costs are not identical in reality.

Indeed, a container shipped from Asia to Europe, will travel 3 000 additional km if it is shipped to the HLH range rather than to the Mediterranean range. Those additional 3 000 km between the Mediterranean range and the HLH range, lead to additional fuel consumption and additional emissions of CO_2, SO_2 and NO_x, even more due to the fact that the frequentation is really high in the English Channel and the North Sea and that additional manoeuvres might be required. Thus, shipments to the HLH range should lead to additional maritime costs than shipments to the Mediterranean range, if the same operational conditions of the maritime segment are applied between those two ranges[31].

In this scenario that is not related to a concrete policy instrument the repartition of the Asian containers in Europe will be analyzed, by considering that the principle of polluter-payer is applied to the maritime segment. That is to say by considering that the maritime costs are directly proportional to the distance travelled, and thus to the consumption of fuel and emissions of pollutants.

To do so an additional costs for the maritime segment will be added to the denominator of the gravity model, as in the formula below:

$$Attrac_{(i,j,m)} = \frac{M_{node\ (i,m)} * M_{port_{(j,m)}}}{(Min.Cost_{(i,j)} + Maritime.Cost_{(i,j)})^{\Delta ij}}$$

Where $Maritime.Cost$ *represents the maritime bonus assigned to each port depending of its range, as defined in Table 27, and all the others parameters being the same as in equation (20) of chapter 5.*

It is expected that this additional maritime cost will affect, the port choice of the shipping companies, especially for hinterland located at the level of the contestable hinterland line.

To determine the value of the additional maritime costs the first idea was to include for each European port, an additional cost that was proportional to the distance between the Suez Canal[32], and each port of destination. To do so first, the distances between the Suez Canal and the ports of destination have been multiplied by a unit maritime kilometer cost. This latest has been determined, by computing the average price of several shipping companies to ship a container from Asia to Europe during the Q4 2013 and Q1 2014 (Drewry Maritime Research, cf. Appendix 10), and by dividing it by the average distance of the journey. It was found that the Asia-Europe unit kilometer cost was of 0.038 €/TEU/km.

[31] This is not the case in realty, as it is know that the ships that operated on the Asia-HLH range have a higher capacity than those operating on the Asia-Mediterranean range, and thus lead to lower kilometer cost per TEU.

[32] Knowing that all the ships making the liaison Asia-Europe pass through the Suez Canal.

The additional maritime cost was then computed by subtracting for each port the minimum value of all the European ports to the shipment cost/price to each port, in order to have a differential between all the European ports.

$$Maritime.Cost_{ij} = Unit\ price * distance_{sj} - Min_k(Unit\ price * distance_{sk})$$

Where $Unit\ price$ *corresponds to the unit kilometer cost defined previously.*

$distance_{sj}$ *is the distance between the Suez canal and the port j*

Then the process was simplified, by only differentiating the additional maritime cost per range (and not for each port). The value of the maritime cost per range have been determined thank to the previous computation.

Table 27: Central scenario for the additional cost of the maritime segment

Range	Maritime additional (€) cost
Bla+Greececk Sea	0
Mediterranean	0
Atlantic	75
UK	150
HLH	150
Baltic	150

This scenario has thus for goal to analyze the sensitivity of the model to the maritime segment. It is not a maritime model, because to come with a real accurate maritime model, far more details regarding the organization of the exploitation of the shipping companies will be required, but this is out of the scope of this thesis, as the focus was on the organization of the hinterland transportation of the maritime containers. Nevertheless, the development of such a maritime model will be the next step to implement for future research.

7.3. Conclusion

To sum up, six scenarios have been defined in this chapter and will be studied in this thesis. All of those scenarios will have the same socio-economic background based on projections of population, GDP and traffic at the horizon 2030, but also on the evolution of the unit transport costs at the same time horizon. The differences between those scenarios will mainly be based on the infrastructures and services considered at the horizon 2030, and on additional hypothesis related to the reduction of the border effects and the analysis of the sensitivity to the maritime segment.

Those scenarios will now be analyzed in the next chapter.

8. Model outcomes for the scenarios in 2030

After having defined the scenarios in chapter 7, it is now interesting to look at what will be their effects on the ports' hinterlands and on the modal share of the hinterland transport solutions in 2030. This chapter will thus answer the sub question 7:

7. What will be the impacts of the creation of new hinterland transport infrastructures and services, under different economic and organizational scenarios, on the ports throughput, the ports hinterlands and the modal share of the different transport solutions on the North Sea-Mediterranean corridor in 2030?

To do so the model presented in chapter 5 and calibrated in chapter 6 will be used. This model allows generating as principal outputs: the ports throughputs; the container traffic between each port and each hinterland zone and the share of the modes used to link each port and hinterland node.

In order to determine what will be the effects of those scenarios, results will be analysed by focusing on the following parameters: the container throughputs of each port range; the container throughputs by ports and by countries; the hinterland of the main ports of the corridor; the modal share per ports and the modal share of the main port/hinterland couples of interest in this research. The analysis of the following parameters will allow determining at what scale the scenarios studied will have effects, in port competition in Europe.

This chapter will in the first section present the results for the reference basic scenario, before to analyse in a second section the outputs of the model for the SMSR scenario under the basic economical and organizational hypotheses. Then, section 3 and 4 will respectively analyse the results of the model for the reduction of the border effects and the integration of the maritime segment for both infrastructure scenarios. Finally, a conclusion on the results obtained for all the scenarios and oriented to the answer of the research question will be given.

8.1. The reference basic scenario in 2030

The reference scenario, that takes into account the new infrastructures that have already been planned by the public authorities for 2030 and the services that go along, will be the point of comparison of all the other scenarios. It is thus important to have a clear picture of this reference, regarding ports' market shares in Europe, ports' hinterland and modal shares of the different transport solutions, in order to can analyse the others scenarios. The structure of the analysis of the reference basic scenario developed in this section, will then applied to all the other scenarios.

8.1.1. Analysis of the market shares of the ranges in Europe

First, it can be observed Figure 27 that the market shares of the ranges in Europe in 2030 are changing with regard to 2007, as the HLH, Atlantic and Black Sea ranges are winning market shares, whereas the Mediterranean, Baltic and UK ranges are losing market shares. Those results are direct consequences from the generation of traffic for 2030 that is based on the GDP and population forecasts (cf. Appendix 9: GDP and Population forecasts take as input in 2030). Indeed, countries having a front on the HLH range have higher GDP and population growth rates for 2030 than countries that have a front on the Mediterranean range, explaining partly the evolution of the market share of the ports.

At this scale it is very difficult to evaluate the influences of the new transport projects, in the repartition of the market shares. To do so, the hinterland of the ports will be analysed in the next sections.

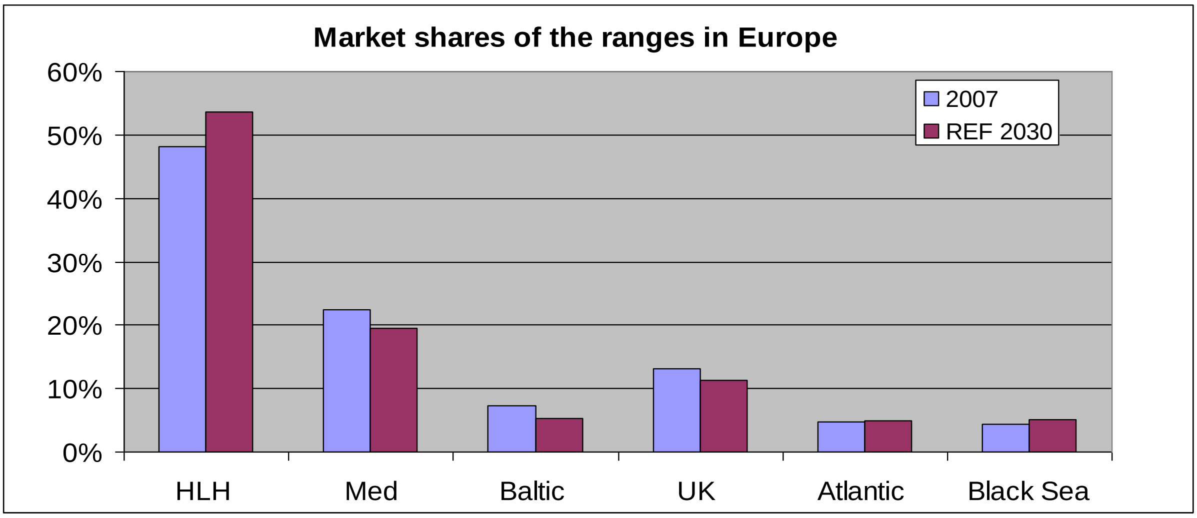


Figure 27: Comparison of the market shares of the ranges between 2007 and the REF scenario in 2030

8.1.2. Analysis of the market shares of the ports in France

The focus of this section will be on the market shares of the European ports in France, as the main infrastructure improvements that are implemented between the base year 2007 and the reference scenario 2030 in Europe are located in this country. It has also been decided to groups the other ports by countries, because it is considered that the ports within Belgium and the Netherlands can benefits from the same hinterland infrastructures, to reach the French hinterland.

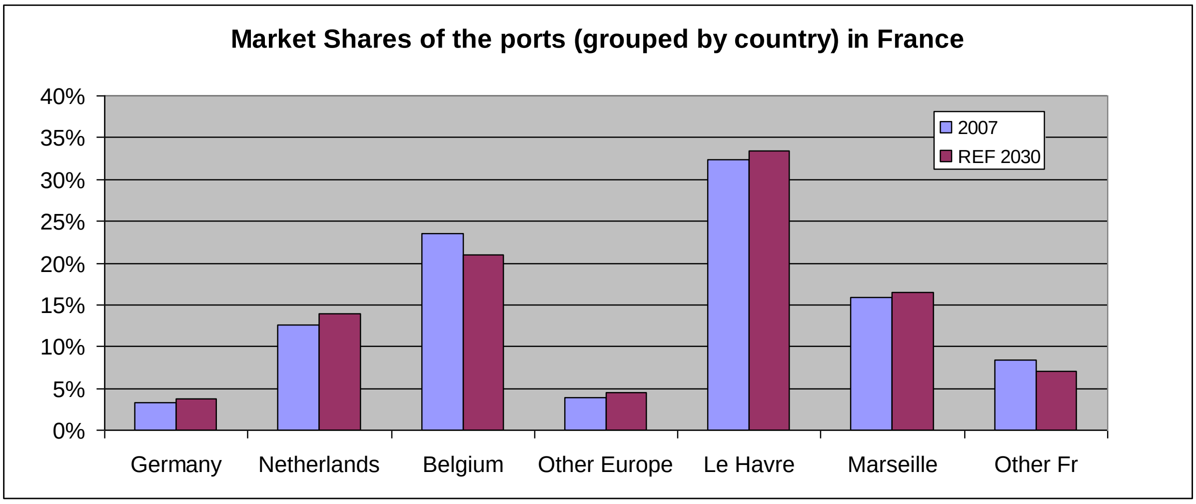


Figure 28 : Market Shares of the European ports in France

The port of Le Havre is the port having the largest market share in France, with 33% in 2030. In the second and third position come the ports of Belgium and the Netherlands with respective market shares of 21 and 14%. If now the comparison is realized between 2007 and 2030, it can be observed that the market shares of all the groups of ports increase by 1%, with the exception of the Belgium ports that see their market share decrease by 3 %, and the group of the other French ports that see its market share decrease by 1%. The decrease of the market share of the Belgium ports can be explained by the specialisation of those ports towards the Mediterranean exchanges, whereas the ports of the Netherlands are more specialized in the relation with Asia. Indeed, between 2010 and 2030 the annual growth rate of the exchange between France and the Mediterranean is of 1.4 %, whereas for the exchanges between France and Asia the annual growth rate is of 4.3 %.

8.1.3. Analysis of the hinterland of the major ports of the corridor

After having analysis the market shares of the European ports in France, it is now interesting to focus on the corridor North Sea-Mediterranean. In order to study the impacts of the development of new infrastructures and services on this corridor, the evolution of the hinterland of the main ports of this corridor will be look closely thanks to Figure 29 and Figure 30.

In those figures it can be observed that at the first glance the hinterlands of the ports for the reference scenario in 2030 are pretty similar to those of 2007. But by looking closely it can be observed that small changes occur. For instance the port of Antwerp is winning market shares in Belgium, Luxembourg and Spain and is losing a little of market shares around Bordeaux. It is not observable on the map but the port of Antwerp is also loosing market shares (between -4.3 to -13 %) on the French regions Lorraine, Franche-Comté, Alsace and Bourgogne. A possible explanation is that there is no creation of new transport services between those regions and the port of Antwerp whereas a rail service is created between Rotterdam and those regions, increasing the competiveness of the port of Rotterdam at the expense of the port of Antwerp.

The port of Rotterdam is winning market shares in the East of the study area that is to say in Poland, Czech Republic, Slovakia and Hungary. It also win market share in France in the regions Rhône-Alpes, Bourgogne, Alsace, Franche-Comté and in the west of France. The gain of market shares in the regions Rhône-Alpes and Bourgogne can be explained by the development of new rail service between the new platform of Salaise/Villefranche and Rotterdam, and in the regions Alsace and Franche-Comté those gains can be explained by the creation of IWW services between the Alsace-Lorraine’s platforms and Rotterdam.

Regarding the French ports, the figure highlights that the port of Le Havre is losing a little bit of market shares in Bourgogne, Franche-Comté, Rhône-Alpes and Auvergne. This can be explained by the development of new IWW and rail services between its concurrent ports (Marseille and Rotterdam) and those regions, whereas the services between Le Havre and those regions are the same as in 2007. Finally, the port of Marseille is winning market shares in Bourgogne, due to the development of new IWW services between Fos-sur-Mer and Salaise/Villefranche, and is losing a little of market share in Rhône-Alpes due certainly to the new concurrency with the port of Rotterdam.

By looking at Figure 31 (left), representing the area in which each port range is the most competitive it can be observed that this figure is almost the same as 2007. The line of contestable hinterland (cf.Figure 31 (right)) seems also to be located at the same place as 2007, signifying that no significant change in the hinterland has been observed between the base and the reference scenarios and thus, that the areas where the competition between the port ranges are the more intense are the same. This is not a really surprising result, as it is expected that the main change will occur between the reference and the SMSR scenario.

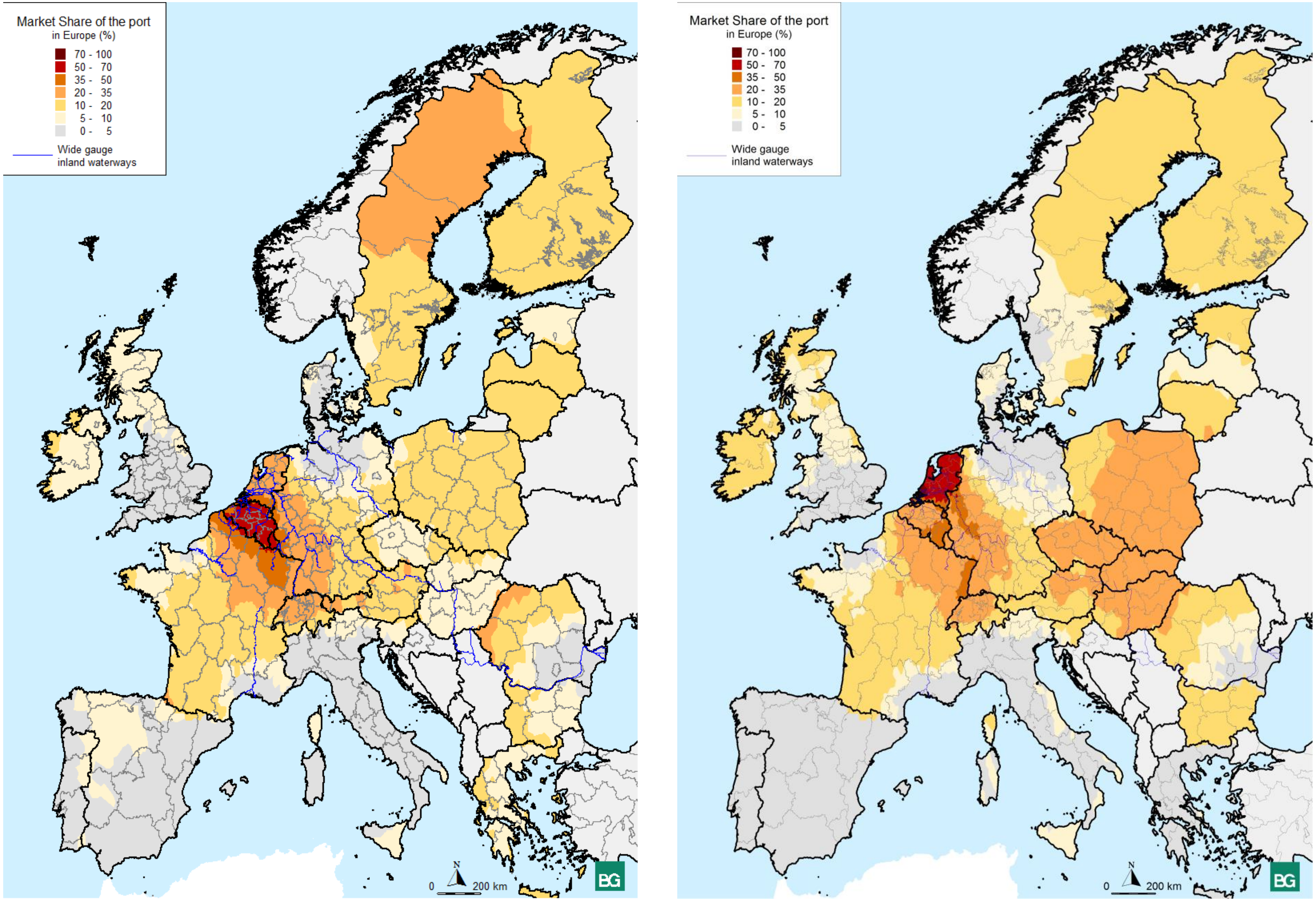
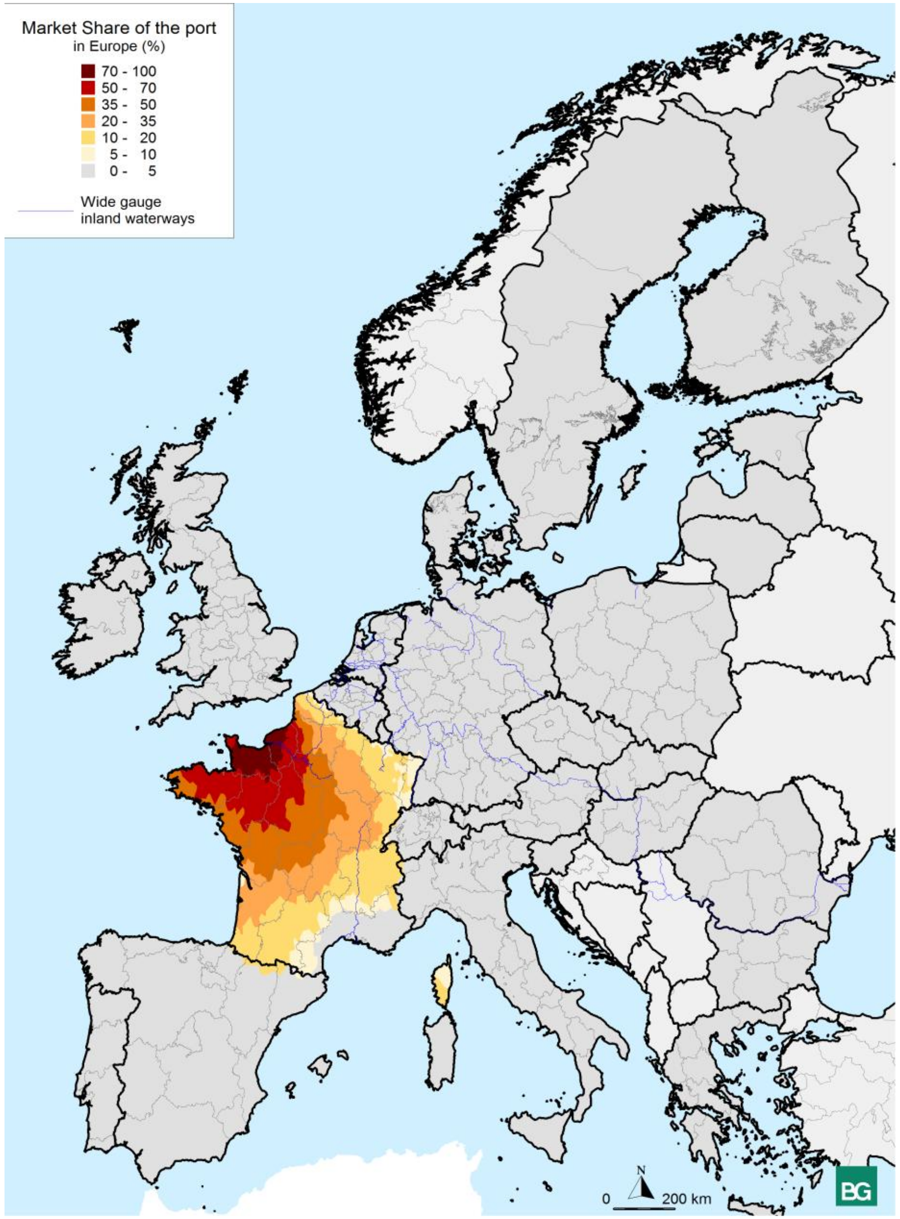


Figure 29: Market Share of the port of Antwerp (left) and Rotterdam (right) for the reference scenario in 2030



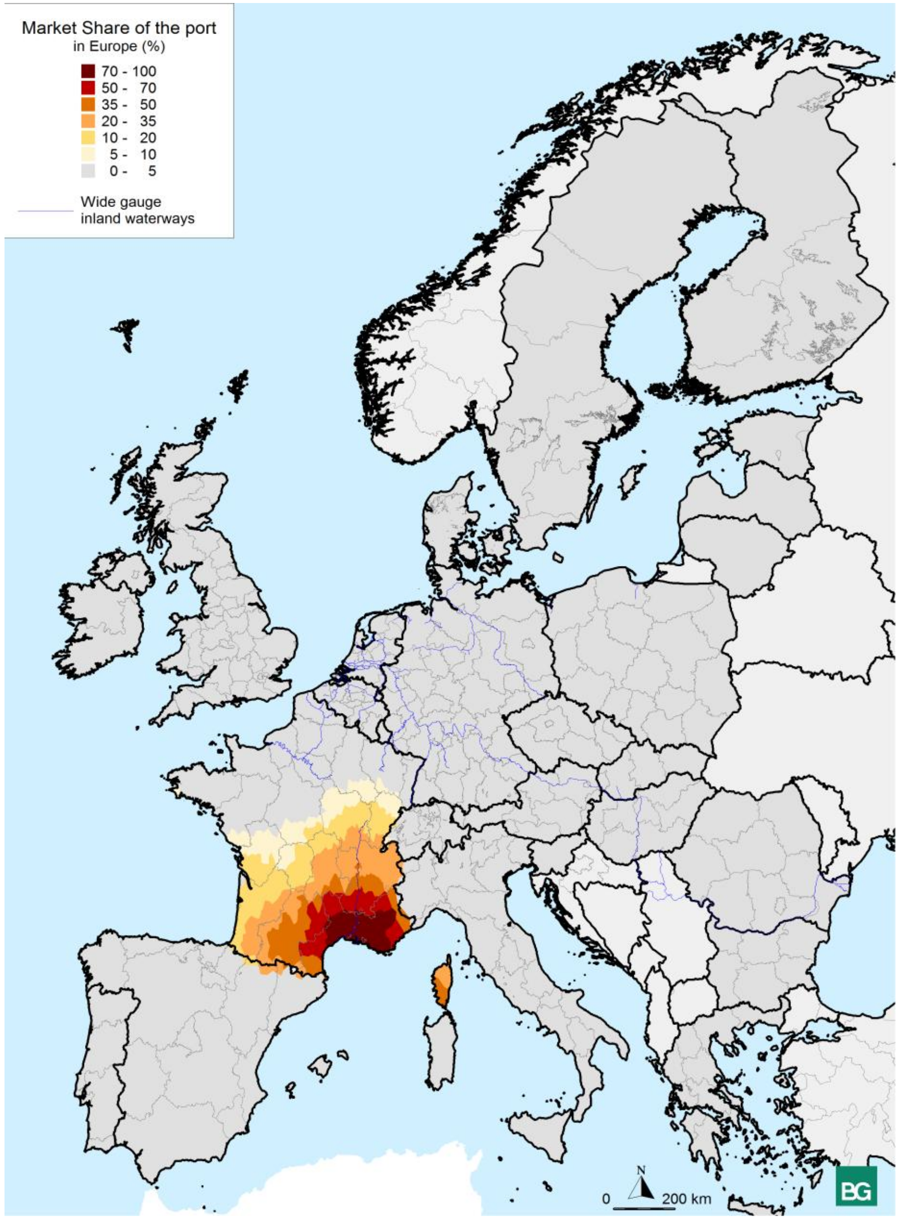
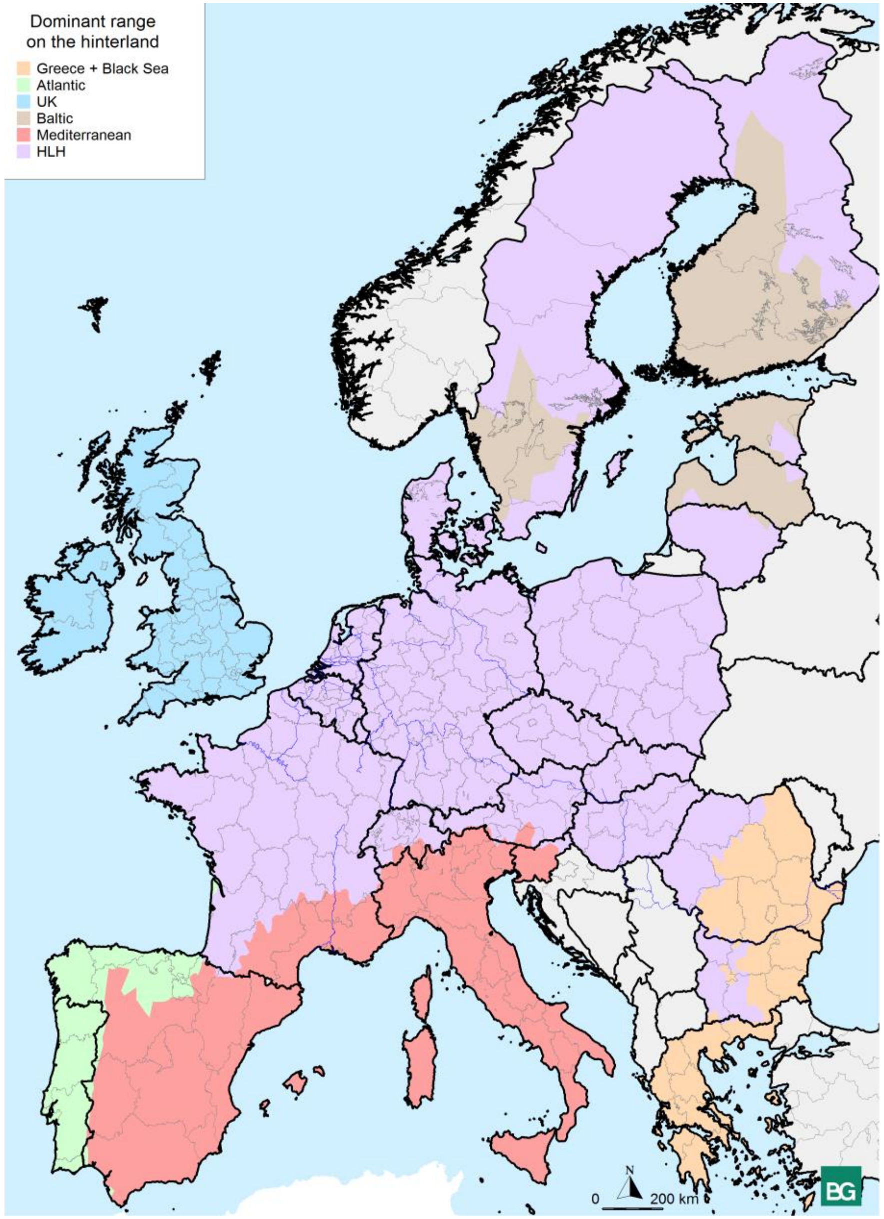


Figure 30 : Market Share of the port of Le Havre (left) and Marseille (right) for the reference scenario in 2030



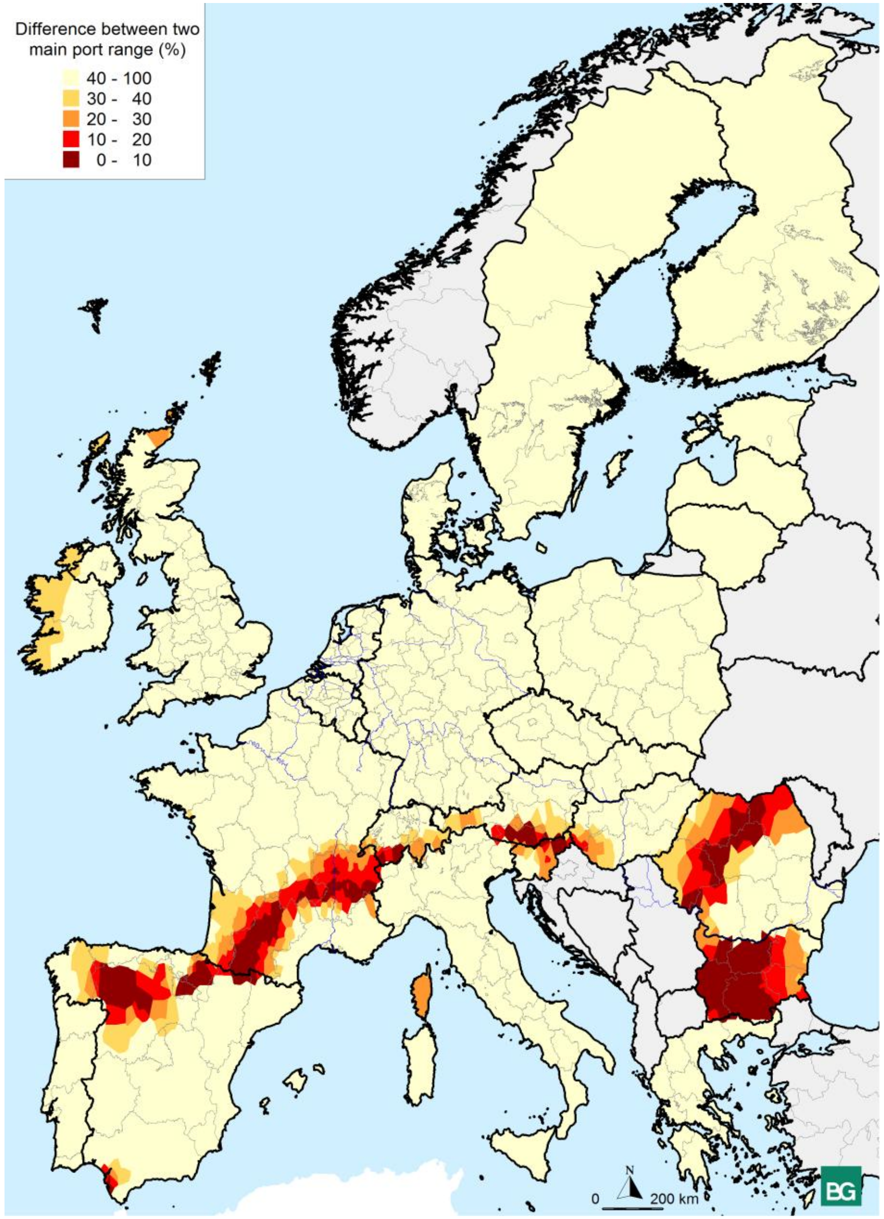


Figure 31 : Main port range in each hinterland region (left) and difference of market share between the two first range (right) for the reference scenario in 2030

8.1.4. Analysis of the modal share

After having analysed the hinterland of the port it is also interesting to have a look at the modal share. Modal spilt in freight transport is an important topic, as in the latest years the focus of the transport policies on sustainable and alternatives modes increases significantly. The planning of the construction of new canals, such as the Canal Seine North Europe and the SMSR canal are direct consequences of those policies. It is thus expected that the creation of the SMSR Canal will lead to a shift from the road to the IWW. To can determine if such a shift will occur, it is first necessary to analyse the modal share in the situation of reference, in the following table.

Table 28 : Modal share of each transport solution per port (grouped by country) in 2030

	Traffic in millions of tons(export+import all the maritime zones)					Modal Share in %			
Port	TOTAL	Road	Rail	IWW	IWW-Rail	Road	Rail	IWW	IWW-Rail
TOTAL 2007	**415.0**	**328.8**	**56.8**	**25.2**	**4.1**	**79.4%**	**13.5%**	**6.1%**	**1.0%**
TOTAL 2030	**800.2**	**577.2**	**134.4**	**75.2**	**13.4**	**72.1%**	**16.8%**	**9.4%**	**1.7%**
Baltic	42.0	41.2	0.8	0.0	0.0	98.1%	1.9%	0.0%	0.0%
UK & Irland	91.2	80.2	11.0	0.0	0.0	88.0%	12.0%	0.0%	0.0%
Germany	143.9	76.3	59.7	7.5	0.4	53.0%	41.5%	5.2%	0.3%
Hamburg	119.3	63.9	48.1	6.8	0.4	54%	40%	6%	0%
Netherlands	129.3	61.6	18.9	42.7	6.1	47.6%	14.7%	33.0%	4.7%
Rotterdam	124.5	57.4	18.9	42.2	5.9	46%	15%	34%	5%
Belgium	126.6	81.2	18.1	20.8	6.4	64.2%	14.3%	16.4%	5.1%
Antwerp	118.4	74.5	16.7	20.8	6.4	63%	14%	18%	5%
France	45.7	35.7	5.3	4.2	0.4	78.2%	11.7%	9.2%	0.9%
Le Havre	27.2	21.0	3.2	2.8	0.2	77.3%	11.7%	10.2%	0.9%
Marseille-Fos	13.2	9.5	2.1	1.4	0.1	72.2%	16.3%	10.5%	1.1%
Autres Fr	5.3	5.2	0.0	0.1	0.0	98.0%	0.3%	1.2%	0.5%
Iberia	95.0	84.6	10.3	0.0	0.1	89.0%	10.9%	0.0%	0.1%
Italy	81.5	71.7	9.7	0.0	0.0	88.1%	11.9%	0.0%	0.0%
Other Mediterranean	29.1	28.7	0.4	0.0	0.0	98.5%	1.5%	0.0%	0.0%
Black Sea	16.0	16.0	0.0	0.0	0.0	99.9%	0.1%	0.0%	0.0%

It can be observed that between the base scenario of 2007 and the reference scenario the share of the road decrease from 79.4 % to 72.1 % on the whole study area, whereas the share of all the three others transport chains increased, from 13.5 to 16.8 % for the rail, from 6.1 to 9.4 % for the IWW and from 1 to 1.7 % for the bi modal.

The decrease of the market shares of the road can be explained by the significant increase of the road costs[33], and to the gain of market shares of the rail and IWW solutions, which are partly due to the development of new infrastructures and services and to the increase of 5 % of the speed in the whole European rail network. It can also be observed that with those assumptions the road market share of the Dutch ports falls below 50 %.

Finally, by focusing on France, it can be observed that the modal share of the road decreases from 86.2 % in 2007 to 78.2 % in 2030, the rail increases from 9.4 % to 11.7 %, and the IWW from 4.4 to 9.3 %. The increase of the modal share of the IWW is principally due to the creation of the SNE Canal. This is verified by the IWW modal share of the port of Le Havre that rises from 4.4 % to 10.2% between 2007 and 2030. The port of Antwerp also benefits a lot from the creation of the SNE canal, by seeing its IWW market share increase from 12 % to 18%.

8.1.5. Conclusion for the reference basic scenario in 2030

To conclude, with the reference basic scenario in 2030, it should be acknowledged that the changes of the market shares of the ports' ranges are mainly the consequence of the evolution of the GDP and the population at the horizon 2030 that have different growth rates depending of the European regions.

In addition, it has been seen that the creation of frequent IWW and rail services had influences on the market share of the ports in their hinterland. Indeed, in this scenario rail and IWW services have been created between the platforms of Salaise/Villefranche and the ports of Rotterdam and Fos-sur-Mer with a frequency of 1 train or barge per day (6 per week). The development of those services has lead to direct changes in the market share of those ports in the regions of those platforms. It should be added that in this scenario all the new services have been created with a frequency of 6 times a week. Such a frequency is quite high, and will probably not be the "real" frequency created at the implementation of the service. It will be interesting to see the influence of fewer services per week, in order to determine from which frequency significant changes in the hinterland can be observed.

From, this scenario it can also be concluded that if no significant changes are realized in the hinterland transport network, the areas in which each range is predominant (cf.Figure 31) do not change. Nevertheless, the creation of new services and of new infrastructures (SNE Canal) can have major impacts on the modal shares of the ports and can influence the market share locally, as outlined in the last section.

[33] The growth rate of all the component of the road costs can be found in Appendix 2: Description of the transport unit costs in 2007 and 2030.

8.2. The Saone Mosel Saone Rhine Basic scenario

After having analyzed the reference scenario, this section will now focus on the consequences of the major infrastructure scenario of this thesis, the SMSR scenario. One of the goals of this thesis is to analyze if only the development of new infrastructures and services in the hinterland could lead to a shift of market share between the ports of the HLH range and those of the Mediterranean and could influence the modal share. To reach this goal an analysis of the results of the model will be realized at different geographical scales: by starting at the global European scale, to then shrink up to the node level, with intermediate steps at the level of France and of the French regions.

8.2.1. Analysis of the market shares of the ranges in Europe

The output of the model highlight that there is almost no change regarding the market shares of the range in Europe, between the reference and the SMSR scenario in 2030. Indeed, the only changes concern the Mediterranean range that is winning 0.01 % of market share in Europe and the HLH range that is losing 0.01 %. This implies that the construction of this new canal in the hinterland is not able to lead to a shift of containers flows between the two port ranges. Nevertheless, it does not mean that the project has no influence at all in the hinterland of the ports. To see, the consequences of this project a zoom on the hinterland of the ports of the North Sea-Mediterranean corridor and on the modal share of the different transport solutions will be realized.

8.2.2. Analysis of the market shares of the ports in France

The SMSR canal will be constructed in France, it is thus expected that the main consequences of the construction of this canal will be observed in that country, explaining the focus on the French hinterland in this thesis. By looking at the evolution of the market shares of the European ports between the reference and the SMSR scenario it can be observed that the ports of the Netherlands are those that increase the most their market shares in France, with an increase of 0.57 %, followed by the port of Marseille with an increase of 0.09 %. In the other hand, all the other ports or grouped of ports see a decrease of their market shares. The reasons for the increase or decrease of the market shares of the ports in France will be provided in the following paragraph.

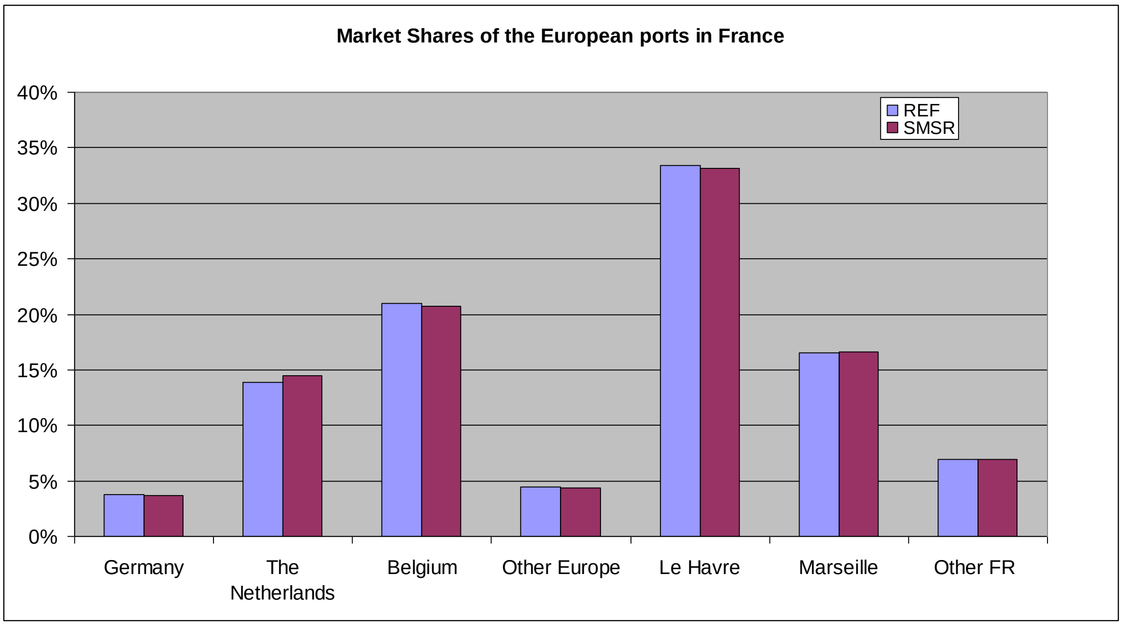


Figure 32: Market Share of the European ports in France for the reference and SMSR scenarios

8.2.3. Analysis of the hinterland of the major ports of the corridor

This paragraph will analyzed if the market shares of the ports on the hinterland, and more specifically on the North Sea-Mediterranean corridor, have undergone major modifications, due to the creation of the SMSR canal and the services that come with it. On the market shares' map of the port of Antwerp (Figure 33, left) it can be observed that the port of Antwerp is losing market shares on the regions Franche-Comté (-1%) and Bourgogne (-2%). This is a direct consequence of the creation of the SMSR Canal that allows the port of Marseille (Figure 34, right) to serve those regions by barge, making this port more competitive in those regions at the expense of the port of Antwerp. This is confirmed by the figure of the port of Marseille where it can be seen that the hinterland of this port extends in the regions Franche-Comté (+ 4%), Bourgogne (+ 2%), Alsace and Lorraine (+ 3%). On the other hand the reverse scenario is observed in the regions Midi-Pyrenees, PACA and Languedoc Roussillon, where the port of Antwerp is winning market share at the expense of the port of Marseille, due to the creation of the SMSR Canal and of new IWW services.

The port of Le Havre (Figure 34, left) is one of the ports that loses the most from the development of the SMSR canal. Indeed, it does not win any market share with the development of this canal, as it is not connected to it. And he loses market shares in the region Bourgogne (-3%), Franche-Comté, Auvergne and Rhône-Alpes (-1% for those three), due to the fact that those regions are now better accessible from the port of Marseille, Rotterdam and Antwerp, by sustainable modes. This is confirmed by the results of Table 29, where it can be observed that the ports of Le Havre see its containers exchange decrease or stagnate, in all the regions, with the exception of the region Alsace where the container trade increases of 1.6%.

With the creation of the canal the port of Rotterdam (Figure 33, right) is winning market share in France, in the region located along and south of the canal, that is to say in the regions Franche-Comté (+2%), Auvergne (+3%), in the north of the region Rhône-Alpes (+4%), and in the regions Languedoc Roussillon (+ 2%) and PACA. This can be explained by the fact that those regions are now directly accessible by barge from the port of Rotterdam thanks to the construction of the SMSR canal. And also because the platforms[34] that are located in those regions, now dispose from direct IWW services to the port of Rotterdam. Moreover, the distance from Rotterdam to those regions are long (over 900 km), so particularly adapted to IWW mode. The port of Rotterdam is nevertheless losing market share in the regions Lorraine and Alsace (-1%) due to the increase of the market share of the port of Marseille, in those regions.

Table 29 gives the relative evolutions, between the reference and the SMSR scenarios, of the container trade between specific ports and the French regions. Only the regions where a change of more than 0.05 %, was observed have been considered, and it has been found that 14 French regions out of 22 see their exchanges of container with the European ports modify due to the implementation of the canal. This table clearly highlights that the Dutch ports, are those that benefit the most at the scale of France, with an increase of 4.1 % of their exchange with the French regions, and Marseille come second with an increase of 0.6%. Nevertheless, Marseille is the port that gains the most in some specific regions, with an increase of 123%, of its containers exchanges with the region of Lorraine, and of 73.4 % with Alsace.

Table 29 : Relative evolution of the trade of containers between the French regions and the ports of interest between the basic reference and SMSR scenario

		Germany	Netherlands	Belgium	Other Europe	Le Havre	Marseille	Other France
	TOTAL	-2.8%	4.1%	-1.0%	-2.4%	-0.6%	0.6%	-0.4%
FR21	Champagne-Ardenne	-0.9%	-0.4%	-0.6%	-0.8%	-0.7%	**20.1%**	-0.6%
FR24	Centre	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	2.1%	-0.1%
FR26	Bourgogne	-11.7%	**24.2%**	-6.8%	-13.6%	-9.6%	**13.7%**	-8.9%
FR41	Lorraine	-3.7%	-2.6%	-3.6%	-4.0%	-3.1%	**122.7%**	-3.5%
FR42	Alsace	-3.1%	-2.8%	-3.0%	-3.0%	1.6%	**73.4%**	-2.8%
FR43	Franche-Comté	**-17.4%**	8.4%	-8.4%	**-15.2%**	-6.1%	**35.2%**	**-15.2%**
FR62	Midi-Pyrénées	0.0%	0.7%	0.0%	-0.1%	-0.1%	-0.1%	0.0%
FR63	Limousin	-0.1%	0.6%	-0.1%	-0.1%	-0.1%	-0.2%	-0.1%
FR71	Rhône-Alpes	-7.0%	**27.3%**	-6.2%	-6.8%	-7.2%	-1.5%	-6.8%
FR72	Auvergne	-3.1%	**18.6%**	-2.7%	-3.3%	-3.3%	-2.9%	-2.8%
FR81	Languedoc-Roussillon	2.2%	**29.2%**	2.8%	-1.0%	-1.4%	-1.5%	-1.1%
FR82	PACA	0.5%	**43.9%**	1.3%	-1.3%	-1.5%	-1.1%	-1.6%
FR83	Corse	-1.4%	**13.7%**	-1.5%	-1.1%	-1.6%	-1.6%	-1.6%

In addition, by comparing the location of the contestable hinterland line between the reference and the SMSR scenario (cf. Figure 31 : Main port range in each hinterland region (left) and difference of market share between the two first range (right) for the reference scenario in 2030 and Figure 35: Contestable hinterland defined by the difference of market share between the two main ranges for the SMSR scenario in 2030), it seems that the only main difference observed is at the north of Lyon, where the Mediterranean range is taking market share back to the HLH range, due to the fact that in the SMSR scenario three layers barges can navigate in and above Lyon. It thus seems that even if the project has effects on the hinterland it does not lead to significant changes regarding the dominancy of the range in the region.

[34] Pagny, Macon, Chalon sur Saone, Salaize, Lyon, Villefranche)

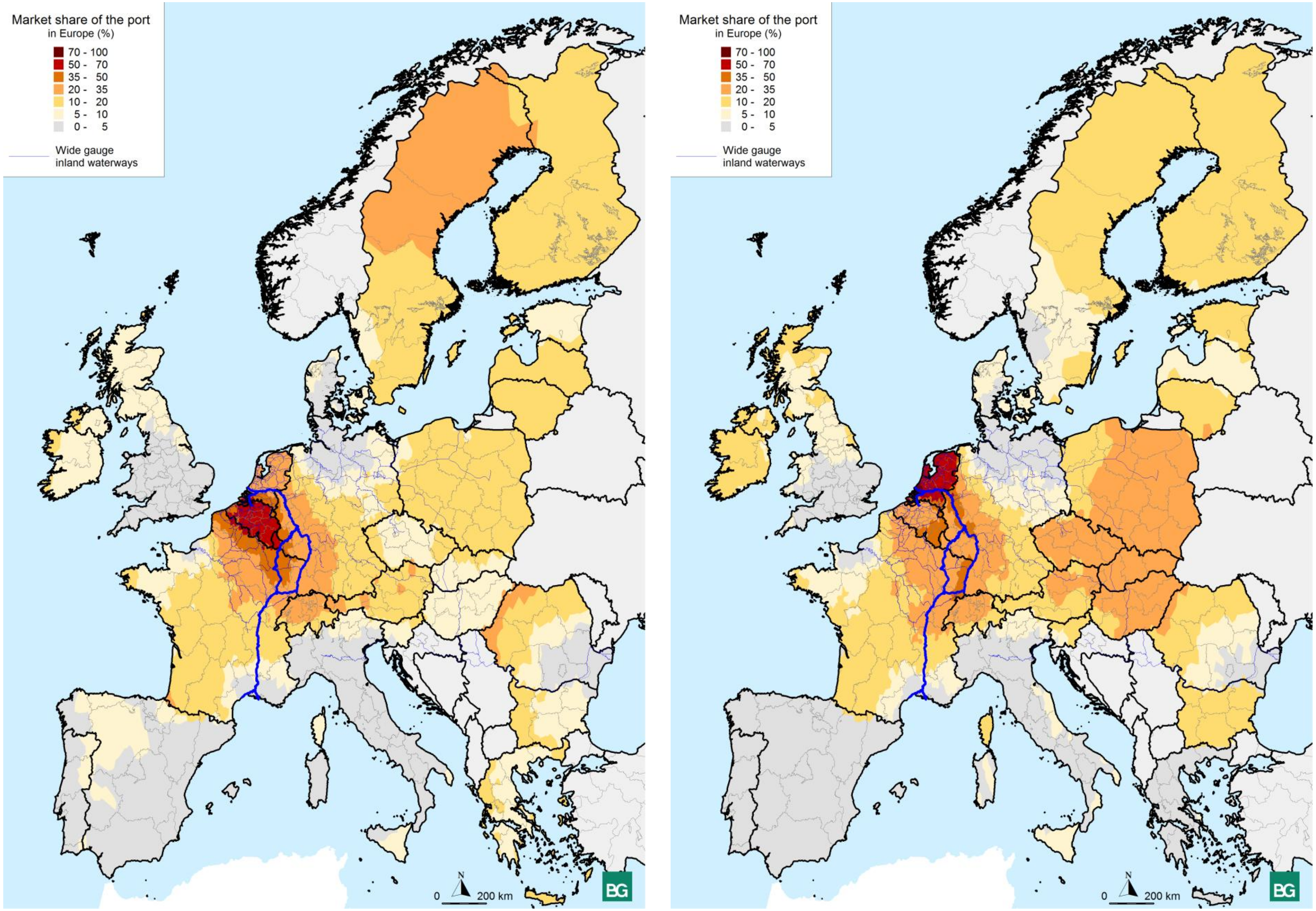


Figure 33: Market Share of the port of Antwerp (left) and Rotterdam (right) for the SMSR scenario in 2030

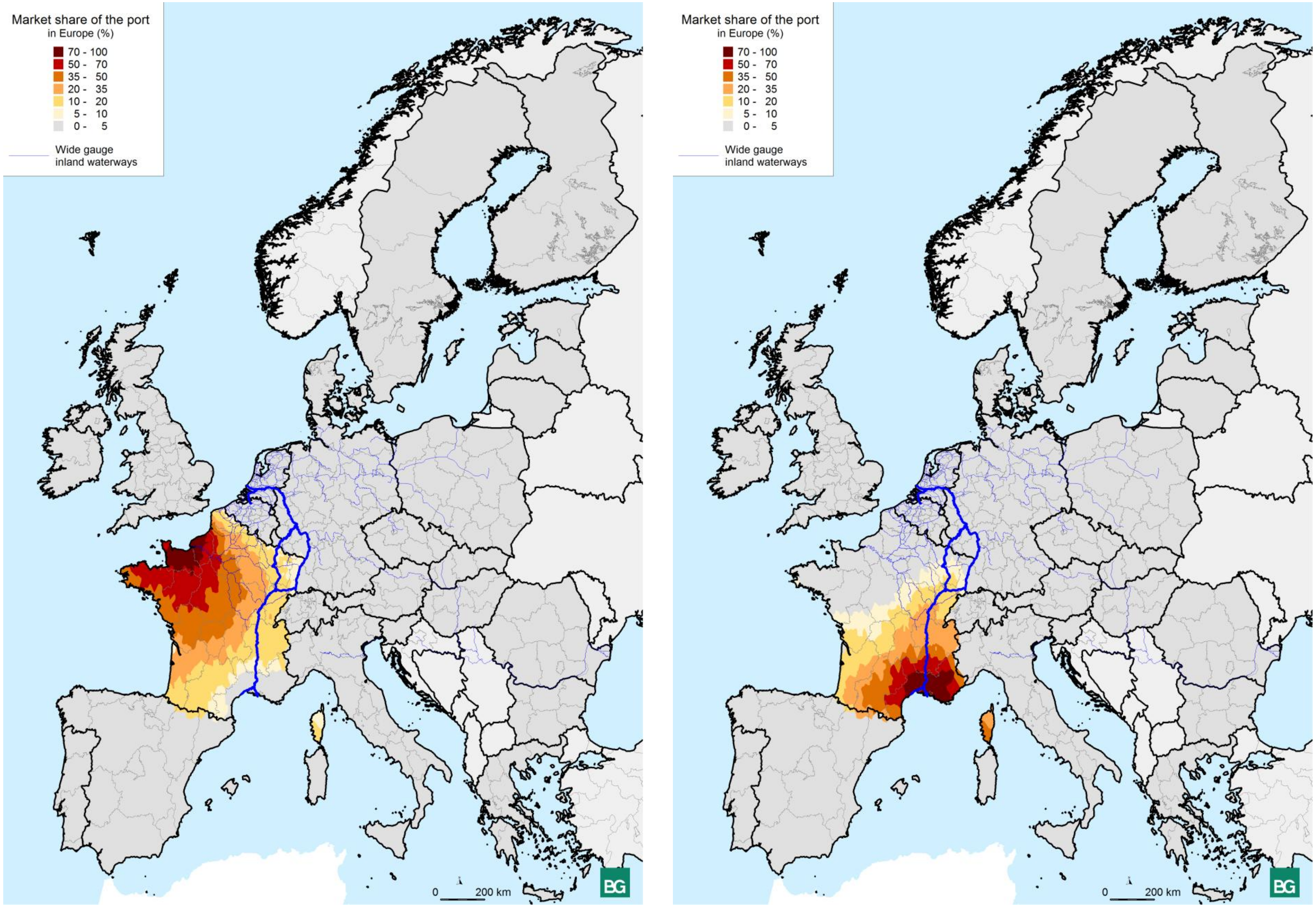


Figure 34: Market Share of the port of Le Havre (left) and Marseille (right) for the SMSR scenario in 2030

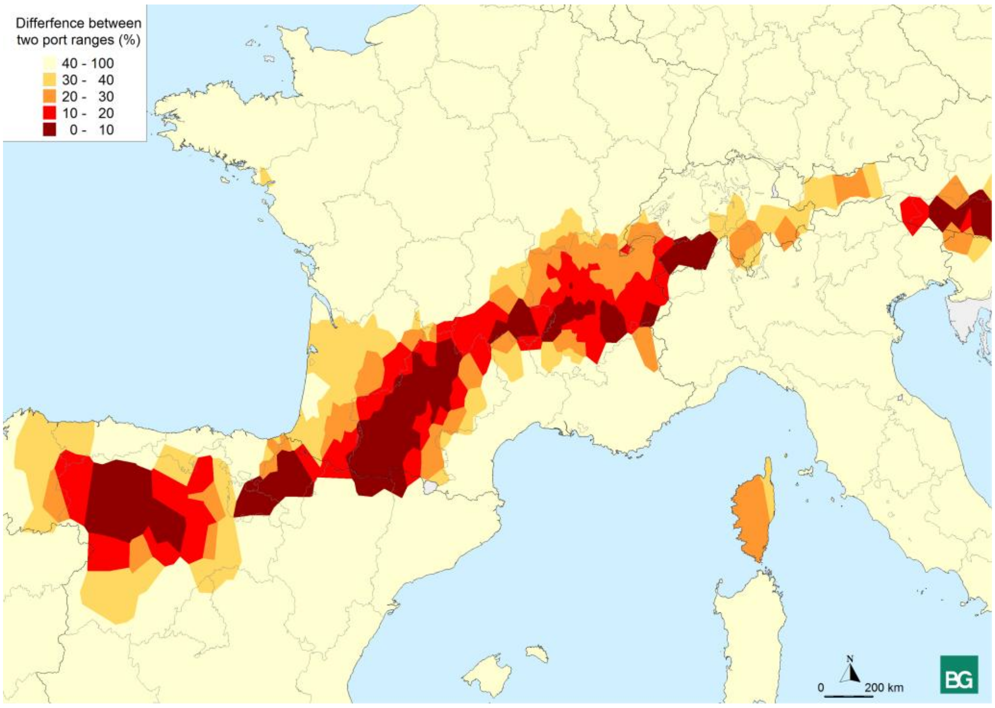


Figure 35: Contestable hinterland defined by the difference of market share between the two main ranges for the SMSR scenario in 2030

After having analysed the consequences of the implementation of the canal at the scale of the French regions, the impacts at the node level will now be considered. To do so, the tons of containers win or lost by the ports of the HLH and Mediterranean ranges will be determined at the node level in Figure 36. It can be seen that the two figures are quasi symmetric meaning that almost all the tons win by one of this two ranges due to the creation of the canal are lost by the other one. This phenomenon of symmetry is highlighted in the table below, that also shows that the project is more profitable to the ports of the Mediterranean range that gained 87 768 tons of containers than to those of the HLH range that lose 65 830 tons.

Table 30: Tons Difference between the reference and SMSR scenario in 2030 for both ranges in the whole Europe

	HLH	Mediterranean	Other ranges
Win	204 063	281 506	3
Loss	-269 893	-193 737	-21 938
Total	-65 830	87 768	-21 935

It can also be observed that as expected in the SMSR scenario, the HLH range is winning market share on the regions situated south of the canal, on the Rotterdam-Marseille axe, and the ports of the South range are winning market share on the regions situated north of the canal, which is consistent with the results of Table 29. There is thus a kind of compensation between the ports of the HLH range and those of the Mediterranean, meaning that both ranges extend their hinterland by winning market shares in regions where they were not preponderant before the construction of the canal, but in another hand they also lose market share in areas in which they were dominant before the construction of this canal.

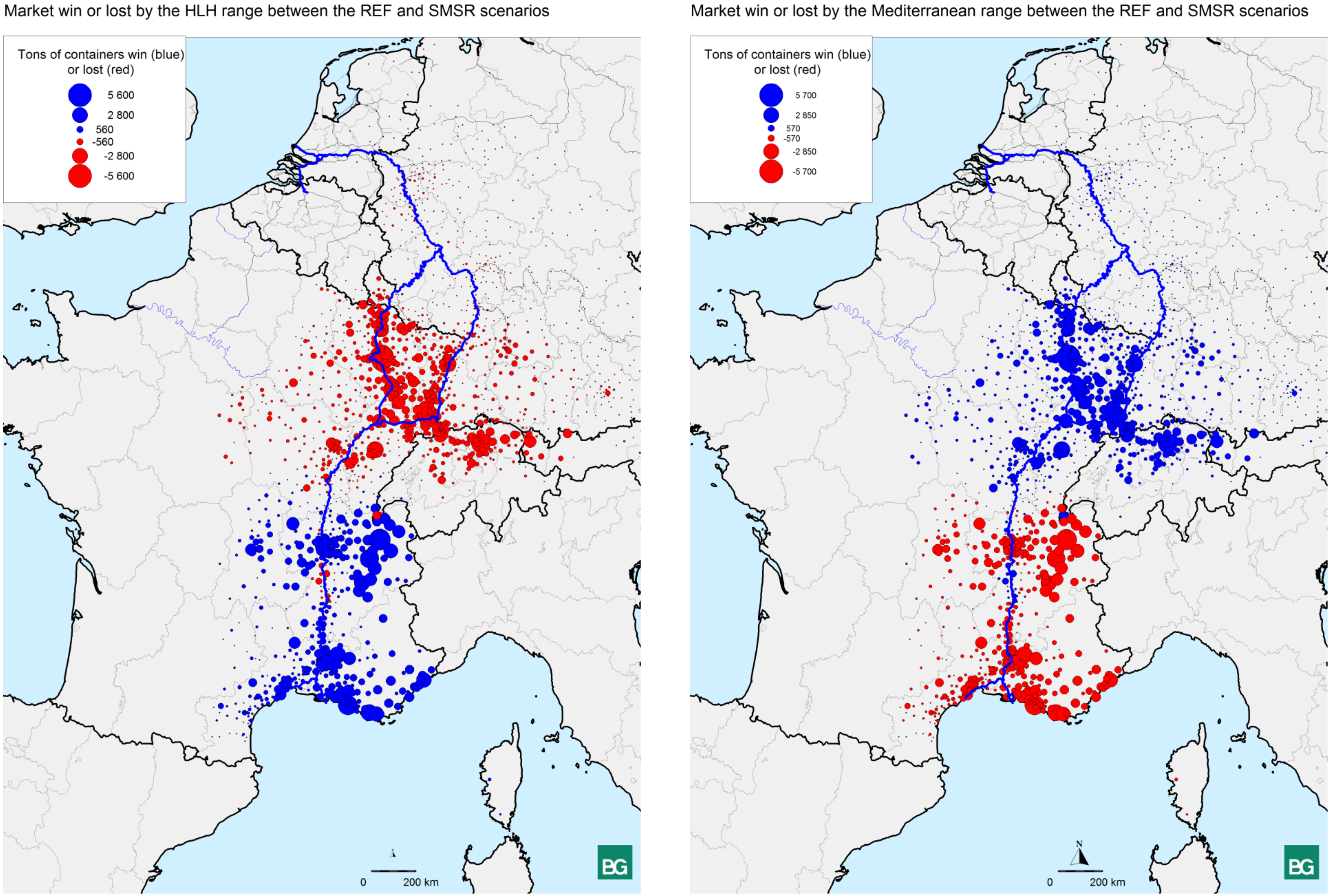


Figure 36 : Market win and lost by the HLH (left) and Mediterranean (right) ranges

8.2.4. Analysis of the modal share after the implementation of the SMSR Canal

After having analysed the hinterland of the ports, a look will be given to the modal share. With the creation of this missing link, the SMSR canal, in the European inland waterway network, it is expected that the modal share of this mode will increase, at the expense of the road mode. This section will demonstrate that is not what happens. To analyse the modal share of the different transport solutions in the case of the SMSR scenario, several tables and figures will be used. First, **Error! Reference source not found.**Table 31 to Table 34, highlight the gains and losses of modal share of each transport solution for some origin-destination couples[35], and Figure 37 represents the difference of traffic between the reference and SMSR scenarios for the rail and IWW solutions[36].

First, it can be observed that the construction of the SMSR canal has **positive effects on the development of the multimodal transport chains including the inland waterway mode,** as at the scale of Europe the modal share of the IWW solutions increase by 3 % and the one of the IWW + Rail solutions of 2 %. Those modal shares rises at the scale of Europe are mainly due to large increases of the modal shares of those intermodal solutions on some specific port-hinterland relations, on the Rhine-Rhone axe. Indeed, significant increase of the IWW modal share is observed for the relations between the port of Marseille and the regions situated north of the canal (Alsace, Lorraine, Franche-Comté, Bourgogne, Benelux, Germany & Switzerland). The same holds from the ports of Antwerp and Rotterdam to the regions situated south of the canal or along the canal (PACA, Rhône-Alpes (RA), Bourgogne and Franche-Comté). In the two previous cases, the gains of market shares of the IWW solutions are realized at the expense mainly of the rail and IWW+rail solutions, and not at the expense of the road as it was expected. For instance, for the relations between the port of Marseille and the German hinterlands, the rail has lost 60 % of market share between the reference and the SMSR scenario. For the IWW solutions, it can also be highlighted that more traffic is gained by the Rhine than by the Mosel between the reference and SMSR scenarios (cf.Figure 37), due to the better conditions of navigation on the Rhine and the higher possibility to consolidate the traffic.

Secondly, for the IWW+Rail solutions the gains of traffic are mainly observed from the German ports with an increase of 50% of this modal share at the port. This considerable increase can be explained by the fact that containers are first shipped by rail, to platforms such as Duisburg and Ludwigshafen, and are then shipped by barge to France, thanks to the creation of the SMSR canal. This explanation is confirmed by the results of Table 32, where it can be observed that the increase of the IWW+Rail modal share mainly concerned the relations between the ports of Hamburg and Bremerhaven, toward the French regions of PACA, Rhône-Alpes and Bourgogne. The same is observed for shipments between the ports of Barcelona and Valencia and the regions Alsace/Lorraine and Germany, with a transhipment from rail to IWW at the platform of Avignon. This high increase of the modal share of the IWW+Rail transport chain highlights that trimodal solutions might be cheaper and more advantageous than simple rail solution, meaning that the additional transhipment might not be such a big barrier in the shipment of goods. It should nevertheless be acknowledged that in the preference of the shippers has not been taken into account, and that by introducing this parameter in the model the modal share of the IWW+Rail solutions might not be so high.

[35] Table 66 highlights the evolution of the modal share at the scale of Europe and of the ports (that are grouped by countries) between the reference and the SMSR scenario, in Appendix 11.
[36] The figure related to the road mode can be found in Appendix 11.

Table 31 : Difference of IWW modal share between the SMSR/REF scenario scenario

Modal share in %	Marseille-Fos	Barcelone-Valence	Genova	Le Havre	Anvers + Zeebrugge	Rotterdam + Amsterdam	Hambourg + Bremerhaven
PACA-LR	0%	0%	0%	0%	27%	68%	0%
RA	9%	0%	0%	0%	22%	59%	0%
Bourgogne	26%	0%	0%	0%	16%	21%	0%
Franche-Comté	44%	0%	0%	-2%	12%	-2%	0%
Suisse	35%	0%	0%	-1%	-1%	-1%	0%
Alsace	69%	0%	0%	-1%	0%	0%	0%
Lorraine	58%	0%	0%	0%	1%	3%	0%
Champagne-Ardennes	30%	0%	0%	0%	0%	1%	0%
Benelux	56%	0%	0%	0%	0%	0%	0%
DE	69%	0%	0%	0%	0%	0%	0%

Table 32 : Difference of IWW+ Rail modal share between the SMSR/REF

Champagne-Ardennes	Marseille-Fos	Barcelone-Valence	Genova	Le Havre	Anvers + Zeebrugge	Rotterdam + Amsterdam	Hambourg + Bremerhaven
PACA-LR	0%	0%	0%	2%	-2%	-23%	25%
RA	0%	0%	0%	2%	1%	-12%	26%
Bourgogne	0%	6%	0%	0%	1%	-1%	17%
Franche-Comté	0%	5%	0%	1%	0%	-1%	7%
Suisse	-6%	12%	0%	10%	0%	0%	0%
Alsace	-7%	27%	0%	3%	0%	0%	0%
Lorraine	-3%	17%	0%	1%	0%	0%	0%
Champagne-Ardennes	-1%	5%	0%	0%	0%	0%	1%
Benelux	-6%	2%	0%	0%	0%	0%	0%
DE	-5%	11%	0%	1%	0%	0%	0%

Table 33 : Difference of Road Market Share between SMSR/REF scenario

Modal share in %	Marseille-Fos	Barcelone-Valence	Genova	Le Havre	Anvers + Zeebrugge	Rotterdam + Amsterdam	Hambourg + Bremerhaven
PACA-LR	0%	0%	0%	-1%	-2%	-7%	-2%
RA	-6%	0%	1%	-1%	-2%	-7%	-4%
Bourgogne	-19%	0%	0%	1%	-16%	-20%	-5%
Franche-Comté	-35%	-1%	-1%	-19%	-29%	-6%	-1%
Suisse	-15%	-1%	0%	-4%	0%	0%	0%
Alsace	-11%	-4%	0%	-3%	0%	0%	0%
Lorraine	-28%	-2%	-1%	-4%	-1%	-3%	0%
Champagne-Ardennes	-15%	-1%	0%	0%	0%	-2%	-1%
Benelux	-5%	0%	0%	0%	0%	0%	0%
DE	-5%	0%	0%	0%	0%	0%	0%

Table 34 : Difference of Rail Market Share between SMSR/REF scenario

Modal share in %	Marseille-Fos	Barcelone-Valence	Genova	Le Havre	Anvers + Zeebrugge	Rotterdam + Amsterdam	Hambourg + Bremerhaven
PACA-LR	0%	0%	0%	-1%	-23%	-38%	-23%
RA	-2%	-1%	-1%	-1%	-21%	-40%	-22%
Bourgogne	-7%	-5%	0%	-1%	-2%	1%	-12%
Franche-Comté	-9%	-4%	1%	21%	17%	9%	-6%
Suisse	-14%	-11%	0%	-4%	1%	1%	0%
Alsace	-50%	-23%	0%	1%	0%	0%	0%
Lorraine	-27%	-15%	0%	4%	0%	0%	0%
Champagne-Ardennes	-14%	-4%	0%	0%	0%	1%	-1%
Benelux	-44%	-2%	0%	0%	0%	0%	0%
DE	-60%	-11%	0%	-1%	0%	0%	0%

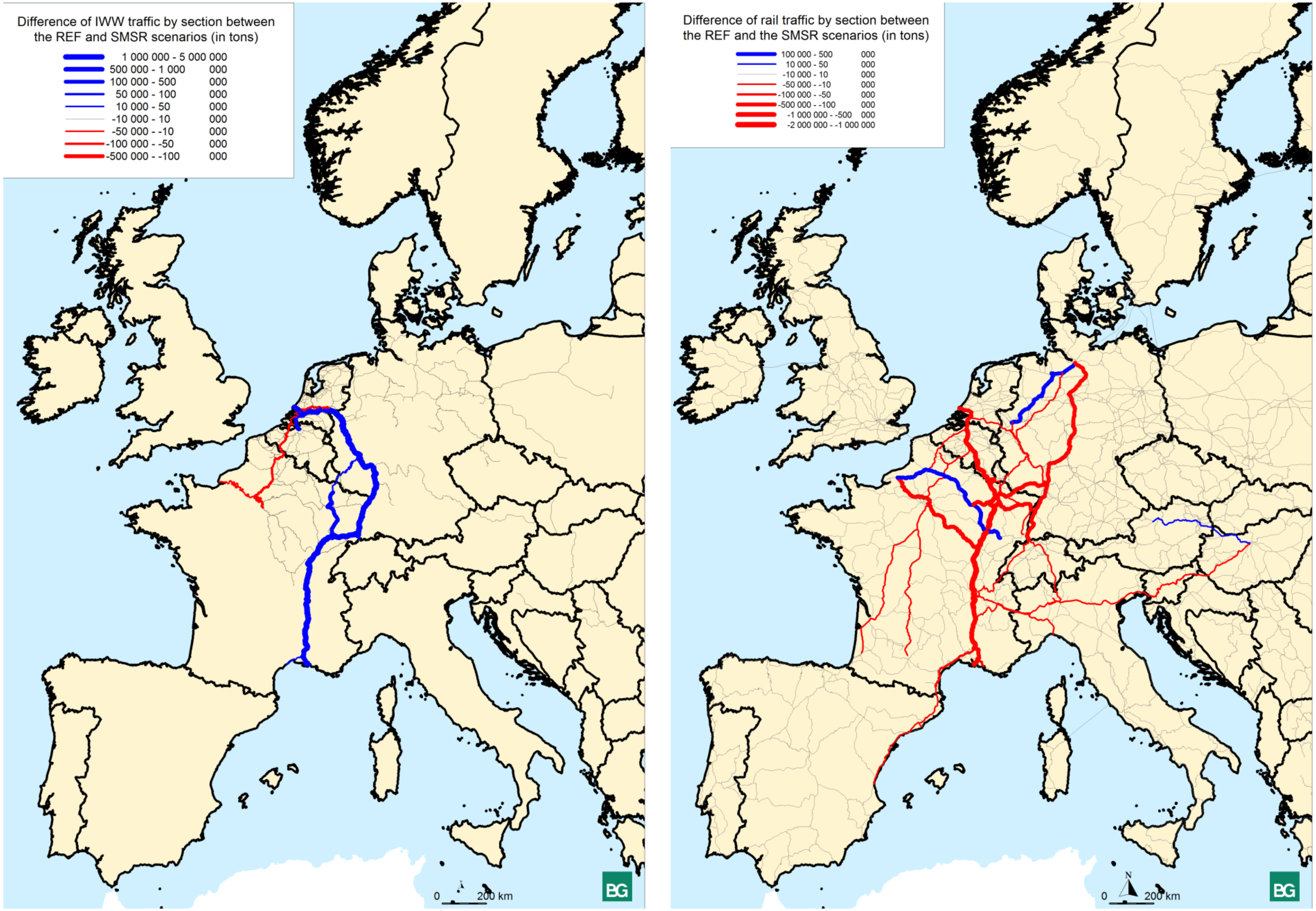


Figure 37: Difference of IWW and rail traffic between the Reference and SMSR Scenarios in 2030 (With bimodal solutions)

With regard to the road mode the main reduction of road's market share is observed at the port of Marseille, for the short and medium distances (until Bourgogne). This is quite logical because nowadays the port of Marseille is the one, from those located on the Rhine-Rhone axes, having the highest road share. Nevertheless, it should be noticed that the global reduction of road traffic between the reference and the SMSR scenario is almost insignificant. Indeed, even after the creation of the SMSR canal the road is still the main mode of transportation in Europe for the hinterland shipment of containers, with a modal share of 72 % in Europe.

8.2.5. Conclusion

This chapter has showed that with the construction of the SMSR canal major shifts of container are not observed from the HLH range toward the Mediterranean range. Indeed, it has been demonstrated that no change in the market share of the port ranges was observed at the scale of Europe. Nevertheless, impacts are observed at a smaller scale, the scale of the North Sea-Mediterranean corridor and more precisely at the level of the French region located along this corridor. The main results are that two ports benefits from the opening of this canal in their exchange with the French regions, the Dutch ports and the port of Marseille, the first one winning market share in region situated south of the canal, and the second one in region situated north of the canal.

From a modal share point of view the result are quite disappointing, because most of the modal share win by the IWW are taken from the rail and not from the road. The only regions that see their road modal share decreased significantly are the regions Bourgogne and Franche-Comté because there were no rail services in those regions, so the IWW is only in concurrence with road.

8.3. Decrease of the border effects scenario

In this section the organizational scenario related to the reduction of the border effects, will be analyzed. The description of this scenario has been provided in Chapter 7.

8.3.1. The reference scenario

First, the reference infrastructural scenario with the reduction of the border effects will be studied. To do so, the same process as in the preceding chapter will be applied.

8.3.1.1. Analysis of the market shares of the port ranges in Europe

With the reduction of the border effects it is the range that contains the major ports, the HLH range, that see its market share increases up to 54.7 % (+1.9%) between the basic reference scenario and the reference scenario with reduction of the border effects in 2030. This can be explained by the fact that those major ports are those that benefit the most from the reduction of the border effects, due to their high attractiveness and thus their higher weight in the gravity model of the distribution module. All the other port ranges have their port throughputs that decrease with this reduction of the border effects; notably the Mediterranean range that has its market share that decrease of 0.31 %. This is due to the fact that those ranges gather only small ports that struggle to exist with the competition of the major European ports.

8.3.1.2. Analysis of the market share of the European ports in France for the reference scenario with reduction of the border effects

At the scale of France, the major European ports (Belgium, Netherlands and Germany) are again those that benefit the most from the reduction of the border effects, as they have more traffic to spread in the hinterland of their neighbouring countries. On the other hand, the port of Le Havre is the one dealing with the major reduction of market share in France (from 34% to 25 %), mainly because of a significant decrease of it captive hinterland (cf. Figure 40).

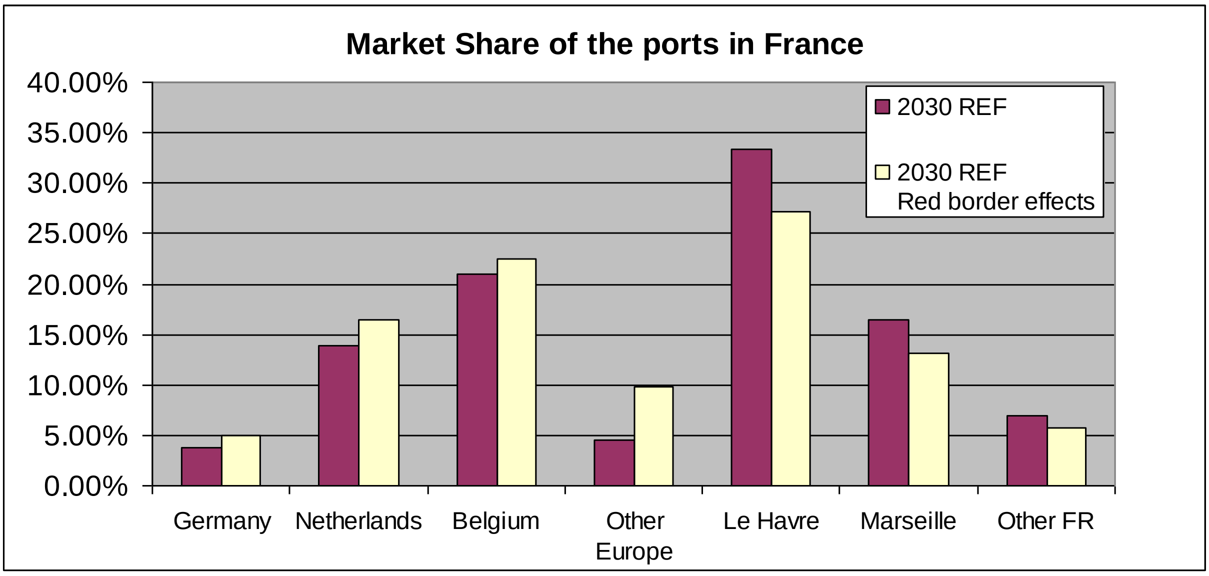


Figure 38: Market Share of the ports in France

8.3.1.3. Analysis of the hinterland of the ports with the reduction of the border effects

In this section the hinterland of the ports of Antwerp, Rotterdam, Le Havre and Marseille are studied. With the reduction of the border effect the port of Antwerp is losing market share in Belgium (from 67% to 66%) and in the French regions Lorraine, Alsace, and Franche-Comté, but on the other hand it is winning market share in Spain and in the all the other French regions. The explanation for those gains and losses of market shares are quite simple. In all the regions in which the port of Antwerp is in competition with the port of Rotterdam, the first one is losing market share, whereas in the regions where it is in competition with smaller ports, the port of Antwerp is winning market share.

With the preceding statement, it is not surprising to observe that the port of Rotterdam is winning market shares in Belgium, along the Rhine in Germany, and in all the French regions. Indeed, this is due to the fact that the port of Rotterdam is the main port in Europe, and thus the one that gains the most from the reduction of the border effects. With the same reasoning the losses of market share of the port of Le Havre in France can be explained by the fact that this port is a port belonging to the "range" range[37], and is really nearby ports belonging to the "world" range that “steal” its market share in France. Nevertheless, Le Havre still remains the main port in France, with a market share of 27 % in the case of the reduction of the border effect, against a market share of 33% in the reference scenario.

[37] The classification of the ranges can be found in Appendix 5.

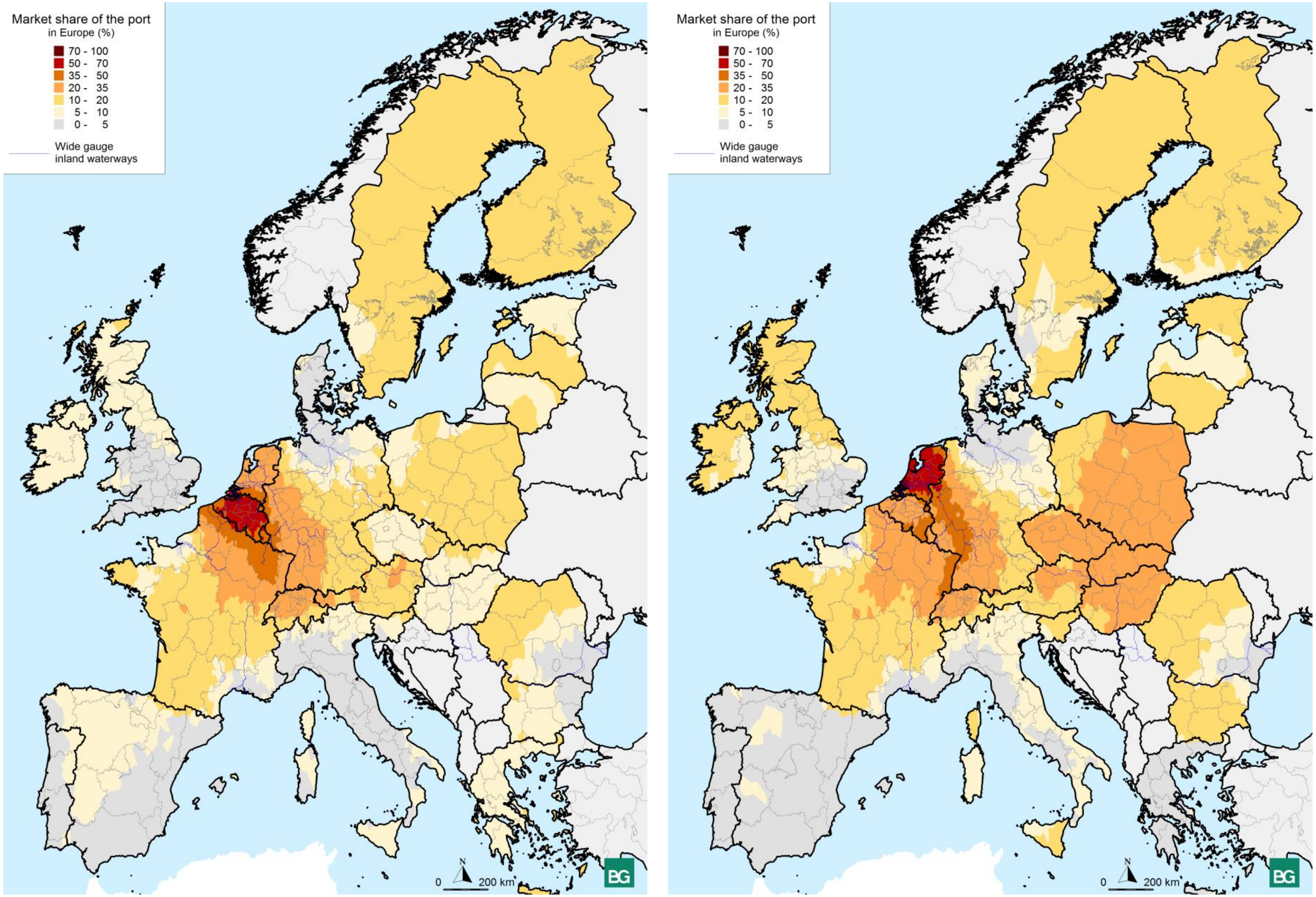
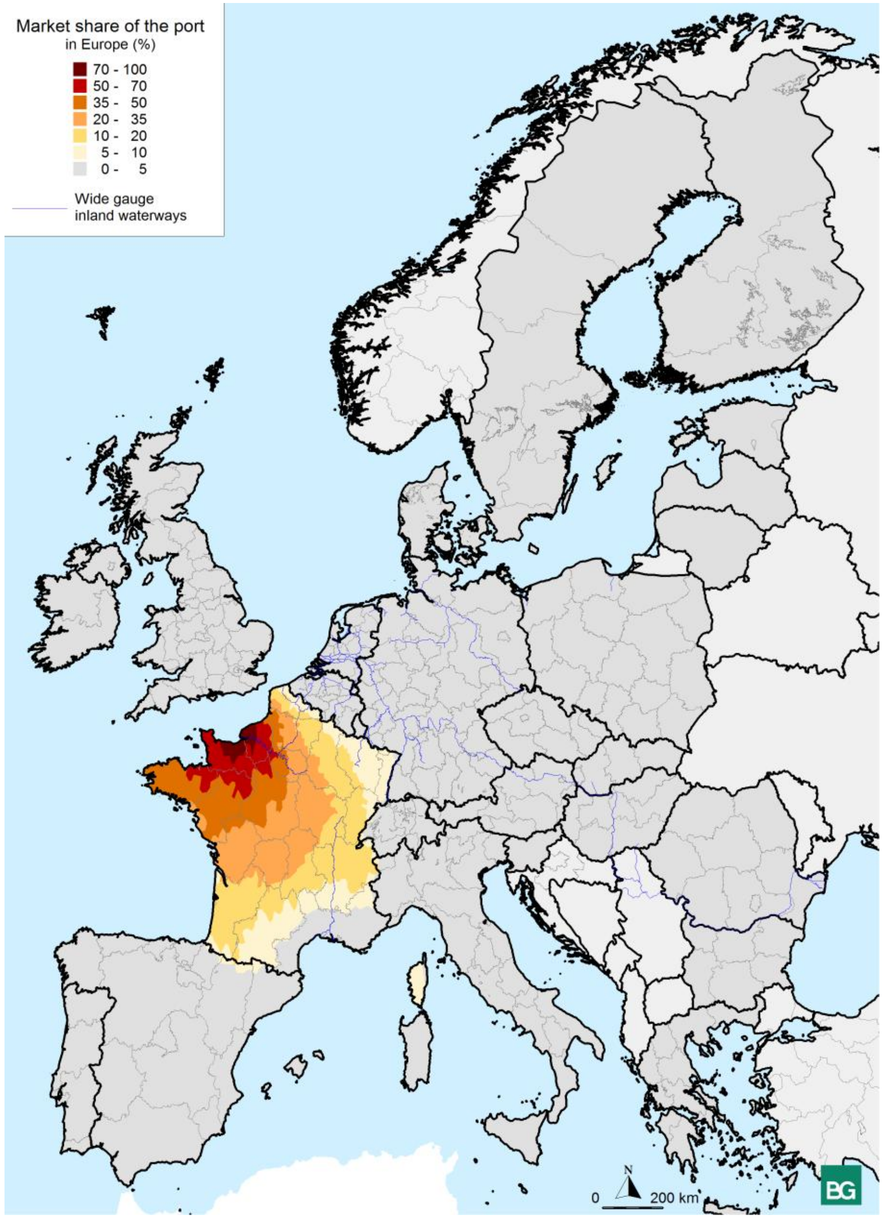


Figure 39: Market Share of the port of Antwerp (left) and Rotterdam (right) for the reference scenario in 2030 with reduction of border effects



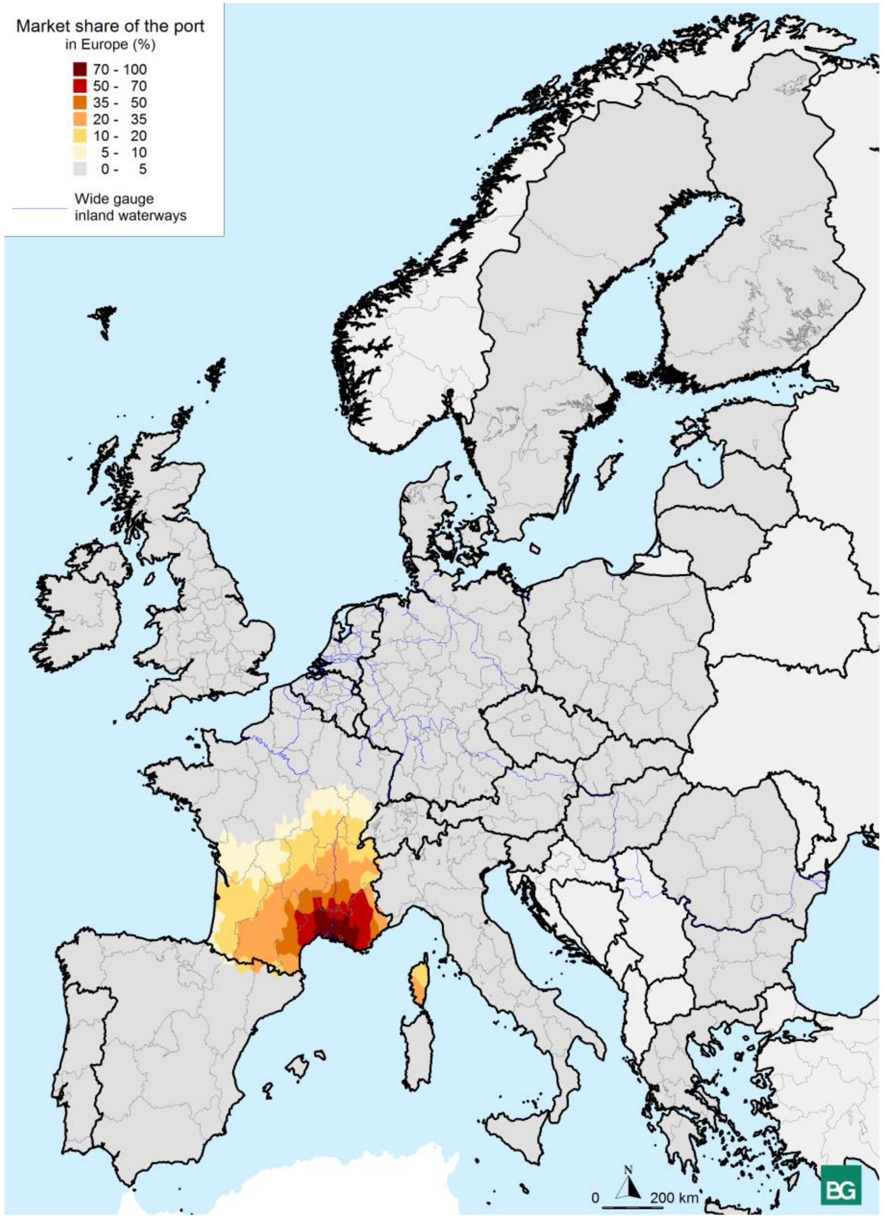


Figure 40 : Market Share of the port of Le Havre (left) and Marseille (right) for the SMSR scenario in 2030 with reduction fo the border effects

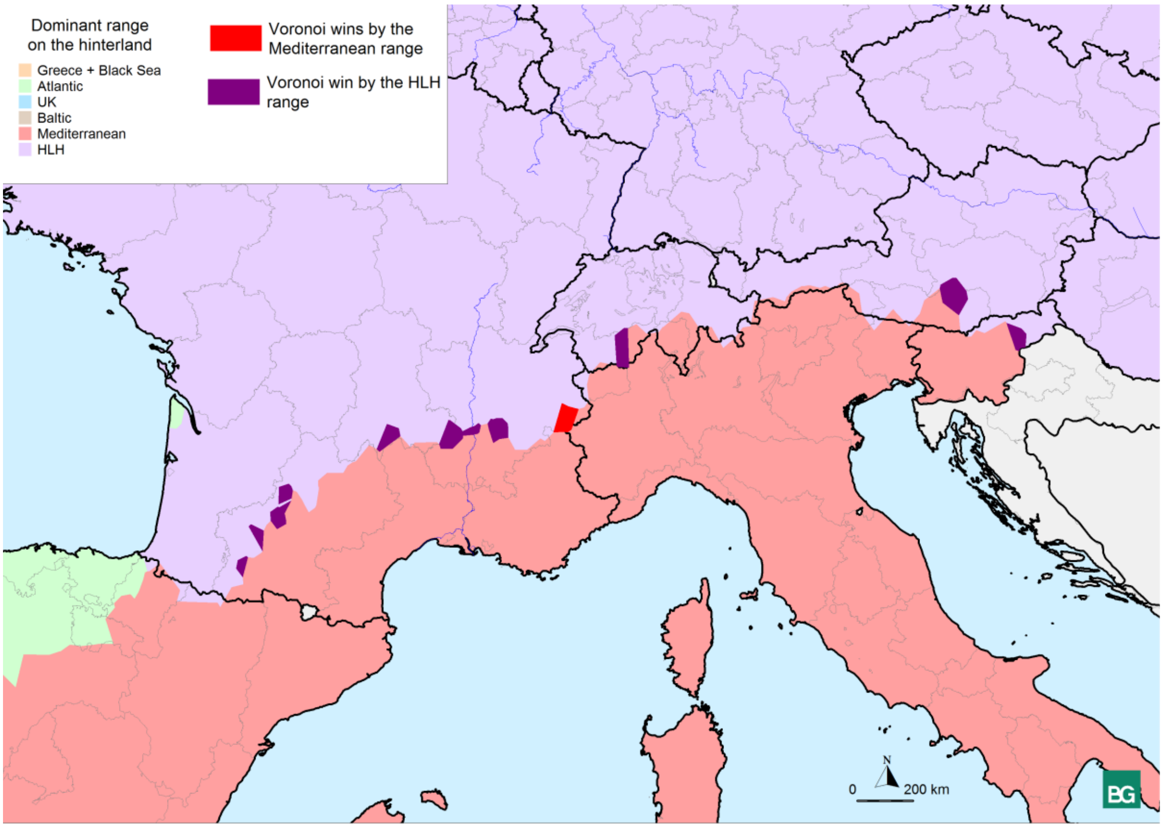


Figure 41: Voronoi zones win by the Mediterranean and HLH ranges

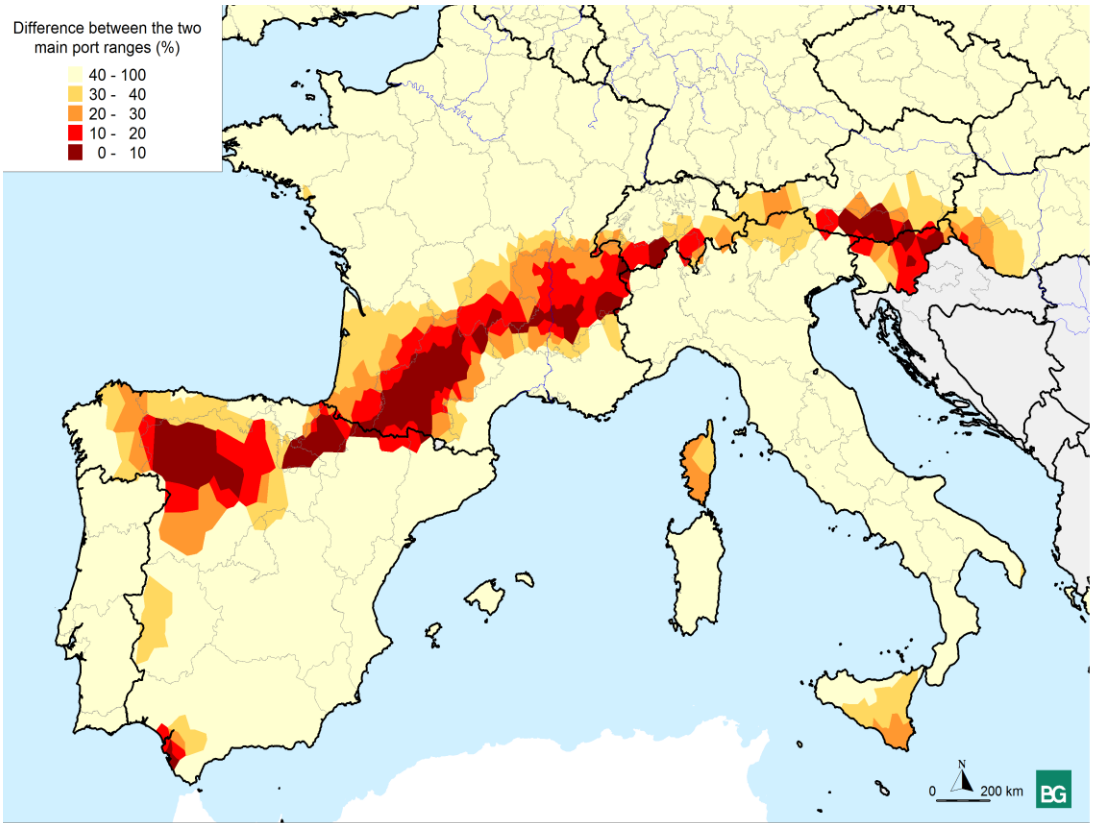


Figure 42: Difference between the two first port ranges for the reference scenario 2030 with reduction of the border effect

With the decrease of the border effect, the port of Marseille sees a reduction of its captive hinterland. Indeed, the zone in which it has a market share above 35% decreases significantly, that is to say in the region PACA, Languedoc-Roussillon, Auvergne, Rhône-Alpes, Midi-Pyrénées and Aquitaine. At a larger scale, the port of Marseille is losing market share in almost all the regions in France, explaining it decreases of market share in France from 16 to 13% with the reduction of the border effects.

After having analysing the market share of each port, and each port range, it seems interesting to have a look at the location of the contestable hinterland line. It can be seen in Figure 42 that the contestable hinterland line get thicker between the reference and the reference with reduction of the border effects scenarios. Indeed, this line is now located on the whole region Rhône-Alpes, and gets thicker in the region Auvergne and Aquitaine. In the region Rhône-Alpes it extends to the South mainly along the Rhone, highlighting that ports of the HLH range are taking market share to the ports of the Mediterranean range. This gain of the HLH+Baltic range on the Mediterranenan+Greece+Black Sea range can also be observed at the borders Austria-Italy and Austria-Slovenia.

Finally, by focusing at the voronoi zones that see their first range change between the reference and reference without border effects scenarios, it can be seen that 16 voronoi zones have their first range that shift from the Mediterranean to the HLH range, whereas only two zones are win by the Mediterranean range on the HLH range. This again highlights that the HLH range is winning market share on the Mediterranean range, with the reduction of the border effects.

8.3.1.4. Analysis of the modal share of the reference scenario with reduction of the border effects

With the reduction of the border effect, it is expected that the modal share will not change that much with regard to the reference scenario. Indeed, by looking at the general market share for the study area at the horizon 2030 with and without border effect in Table 35, it can be seen that the modal shares are almost the same.

The small difference results in the fact that the modal share of the road decrease of around 1 %. This can be explained by the fact that with the decrease of the border effects, it is expected that more long distance shipments will be observed in Europe, are the major ports will extend their hinterland further away. And longer shipments are more favourable to alternatives modes.

Table 35: Modal share of each transport solutions per port (grouped by country) for the reference scenario with and without border effects

	Reference 2030									Reference 2030 with reduction of the border effects								
Traffic in million of tons	Traffic in million of tons per port					Modal Share in %				Traffic in million of tons per port					Modal Share in %			
Port	TOTAL	Road	Rail	IWW	IWW-Rail	Road	Rail	IWW	IWW-Rail	TOTAL	Road	Rail	IWW	IWW-Rail	Road	Rail	IWW	IWW-Rail
TOTAL 2030	**800.2**	**577.2**	**134.4**	**75.2**	**13.4**	**72%**	**17%**	**9%**	**2%**	**800.2**	**568.7**	**138.8**	**78.1**	**14.6**	71.1%	17.3%	9.8%	1.8%
Baltic	42.0	41.2	0.8	0.0	0.00265	98.1%	1.9%	0.0%	0.0%	**38.8**	**38.1**	**0.7**	**0.0**	**0.0**	98.2%	1.8%	0.0%	0.0%
UK & Irland	91.2	80.2	11.0	0.0	0.0008	88.0%	12.0%	0.0%	0.0%	90.9	80.7	10.2	0.0	0.0	88.8%	11.2%	0.0%	0.0%
Germany	143.9	76.3	59.7	7.5	0.4	53.0%	41.5%	5.2%	0.3%	142.7	77.7	57.4	7.1	0.5	54.4%	40.2%	5.0%	0.3%
Hamburg	119.3	63.9	48.1	6.8	0.4	53.6%	40.3%	5.7%	0.4%	116.9	63.9	46.1	6.4	0.5	55%	39%	5%	0%
Netherlands	129.3	61.6	18.9	42.7	6.1	47.6%	14.7%	33.0%	4.7%	139.0	64.5	21.0	46.5	7.1	46.4%	15.1%	33.4%	5.1%
Rotterdam	124.5	57.4	18.9	42.2	5.9	46.1%	15.2%	33.9%	4.7%	133.8	60.1	21.0	45.8	6.9	45%	16%	34%	5%
Belgium	126.6	81.2	18.1	20.8	6.4	64.2%	14.3%	16.4%	5.1%	129.0	82.1	19.7	21.1	6.1	63.6%	15.3%	16.4%	4.7%
Antwerp	118.4	74.5	16.7	20.8	6.4	62.9%	14.1%	17.6%	5.4%	118.4	73.8	17.3	21.1	6.1	62%	15%	18%	5%
France	45.7	35.7	5.3	4.2	0.4	78.2%	11.7%	9.2%	0.9%	41.4	31.5	5.9	3.4	0.6	76.0%	14.4%	8.1%	1.5%
Le Havre	27.2	21.0	3.2	2.8	0.2	77.3%	11.7%	10.2%	0.9%	25.1	18.8	3.6	2.3	0.4	74.9%	14.4%	9.2%	1.5%
Marseille-Fos	13.2	9.5	2.1	1.4	0.1	72.2%	16.3%	10.5%	1.1%	11.9	8.3	2.3	1.0	0.2	70.1%	19.5%	8.6%	1.8%
Autres Fr	5.3	5.2	0.0	0.1	0.0	98.0%	0.3%	1.2%	0.5%	4.4	4.3	0.0	0.0	0.0	98.0%	0.3%	1.1%	0.6%
Iberia	95.0	84.6	10.3	0.0	0.1	89.0%	10.9%	0.0%	0.1%	95.4	82.4	12.8	0.0	0.2	86.4%	13.4%	0.0%	0.2%
Italy	81.5	71.7	9.7	0.0	0.0	88.1%	11.9%	0.0%	0.0%	80.8	70.2	10.6	0.0	0.0	86.9%	13.1%	0.0%	0.1%
Other Mediterranean	29.1	28.7	0.4	0.0	0.0	98.5%	1.5%	0.0%	0.0%	28.7	28.1	0.6	0.0	0.0	98.1%	1.9%	0.0%	0.0%
Black Sea	16.0	16.0	0.0	0.0	0.0	99.9%	0.1%	0.0%	0.0%	13.5	13.5	0.0	0.0	0.0	99.9%	0.1%	0.0%	0.0%

8.3.2. The SMSR scenario with reduction of the border effects

After having analysed the impacts of the reduction of the border effects on the reference scenario, it is interesting to determine what consequences the combination of the construction of the SMSR project and the reduction of the border effects can have on the hinterland. The SMSR scenario with reduction of the border effects will be mainly compared with the reference scenario with reduction of the border effects. Only some comparison will be made with the basic SMSR scenario to determine under which economic and organisational situations the project is the most beneficial.

8.3.2.1. Analysis of the market shares of the ranges in Europe for the SMSR scenario with reduction of the border effects

By comparing the SMSR scenario, with the reference scenario with reduction of the border effects, it can be observed that the containers throughputs of the ranges are pretty similar in both scenarios. The only difference concerns the Mediterranean range that wins 0.01 % of market share.

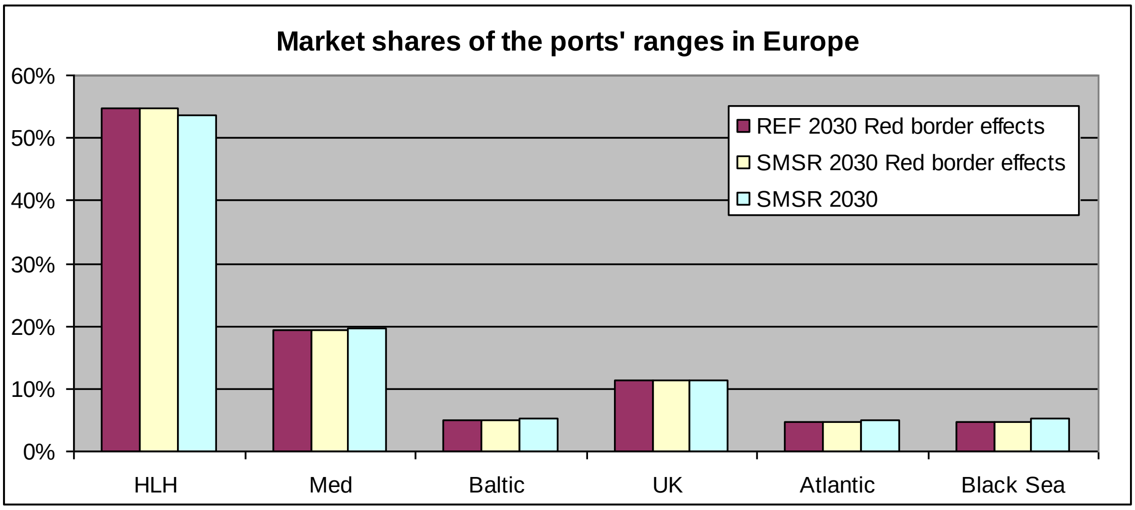


Figure 43: Market Share of the ports 'range in Europe

Thus, from the analyses of the reference and SMSR scenarios in both organisational situation: basic 2030 and reduction of the border effects; it seems that the scale of the whole Europe and of the ranges is too large to analyse the effects of the SMSR project. That is why a deeper analysis will be realized at the scale of the corridors, and at the node level.

If now the SMSR scenarios with and without reduction of the border effects are compared, it is observed that the project is more beneficial for the Mediterranean range in the case of the scenario without the reduction of the border effects, as will be outlined in the next sections.

8.3.2.2. Analysis of the market shares of the ports in France and of the hinterland of the ports for the SMSR scenario with reduction of the border effects

With the creation of the SMSR, it is again the Dutch ports that increase the most their market shares in the French hinterland (+1%), against a decrease of 1 % for the Belgian ports.

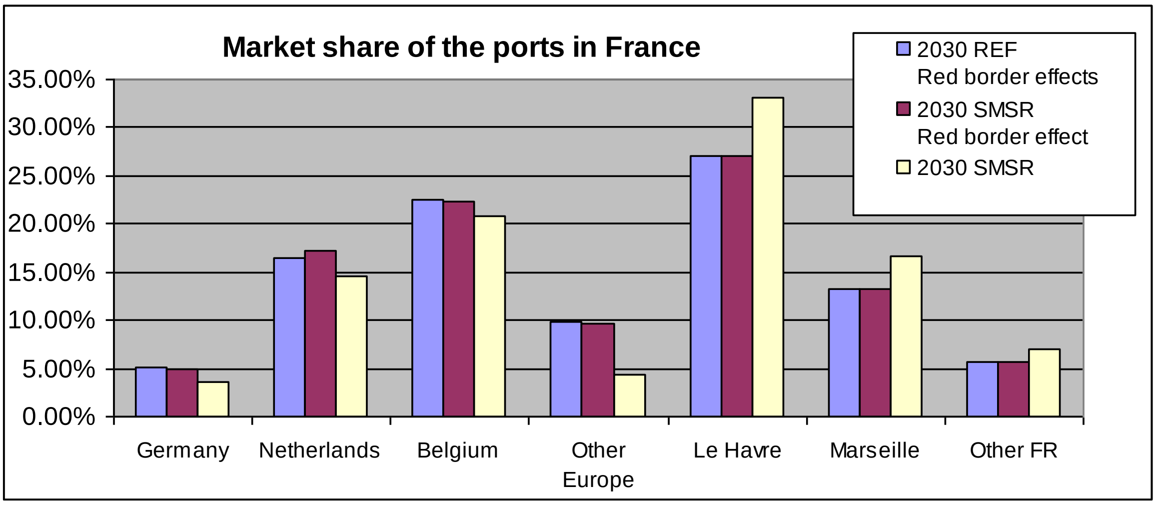


Figure 44: Market Share of the port in France

By now focusing on the four ports that are of interest in this thesis, it is observed on Figure 46 : Market Share of the port of Antwerp (left) and Rotterdam (right) for the SMSR scenario in 2030 with reduction of border effect that the port of Antwerp is losing market share in the regions Franche-Comté, Lorraine, Rhône-Alpes and Alsace (1% in each of those regions). The explanation is the same that in the basic scenario, that is to say an increase of the concurrency of the ports of Marseille and Rotterdam in those regions due to the construction of the canal. On the other hand, the port of Rotterdam increases significantly its market shares in the regions Rhône-Alpes, Auvergne, Bourgogne, PACA and Languedoc Roussillon, thus in the regions situated south of the canal. If those results are compared with those obtained for the basic 2030 SMSR scenario, it can indeed be observed that the port of Rotterdam extend far more its hinterland to the South of France to finally gather 17% of the port market shares in France (against 15 % in the case of the basic SMSR scenario).

The port of Le Havre does not seem to be really impacted by the construction of the canal in the reduction of the border effect context, contrary to what was observed in the basic situation. Indeed, its market share in France stays constant between the two scenarios, and at the scale of the regions the same is observed, except in Rhône-Alpes, Auvergne, Bourgogne and Franche-Comté (cf. Figure 46) where it is losing 1% of market share, due to the higher concurrency of the other ports.. Finally, the port of Marseille is winning market share in the regions Lorraine, Alsace and Franche-Comté but also in Rhône-Alpes and Bourgogne with respect to the reference scenario with reduction of the border effects, but he is also losing market share in the regions PACA and Languedoc Roussillon. The same reasons as for the basic scenarios explained those results (cf. §8.2.3). Nevertheless, the main difference with regard to the basic scenarios, is that the penetration of the port of Marseille in the regions located north of the canal are of less importance.

For further description of the hinterland, the relative evolution of the containers trade between the French regions and the ports between the reference and SMSR scenarios with reduction of the border effects can be found in Appendix 12.

By analysing the line of contestable hinterland line, it can be observed that this line at the level of the Rhone has been moved to the South with regard to its location in the case of the reference scenario with reduction of the border effects. Indeed, the differences of market shares between the two first ranges decrease in the north of the region PACA (the colour is darker). And the differences increase in the north of the region Rhône-Alpes (colour lighter). This implies that the ports of the HLH ranges extend their hinterland to the South with the construction of the canal in the case of the reduction of the border effects, and is thus consistent with the results observed above.

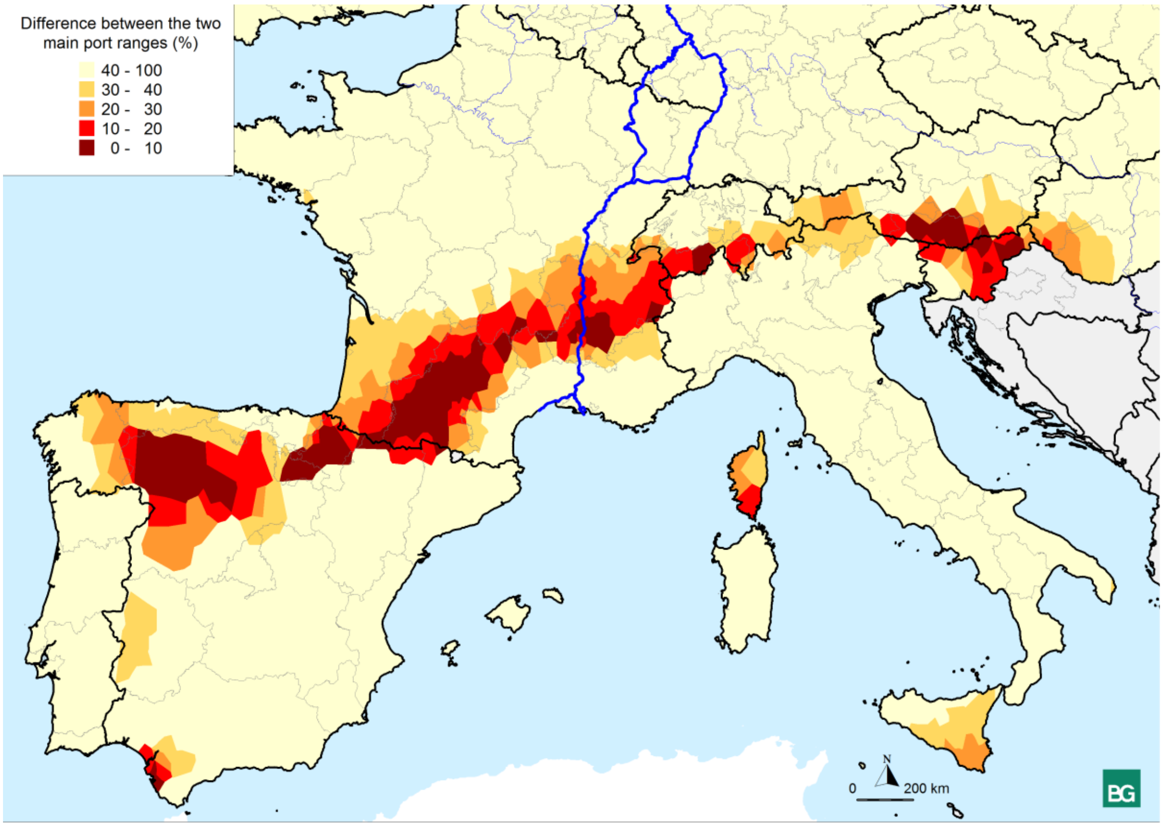


Figure 45: Difference between the two first port ranges for the SMSR scenario 2030 with reduction of the border effects

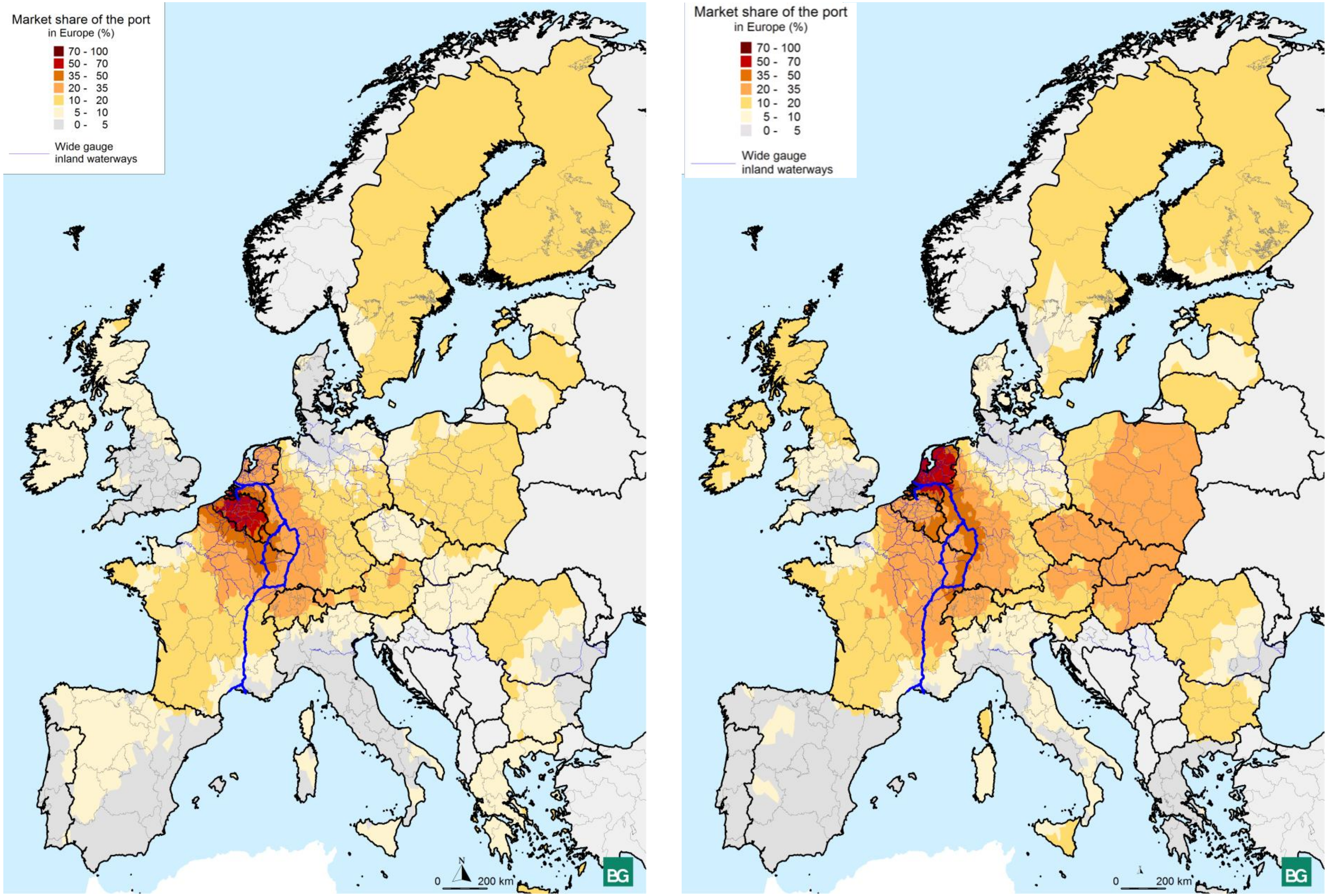
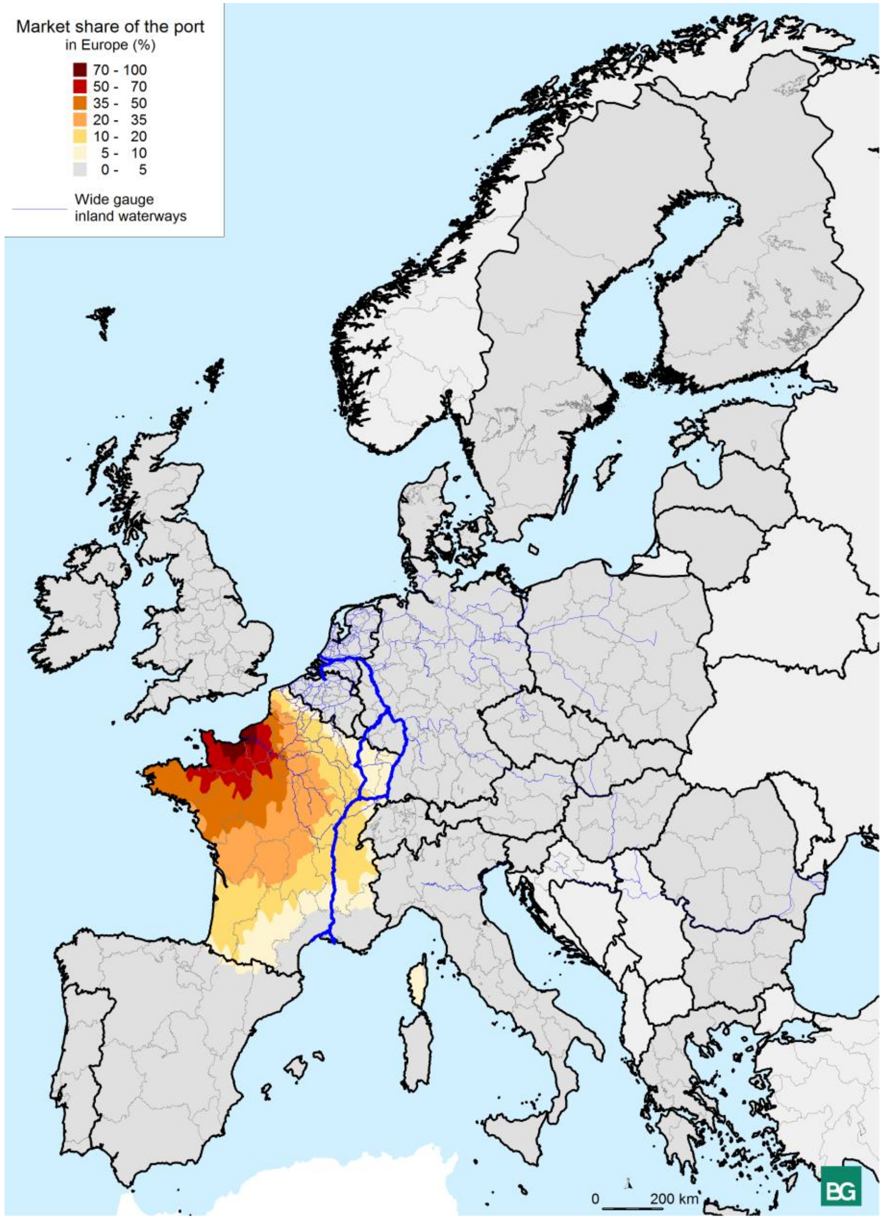


Figure 46 : Market Share of the port of Antwerp (left) and Rotterdam (right) for the SMSR scenario in 2030 with reduction of border effect



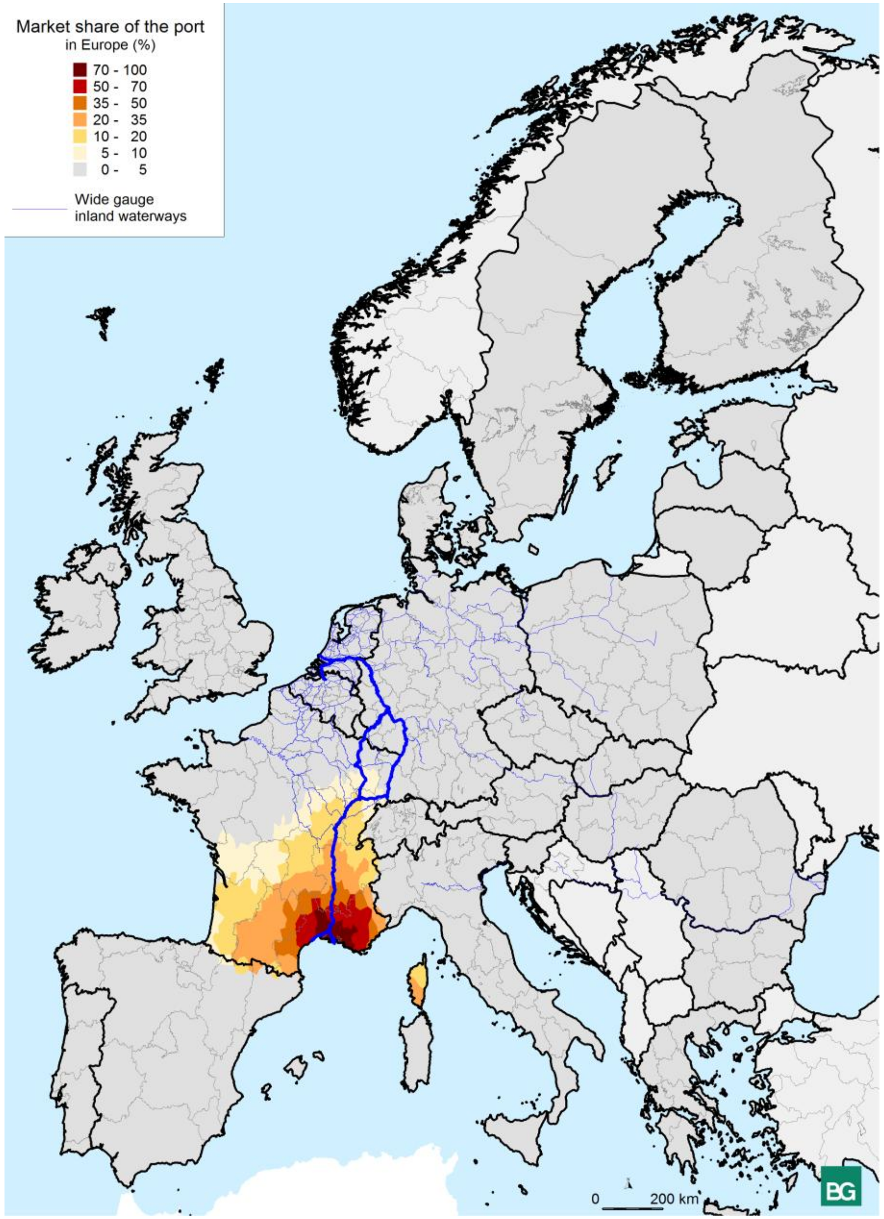


Figure 47 : Market Share of the port of Antwerp (left) and Rotterdam (right) for the SMSR scenario in 2030 with reduction of border effect

Finally, if attention is given to the tons of containers win or loss by each port range at the node level (cf. Figure 48), the same main trends as in the basic scenario are observed, meaning that the Mediterranean range is winning tons, whereas the HLH range is losing tons. Nevertheless, the gains for the Mediterranean ranges are divided by two when comparing with the basic scenarios. In addition, the losses of the HLH range in these scenarios are insignificant with an amount of 229 tons, equivalent to around 25 containers.

Table 36: Tons of containers win and loss by the HLH range between the reference and the SMSR scenario in the case of the reduction of the border effects (in tons)

	Reduction border effect		
	HLH	MED	Other ranges
Gain	278 170	296 076	8
Loss	-278 399	-255 833	-40 050
Total	-229	40 243	-40 042

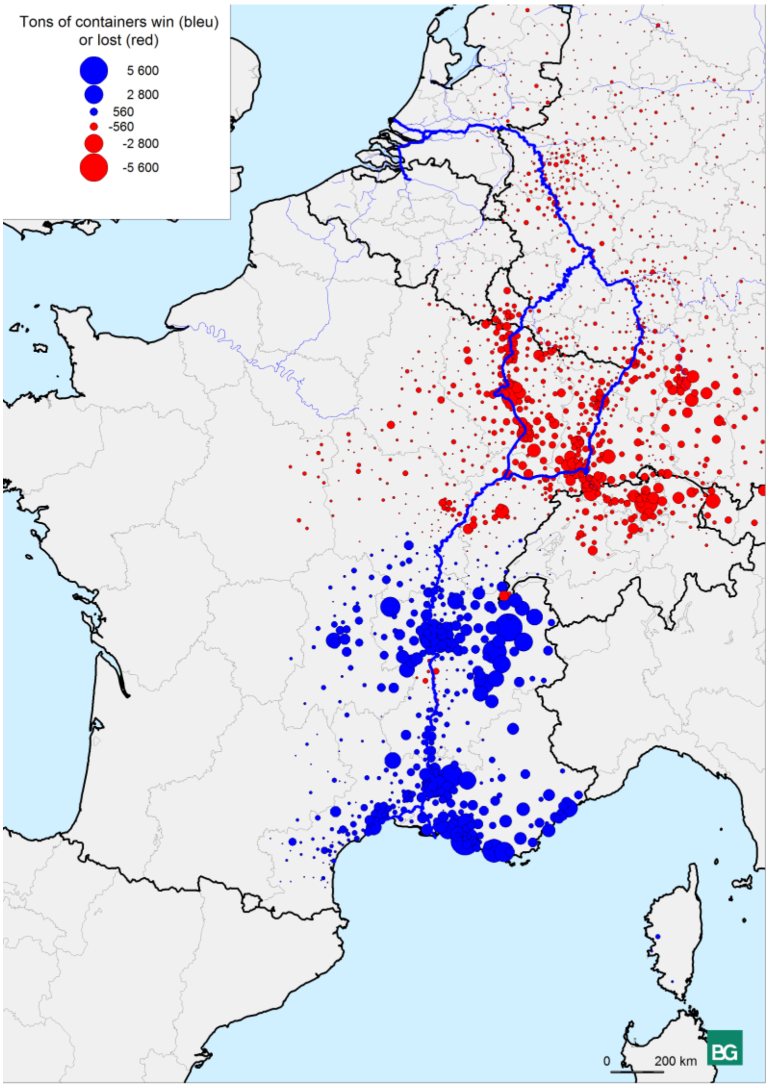


Figure 48: Tons of containers win and lost at the node level by the HLH range between the reference scenario with reduction of the border effects and the SMSR scenario with reduction of the border effects.

8.3.2.3. Analysis of the modal share of the SMSR scenario with reduction of the border effects

After having analysed the effect on the hinterland, it is interesting to focus on the consequences of this scenario on the modal share. Table 37, give an overview of the evolution of the modal share at the scale of Europe and at the scale of the ports, and Table 38 and Table 39, detail those modal shares for some port-hinterland couples.

On the whole study area, it can be observed that between the reference and SMSR scenarios with reduction of the border effects, the modal share of the rail and road solutions decrease by 0.2 % at the scale of Europe, whereas the modal share of IWW increases by 0.3 % and the one of the IWW+Rail solutions increases by 0.2 %.

The main changes of modal shares are observed in France, the country in which the SMSR canal is constructed, with an increase of the IWW modal share from 8.1 to 10.1 %. This is especially due to the increase of IWW modal share of the port of Marseille that benefits the most from the creation of the SMSR canal. Indeed, in the SMSR scenario with reduction of the border effects it can be observed that the rail and IWW modal share are equal in Marseille, around 15 %, whereas before the creation of the canal the modal shares were of 19.5 % for the rail and 8.6 % for the IWW. In addition, the road modal share decreases from 70.1 % to 65.8 %.

As in the scenarios without reduction of the border effects, it can be observed that the gains of IWW modal shares and IWW+Rail modal share are observed on the same port-hinterland relations (cf. § 8.2.4).

Finally, by comparing the SMSR basic 2030 scenario and the SMSR with reduction of the border effects scenario, it can be observed that the market share of the road solutions decrease at the scale of Europe between the two scenarios (from 72.0 % to 70.9 % for the road), and increase for all the other modes: from 16.6 to 17.1 % for the rail, from 9.7 to 10.1 % for the IWW and from 1.7 to 1.9 % for the IWW+Rail. Those results can be explained by the increase of the shipment distances for the SMSR with reduction of the border effects scenario that are more favourable to the alternatives modes.

Table 37: Modal share of each transport solutions per port (grouped by country) for the reference and the SMSR scenarios with border effects

	Reference 2030 with reduction of the border effects									SMSR scenario with reduction of the border effects								
Traffic in million of tons	Traffic in million of tons per port					Modal Share in %				Traffic in million of tons per port					Modal Share in %			
Port	TOTAL	Road	Rail	IWW	IWW-Rail	Road	Rail	IWW	IWW-Rail	TOTAL	Road	Rail	IWW	IWW-Rail	Road	Rail	IWW	IWW-Rail
TOTAL 2030	**800.2**	**568.7**	**138.8**	**78.1**	**14.6**	**71.1%**	**17.3%**	**9.8%**	**1.8%**	**800.2**	**567.6**	**136.8**	**80.7**	**15.1**	**70.9%**	**17.1%**	**10.1%**	**1.9%**
Baltic	38.8	38.1	0.7	0.0	0.0	98.2%	1.8%	0.0%	0.0%	38.8	38.1	0.7	0.0	0.0	98.2%	1.8%	0.0%	0.0%
UK & Irland	90.9	80.7	10.2	0.0	0.0	88.8%	11.2%	0.0%	0.0%	90.8	80.7	10.2	0.0	0.0	88.8%	11.2%	0.0%	0.0%
Germany	142.7	77.7	57.4	7.1	0.5	54.4%	40.2%	5.0%	0.3%	142.6	77.6	57.0	7.1	0.8	54.4%	40.0%	5.0%	0.5%
Hamburg	116.9	63.9	46.1	6.4	0.5	55%	39%	5%	0%	116.7	63.9	45.8	6.4	0.7	54.7%	39.2%	5.5%	0.6%
Netherlands	139.0	64.5	21.0	46.5	7.1	46.4%	15.1%	33.4%	5.1%	139.5	64.3	20.5	47.9	6.9	46.1%	14.7%	34.3%	5.0%
Rotterdam	133.8	60.1	21.0	45.8	6.9	45%	16%	34%	5%	134.3	59.9	20.5	47.3	6.6	44.6%	15.2%	35.2%	4.9%
Belgium	129.0	82.1	19.7	21.1	6.1	63.6%	15.3%	16.4%	4.7%	128.8	81.9	19.3	21.5	6.1	63.6%	15.0%	16.7%	4.8%
Antwerp	118.4	73.8	17.3	21.1	6.1	62%	15%	18%	5%	118.2	73.6	17.0	21.5	6.1	62.3%	14.4%	18.2%	5.2%
France	41.4	31.5	5.9	3.4	0.6	76.0%	14.4%	8.1%	1.5%	41.5	31.0	5.5	4.2	0.8	74.7%	13.2%	10.1%	2.0%
Le Havre	25.1	18.8	3.6	2.3	0.4	74.9%	14.4%	9.2%	1.5%	25.1	18.8	3.6	2.3	0.4	74.9%	14.3%	9.2%	1.7%
Marseille-Fos	11.9	8.3	2.3	1.0	0.2	70.1%	19.5%	8.6%	1.8%	12.1	7.9	1.9	1.8	0.4	65.8%	15.8%	15.2%	3.1%
Autres Fr	4.4	4.3	0.0	0.0	0.0	98.0%	0.3%	1.1%	0.6%	4.4	4.3	0.0	0.0	0.0	98.0%	0.3%	1.1%	0.6%
Iberia	95.4	82.4	12.8	0.0	0.2	86.4%	13.4%	0.0%	0.2%	95.4	82.4	12.6	0.0	0.4	86.4%	13.2%	0.0%	0.4%
Italy	80.8	70.2	10.6	0.0	0.0	86.9%	13.1%	0.0%	0.1%	80.7	70.1	10.5	0.0	0.0	86.9%	13.0%	0.0%	0.1%
Other Mediterranean	28.7	28.1	0.6	0.0	0.0	98.1%	1.9%	0.0%	0.0%	28.7	28.1	0.6	0.0	0.0	98.1%	1.9%	0.0%	0.0%
Black Sea	13.5	13.5	0.0	0.0	0.0	99.9%	0.1%	0.0%	0.0%	13.5	13.5	0.0	0.0	0.0	99.9%	0.1%	0.0%	0.0%

Table 38: Difference of IWW (left) and IWW+ Rail (right) modal share between the SMSR/REF scenarios with red of border effects

Part modale en %	Marseille-Fos	Barcelone-Valence	Genova	Le Havre	Anvers + Zeebrugge	Rotterdam + Amsterdam	Hambourg + Bremerhaven
PACA-LR	0%	0%	0%	0%	27%	69%	0%
RA	9%	0%	0%	0%	20%	59%	0%
Bourgogne	26%	0%	0%	0%	15%	21%	0%
Franche-Comté	44%	0%	0%	-2%	12%	-2%	0%
Suisse	36%	0%	0%	-1%	-1%	-1%	0%
Alsace	69%	0%	0%	-1%	0%	0%	0%
Lorraine	58%	0%	0%	0%	1%	3%	0%
Champagne-Ardennes	30%	0%	0%	0%	0%	1%	0%
Benelux	49%	0%	0%	0%	0%	0%	0%
DE	68%	0%	0%	0%	0%	0%	0%

Part modale en %	Marseille-Fos	Barcelone-Valence	Genova	Le Havre	Anvers + Zeebrugge	Rotterdam + Amsterdam	Hambourg + Bremerhaven
PACA-LR	0%	0%	0%	2%	-2%	-23%	27%
RA	0%	0%	0%	2%	1%	-12%	25%
Bourgogne	0%	6%	0%	0%	1%	-1%	16%
Franche-Comté	0%	5%	0%	0%	0%	-1%	7%
Suisse	-6%	12%	0%	10%	0%	0%	0%
Alsace	-7%	27%	0%	3%	0%	0%	0%
Lorraine	-3%	17%	0%	1%	0%	0%	0%
Champagne-Ardennes	-1%	5%	0%	0%	0%	0%	1%
Benelux	-6%	1%	0%	0%	0%	0%	0%
DE	-4%	11%	0%	1%	0%	0%	0%

Table 39: Difference of Rail (left) and Road (right) modal shares between the SMSR/REF scenarios with red of border effects

Part modale en %	Marseille-Fos	Barcelone-Valence	Genova	Le Havre	Anvers + Zeebrugge	Rotterdam + Amsterdam	Hambourg + Bremerhaven
PACA-LR	0%	0%	0%	-1%	-23%	-38%	-24%
RA	-2%	-1%	1%	1%	-20%	-40%	-21%
Bourgogne	-7%	-5%	0%	-1%	-2%	1%	-11%
Franche-Comté	-9%	-4%	1%	21%	16%	9%	-6%
Suisse	-15%	-11%	0%	-4%	1%	1%	0%
Alsace	-50%	-23%	0%	1%	0%	0%	0%
Lorraine	-27%	-15%	0%	4%	0%	0%	0%
Champagne-Ardennes	-14%	-4%	0%	0%	0%	1%	-1%
Benelux	-41%	-1%	0%	0%	0%	0%	0%
DE	-59%	-11%	0%	0%	0%	0%	0%

Part modale en %	Marseille-Fos	Barcelone-Valence	Genova	Le Havre	Anvers + Zeebrugge	Rotterdam + Amsterdam	Hambourg + Bremerhaven
PACA-LR	0%	0%	0%	-1%	-2%	-7%	-3%
RA	-7%	0%	1%	-1%	-2%	-7%	-4%
Bourgogne	-19%	0%	0%	1%	-15%	-20%	-5%
Franche-Comté	-35%	-1%	-1%	-19%	-28%	-6%	-1%
Suisse	-15%	-1%	0%	-4%	0%	0%	0%
Alsace	-11%	-4%	0%	-3%	0%	0%	0%
Lorraine	-28%	-2%	-1%	-4%	-1%	-3%	0%
Champagne-Ardennes	-15%	-1%	0%	0%	0%	-2%	-1%
Benelux	-3%	0%	0%	0%	0%	0%	0%
DE	-5%	0%	0%	0%	0%	0%	0%

8.3.3. Conclusion

In this section the two infrastructure scenarios, the reference scenario and the SMSR scenario have been analysed by considering a reduction of the border effects. By taking, such hypotheses it can be observed that the major ports belonging to the "World" class[38] are taking market share to the smaller ports that belong to the lowest classes. In France, this implies that the modal shares of the French ports decrease at the favour of the ports of Rotterdam and Antwerp, for both infrastructure scenarios.

The consequences of this higher penetration of the ports of Antwerp and Rotterdam in France, is the slight shift to the south of the contestable hinterland line in France on the corridor of interest. A first shift occurs to the south for the reference scenario with reduction of the border effects and the line is again shift toward the south with the implementation of the SMSR canal. It can thus be concluded that with the reduction of the border effects, the ports of Antwerp and Rotterdam are winning market shares on the ports of the Mediterranean range.

By looking at the modal spilt in the case of the reduction of the border effects, it can be seen that the rail is winning modal shares, with regard to the basic scenarios. This is due to the fact that containers are shipped on longer distances. Finally, the impacts of the creation of the SMSR canal on the modal share are pretty similar to those observed without the reduction of the border effects (cf. Tables 30-33 and 37-38).

[38] Cf. Appendix 5.

8.4. The maritime scenario: sensitivity to the maritime costs

For this latest scenario, in which the sensitivity of the model to the maritime segment will be analyzed, only the exchanges between Europe and Asia will be considered. The model used for this scenario is the one calibrated for the exchanges with all the partner maritime zones. For this scenario the analysis of the modal shares will be left out, as it is expected that this scenario will only have little influence on modal shares.

8.4.1. The basic reference scenario in 2030 for Asia-Europe trade

In order to analyze the sensitivity of the model to the maritime segment for the relation Asia-Europe, the characteristics of the ports' hinterland for the relation Asia-Europe for the basic reference scenario in 2030 will be first presented in this paragraph.

8.4.1.1. Analysis of the market shares of the ports' ranges in Europe for the relation Asia-Europe in the case of the basic reference scenario in 2030

Figure 49: Market shares of the ranges for the relation Asia-Europe highlights that the HLH range is even more dominant in Europe for the container trade with Asia, than for trade with all the partner maritime zones. Indeed, for the relation Asia-Europe the market share of the HLH range is of 63%, thus increased of 10 % with regard to its market share with all the partner maritime zones.

In addition, it can be observed that the Baltic has a really low market share for trade with Asia. This is due to the structure of the data, since containers shipped from Baltic to Asia are registered as two distinct container shipments in the data used as input. One shipment being registered as an intra EU shipment from Baltic to the HLH range for instance and the second one as a shipment from the HLH range to Asia. This explains why the simulated exchanges between Asia and the Baltic are that low.

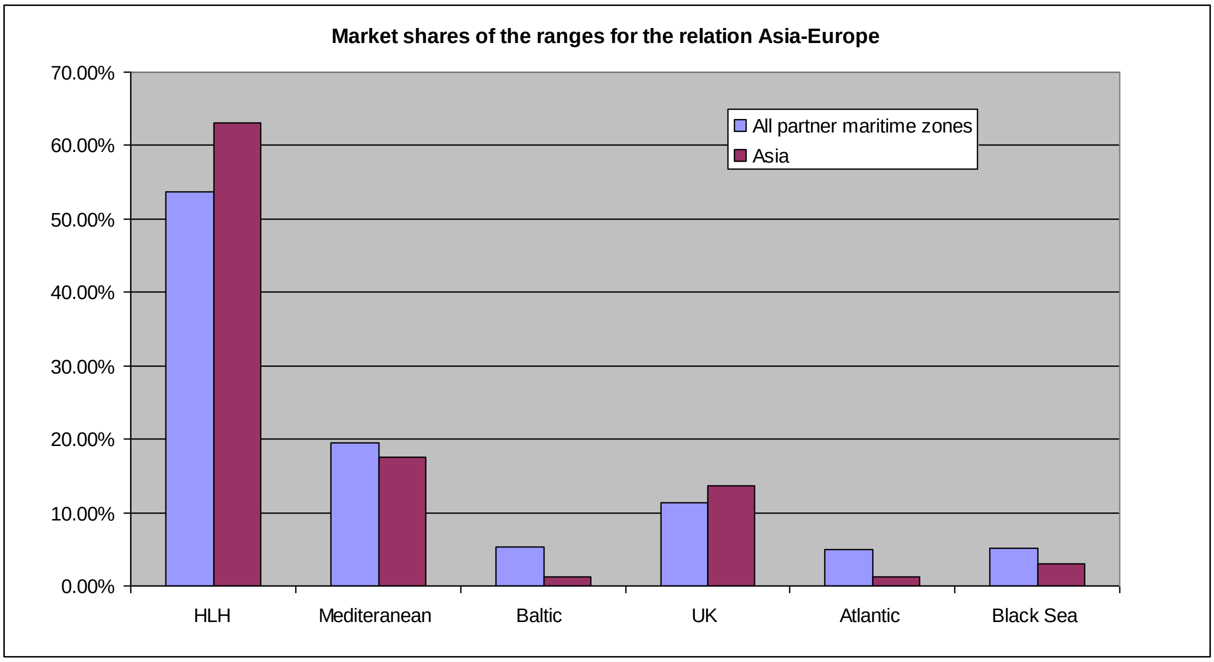


Figure 49: Market shares of the ranges for the relation Asia-Europe

8.4.1.2. Analysis of the market shares of the ports in France and of the hinterland of the ports for the relation Asia-Europe for the basic reference scenario in 2030

In Figure 50 it can be seen that two ports are mainly oriented towards the Asia-France trade, the port of Rotterdam, and the port of Le Havre. The exchanges with Asia represent 57%[39] of the container market of Rotterdam, which is by consequence far more dominant for this type of exchange in its hinterland. This is confirmed by the fact that the market shares of the Dutch ports increase with regard to the trade with all the partner maritime zones, in Belgium and France in the regions located nearby the border that is to say, Lorraine and Champagne-Ardenne, but also along the Rhine in Germany and in Switzerland, as can be observed by comparing **Figure** 30 & Figure 51. The port of Le Havre is also mainly dedicated to the relation with Asia, as this trade relation represent 55 % of its container market. For Asia trade it gathers 38 % of the market shares in France (against 34 % for all the partner maritime zones).

On the other hand, the Belgium ports have less influence in Europe for the specific trade with Asia, with a market share of only 15 % in France. This is explained by the fact that Asia trade only represent 25 % of the container market of the port of Antwerp. Finally, the market share of the port of Marseille in France for the relation with Asia is pretty similar to the one for all the partner maritime zones, leading to the fact that the group of the Dutch ports becomes the second "port" in France, for the relation with Asia passing the port of Marseille. The hinterland of the port of Marseille for the Asia trade is also pretty similar to what is observed for the exchange with all the partner maritime zones.

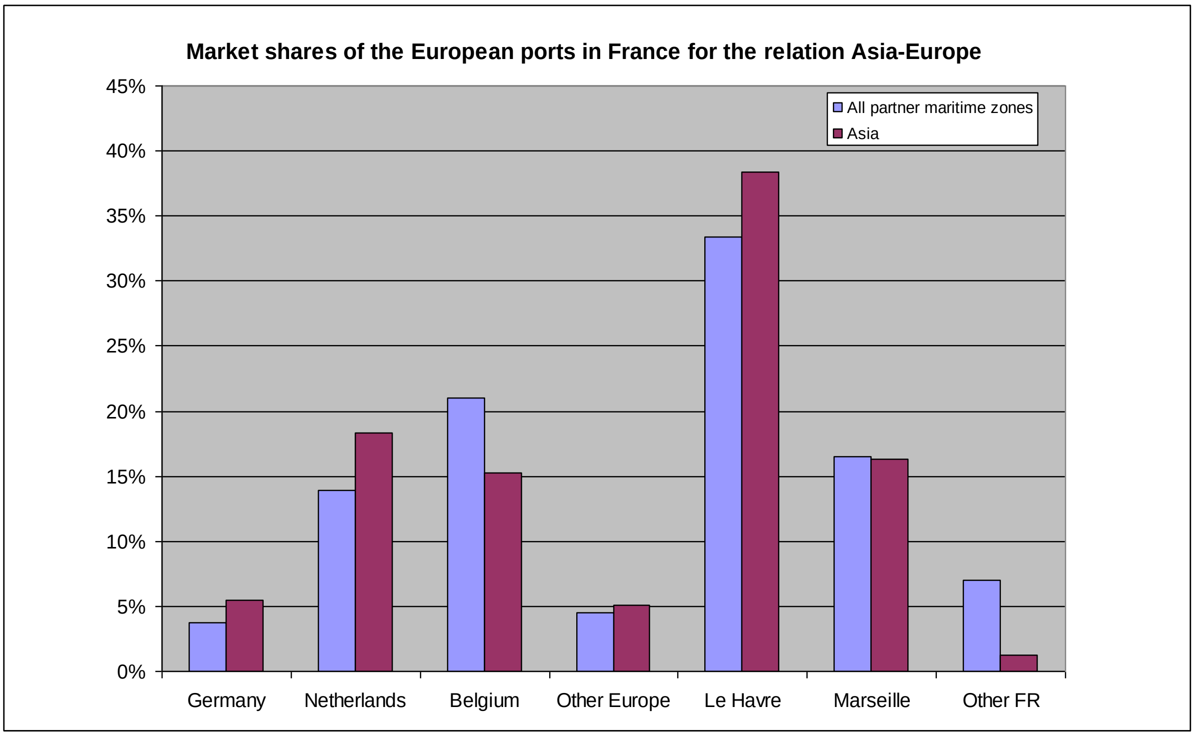
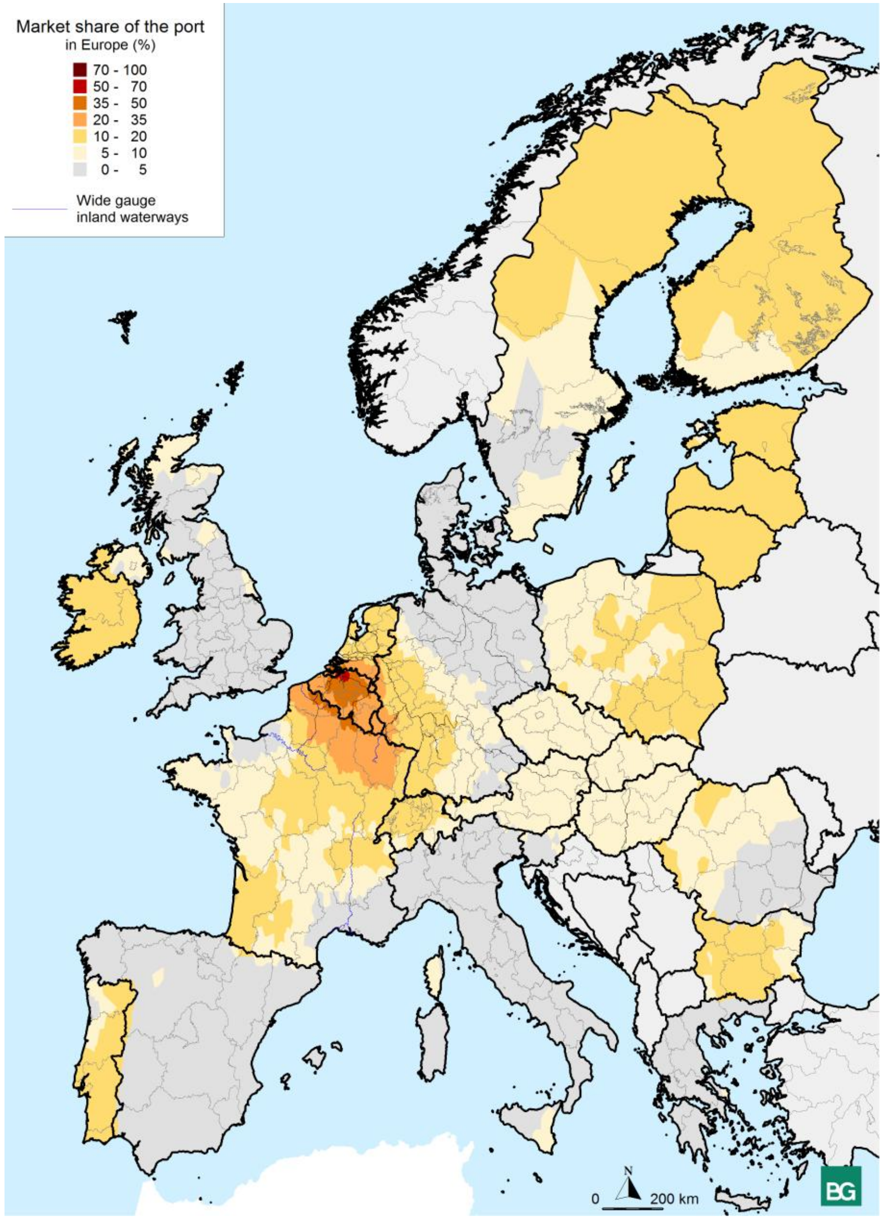


Figure 50: Market shares of the European ports in France for the relation Asia-Europe

[39] In 2013, the exchange with Asia represented 45 % of the container market share of Rotterdam, and 48% in 2012 (Port of Rotterdam, 2014)



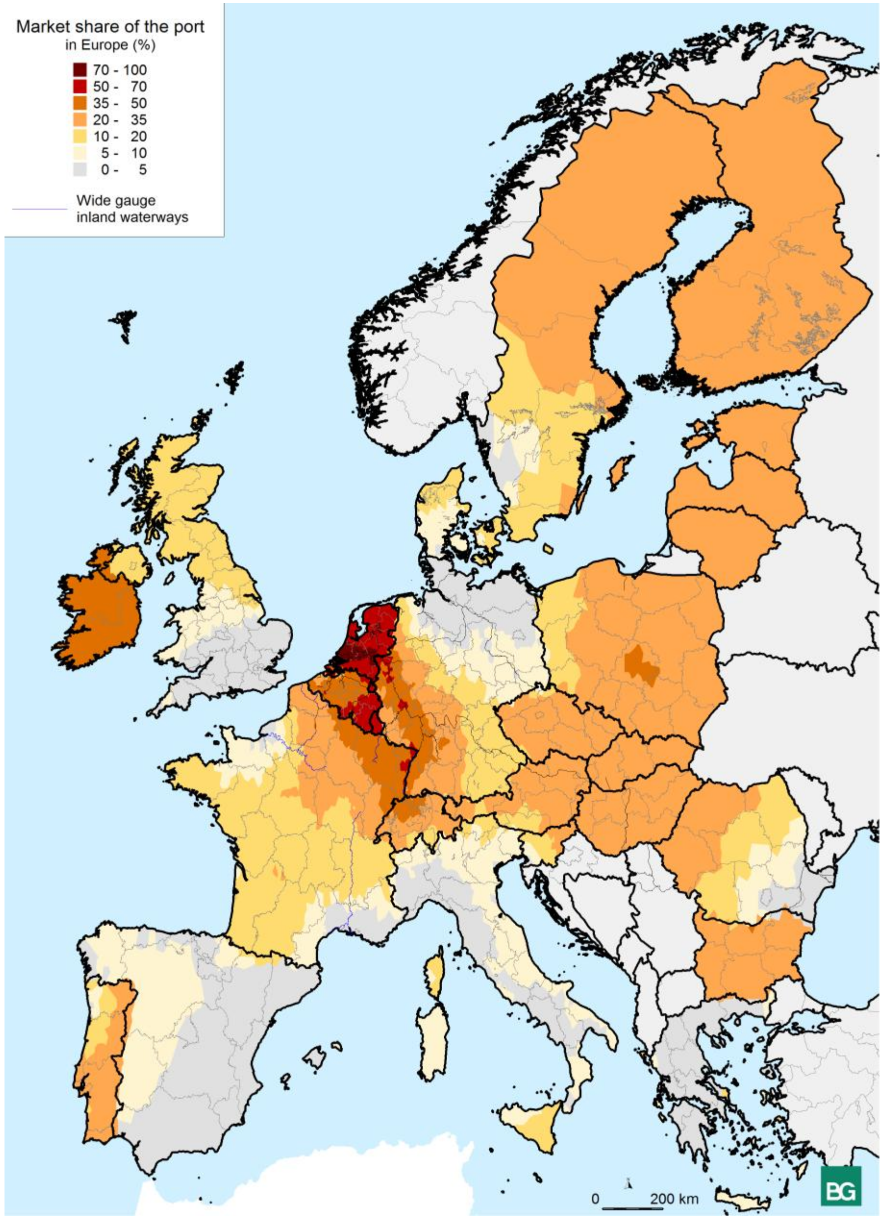


Figure 51: Market Share of the port of Antwerp (left) and Rotterdam (right) for the relation Asia-Europe for the reference scenario in 2030

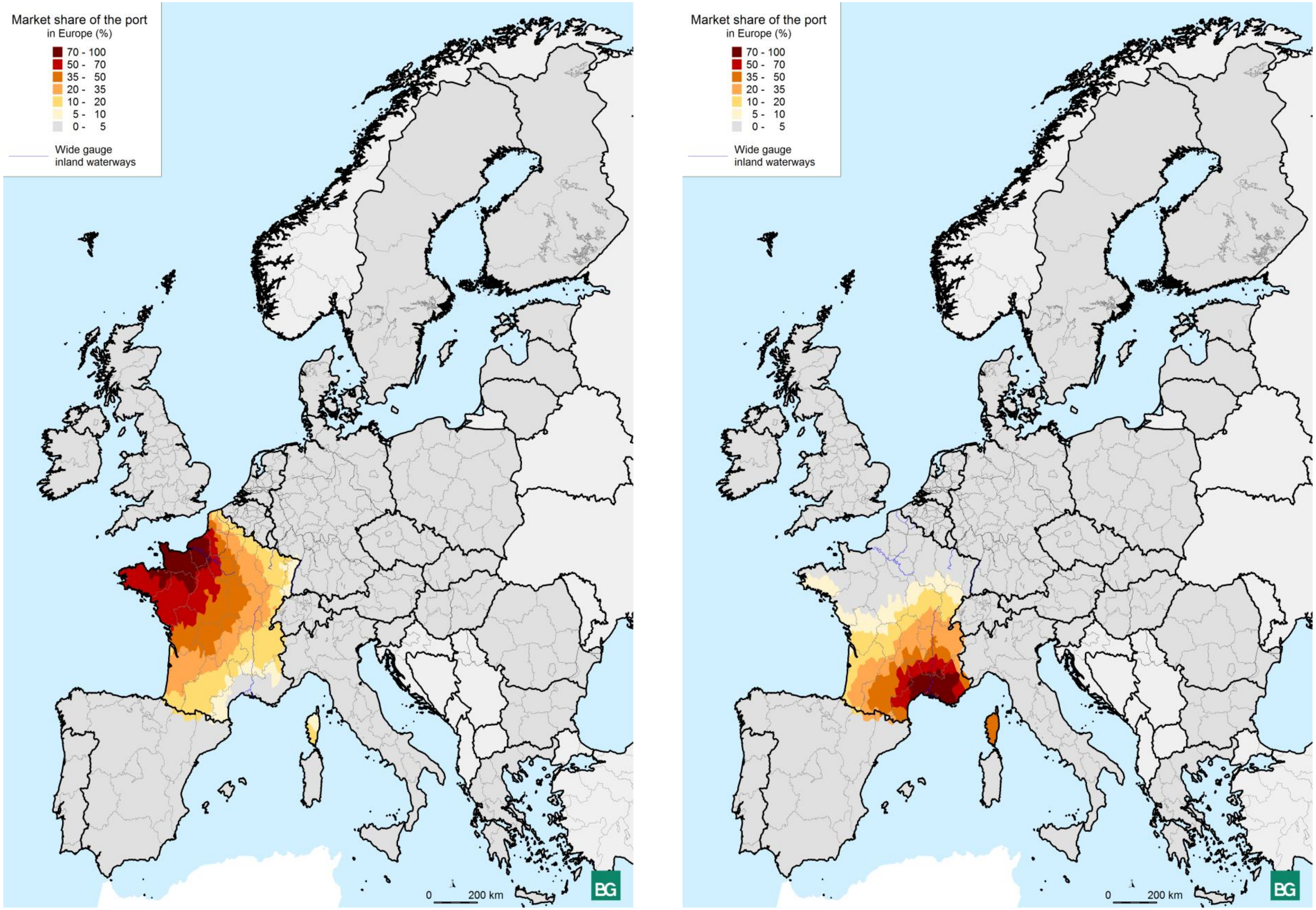


Figure 52: Market Share of the port of Le Havre (left) and Marseille (right) for the relation Asia-Europe for the reference scenario in 2030

For the Asia-Europe trade, the contestable hinterland line (cf. Figure 53) is located almost at the same place than for the exchanges with all the partners maritime zones, along the corridor of interest. Nevertheless, the darker line, that is to say the area where the difference between the two first ranges is the smallest, is thicker in the region Rhône-Alpes than in the case where all the partner maritime zones are merged. The whole line is also a little larger by extending in the region Bourgogne. This implies that the competition is higher between the two ranges in this zone, meaning that the ports of the Mediterranean range are more competitive in Rhône-Alpes and Bourgogne for the Asian exchanges than for the exchanges with all the partner maritime zones. This can be explained by the fact that the Mediterranean range has an advantage with regard to the HLH range for the exchange with Asia, a reduction of around 3 000km of the distance of the maritime segment.

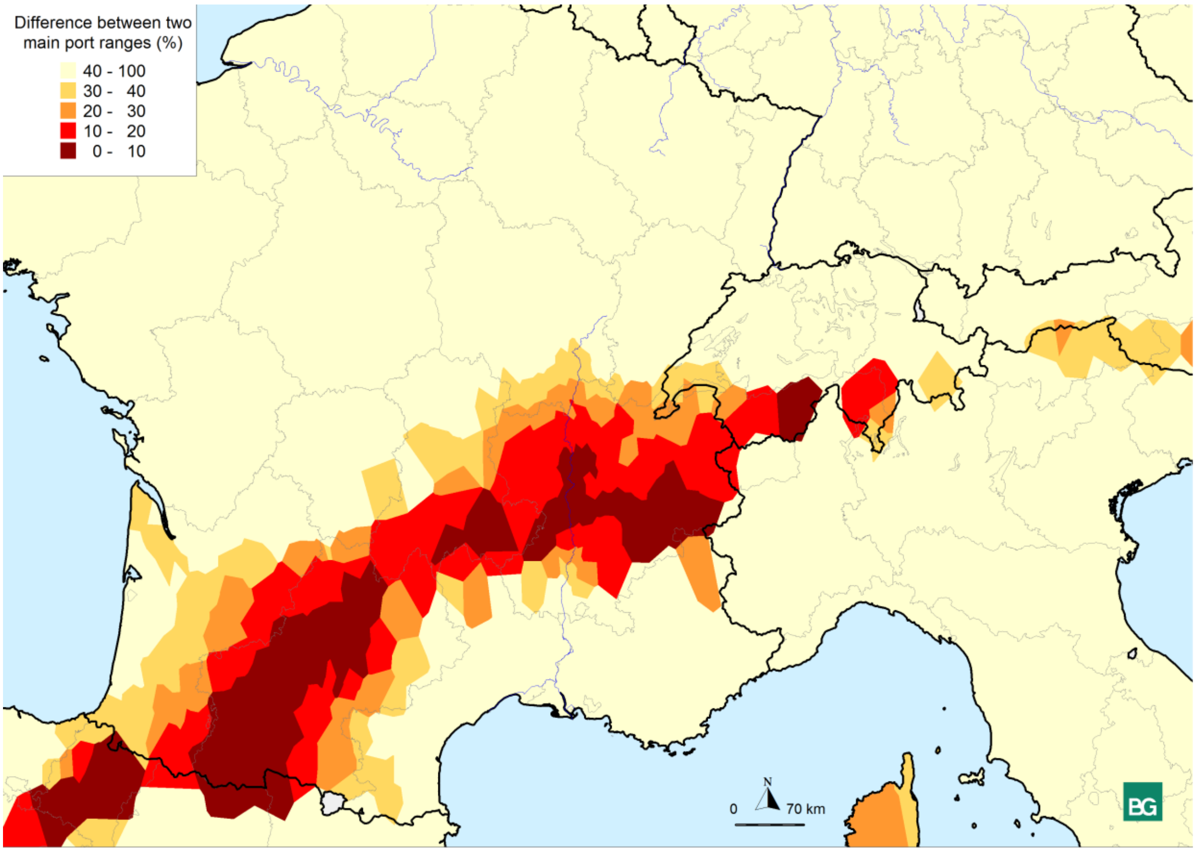


Figure 53 : Difference between the two first port ranges for exchange with Asia for the REF basic scenario 2030

8.4.2. The reference scenario with sensitivity to the maritime costs in 2030

In this section the results of the modelling for the Europe-Asia trade with integration of the maritime segment will be analysed. The method of integration of the maritime segment into the model has been explained in Chapter 7.

8.4.2.1. Analysis of the market shares of the port ranges in Europe for the relation Asia-Europe for the reference maritime scenario in 2030

First at the scale of the ranges, it can be observed that as expected, with the incorporation of the maritime segment, the market share of the HLH range in Europe decreases of 0.61 % to reach a value of 62.5 %, whereas the one of the Mediterranean range increase by 2.22 % to reach a value of 19.9 %. This corresponds to an increase of 12.6 % of the port throughputs of the Mediterranean ports in Europe, and a decrease of 0.96% of the ports' throughput of the HLH range. This shows that by increasing the cost of the shipment of containers to the HLH range with respect to the Mediterranean range, the attractiveness of the HLH ports decrease.

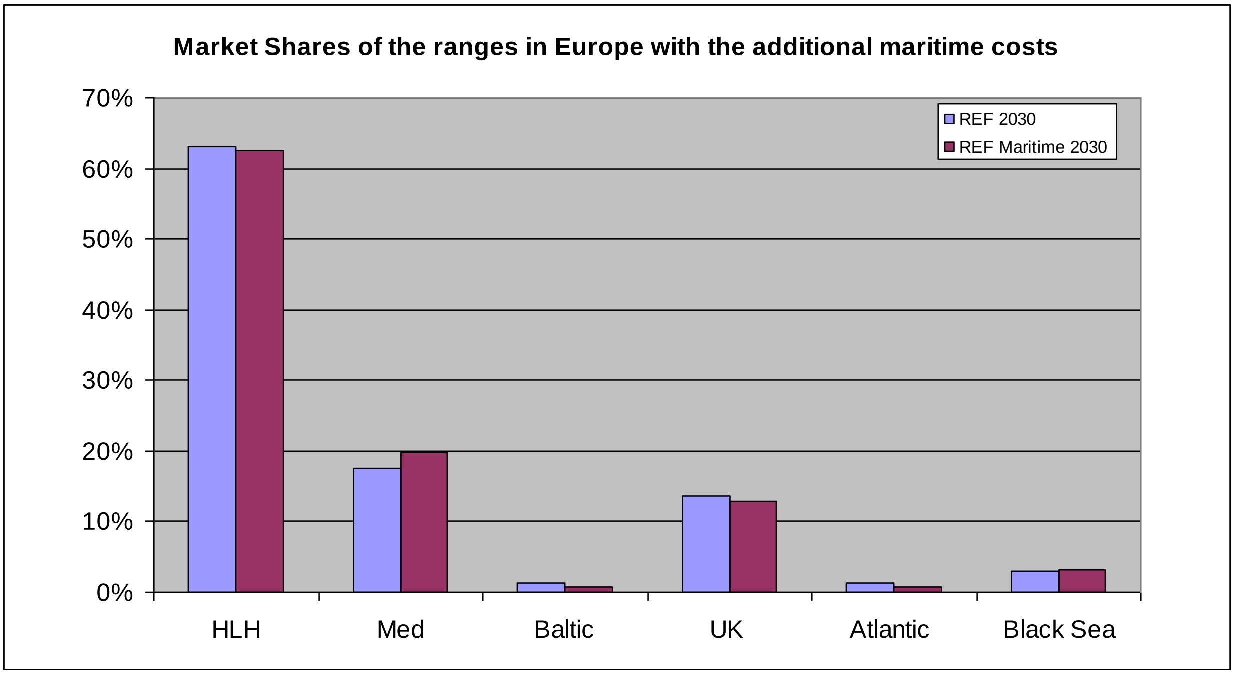


Figure 54: Market Share of the range with the additional maritime costs

8.4.2.2. Analysis of the market shares of the ports in France for the relation Asia-Europe for the reference maritime scenario in 2030

By looking more specifically to the market shares of the European ports into the French territory, it can be observed that with the integration of the maritime segment, the port that gains the most of market shares in France is the port of Marseille, with a gain of 4 %, becoming moreover the second port in France for trade with Asia, instead of the Dutch ports. The other European ports see also an increase of their market shares of 2%, due to the gains of market shares of the Spanish and Italian ports that belong to the Mediterranean range. The main French container port, the port of Le Havre, sees a decrease of its market share in France of 7%.

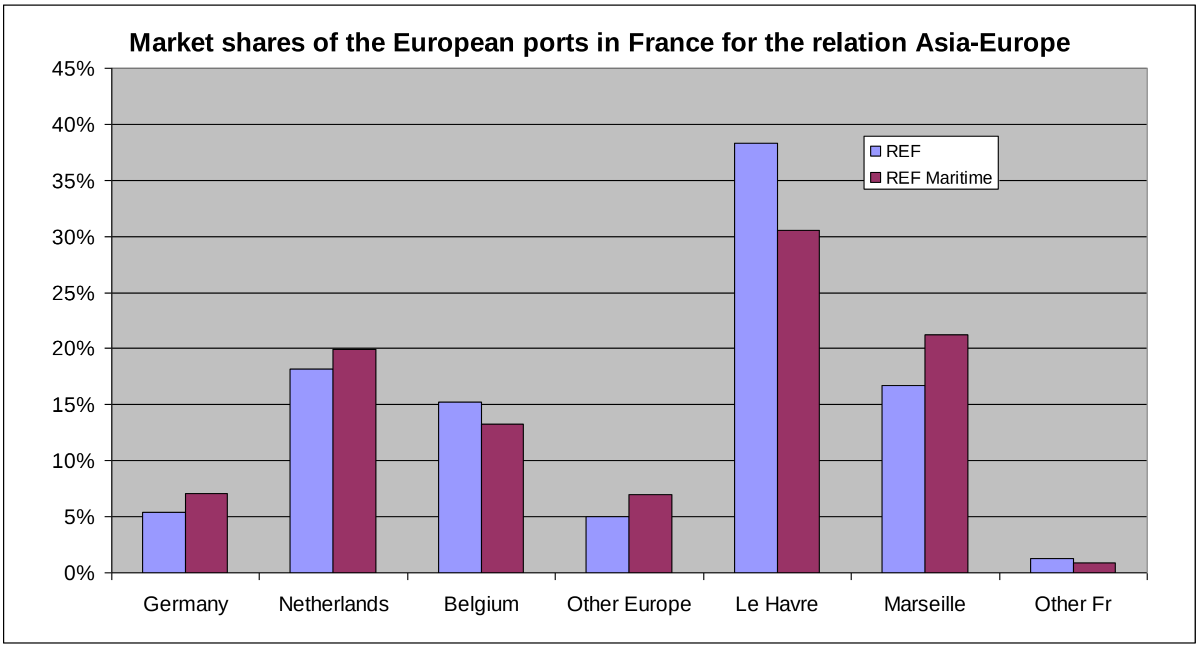


Figure 55: Market shares of the European ports in France for the relation Asia-Europe in the basic and maritime reference scenarios

What was unexpected is the increase of the market share of the Dutch ports in France that leads to only a small diminution of the market share of the HLH range in Europe. This is due to the fact that the integration of the maritime segment into the model leads to compensatory effects between the ranges situated in Northern Europe. Indeed, as the additional costs for the maritime segment is the same for the UK, HLH and Baltic ranges; there are compensatory effects between those ranges that can be explained as follow:

- the Mediterranean range is winning market shares on the four ranges situated in Northern Europe, that is to say, the Atlantic, UK, HLH and Baltic ranges.
- but in Northern Europe, shifts of market shares also occur, due to the fact that the important factor taken into account in the port choice model is the relative difference of costs between the ports. But as the additional costs of the maritime segment is the same for the three ranges of the North Sea, this relative difference between the port decreases, giving more weight to the port throughput in the gravity model, thus advantaging again the major ports. That is why the HLH range is winning market shares on the UK and Baltic ranges for hinterland located in Northern Europe.

8.4.2.3. Analysis of the ports' hinterlands for the relation Asia-Europe for the reference scenario with integration of the maritime segment

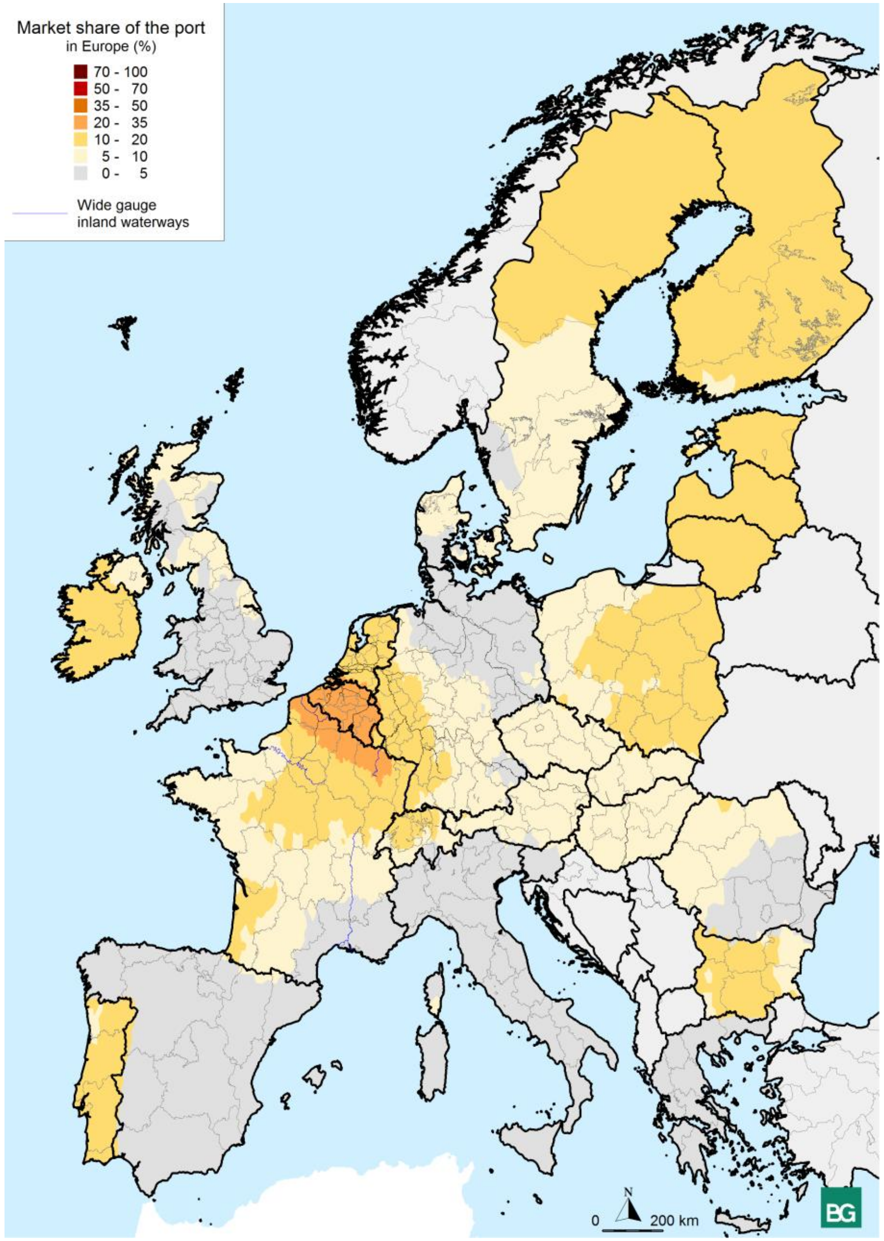
On Figure 56 & Figure 57, it can be observed that with the incorporation of the maritime segment the port of Antwerp is losing market share in Belgium, and in the French regions located at the border with Belgium that is to say: Nord-Pas-de-Calais, Picardie, Champagne-Ardenne and Lorraine. It can be seen that the market shares lost in those regions are win by the port of Rotterdam. Indeed, in Belgium the market share of the Dutch ports increase from 46 to 61 % between the basic reference and reference with maritime additional cost scenario, whereas the market share of the Belgium ports decrease from 52 to 33%.

On the other hand the market share of the port of Rotterdam decreases in Germany along the Rhine. Indeed, in the districts of Karlsruhe, Freiburg, Darmstadt, Dusseldorf, Koln, Koblenz and Rheinhessen-Pfalz the market share of the Dutch ports decrease from 42 to 34 %, whereas the market share of the German ports increase from 40 to 50 %. The port of Rotterdam is also losing market shares in the French regions of Lorraine and Franche-Comté, as in Switzerland. In Lorraine the market shares lost by the port of Rotterdam are won by the ports of Germany, Le Havre and Marseille and in the region Franche-Comté they are won by the port of Marseille, and the Spanish and the Italian ports. The market shares won by the Mediterranean ports are the consequences of the integration of the maritime segment in the model, whereas the market share won by the other ports of the HLH range are due to the smoothing effect that the additional costs for the maritime segment create.

The port of Le Havre has it market share in France that decreases quite considerably from 38 % to 31% with the integration of the maritime segment. This is due to a reduction of its market share in all the French regions, with the exception of the region Alsace and Franche-Comté where this port is winning market share.

As already, mentioned in the preceding section the port that gains the most with the integration of the maritime segment in the model, is the port of Marseille. Its market share in France increases from 17 to 21%, with an increase in all the regions in France, but above all in the regions Aquitaine, Midi-Pyrenees, Rhône-Alpes and Auvergne, due to a large decrease of the market share of the ports of the HLH ranges in those regions.

The gains of hinterland and market shares by the port of the Mediterranean are clearly represented in Figure 58 and in Figure 59 that represent the first range for each voronoi zone for the basic reference and maritime reference scenario. Indeed, on those figures it can be seen that the contestable hinterland line shifts significantly towards the north on the corridor of interest, that is to say in the Region Rhône-Alpes.



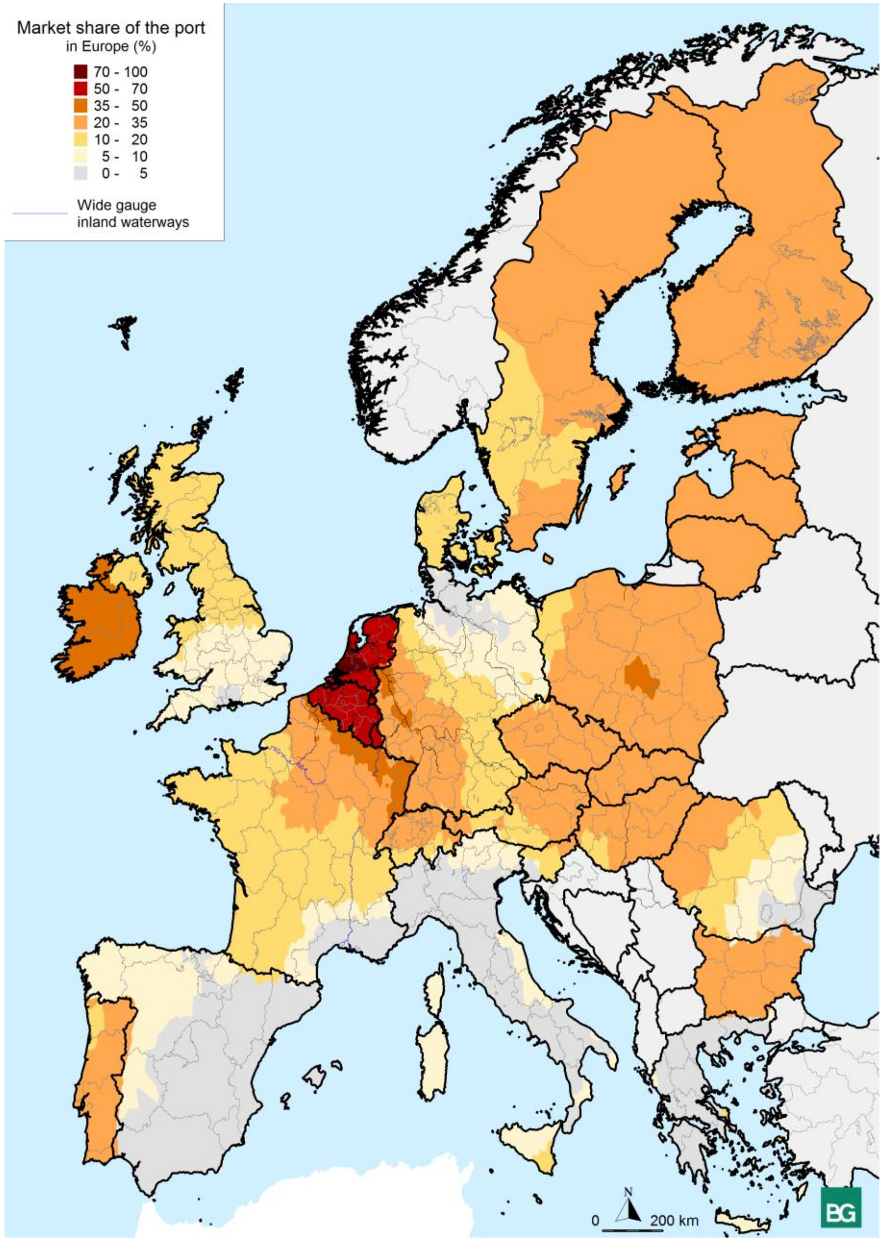


Figure 56: Market Shares of the port of Antwerp (left) and Rotterdam (right) for the relation Asia-Europe for the reference maritime scenario in 2030

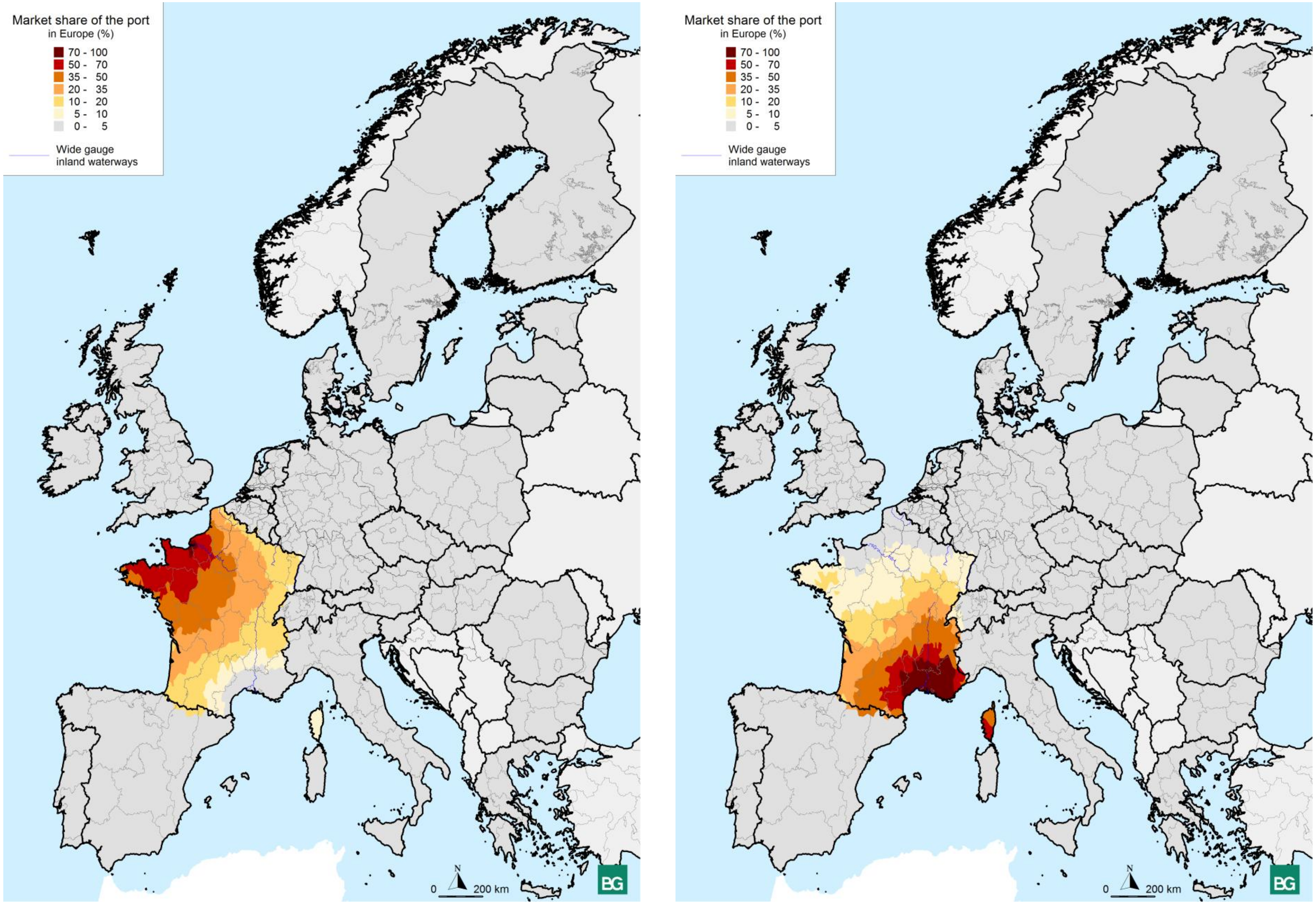
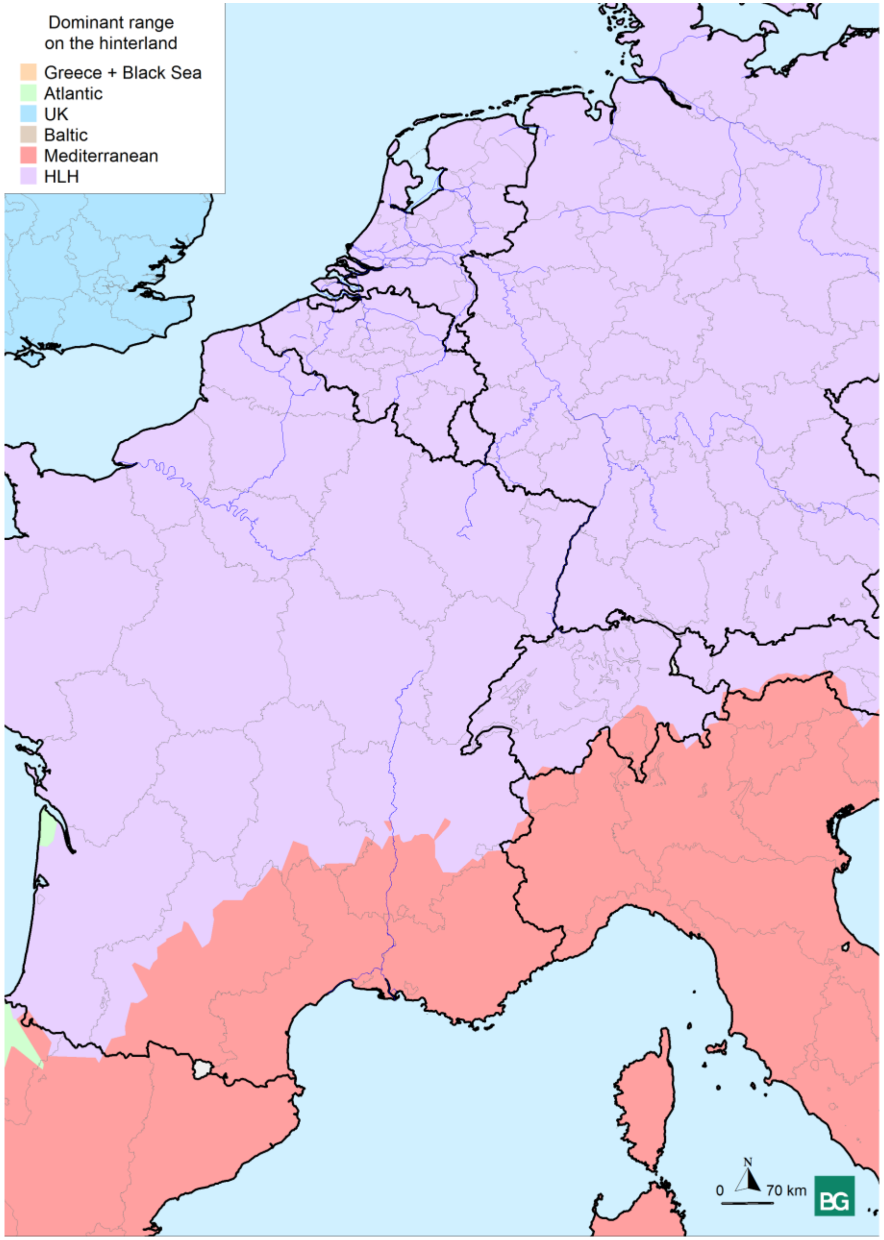


Figure 57 : Market Shares of the port of Le Havre (left) and Marseille (right) for the relation Asia-Europe for the reference maritime scenario in 2030



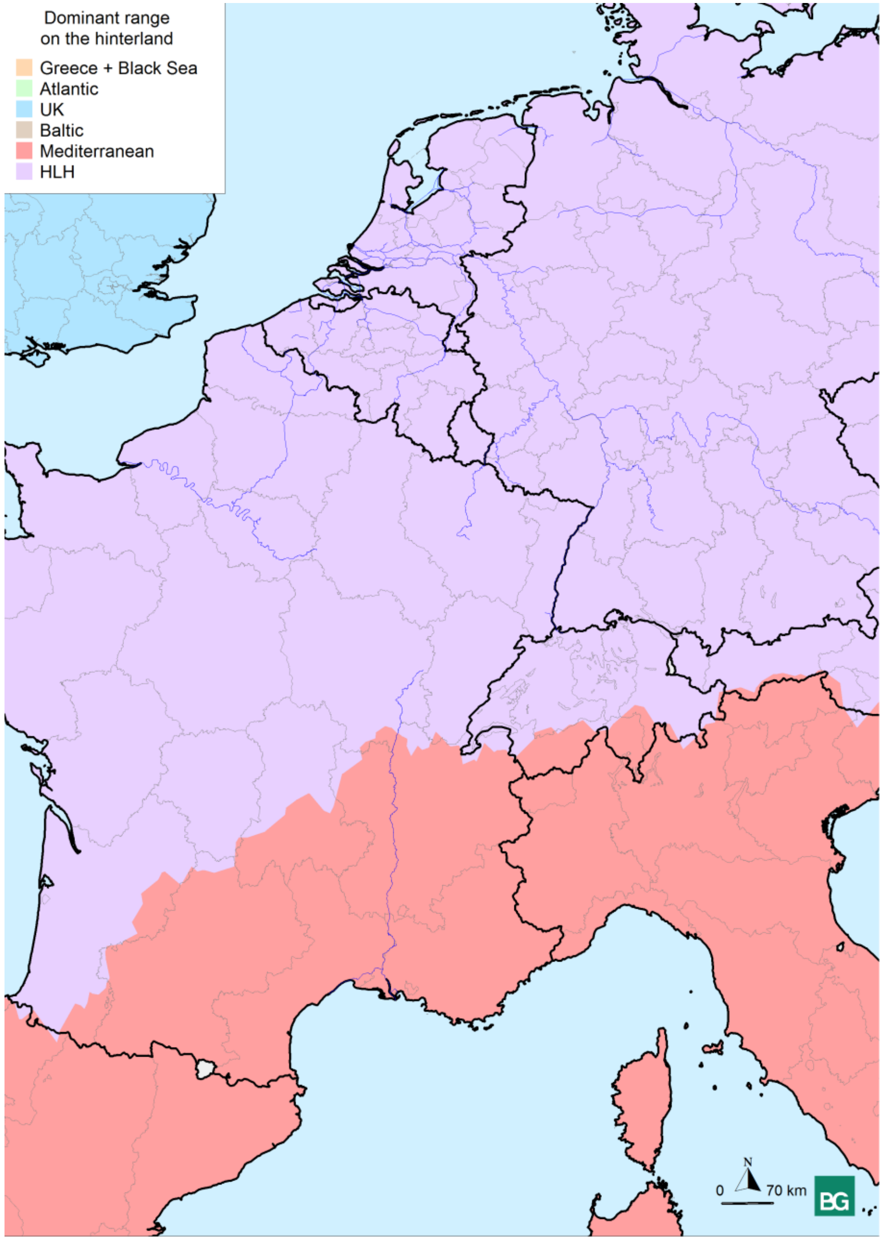


Figure 58 : Main port range in each voronoi zone of the corridor for the basic reference scenario (left) and the reference maritime scenario (right)

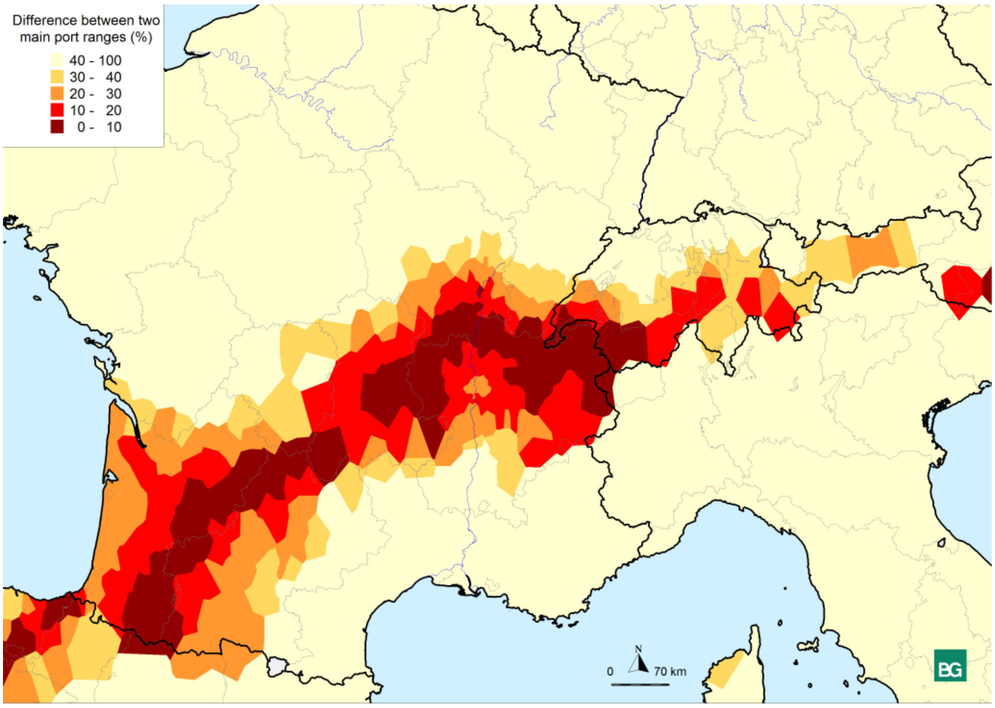


Figure 59 : Difference between the two first port ranges for the Reference maritime scenario 2030

It has been demonstrated previously, that the region Rhône-Alpes is the region of the study area that is subjected to the main impacts due to the integration of the maritime segment in the model. In order to have a clearer view of the impacts on this region, a zoom has been realized on it. On Figure 60 it can be observed that the ports of the Mediterranean ranges are winning market shares in this region, with respectively an increase of 9% for the port of Marseille, an increase of 1% for the Spanish ports and of 2% for the Italian ports. Whereas all the ports of the HLH range are loosing market share: - 1% for Germany, -3 % for the Netherlands and Belgium, -4% for Le Havre. Thus, the expansion of the Mediterranean range on the corridor of interest is mainly due to the extension of the hinterland of the port of Marseille.

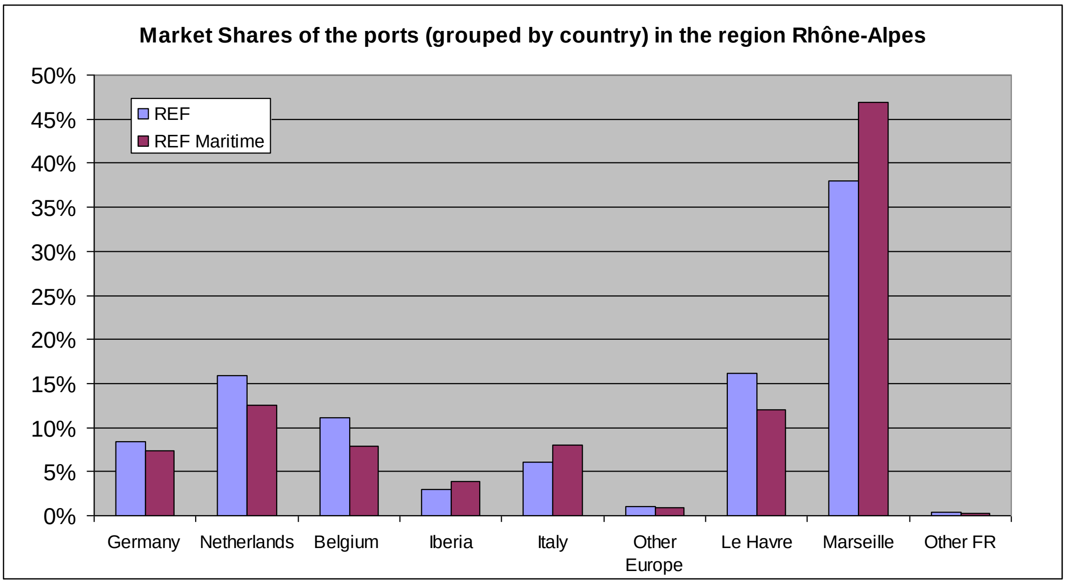


Figure 60 : Market Share of the ports grouped by country in the region Rhône-Alpes.

8.4.3. The SMSR scenario with sensitivity to the maritime costs in 2030

In this section the analysis of the SMSR scenario in the case of the integration of the maritime segment will be analyzed.

8.4.3.1. Analysis of the market shares of the ranges and of the European ports in Europe for the relation Asia-Europe for the SMSR maritime scenario

As already observed in the previous scenario, the implementation of the SMSR scenario leads to almost no change of market shares at the scale of the ranges in Europe, because this scale is too large to can observe the impacts of the project. Nevertheless, it is in this scenario that the Mediterranean range wins the most of market shares in Europe with the implementation of the canal with an increase of 0.03 %, whereas the HLH range looses 0.03 % of market share in Europe[40].

By looking at the market share of the ports in France, it can be observed that same two ports/groups of ports, as in the other economic and organizational scenarios, are winning market share between the reference and SMSR scenario with integration of the maritime segment, there are the Dutch ports (+0.3%) and the port of Marseille (+0.4%). It can also be seen that with the implementation of the canal, the port of Marseille consolidate its place as second port in France for the exchange with Asia with a market share of 22 %, against 20 % for the Dutch ports.

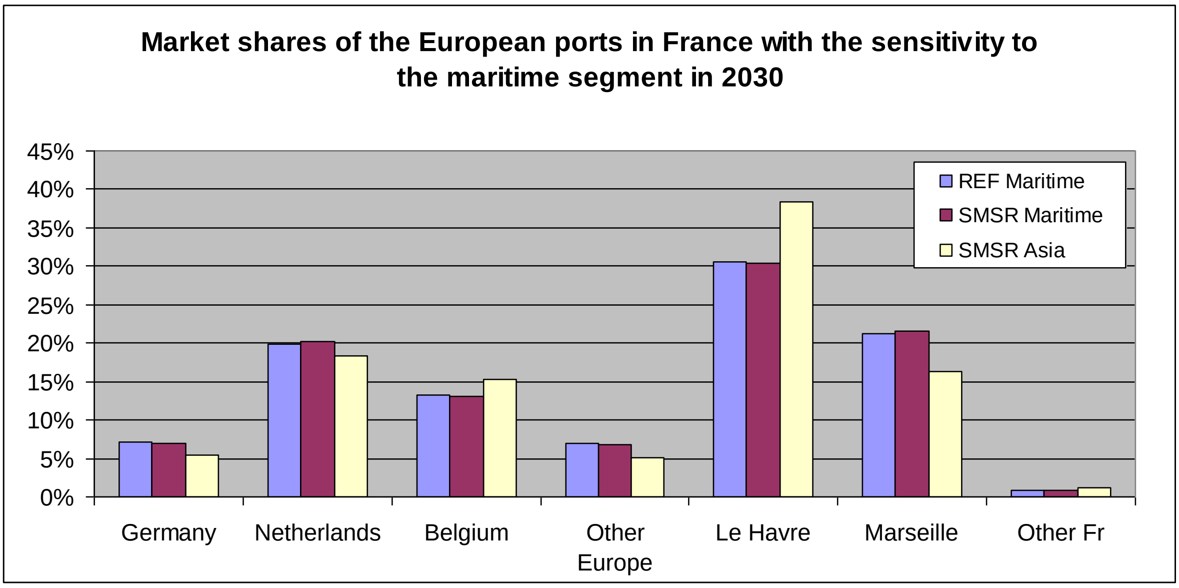


Figure 61: Market Share of the European ports in France for trade with Asia

[40] It should nevertheless, be noticed that in this case only the relation with Asia is considered, the trade relation that might be one of the most impacted by the opening of the canal, as its route pass through the Mediterranean.

8.4.3.2. Analysis of the hinterland of the ports for the relation Asia-Europe for the SMSR maritime scenario

It has been noticed in the previous scenario that the SMSR project as mainly influences on the ports of Marseille and Rotterdam, because there are the two ports that are directly connected to the Rhine-Rhone axe. That is why in this latest sub scenarios only those two ports will be analyzed as the results for the ports of Antwerp and Le Havre are pretty similar to those of the two other economic and organizational scenarios.

By comparing the SMSR maritime scenario with the SMSR maritime scenario it can be observed that the port of Rotterdam is winning market shares principally along the canal and the Rhone in the regions Bourgogne (+3%), Rhône-Alpes (+2%), Auvergne (+3%) and the regions located in the South of France (PACA, Languedoc-Roussillon, Midi-Pyrenees). But this port is also loosing market shares in Lorraine (-3%), Alsace (-2%) and Champagne-Ardennes (-1%), As already observed previously in the other organizational scenarios, the port of Marseille is winning market shares in the regions situated north of the canal, in Lorraine (+7%), Alsace (+5%), Franche-Comté (+6%), Bourgogne (+4%, Champagne-Ardenne (+1%) and Centre (+ 1%). This port is losing market share in the region Languedoc-Roussillon (-1%) and PACA (-1%).

Thus with the implementation of the SMSR canal it can be observed that the ports of Marseille and Rotterdam, win and lost their market shares in the same regions as in the basic scenario. But the main difference is that with the opening of the canal in the maritime scenario the gains of market shares of the port of Marseille in the regions located north to the canal are more important reaching value of +5 to +7 %, whereas in the basic scenario the maximum increase was of + 4%. As a reverse result the port of Rotterdam is losing more market shares in the regions Alsace and Lorraine.

This is confirmed by the analysis of the tons of containers win and lost by each port range, at the node level in the hinterland. Indeed, in Table 40 it is observed that the project is again beneficial for the Mediterranean ports and lead to reduction of the throughputs of the HLH range. But the specificity of this scenario is that the gains and losses for both ranges are more important. Indeed, in the case of the basic scenario the gains for the Mediterranean range were of 87 768 tons, in the case of the reduction of the border effects the gains were of 40243 tons, whereas in the maritime scenario the gains for the Mediterranean range are of 166 907 tons.

Table 40 : Tons differences between the reference and the SMSR scenarios with integration of the maritime segment in the whole Europe (in tons)

	Maritime scenario		
	HLH	Mediterranean	Other ranges
Win	87 104	251 139	1
Loss	-242 193	-84 231	-11 828
Total	-155 088	166 907	-11 827

For further description of the hinterland, the relative evolution of the containers trade between the French regions and the port of interest between the maritime reference and SMSR scenarios can be found in Appendix 12.

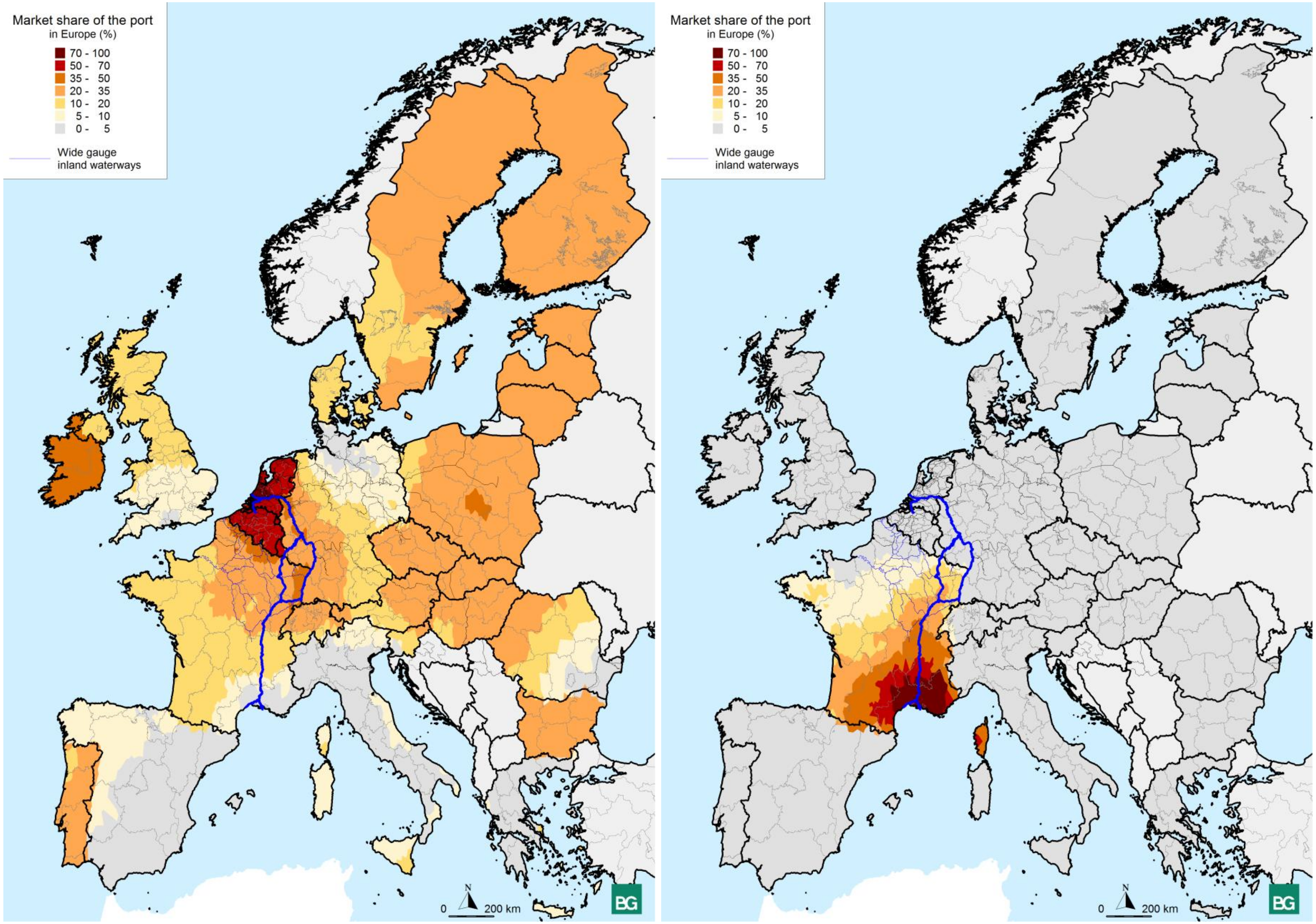


Figure 62: Market Share of the port of Rotterdam (left) and Marseille (right) for the relation Asia-Europe for the reference maritime scenario in 2030

Finally, by focusing on the contestable hinterland line (cf. Figure 63) and comparing it with the reference maritime scenario, it can be observed that this line become larger especially at the north of the region Rhône-Alpes. This signifies that after the implementation of the SMSR canal, the Mediterranean ports become more competitive in the region Bourgogne.

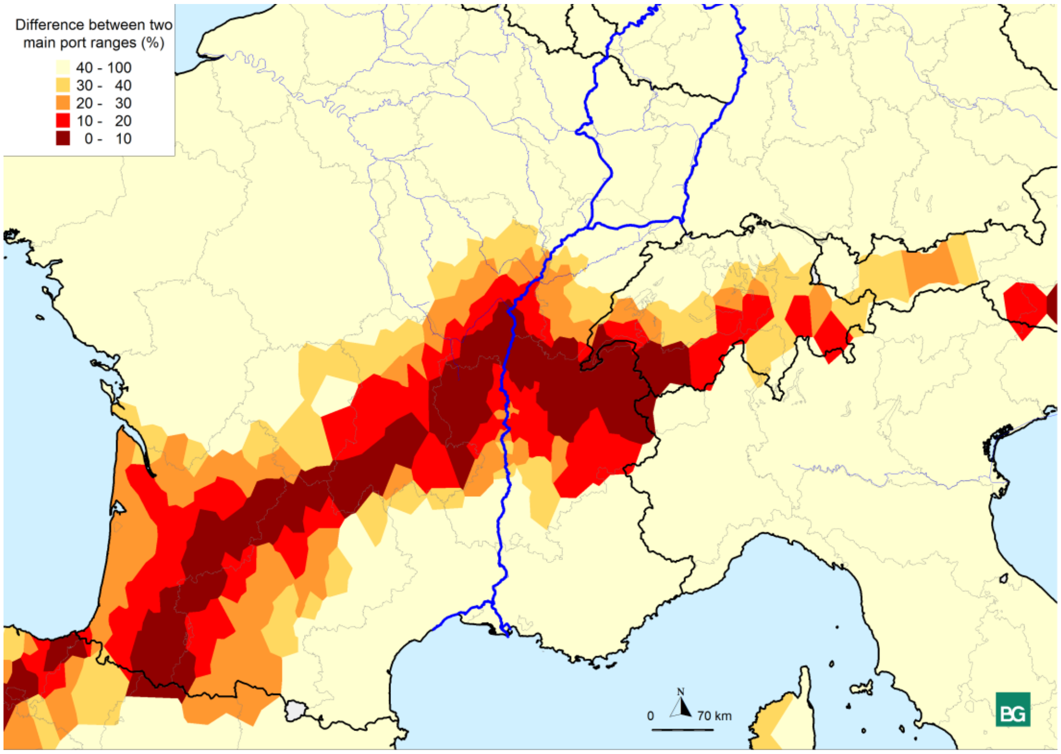


Figure 63: Difference between the two first port ranges for the SMSR maritime scenario in 2030

8.4.3.3. Conclusion of the sensitivity to the maritime segment scenario

In this scenario, it has been observed that with the integration of the maritime segment in the model, the Mediterranean range extends considerably its hinterland in France to the north, by taking market shares to the HLH range. It notably increased considerably its dominancy in the region Rhône-Alpes. It has also been demonstrated that it is under the maritime scenario that the SMSR project is the most beneficial to the ports of the Mediterranean. On the contrary, it is also under this scenario that the ports of the HLH range lost the most of tons of containers.

It can be noticed that the variation of the containers throughputs of the HLH and Mediterranean ranges seems quite low with respect to the increase of the maritime costs that represent around 15 % of the average price of shipment of a container from Asia to Europe (determined in Appendix 10). This small variation of the throughputs can be explained by the fact that in the gravity model, the port throughputs of 2007 are used for the attraction of a specific port. It is thus really difficult to make the port throughput move significantly, as the model translates the actual phenomenon of traffic distribution among the ports. In addition, the inclusion of the maritime segment, decrease the relative costs difference between the ports of the same range, leading to smoothing effect within one range in favour of the ports having the largest throughput.

Finally, it seems that if the maritime segment wants to be integrated in the model, it should be done since the phase of calibration, and it might also be more appropriate to consider a model based on a utility function rather than on a gravity model.

8.5. Conclusion of the results of the modelling of the scenarios

In this chapter, the scenarios of this research have been analyzed after having being modeled. The first result of importance is that the supremacy of the HLH range in Europe for container handling will continue to increase between 2007 and 2030. This supremacy of the HLH range will go with a significant reduction of the road modal share from 79.4 % to 72.1 %, mainly due to the increase of the road unit costs in 2030.

From this chapter it can also be concluded that the construction of the SMSR canal will not have significant effects on the containers throughput of the HLH range and the Mediterranean range, under all the economic and organizational scenarios at the time horizon 2030. Indeed, this project has too little impacts at the scale of the whole European hinterland. Nevertheless, by focusing on a smaller scale the North Sea-Mediterranean corridor the impacts of the project come up. It can indeed be observed that this project will benefit more to the Mediterranean range than to the HLH range, leading to a shift of the contestable hinterland line to the north with regard to the reference situation. At the scale of the ports it is the Dutch ports and more specifically the port of Rotterdam that sees its hinterland increases the most with the implementation of the canal, the second port that benefits from this canal being the port of Marseille. In another hand, the ports of Le Havre and Antwerp will lose market share on the corridor with the implementation of this canal.

In addition with the implementation of the SMSR project it can be observed that the modal share of the IWW and IWW+rail solutions increase slightly at the scale of Europe. This small increase at the scale of Europe is due to large increase of the modal shares of those solutions on the Rhine-Rhone axes and more particularly between the Belgium and Dutch ports and the French regions situated south of the canal and between the port of Marseille and the regions situated north of the canal. Another particularity is that the gains of the IWW and IWW+Rail solutions are mainly due to the loss of market share of the rail solutions.

The main conclusion from the border effects scenario is that the major ports are winning market shares on the smaller port, and that by consequence the HLH range is increasing its market share in France, at the expense of the French ports. The maritime scenario, leads on the contrary to gains of market shares by the Mediterranean range at the scale of Europe, leading to a shift of the contestable hinterland line to the North. It is also under this scenario that the SMSR project is the most beneficial to the Mediterranean range, and that the rail modal share increase the most due to the increasing average distances of the shipment.

9. Conclusion and Recommendations

This study had two main goals:

1. To answer the research question, that is to say to determine if the improvement of the hinterland transportation of the maritime containers, by creation of new infrastructures and services, on the corridor North Sea-Mediterranean Sea will lead to shifts of container flows between the ports of the HLH range and the Mediterranean range and to modification of modal shares on the corridor of interest.
2. To develop a port choice model that focuses on the hinterland segment of the global maritime chain and that allows to model changes in hinterland transport infrastructures and creations of new transport services at future time horizon

In this conclusion, first the replies to the research sub questions will be given, then the main research question will be answered and finally recommendations will be given about the suggested future improvements for the PortPrint model, and about the other means, different from the creation of new infrastructures and services, that need to be taken into account for the improvement of the quality of the hinterland connections.

9.1. Answers to the sub questions of the research

To can answer the main research question, it has been necessary to develop a model of port competition in Europe that can take into account the modifications on the hinterland segment of the global maritime chain. To develop this model, the process of port competition has been studied. It has been determined that port competition is mainly influenced by three factors that are the maritime segment, port transit, and hinterland transportation. Nowadays, hinterland transportation is the factor that gathers all the attention for possible improvements in the container market, as it is the main bottleneck in the global maritime chain.

As it is expected that the maritime segment and the transit in the port will not face significant changes, or only locally for port transit, in the next 20 years it has been decided to specialize the maritime model specifically toward the hinterland segment of the global maritime chain, segment to be analyzed in this thesis. Thus, it was considered that the maritime segment and port transit are constant in all the European ports. The focus on the hinterland segment of the maritime chain allows detailing this segment really precisely by specifying the exchanges at the node level in the hinterland, and by describing the costs of each hinterland transportation solution really into details.

In this thesis, three modes have been considered, divided into four transport solutions: Road, IWW+Road, Rail+Road and IWW+Rail+Road. Usually, containers are predominantly transported from the port to their hinterland by using trucks. Nevertheless, the alternatives modes, that are rail and IWW, are more and more used and have the favor of many actors for future development. Those modes can only be used if there is sufficient demand for it, and if the shipment concerns long distances, because they have drawbacks with regard to road. Those drawbacks are mainly the additional transshipments and the pre/end haulage by truck, even if in the case of maritime container only one haulage is necessary.

The port competition model that has been used in this thesis is a four step model, in which the generation of traffic has been realized based on the Comext (Eurostat database) data that have then been disaggregated at the NUTS 2 and node levels. For the distribution a gravity model has been used, and the modal spilt has been realized thank to the model of Abraham.

The corridor of interest in this thesis is the North Sea-Mediterranean corridor, due to the focus on the HLH and Mediterranean ports. Nowadays, the ports of the HLH range gather 45 % of the European container market shares against 25 % for the Mediterranean range. This distribution of the market shares among the European ports is mainly explained by the fact that the HLH range gathers the three main European containers ports that are Rotterdam, Antwerp and Hamburg. But one of the questions interesting to answer is the following: Are they specific reasons to explain the predominance of the HLH range on the Mediterranean range? The main explanations seem to be that northern Europe gathers more economic activities and population that southern Europe, they also gather the biggest, more efficient and more reliable ports of Europe, that lead to the larger economies of scale, and they benefit from favorable geographical characteristics. Another explanation is that they benefit from better hinterland connection with their hinterland.

That is why in this thesis, the infrastructure scenarios rest mainly on the improvements of the transport connections from the ports of the Mediterranean to their hinterland, in order to determine the impacts of those improvements on the port competition between the Mediterranean and the HLH ranges. The improvements of the hinterland connections are translated by the development of new rail and IWW services in the reference scenario and by the implementation of the SMSR canal, in the SMSR scenario.

In order to determine the consequences of the improvements of the hinterland connections, the economical and organisational conditions under which those improvements will take place have been defined. Three scenarios have been considered in this thesis, the basic scenario that relies on containers projection for 2030 based on socio-economic hypotheses taken from European scenarios and on transportation unit costs provided by VNF for the economic evaluation of the SMSR project. Another scenario takes the economic hypothesis of the basic scenario, but also considers a reduction of the border effects between the European countries at the horizon 2030. And the last scenario considers that the cost of shipment of containers on the maritime segment is dependent of the distance of navigation.

9.2. Answers to the main research question

In the previous section the answers to the sub questions have been sum up, reminding the process that have been developed in this thesis to answer the main research question. The answer to this research question will now be given.

9.2.1. The consequences of the creation of new transport infrastructures and services on the North Sea-Mediterranean corridor, on the containers flows of the ports of the HLH and of the Mediterranean ranges

From the results of chapter 8, it can clearly be concluded that the improvements of the hinterland transportation network that have been considered in this thesis, do not lead to a considerable shift of market shares from the HLH range to the Mediterranean range at the European scale. Indeed, the Mediterranean range is only winning 0.01% of market share in Europe (for the basic and the reduction of the border effects economic scenarios), with the implementation of this canal.

Nevertheless, by looking at a smaller scale than the whole Europe, for instance on the North Sea-Mediterranean corridor on more particularly on the French hinterland, the impacts of the project are more visible. Indeed, the creation of the SMSR canal is beneficial to two ports/group of ports in Europe, the Dutch ports and the port of Marseille, that see their trade with the French hinterland increase of respectively 4.1% and 0.6 %, between the reference scenario in 2030 and the SMSR scenario under basic economic and organizational conditions.

In addition, the market shares gains of the Dutch ports are mainly realized in regions that are located along and south of the canal, whereas the port of Marseille is winning market shares in regions located along and north to the canal, but only in France. Indeed, under all the economic and organizational scenarios, the opening of the SMSR canal does not allow the port of Marseille to extend its hinterland beyond the French borders.

In order to analyse the evolution of the hinterland, the concept of contestable hinterland line, has been developed in this thesis. It consists for all the nodes of the study area to compute the difference of market shares between the first and second ranges for that node. The smaller the difference, the higher the competition between those two ranges. The nodes having the smaller differences have been assigned a dark colour on the map, and create a line in the hinterland. By looking at the position of this contestable hinterland line between the reference and the SMSR scenarios on the North Sea-Mediterranean corridor, it can be observed that there is a slightly shift toward the north. This is consistent with the fact that with the opening of the SMSR canal, it is the Mediterranean range that benefits the most whereas the HLH range is losing market share.

It is also important to compare the results of the two divergent organizational scenarios with the basic scenario. It is observed that by comparing the reference basic scenario and the reference scenario with reduction of the border effects, the contestable hinterland line shifts slightly to the south, showing that the major ports (Antwerp and Rotterdam) that belong to the HLH range, win market shares on the smaller ports. For the maritime scenario, a large shift of the contestable hinterland line is observed to the north, showing that the Mediterranean range is extending its hinterland to the north at the expense of the HLH range, by the implementation of an additional maritime cost between those two ranges.

Thus, from what precedes it can be stated that the creation SMSR scenario will be the most beneficial for the Mediterranean range in the case of the maritime scenario, and the less beneficial in the case of the reduction of the border effects.

The impacts of the infrastructure improvements and organizational changes have been observed on the ports throughputs and hinterlands, it is also interesting to determine the impacts of the implementation of the North Sea-Mediterranean corridor on modal spilt.

9.2.2. The consequences of the creation of new transport infrastructures and services on the North Sea-Mediterranean corridor, on the modal spilt

Between the base scenario in 2007 and the basic reference scenario in 2030 the road modal share decreases considerably, from 79.4 % to 72.1 %, mainly because of the high increase of the road unit costs in 2030, but also due to the development of new IWW and rail services. This decrease of the road modal share is pretty high in countries that offer good alternatives transport solutions and where new IWW and rail services have been created and goes along with an increase of the modal share of the three other alternatives transport solutions.

With the implementation of the SMSR project the modal shares of the IWW and IWW+Rail solutions increase slightly at the scale of Europe. This small increase at the scale of Europe is due to large increases of the modal shares of those solutions on the Rhine-Rhone axes and more particularly between the Belgium and Dutch ports and the French regions situated south of the canal and between the port of Marseille and the regions situated north of the canal. That is to say, on the port-hinterland relations where the gains of traffic have been observed with the creation of the SMSR canal.

Another particularity is that the gains of the IWW and IWW+Rail solutions are mainly due to the loss of market share of the rail solutions. This can be explained by the fact that with the current forecast of the unit costs of the road mode in 2030, this mode is still more advantageous than the alternatives modes. To see a drastic shift toward the rail and IWW solutions, is seems necessary to proceed to a considerable increase of the road cost.

In the reference scenario with reduction of the border effects, it can be observed that the alternatives modes are even more used, than in the basic reference scenario. This is due to the fact that with the reduction of the border effects, the major ports become even more attractive and thus the hinterland shipment distances of the containers increase, which is favorable to the alternatives modes.

9.2.3. Conclusion

To conclude, it can be said that the ports of the HLH range will stay dominant in Europe with the implementation of the North Sea-Mediterranean corridor, and that the implementation of this corridor will lead to small shift of the modal share towards the IWW and IWW+Rail solutions at the scale of Europe.

9.3. Limits and recommendations for further development of the model

In this paragraph, first the limits of the model will be displayed, then suggested improvements for future research will be formulated.

9.3.1. The PortPrint model: a tool to model the modifications of the hinterland segment of the whole containers maritime chain

The model used in this thesis, has been developed to model the influence of changes in the hinterland segment of the global container maritime chain, on the process of port choice decision making among a large amount of ports in Europe. Those modifications of the hinterland segment refer to:

- modifications of the transport infrastructures by creation or suppression of some links in the network or improvement of the characteristics of the existing links;
- creation of new rail and IWW services;
- increase or decrease of the unit transport costs for the different hinterland modes.

The results observed in the previous chapters show that this model is a good tool to can model port choice decision making when the only changes with regard to the current situation concern the hinterland transportation segment. Nevertheless, for changes related to other segments of the maritime chain the model reaches its limits.

This has been noticed in this thesis, with the integration of the maritime segment in the model. The results obtained for the maritime scenario seem to be quite alleviated with regard to what was expected. This is mainly due to the fact that in the model the factor of attractiveness of the port is the container throughput of this port in 2007. The conclusion is thus made that the model cannot take into account considerable changes about the port throughputs in the future that are not related to the hinterland segment.

It should thus be noticed that the model should be used, as all the other models, only for the purpose it has been created that is to say, to evaluate the influence of changes in the hinterland transportation networks and services on port choice in Europe.

9.3.2. Suggested future improvements for the PortPrint model

The PortPrint model has been developed specifically during this thesis. Even if it has been demonstrated that this model allowed to model the influence of changes in the hinterland segment on port choice decision making, improvements of this model are still possible and even recommend. That is why improvements for further research will be suggested in this section.

First, this model could be made more accurate from a scientific point of view by substituting the actual impedance function, which corresponds to the minimum costs of all the transport solutions between a port i and a hinterland node j, by the logsum. The reasons for such a substitution have been developed in chapter 5. During this thesis I tried to realize this substitution myself, but I was unable to come with a good calibration of the model. This is partly due to the fact that the data available to calibrate the model are really scarce. For a future research it will be recommended to apply the logsum and to try to find a way to calibrate the model in an accurate way.

Then, it can be stated that some characteristics of the hinterland transportation process have not been taken into consideration in the PortPrint model. Indeed, in this model the modal share of the hinterland haulage is mainly based on the cost of each transport solution, whereas in realty other factors have influences on the modal share. The organization and complexity of the hinterland haulage that have been taken into account in the model through a parameter is one of those factors. Another factor that will be of interest for the determination of the modal share from a port to its hinterland is the strategy of the port toward modal spilt. For instance, the ports of Hamburg and La Spezia have a strategy really orientated towards rail, explaining the high modal share of rail for inland transportation. This factor is not taken into account in the PortPrint model, it will be interesting to can integrate such a factor in the model to lead to more accurate results with regard to modal share, even if it is a factor really difficult to quantify.

Another factor that has only been partially taken into account in the model, which had influence on the modal spilt, is the structure of the logistics chains. In the PortPrint model intermodal platforms have been taken into account, but the distribution centres (DC) have not been considered, contrary to the SMILE model (Tavasszy et al, 2009). The location of those DC can have several consequences on the distribution of goods in the hinterland, notably if they are located in the vicinity of the ports. It might be interesting in the future to integrate them in the model, to take their influences into account in the flows of containers in the hinterland.

It seems also interesting to integrate the congestion that occurs in the port in this model. The consideration of the congestion in the port is indeed one of the elements that is of high importance for the shippers and that can decrease significantly the reliability of the global maritime chain. The difficulty to integrate it in the model is to quantify it in a homogenous way among all the ports. The congestion in the hinterland network can also have influence on the choice of the shippers; nevertheless it seems to have less influence than the congestion in the port.

The three latest factors that have been stated in this paragraph, seems interesting to consider in future, model. Nevertheless, the main difficulty will be to quantify those factors for the 130 ports of the study area in a comparable scale. The integration of all those elements might also be difficult with the actual structure of the model. If those factors have to be integrated in the PortPrint model, it might rather be advised to use a utility function and thus to use a logit model for the distribution module, instead of a gravity model. Nevertheless, this is left for future research.

Finally, one of the future developments that might lead to considerable improvement of the model is the provision of additional data for the calibration of the model. This seems feasible, by developing enquiries that allows obtaining information on the total transport chain of the shipment, from its origin to its final destination, with all the intermediary stops and modes used in the global maritime chain. The main constraints to obtain those data will be on the application/establishment of such an enquiry, and the willingness of the actors to share confidential/commercial data.

The model that has been used in this thesis, allows having a really good description and consideration of the hinterland network and services in Europe. Nevertheless, the description of the hinterland network in the other part of the world is missing. It will be interesting to develop this model at a worldwide scale, in order to can combine it, with model that focus on the maritime segment and the port transit. Indeed, models have already been developed on those specific points. It seems interesting in the future to combine those models in order to come with a model that will be able to model the global maritime chain, from the hinterland of origin to the hinterland of destination. The difficulty by combining all those models will be to make the combine model applicable in practice, with acceptable running time.

9.4. Other means of improvement of the quality of the hinterland connections

Finally, to conclude it can be stated that even if in this thesis the focus has been on infrastructure improvements and creation of new services in the hinterland, there are other means to improve the hinterland connections of the ports. These means are: the organizational and management aspects of the global transport chains, and they are of equal importance than the infrastructure considerations. Among those organizational and management aspects, the process of developing a better link between the mode of transport and the volume to be transported can be quoted; as the development of a better cooperation between the different actors of the global maritime chains. Indeed, this latest measure will improve the exchange of information between the actors, leading to a better optimization of the hinterland transport, and thus making the global maritime chain more efficient, which is the final goal.

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Appendices

Appendix 1: Determination of the container matrix

In this appendix the methodology of the determination of the exchange OD matrices, between each country of the study zone and the partner maritime zones will be provided.

As mentioned in $ 5.1.2, first the products that are usually classify according to the NST/R or HS classification have been divided into 16 groups:

Table 41 : Groups of products

Groups of product	Correspondance NST/R	Correspondance HS
P1 – Cereals and agricultural products	00 01 04 06 09 17 18	1 6 10 11 12 13 14 15 23 40 41
P2 – Foodstuffs	02 11 12 13 16	9 16 17 18 19 20 21 24 (22)
P3 – Foodstuffs packed	03 14	2 3 4 5 7 8
P4 – Wood and paper pulp	05 84	44 45 46 47 48
P5 – Iron ore	41 45 46	26
P6 –Petroleum products and coal	21 22 23 (31) 32 33 34	27
P7 – Metallurgic products	51 52 53 54 55 56	72 73 74 75 76 78 79 80 81
P8 – Cement and other manufactured building materials	64 69	68 69 70
P9 –Natural mineral and building materials	61 62 63 65	25
P10 – Basic chemical products	81 83	28 29
P11 – Fertiliser	71 72	31
P12 –Other cheminal products (among with plastic material)	82 89 (891)	30 32 33 34 35 36 37 38 39
P13 – Transportation material	91 92 939	86 87 88 89
P14 – Capital goods	931	84 85
P15 – Textile/clothing	96	50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67
P16 – Other manufactured products	94 95 97 99	42 43 49 71 82 83 90 91 92 93 94 95 96 97 99

Then, it was necessary to determine which groups of products were containerisable. The product 1 contains both bulk products and containerisable products it is thus necessary to determine the rate of agricultural products that can be containerized. To do so the following formula is applied:

$$Rate.of.Containerisable.for.P1 = 1 - \frac{Tons.Bulk.P1.of.Ports.EU27}{Total.Tons.P1.of.Countries.EU27}$$

This rate is compute for the whole Europe with all the partners' maritime zones defined in § 5.3.3. The data related to $Tons.Bulk.P1.of.Ports.EU27$ being obtained from Eurostat Port data and those related to $Total.Tons.P1.of.Countries.EU27$ obtained from the Comext database.

Products P5, P6, P9 and P10 are bulk products they are thus not taken into account in the containerization. Indeed, they are always transported as bulk cargo.

Products P2, P3, P8, P14, P15 and P16 are unitized products. Products P4, P7, P11, P12, and P13 are general cargo products. It is considered that for maritime transportation both those groups of products might be containerisable. Indeed, general cargo products and unitized products can be transported either in container or as general cargo.

So the products that might be containerisable are:

$$
\begin{aligned}
\mathrm{Pr}oducts.Containerisable = P1 * Rate.of.Containerisable.pour.P1 + P2 + P3 + P4 + P7 + P8 \\
+ P11(without.natural.fertilizer) + P12 + P13 + P14 + P15 + P16
\end{aligned}
$$

The data regarding the products containerisable are obtained from the Comext (Eurostat) database and are obtained in tons per country.

After having determined the tons of products that might be containerisable it is necessary to determine the rate of containerization in the ports. It is determined as follow:

$$
Rate.of.Containerisation.in.the.ports = \frac{Tons.Container.of.Ports.EU27}{Tons.(Container + General.C\arg o).of.Ports.EU27}
$$

This rate of containerization expresses the percentage of containerisable products that are transported by containers, the other share being transport as generalized cargo or unitized products. It thus refers to the way goods are transported. The rate of containerization is obtained by large ports zones (Asia, North America, South America, Africa, Mediterranean, and Europe) from the port data.

So the number of tons that will be transported by container is:

$$
Container = Tons.of.\mathrm{Pr}oducts.containerisable * Rate.of.Containerisation.in.the.ports
$$

Appendix 2: Description of the transport unit costs in 2007 and 2030

In this appendix the road, rail and IWW unit costs will be described.

1. The road costs

In Chapter 5, it has been specified that the costs of driving through a section a, is equal to:

$$\mathbf{Cost_a = C\_Fkm_a + C\_Time_a \ + C\_Toll_a \ + C\_Energy_a}$$

Nevertheless, the components of those costs have not been detailed. In this section the unit road costs will be described and their value will be given.

$\mathrm{C\_Fkm_a}$ corresponds to the fixed kilometre cost and can be defined by:

$$\mathbf{C\_Fkm_a = Lg_a * (C\_tyre + C\_repar)} \qquad (2)$$

$\mathrm{C\_Time_a}$ corresponds to **t**he hourly cost on a section and can be defined by:

$$\mathbf{C\_Time_a = Time_a * (C\_salary + C\_day)} \qquad (3)$$

$\mathrm{C\_Toll_a}$ corresponds to the toll on the infrastructure and be defined by:

$$\mathbf{C\_Toll_a = (Lg_a * \ P\_km_a) + \ P\_punct_a} \qquad (4)$$

Finally, $\mathbf{C\_Energy_a}$ corresponds to the cost of energy and can be defined by:

$$\mathbf{C\_Energy_a = Lg_a * Conso_a * \ (C\_Fuel + C\_TIPP + C\_Tcarb)} \qquad (5)$$

With

$Cost_{(a)}$: Cost of driving through section a

$Lg_{(a)}$: Length of the section

$Time_{(a)}$: Travel time on section a

C_Tyre: Fixed kilometer cost related to the tires

C_repar: Cost kilometer related to the repairs and maintenance of the vehicles

C_salary: Salary, expenses and travel costs of the driver

C_day: Fixed daily cost (Amortization of the vehicle and structural costs)

$P\_km_{(a)}$: The kilometer toll associated to the section a. If no toll is associated then the value is nul

$P\_punct_{(a)}$: The local toll associated with the section a. If no toll is associated then the value is nul

$Conso_{(a)}$: The unit km consumption in liter of an heavy good vehicle on the section a. It is dependent of the average speed of the vehicle on the section.

C_Fuel: The unit costs of a liter of fuel

C_TIPP: The unit cost of the TIPP by liter of fuel

C_Tcarb: The unit cost of the carbon tax by liter of fuel

After having defining the form of the equation, it is important to know which value have been taken for all the unit costs used in those equations. That is what is going to be done in the next paragraphs.

1.1 Evaluation of the road costs

The evaluation of the road costs between an origin and a destination depend of three factors:

- the exploitation costs specific to the road mode that are independent of the infrastructure that has been used,
- the variable costs that are function of the characteristics of the transport network,
- the temporal rupture generated by the driving cycle.

1.1.1 The exploitation costs independent of the characteristics of the infrastructure

First, the value of the unit road costs that are independent from the infrastructure used will be specified. Those costs gather: the fixed kilometer costs and the hourly cost, knowing that the hourly costs are dividing in fixed cost per hour (C_salary) and fixed cost per day (C_day). Those value are extracted from the results of the enquiry realized by the Comité National Routier (CNR, 2010) on 220 long distance transport companies on the conditions of exploitation of the vehicle and the costs (fixed, employee and km).

First, it should be acknowledged that it is considered that the numbers of day of exploitation per year are of 237 and that the average number of TEU transport per HGV is f 1.8. The following values for 2007 are used by the model:

Table 42 : Road costs independent of the infrastructure

Road cost independent of the infrastructure			2007
Fixed kilometer costs (C_tyre+C_maintenance)			
	Tyres	€07/km	0.04
	Maintenance and repairs	€07/km	0.12
	Total maintenance	€07/km	0.15
Hourly costs (C_salary)			
	Salaries and expenses	€07/h	17.24
	Travelling costs	€07/h	2.76
	Total fixed costs per hour	€07/h	20
Fixed daily costs (C_day)			
	Vehicle insurance	€07/d	12.8
	Taxes	€07/d	2.5
	Ownership vehicle	€07/d	54.23
	wnership towed vehicle	€07/d	16.02
	Structural costs	€07/d	79.19
	Dmamages	€07/d	0
	Total fixed costs per day	€07/d	164.8

1.1.2 The variable costs dependent of the characteristics of the infrastructure

The variable costs are assigned to the section of the road network. The road cost thus depends of the sections used to link an origin and a destination. Two categories of cost depend of the infrastructure: the costs of energy and the tolls.

a) The cost of energy

The cost of energy is function of the consumption of the vehicles and refers to two dimensions: the fuel's costs (without taxes) and the diesel fuel tax. The data related to the costs of energy have for source SETEC-STRATEC (2010).

- *The consumption of vehicles in function of the average speed*

The unit consumption of vehicles depends of the speed of the vehicles and thus of the type infrastructure used (indeed in this model each type of road infrastructure has been assigned a speed). In order to take this variation and the quality of the infrastructure into account, this parameter is modulated in function of a consumption indicator specific to each type infrastructure.

The base value of fuel consumption that is used in this model is the one for an average speed of 68.4 km/h (CNR, 2010). On highway the consumption of the same HGV decrease by 7 %, and increase of 18% and 34 % on the main and secondary roads. The consumption of fuel on each infrastructure is computed by multiplying the consumption at the speed of 68.4 km/h by a coefficient of consumption.

- Fuel costs

In this thesis it has been considered that the fuel costs in 2007, is of 0.49 €/L, due to a barrel price of 72.5 $. This costs is then assumed to be of 0.69 €/L in 2030 due to a barrel price of 93.3 $.

- *The kilometer costs related to the fuel*

Finally, the kilometer costs related to energy are thus differentiated in function of the type of infrastructure, considering a variable consumption in function of the average speed. In this research it is assumed that in 2007 the fuel costs is of 0.182 €07/L .

- *The diesel fuel tax*

In addition to the energy costs, it is also necessary to take into account the diesel fuel tax. The diesel fuel tax was fixed in France in 2007 to 0.426 € per liter (CNR, 2010). Its cost is directly related to the consumption of the vehicles and to the type of infrastructure as indicated in the following table.

Table 43: Consumption in function of the type of infrastructure

Type of road	Average speed in km/h	Coefficient of consumption	Consumption in L per km	Fuel cost in € per km	Diesel fuel tax per container in € per km
Highway	80	0,931	0,347	0,169	0,148
2*2 voies	70	0,989	0,369	0,18	0,157
Average speed CNR	68,4	1	0,373	0,182	0,159
Main/National road	50	1,184	0,442	0,215	0,188
Secondary road	40	1,343	0,501	0,244	0,213

b) The tolls

The highway tolls are diverted from the tolls of the highway concession companies in 2007. The following costs have been applied. The tolls are assigned to the infrastructure.

Table 44: Road tolls in 2007, without taxes (Source: BG, 2014)

Highway toll per km in 2007	Cost in € per HGV/km
French Highway concession	0,208
Spain	0,144
Italy	0,128
Rest of Europe	0,136

The reductions grant in function of the frequency at which HGV used the highway cannot exceed 13 % of the price of the toll. It has been decided to diminish the toll of 10 % to take the reductions into account.

1.1.3 The temporal rupture generated by the driving cycles

The travel time between an origin O and a destination D corresponds to the sum of the driving time on the sections selected by the shortest path, and of the rest and break times. Those rest and break times that are components of the driving cycle can considerably increase the travel time, and create border effects in the evaluation of the costs of the road transport. The driving cycle are determined by the European regulation n°561/2006 that prescribes a break of 45 minutes for every 4.5 hours of driving and a minimal rest of 9 hours after 9 driving hours.

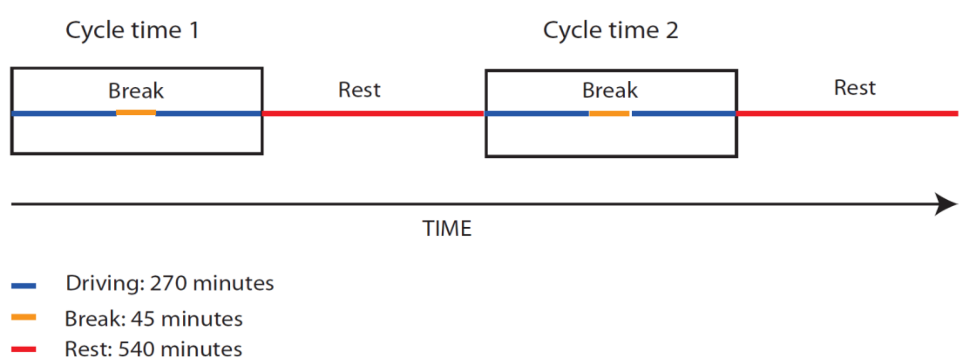

Figure 64: Structure of the driving cycle considered in the model

Thus the total road costs are then the sum of the driving cost and the break and rest costs. This cost thus integrates the cost of immobilization of heavy good vehicle due to those breaks and rests. The income of the driver is not taken into account during the rest considering that the driver can use this time as he wants.

1.2 Evolution of the road costs at the horizon 2030

In this thesis, it is assumed that the load of the heavy good vehicles is going to increase. The hypothesis is made that this increase will have the following pattern: 6.9 % between 2007 and 2030[41].

- **Evolution on the other costs than energy or toll**

The evolution of the costs of exploitation costs for 2030 are defined from the time series between 2000 and 2011 that are extracted from the CNR indicators of an HGV of 40 tones between 2000 and 2010. They allow computing the average annual growth rate during this period.

Table 1 : Time series of the exploitation costs between 2000 and 2011 (CNR, n.d.)

		Infrastructure costs	Maintenance	Driver	Travel costs	Equipment	Stuctural costs
2000	Decembre	100	100	100	100	100	100
2001	Decembre	101	102	101	101	99	101
2002	Decembre	102	103	106	101	97	101
2003	Decembre	104	104	104	101	96	100
2004	Decembre	105	106	105	102	95	101
2005	Decembre	106	108	104	102	97	97
2006	Decembre	108	111	102	103	99	97
2007	Decembre	107	113	103	102	98	99
2008	Decembre	127	119	107	103	105	102
2009	Decembre	130	120	106	102	108	102
2010	Decembre	129	122	106	103	109	102
2011	Decembre	130	128	104	102	106	99
Growth rate 2000-2011		2,33%	2,06%	0,26%	0,06%	0,62%	-0,21%

The evolution of the costs that are indepedent from the characteristics of the infrastructures between 2007 and 2030, are summed up in the following table.

Road cost independent of the infrastructure		2007	2030	Annual growth 2007-2030
Fixed kilometer costs (C_tyre+C_maintenance)				
Tyres	€07/km	0.04	0.06	2.06%
Maintenance and repairs	€07/km	0.12	0.19	
Total maintenance	€07/km	0.15	0.25	
Hourly costs (C_salary)				
Salaries and expenses	€07/h	17.24	18.31	0.26%
Travel expenses	€07/h	2.76	2.8	0.06%
Total fixed costs per hour	€07/h	20	21.1	
Fixed daily costs (C_day)				
Vehicle insurance	€07/d	12.8	12.19	-0.21%
Taxes	€07/d	2.5	2.41	
Ownership vehicle	€07/d	54.23	62.5	
Ownership towed vehicle	€07/d	16.02	18.46	
Structural costs	€07/d	79.19	75.45	0.62%
Damages	€07/d	0	0	0
Total fixed costs per day	€07/d	164.8	171	

Table 45 : Exploitation costs in 2007 and 2030

[41] Those hypothesis are taken from the study Seine North Europe (Setec-Stratec, 2010)

- **Evolution of the costs that are dependent from the characteristics of the infrastructures.**

As explained in the previous section the energy and toll costs depend of the type of infrastructure used. The evolution of those costs at the horizon 2030, will be given by indicating the annual growth rate between 2007 and 2030, for all the categories.

Table 2 : Evolution of the energy and toll costs at the horizon 2030

Energy		Annual growth rate between 2007 and 2030
	Consumption	-0.45%
	Fuel cost	2.36%
	Diesel fuel tax	-0.44%
Toll		0.50%

In addition, it can be state that in 2030 an additional tax is added, the carbon fuel tax. This carbon fuel tax been is considered with a value of 50 €/tonne of CO in 2030.

- **Average costs at the different horizons**

The indicateurs taken into account induce an increase of the road cost among the time. This increase is nevertheless slightly compensate d by the productivity gains of the road mode through the increase of the average load within the time.

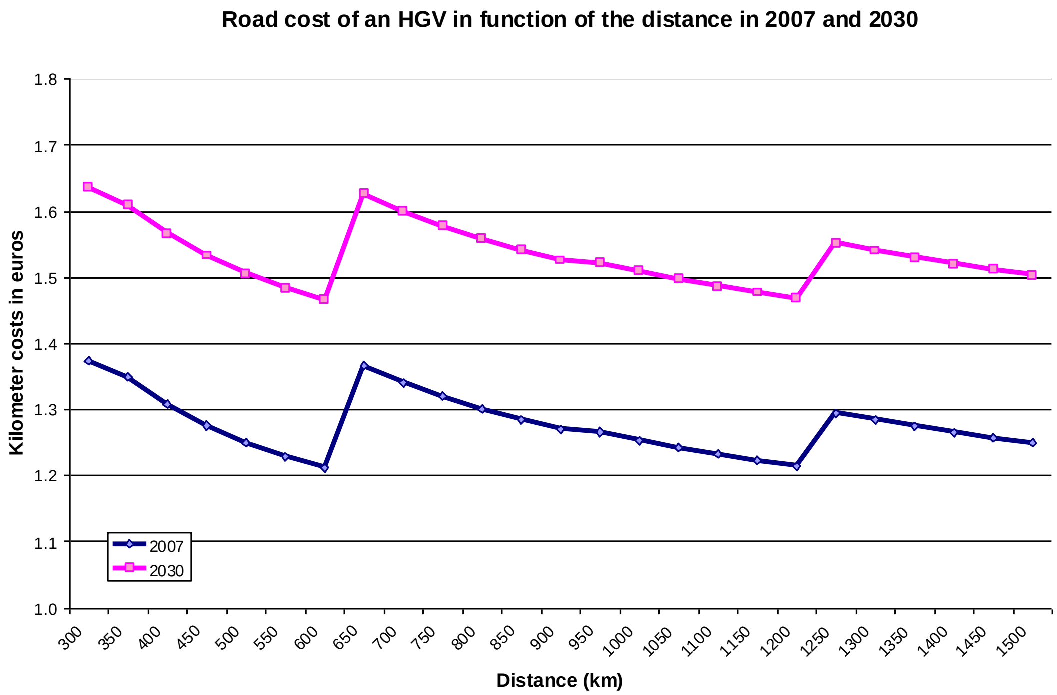

Figure 65: Road costs of an HGV at different time horizons for an average speed of 68.4 km/h

Table 46: Evolution of the average road costs between 300 and 1500 km

	Year	Load HGV	Average cost per HGV	Average cost per ton
Cost per km	2007	17.3	1.27 €	0.073 €
	2030	18.5	1.48 €	0.080 €
Growth rate per year	2007 - 2030	0.29%	0.67%	0.38%

2. The rail costs

The hypotheses of the rail costs are based on the exploitation costs model reconstituted in the study of the bypass of Nîmes-Montpellier. Hypotheses adjust later in the study of GPSO and LNMP (Ligne nouvelle Montpellier Perpignan) and that are used today as references by Réseau Ferré de France.

In this study the focus will be only on the combined train transport. The marshalling train, whole train and car train will not be considered because there are not relevant in the study of the maritime containers.

First the costs of exploitation of the train that are independent of the infrastructure used will be defined with notably the specification of the time and kilometer components but also the cost of the setting up of the train. Then the fees to can run a train on the infrastructure will be mentioned, before to conclude this section with a comparison of the costs at the horizon 2007 and 2030.

2.1 The costs of exploitation

The exploitation costs of the combined train are modeled as a binomial function:

- A **time component** that included the staff expenditures, but also the amortization and maintenance costs, that will have consequences on the productivity of the material.
- A **kilometer component** that integrates hypothesis on the tolls of infrastructure, the consumption of energy and train maintenance.

For the intermodal transport services the model simulates also the pre and end road haulage as explained in chapter 5.

The evolution of the costs of exploitation at the different horizons is the result of the integration of several factors:

- An increase of the working days per year,
- An increase of the productivity of the employees,
- An increase of the average load of the trains.

Determination of the value of Crail_km and Crail_Time (§ 5.4.3.2.2) in 2007 and 2030

Table 47: Rail costs per train in 2007-2030 and variation of those costs

Kilometer costs (€/km) Crail_km	2007	2030	Variation 2030-2050
Maintenance loco	0.68 €	0.61 €	-10%
Energy	0.81 €	0.81 €	0%
Maintenance wagons	2.37 €	2.08 €	-12%
Total kilometer costs without structural cost	3.86 €	3.50 €	-9%
Structural cost	0.31 €	0.23 €	-26%
Total kilometer costs	**4.17 €**	**3.73 €**	**-10%**
Hourly costs (€/h) Crail_time			
Drivers	122.56 €	86.69 €	-29%
Ownership locomtive	213.38 €	150.73 €	-29%
Ownership wagons	208.18 €	206.79 €	-1%
Total hourly costs without structural costs	544.12 €	447.18 €	-18%
Structural costs	43.53 €	30.96 €	-29%
Total hourly costs	**587.65 €**	**478.27 €**	**-19%**
Constant	- €	- €	
Number of annual hours per loco	**2 100**	**2 519**	**20%**
Average load train	**433**	**464**	**7%**
Working days	**235**	**273**	**16%**

Determination of the cost of the setting up of the train (equation (11) Crail_Form_train in § 5.4.3.2.2)

The rail operation requires considering the rail costs at two different speeds: the speed of the train and the commercial speed (time disposal of the wagons) considering notably the immobilization time of the wagon (composition decomposition of trains) at the end of the route. The time required for the make up of trains is of 6 hours for combined trains. The costs of this phase consists of the multiplication of the time of the made up of the train multiply by the cost of ownership of the wagons.

Table 48: Cost of the setting up of the train Crail_Form_train

	2007	**2030**
Setting up time of the train in hours	6	6
Setting up costs of the train (per train)	1 249,07 €	1 240,74 €
Setting up costs of the train (par tons)	2,88 €	2,67 €

In addition, it can also be précised that the costs of ownership of the containers is estimated at 5 € per day and per container. This cost does not change at the different horizons.

2.2 The railway network usage fees

The usage fees on the sections are decomposed in two segments: the minimal service fees and the fees related to the transport of electricity (RCE/RCTE). The minimal service fees are composed of a booking fee based on the train_path.km and a traffic fee based on train.km. The booking fees depend of the tariff category[42] of the section and on the time of the day during which the train circulate.

The integration of the rail usage fees in the model required several adjustement:

- As the model is not dynamic on one day, the usage fees of the normal hours have been considered in the model.
- In order to have homogeneity on the wole network, these fees have been apply on the whole rail European network. The sections outside France are considered to belong to category C.

Since 2007 the railway usage fees changed considerably, with a high modification of the fees for the categories B and C, by the high increase of the traffic fees and the implementation of an additional hour category.

The transport electricity fee was in 2007 of 0.657€ by train.km including both RCE and RCTE (BG, 2014).

Table 49 : Minimal fees on the French network in 2007-2012-2030 (€ 2007) (RFF, 2007 & 2012)

	Tariff category	Normal hour 2007	Normal hour 2012	Normal hour 2030
Booking fees	A	**5,285 €**	**4,518 €**	5.482 €
	B	**1,629 €**	**2,125 €**	2.578 €
	C	**0,915 €**	**1,023 €**	1.241 €
	D	**0,052 €**	**0,407 €**	0.494 €
	E	**0,005 €**	**0,060 €**	0.073 €
Traffic fees		**0,459 €**	**3,019 €**	3.663 €
TOTAL Minimal service fees	A	**5,744 €**	**7,536 €**	9.145 €
	B	**2,088 €**	**5,144 €**	6.241 €
	C	**1,374 €**	**4,042 €**	**4.904 €**
	D	**0,511 €**	**3,426 €**	4.157 €
	E	**0,464 €**	**3,078 €**	3.736 €
RCE-RTE		**0,657 €**	**0,658 €**	0,848 €
Total C		**2.031 €**	**4.700 €**	**5.752 €**

The evolution of the fees at the horizon 2030 has been determined by applying the following annual growth rate.

Table 50 : Growth rate of the network usage fees

[42] The French railway network has been divided into 8 tariff categories: three categories for the LGV that are thus not considered for freight, and five categories on the rest of the network (A, B, C, D and E). The network has been divided into 1500 sections belonging to one of the previous category (Dehornoy, 2007)

Growth rate % per year	2012-2025	After 2025
RCTE / RCE	1,97%	0,00%
Minimal services fees	1,08%	1,08%

The railway costs are the sum of the exploitation costs and the railway fees. The following graph represents the evolution of the rail costs in function of the distance per tons.

2.3 Cost related to the transshipment of containers from the rail to the road

Due to the lower density of the rail network with regard to the road network, pre or end haulage of containers by road are necessary. This implies additional costs. For instance, the loading and unloading of train assumed that the Heavy good vehicle and its driver are at the terminal during 1 hour to deliver the container and realize the administrative paper work. During this hour, the hourly cost for the driver is taken into account, as the daily costs for the heavy good vehicle. Finally, in the model the rail-road transshipment cost is fixed at 50 Euros/containers for each handling.

To the preceding costs, the cost of immobilization of the containers during the rail segment should be added. It is fixed to 5 €/day between the hour of the reception and the hour of provision of the container.

2.4 Evolution of the rail costs at different time horizons

The rail costs correspond to the sum of the exploitation costs and the network usage fees pay to the rail infrastructure provider. In the following picture it can be observed that the unit costs per tons decrease with the distance due to the fact that the constant of exploitation is smoothed progressively with the distance. It can also be observed that the rail costs in 2030 are more expensive than those in 2007. This is due to the fact that the increase of the network usage fees compensates the gain in productivity observed between 2007 and 2030.

It can be observed from Figure 67 that the evolution of the costs leads to a redistribution of the share. In 2007, the fees represent 12 % of the rail costs, and in 2050 it represents 36 %, whereas all the other components see their shares and value decrease.

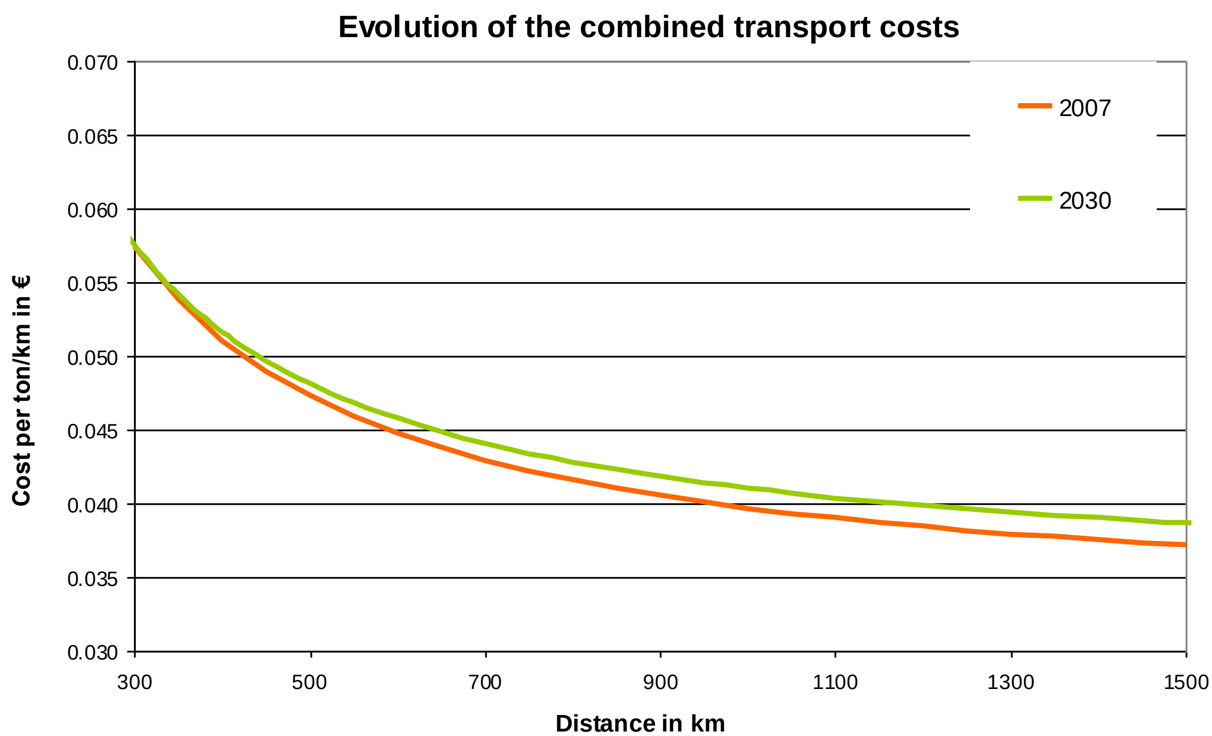

Figure 66 : Evolution of the combined transport costs per ton.km (€2007)

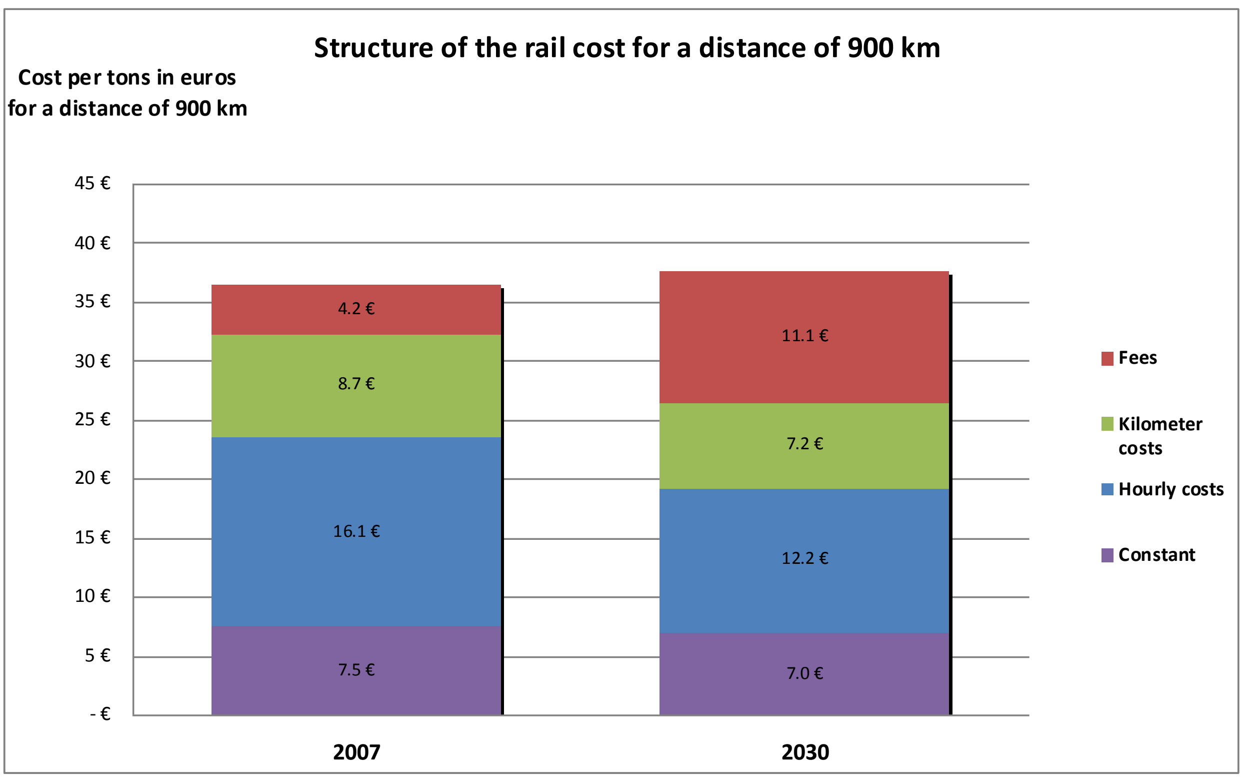

Figure 67 : Structure of the rail costs per tons (€2007).

3 The inland waterway unit costs

3.1 Structure of the IWW costs

The function of cost for IWW is expressed as a duo with:

- A kilometer cost including:
  - Fuel
  - Inland waterway toll
- A hourly/fixed cost including
  - Amortization of the material
  - Staff expenditures
  - Maintenance
  - Insurance
  - Structural costs

The function of cost applied to each operation of transport along the door-to-door chain: exploitation on the section, transit at a node (transshipment, waiting time). Those functions are detailed by type of barge. In this section the method of determination of the kilometer costs will be detailed, and for the hourly costs solely the value used in this research at the different time horizon and under the different project consideration will be specified.

3.2 Capacity of the barge and exploitation hours

The numbers of containers that can be transported by type of barge depend of the air draft under the bridge. The table below summarized the number of containers that each barge can transport depending of the number of layers.

Table 51 : Capacity of the barge in function of the number of layers

Number of layers of containers	Unit	Classe IV RHK	Classe Va Large Rhine Vessel (110m)
2	#TEU	60	104
3	#TEU	90	156
4	#TEU		208

Table 52 : Exploitation and annual service hour per type of barge (Source: VNF (2011), SETEC-STRATEC (2010), CNFR, PLANC)

Parameters	Classe IV RHK	Containers	
		Classe Va Large Rhine vessel (110m) Mosel / Rhine	Classe Va Large Rhine vessel (110m) Rhone
Type of exploitation			
2007 & Reference 2030	15h/J	22h/J	18h/J
SMSR 2030	15h/J	22h/j	
Number of day /year			
2007 & 2030	232	350	350

3.3 Variable kilometer costs

The variable costs are made of: the fuel costs, the carbon tax and the toll in €/t-km. The specification if those three components will be provided in the following sections.

3.3.1 Consumption of fuel oil

In the table below the value of the consumption of fuel oil by type of barge are given. The assumption has been made that by 2030 the fuel consumption of the barge will decrease.

Table 53 : Unit consumption of the barge in 2007

Parameters	Unit	RHK	Large Rhine Vessel
2007	Tep/km	0,0062	0,0076
2030	Tep/km	0,0042	0,052

3.3.2 Taxes

In 2007 the TIPP (tax on the fuel in France), was of 0.0566 €/L. Nevertheless, since then this tax has been removed for freight transportation by IWW since the 1st January 2011. Regarding the carbon tax there was no carbon tax in France, but it is planned to implement such a tax by 2030, with the following value for 2030.

Table 54 : Carbon tax in 2030

Parameters	Unit	2007	2030
Parameters	€07 / T CO2	0	97
	€07 / tep	0	315

3.3.3 IWW Tolls

The tolls for using the IWW and the ports are really different depending of the countries. For those tolls, an average tone-km price has been considered for each country.

- French IWW

On the French IWW, the tolls are constituted:

- An access fee to the network depending of the gauge of the barge. In this table DWT corresponds to the dead weight tons.

Table 55: Access fees to the network (Source: VNF, 2008)

Gauge of the barge	Access fees (€09/trip)
DWT>5000 T	76,75
between 3000 and 4999 T	67,05
between 1700 and 2999 T	62,52
between 1100 and 1699 T	59,4
between 500 and 1099 T	53,48
between 200 and 499 T	36,54
DWT<199 T	20,48

- A variable term by ton-km transported in function of the network used

Table 56: Variable term of the VNF toll

Gauge of the network	rate (c€09/Tkm)
Large gauge canal	0,0993
Small gauge canal	0,0784

There is also a special tariff for the use of the lock outside of the legal opening hours, but they are marginal, that is why they will not be considered in this study. On the charged network the average toll featured by VNF is of 1.3 €/ 1000 t-km.

- International IWW of the Mosel

The charged containers have to pay on the Mosel is as follow:

Table 57 : Toll for containers on the Mosel

Size of the containers	Toll (c09/Tkm)
Below or equal to 20 feet	2,5
Above 20 feet	5

- Belgian IWW

In Belgium the maximum toll is determined by the federal law on the IWW. Flanders divided by 10 the toll in 1998. Nowadays the toll is of 0,025c€ by tone/kilometer. In the model a value of 0.25 €/ 1000 t-km has been taken.

The other region of Belgium adapted different strategy to react to this change. The region of Brussels decided to keep its toll of 2.5€/1000 t-km and the Wallonia decided to remove totally the tolls.

- Dutch IWW:

On the Dutch IWW no toll is required to use the IWW.

- German IWW:

The prices of the German IWWs are very complex. The international IWW as the Rhine is free of charge, but the other have tolls that can vary considerably from one to another. It has been considered from a study of BG that the unit toll apply is of 0,089c€ by t-km on the whole network. In the model it is considered that the toll evolved as the inflation.

3.4 Total unit costs for containers on the IWW in 2007 and in 2030 with and without the SMSR canal

In the previous section the conditions of exploitation of the barge and the unit costs for the transportation of containers on IWW have been specified. In this section, the following table will sum up all those information, by in addition giving the fixed unit costs at the different time horizons.

Table 58 : Unit Costs of the inland waterway in 2007 for containers

		Unit	1 layer	2 layers: Large Rhine Vessel			3 layers: Large Rhine Vessel			4 layers: Large Rhine vesssel-Rhine
			RHK	**Moselle**	**Rhone**	**Rhine**	**Moselle**	**Rhone**	**Rhine**	
Parameters of exploitation										
	Average weight transported in a barge	T ou TEU	26	88	88	88	133	133	133	177
	Hours of exploitation	H	1690	6429	5386	6429	6429	5386	6429	6429
	Annual t-km	M t-km	2,1	3,6	2,3	3,6	5,4	3,4	5,4	7,2
Variable costs										
	Energy	€07/km	3,93	4,43	4,87	4,43	4,43	4,87	4,43	4,43
	TIPP	€07/km	0,29	0,36	0,36	0,36	0,36	0,36	0,36	0,36
	Carbon Tax	€07/km	0	0	0	0	0	0	0	0
	Inland Waterway toll	€07/km	0,03	0,12	0,09	0	0,19	0,13	0	0
	Total variable costs	€07/km	4,25	4,92	5,33	4,8	4,98	5,37	4,8	4,8
	Total variable costs per t-km	**€07/tkm**	**0,1666**	**0,0557**	**0,0603**	**0,0542**	**0,0376**	**0,0405**	**0,0362**	**0,0271**
Fixed costs										
	Ownership cost of the barge	€07/h	74,1	29,2	36,3	29,2	29,2	36,3	29,2	29,2
	Crew salary	€07/h	56,2	57,1	33,2	57,1	57,1	33,2	57,1	57,1
	Repairs and maintenance	€07/h	11,1	5	6,6	5	5	6,6	5	5
	Insurance	€07/h	19,4	6,3	8,3	6,3	6,3	8,3	6,3	6,3
	Structural costs	€07/h	13	4,7	5,7	4,7	4,7	5,7	4,7	4,7
	Total fixed costs	€07/h	173,8	102,4	90,1	102,4	102,4	90,1	102,4	102,4
	Total fixed costs t-h	**€07/T.h**	**6,82**	**1,16**	**1,02**	**1,16**	**0,77**	**0,68**	**0,77**	**0,58**
	Total	**€07/tkm**	**0,308**	**0,239**	**0,275**	**0,238**	**0,16**	**0,184**	**0,158**	**0,119**
	Annual Total	**k€07**	**638,7**	**857,9**	**621,7**	**852,8**	**860,4**	**622,8**	**852,8**	**852,8**

Appendix 3: Additional costs of the intermodal solution per countries

Table 59 : Additional costs of the intermodal solutions per countries

Countries	Additional Cost of intermodal solution	Countries	Additional cost of intermodal solution
Austria	1.05	**Latvia**	1.25
Belgium	1.05	**Lithuania**	1.25
Bulgaria	1.3	**Luxembourg**	1.5
Cyprus	1.3	**Netherlands**	1.05
Czech Republic	1.15	**Poland**	1.2
Denmark	1.1	**Portugal**	1.15
Estonia	1.25	**Romania**	1.3
Finland	1.15	**Slovenia**	1.1
France	1.15	**Slovakia**	1.15
Germany	1.05	**Spain**	1.15
Greece	1.25	**Sweden**	1.1
Hungary	1.15	**Switzerland**	1.5
Ireland	1.25	**United Kingdom**	1.5
Italy	1.05		

Appendix 4: The Poisson estimator method for determination of the distribution function

This poisson estimator method consist of determining the distribution function $F(c_{ij})$, by assuming that this function can be considered as a piecewise constant function. The travel costs axis is divided into a limited number of cost bins, and for each cost bin a distribution function value is assigned. The mathematical form is express below:

$$F(c_{ij}) = \sum_k F_k * \nabla_{ij}^k , \qquad \nabla_{ij}^k \in \{0,1\}$$

With *F_k value of the distribution function for the cost bin k*
∇_{ij}^k equals 1 when generalized travel costs c_{ij} are in cost bin k and 0 otherwise.

Then it is assumed that the OD cells T_{ij} are Poisson distributed, that is to say:

$$P[T_{ij}] = \frac{\exp(-Q_i X_j F^k) * (Q_i X_j F^k)^{T_{ij}}}{T_{ij}!}$$

Then the method consists of maximizing the loglikehood of the observing the OD matrix of the survey:

$$Max \ln(\prod_{i,j|S_{ij=1}} \frac{\exp(-cQ_i X_j F^k) * (cQ_i X_j F^k)^{n_{ij}}}{n_{ij}!})$$

With *n_{ij} the number of observed trip in OD-cell i-j*
S_{ij}=1 if OD-pair is represented in the survey, 0 whereas

Appendix 5: Definition of the categories of ports

Table 60: Definition of the class of the port

Port Range	id ranking	Min tones	Max tones
World	1	Above 30 000 000	
Range Port	2	10 000 000	30 000 000
National	3	5 000 000	10 000 000
Intermediary	4	2 000 000	5 000 000
Regional	5	1 000 000	2 000 000
Local	6	Below 1 000 000	

Appendix 6: Data for the calibration

In order to calibrate the model the following data have been used.

- **Data of the Cour des Comptes (2006) for the year 2004**

Table 61: Data of the market share of the French ports and other sports on the French regions in 2004

Nuts2	Région	Ports français	Ports étrangers	Total	%	%
FR10	Ile-de-France	2 427 110	1 690 927	4 118 037	58.9%	41.1%
FR21	Champagnes Ardennes	175 439	372 559	547 998	32.0%	68.0%
FR22	Picardie	282 386	488 857	771 243	36.6%	63.4%
FR23	Haute Normandie	2 164 286	344 995	2 509 281	86.3%	13.7%
FR24	Centre	432 205	246 791	678 996	63.7%	36.3%
FR25	Basse Normandie	255 346	46 717	302 063	84.5%	15.5%
FR26	Bourgogne	222 722	238 259	460 981	48.3%	51.7%
FR30	Nord Pas-de-Calais	819 516	2 401 795	3 221 311	25.4%	74.6%
FR41	Lorraine	48 094	1 248 892	1 296 986	3.7%	96.3%
FR42	Alsace	100 905	914 552	1 015 457	9.9%	90.1%
FR43	Franche Comté	67 643	222 033	289 676	23.4%	76.6%
FR51	Pays de Loire	690 432	406 688	1 097 120	62.9%	37.1%
FR52	Bretagne	689 959	337 607	1 027 566	67.1%	32.9%
FR53	Poitou Charentes	235 760	122 656	358 416	65.8%	34.2%
FR61	Aquitaine	487 263	286 407	773 670	63.0%	37.0%
FR62	Midi Pyrénées	159 746	203 009	362 755	44.0%	56.0%
FR63	Limousin	28 173	10 222	38 395	73.4%	26.6%
FR71	Rhône-Alpes	1 089 924	744 658	1 834 582	59.4%	40.6%
FR72	Auvergne	156 244	107 240	263 484	59.3%	40.7%
FR81	Languedoc Roussillon	644 293	105 447	749 740	85.9%	14.1%
FR82	PACA	1 021 784	359 116	1 380 900	74.0%	26.0%
FR83	Corse	2 655	1 811	4 466	59.4%	40.6%
TOTAL		**12 201 885**	**10 901 238**	**23 103 123**	52.8%	47.2%

- **Customs' data and external commerce in 2005 (Samarcande, 2007)**

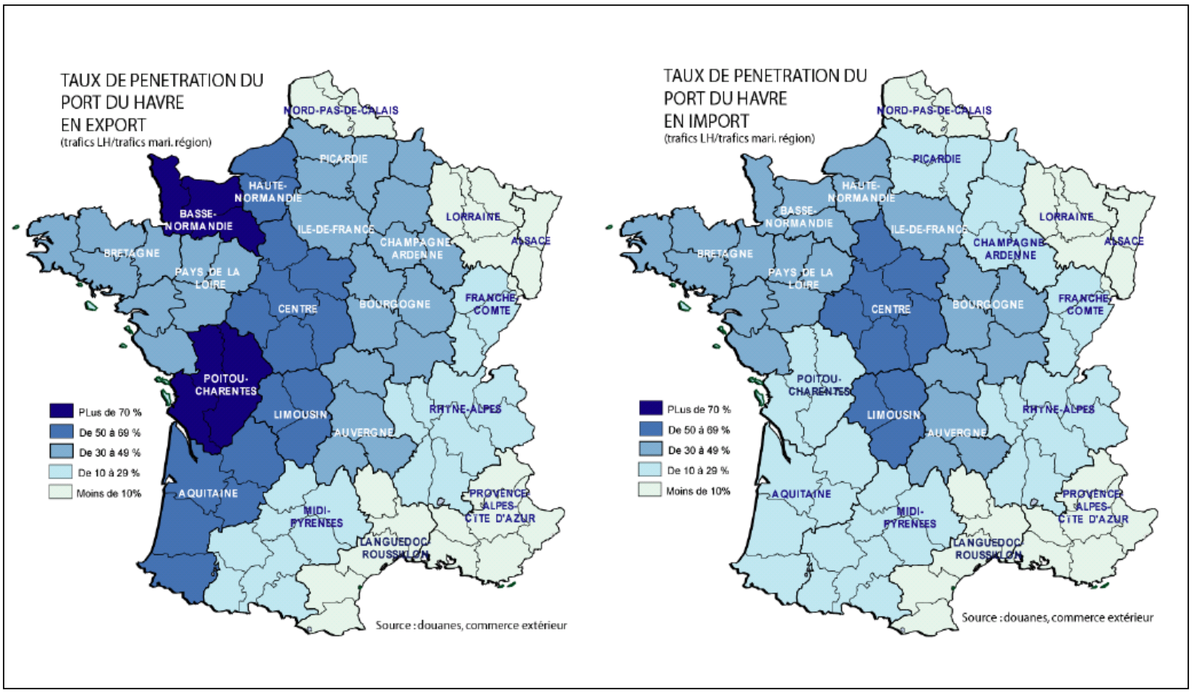

Figure 68: Market Share of the port of Havre in 2005

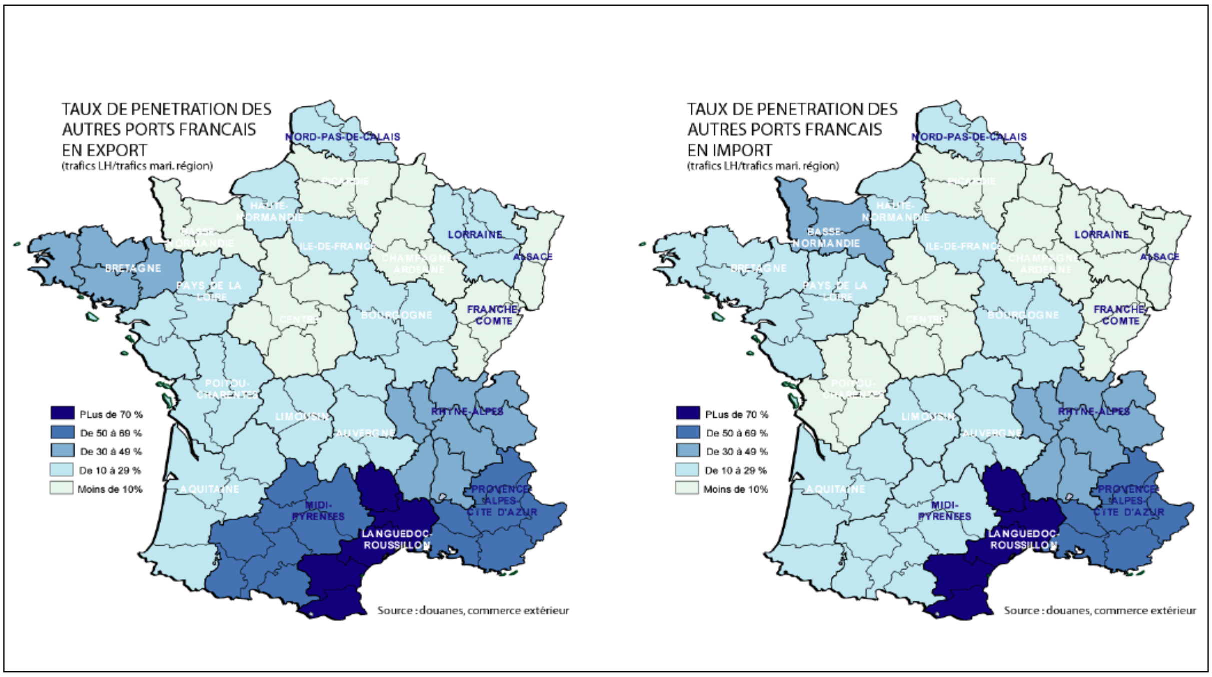

Figure 69: Market Share of other French ports

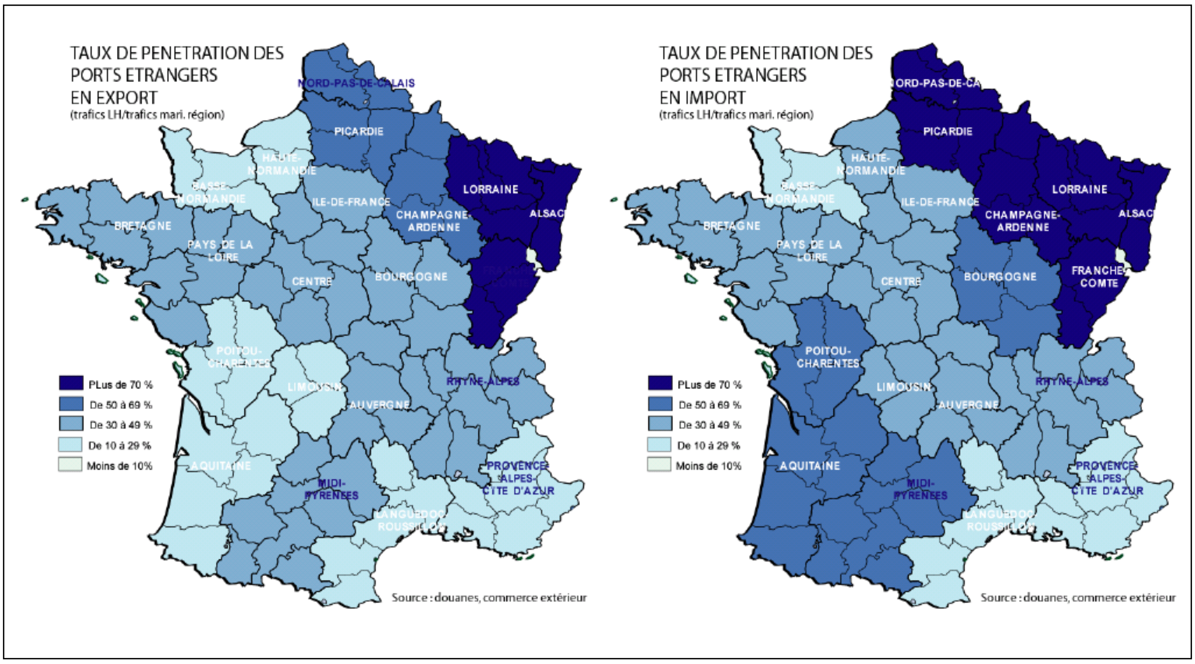

Figure 70: Market share of non French ports

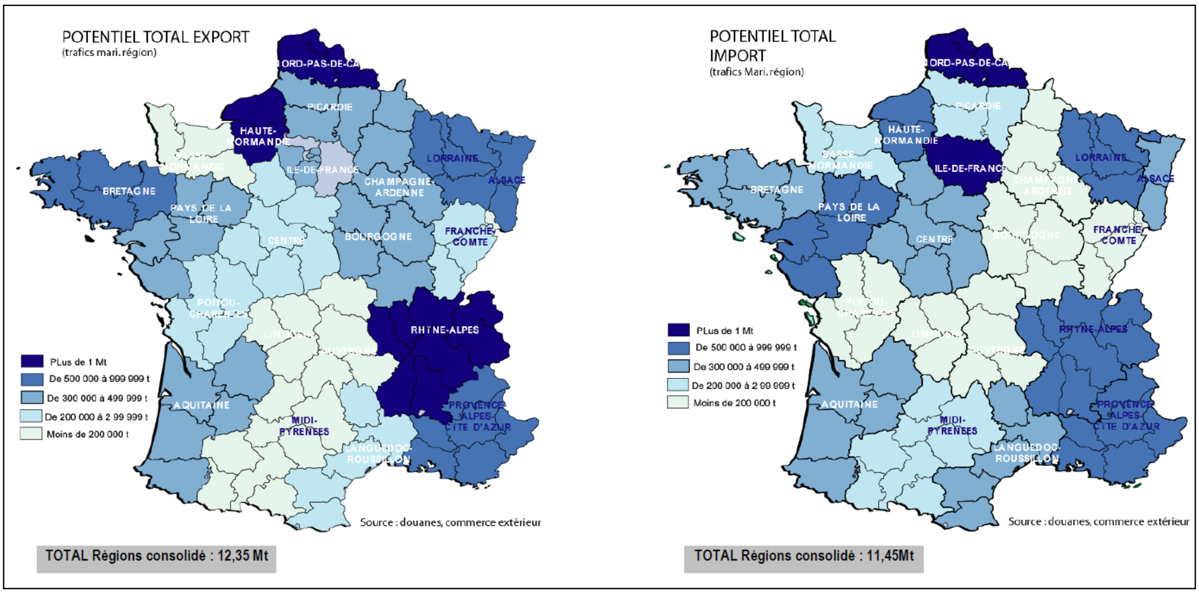

Figure 71: Traffic of containers in 2005

Appendix 7: Simulation of the hinterland of the maritime ports

1. Reconstitution of the ports' hinterland in the French regions

Table 62 : Ports' Hinterland in France

		Traffic in thousand of tonnes (grouped by countries)													
code zone	Mame of the regin	TOTAL	Baltic	UK & Irland	Germany	Netherlands	Belgium	Le Havre	Marseille	Other FR	France	Iberia	Italy	Other MED	Black Sea
	TOTAL	44 862	5	395	1 445	5 669	10 576	14 532	7 152	3 762	25 446	635	684	6	0
FR10	Île de France	6 680	0	73	160	940	1 705	3 174	155	444	3 774	15	13	0	0
FR21	Champagne-Ardenne	811	0	10	37	206	316	181	18	38	237	2	3	0	0
FR22	Picardie	1 479	0	14	36	288	503	494	16	124	634	2	2	0	0
FR23	Haute-Normandie	5 360	0	24	37	224	413	3 965	25	665	4 656	4	3	0	0
FR24	Centre	1 075	0	14	42	150	199	537	37	84	658	7	5	0	0
FR25	Basse-Normandie	557	0	6	7	24	44	415	5	56	475	1	1	0	0
FR26	Bourgogne	734	0	9	47	114	188	232	91	33	355	9	12	0	0
FR30	Nord - Pas-de-Calais	6 291	0	54	127	1 259	3 468	756	31	587	1 374	4	4	0	0
FR41	Lorraine	1 711	0	12	110	450	857	189	34	43	267	6	9	0	0
FR42	Alsace	1 366	0	8	156	503	473	129	44	29	202	5	18	0	0
FR43	Franche-Comté	463	0	5	50	114	140	80	46	13	140	5	10	0	0
FR51	Pays de la Loire	2 990	0	45	96	253	408	1 503	95	550	2 148	28	11	0	0
FR52	Bretagne	1 774	0	32	50	141	188	965	56	327	1 348	11	4	0	0
FR53	Poitou-Charentes	1 069	0	14	37	101	180	419	80	207	706	23	8	0	0
FR61	Aquitaine	1 803	0	18	76	198	374	358	314	320	991	121	24	0	0
FR62	Midi-Pyrénées	509	0	5	19	51	82	67	201	21	289	52	11	0	0
FR63	Limousin	132	0	2	7	20	20	47	14	16	77	5	2	0	0
FR71	Rhône-Alpes	3 991	1	35	251	449	684	670	1 489	118	2 277	106	187	2	0
FR72	Auvergne	564	0	7	30	73	86	166	144	31	342	15	12	0	0
FR81	Languedoc-Roussillon	1 379	0	4	19	34	94	58	960	23	1 042	154	31	0	0
FR82	PACA	4 105	0	6	50	78	151	124	3 289	32	3 446	59	313	1	0
FR83	Corse	18	0	0	1	2	2	2	7	1	9	1	3	0	0

2. Reconstitution of the port traffics

id port	name port	Country	Observed port traffic without tranship (millions tonnes)	Simulated without tranship (millions tonnes)	GEH
1	Antwerp	Belgium	55,63	58,97	0,44
2	Zeebrugge	Belgium	6,27	3,95	1,03
4	Varna	Bulgaria	1,07	1,41	0,31
3	Burgas	Bulgaria	0,29	0,65	0,53
5	Limassol	Cyprus	0,97	1,48	0,47
13	Aarhus	Denmark	2,97	2,04	0,58
16	Kobenhavns	Denmark	1,37	1,38	0,01
12	Aalborg	Denmark	0,29	0,29	0,01
14	Esbjerg	Denmark	0,28	0,17	0,22
15	Fredericia	Denmark	0,26	0,20	0,12
17	Tallinn	Estonia	1,36	0,63	0,73
36	Kotka	Finland	3,94	1,61	1,40
34	Helsinki	Finland	3,72	3,32	0,21
40	Rauma	Finland	1,56	0,69	0,82
32	Hamina	Finland	1,14	0,43	0,80
33	Hanko	Finland	0,47	0,15	0,56
38	Pori	Finland	0,41	0,20	0,38
37	Oulu	Finland	0,38	0,39	0,02
41	Turku	Finland	0,23	0,21	0,04
35	Kemi	Finland	0,22	0,21	0,03
39	Raahe	Finland	0,11	0,08	0,08
45	Le Havre	France	15,21	15,77	0,14
46	Marseille	France	7,57	7,53	0,02
47	Nantes Saint-Nazaire	France	1,33	1,04	0,27
44	Dunkerque	France	1,22	0,93	0,27
48	Rouen	France	1,05	1,43	0,34
42	Bordeaux	France	0,50	0,33	0,25
43	Brest	France	0,22	0,09	0,32
128	Port-la-Nouvelle	France	0,00	0,00	0,00
127	Sete	France	0,00	0,00	0,00
9	Hamburg	Germany	43,62	47,00	0,50
7	Bremerhaven	Germany	16,97	13,42	0,91
11	Luebeck	Germany	2,39	0,75	1,31
8	Cuxhaven	Germany	0,32	0,08	0,54
6	Bremen	Germany	0,12	0,13	0,01
10	Kiel	Germany	0,12	0,03	0,32
50	Piraeus	Greece	4,26	5,51	0,57
51	Thessaloniki	Greece	3,59	2,51	0,62
52	Volos	Greece	0,15	0,11	0,12
49	Heraklion	Greece	0,10	0,14	0,11
57	Dublin	Ireland	5,67	4,05	0,74
55	Cork	Ireland	1,59	0,70	0,83
58	Waterford	Ireland	1,32	0,46	0,90
56	Drogheda	Ireland	0,20	0,09	0,27
63	Genova	Italy	13,48	17,36	0,99
65	La Spezia	Italy	7,79	7,50	0,11
66	Livorno	Italy	5,53	5,66	0,06
75	Venezia	Italy	2,97	2,62	0,21
69	Ravenna	Italy	2,51	2,37	0,09
67	Napoli	Italy	2,29	5,27	1,53
70	Salerno	Italy	2,20	1,91	0,20
71	Savona - Vado	Italy	2,07	1,87	0,15
74	Trieste	Italy	1,49	0,95	0,49
59	Ancona	Italy	1,17	0,51	0,72
64	Gioia Tauro	Italy	1,40	1,17	0,20

68	Palermo	Italy	0,40	0,24	0,30
72	Taranto	Italy	0,81	1,49	0,64
73	Trapani	Italy	0,21	0,09	0,31
62	Civitavecchia	Italy	0,21	0,14	0,17
61	Catania	Italy	0,19	0,23	0,09
60	Cagliari	Italy	0,40	0,39	0,02
77	Riga	Latvia	1,84	1,51	0,25
78	Ventspils	Latvia	0,17	0,09	0,22
76	Klaipeda	Lithuania	2,25	1,29	0,72
81	Rotterdam	Netherlands	56,47	56,16	0,04
79	Amsterdam	Netherlands	2,60	1,89	0,47
80	Moerdijk	Netherlands	0,24	0,14	0,22
82	Vlissingen	Netherlands	0,13	0,05	0,27
129	Gdynia	Poland	4,79	1,78	1,66
93	Gdansk	Poland	0,52	0,22	0,49
94	Szczecin	Poland	0,42	0,19	0,41
97	Lisboa	Portugal	4,48	3,55	0,47
96	Leixoes	Portugal	3,50	3,45	0,02
98	Sines	Portugal	1,64	0,51	1,09
95	Figueira da Foz	Portugal	0,13	0,05	0,24
99	Setubal	Portugal	0,09	0,14	0,15
100	Constanta	Romania	3,09	6,02	1,37
109	Koper	Slovenia	2,43	1,40	0,74
30	Valencia	Spain	15,51	16,20	0,17
20	Barcelona	Spain	12,22	12,51	0,08
21	Bilbao	Spain	4,66	6,17	0,65
18	Algeciras	Spain	2,91	3,39	0,27
31	Vigo	Spain	1,81	2,02	0,15
22	Cadiz	Spain	1,04	1,50	0,41
19	Alicante	Spain	0,89	0,76	0,15
24	Castellon de la plana	Spain	0,83	0,57	0,31
28	Palma Mallorca	Spain	0,60	0,21	0,62
23	Cartagena	Spain	0,41	0,39	0,03
27	Marin-Pontevedra	Spain	0,31	0,21	0,20
29	Tarragona	Spain	0,31	0,20	0,23
25	Gijon	Spain	0,13	0,47	0,61
26	Málaga	Spain	0,08	0,24	0,38
102	Goteborg	Sweden	5,96	7,11	0,45
104	Helsingborg	Sweden	1,46	1,21	0,22
101	Gavle	Sweden	0,62	1,13	0,54
105	Malmo	Sweden	0,35	0,38	0,04
108	Stockholm	Sweden	0,23	1,63	1,46
107	Oxelosund	Sweden	0,18	0,37	0,36
106	Norrkoping	Sweden	0,15	0,31	0,34
103	Halmstad	Sweden	0,11	0,07	0,12
115	Felixstowe	United Kingdom	20,34	14,84	1,31
130	Southampton	United Kingdom	9,71	9,85	0,04
121	London	United Kingdom	6,07	8,42	0,87
120	Liverpool	United Kingdom	4,95	6,24	0,54
122	Medway	United Kingdom	2,67	2,62	0,03
114	Forth	United Kingdom	2,33	1,31	0,76
111	Belfast	United Kingdom	2,00	0,50	1,34
119	Hull	United Kingdom	1,81	1,30	0,41
124	Tees & Hartlepool	United Kingdom	1,13	0,87	0,25
112	Bristol	United Kingdom	0,79	1,12	0,34
118	Grimsby &	United Kingdom	0,76	0,53	0,28
117	Goole	United Kingdom	0,55	0,58	0,04
123	Portsmouth	United Kingdom	0,35	0,32	0,06
125	Tyne	United Kingdom	0,31	0,24	0,15
113	Cardiff	United Kingdom	0,23	0,24	0,02
126	Warrenpoint	United Kingdom	0,21	0,03	0,52
110	Aberdeen	United Kingdom	0,13	0,07	0,18
116	Edinburgh	United Kingdom	0,00	0,00	0,00

Appendix 8: French regions

Figure 72: Map of the French regions

Appendix 9: GDP and Population forecasts take as input in 2030

Table 63: GDP for 2030 according to the scenario "décennie perdue" (Source: DG ECFIN (for the projections), Eurostat for 2010, 2011 & 2012/ Unity: Million Euro)

Country	2010	CAGR 2010-2011%	CAGR 2011-2012%	11-25%	26-60%	2025	2030	2060	10-30%
AT	285 165	2,8%	0,9%	1,50%	1,36%	358 955	384 037	575 931	1,50%
BE	355 740	1,8%	-0,1%	1,50%	1,67%	439 040	476 945	783 887	1,48%
BG	36 052	1,8%	0,8%	1,70%	1,10%	46 059	48 649	67 547	1,51%
CY	17 406	0,4%	-2,4%	1,73%	1,89%	21 317	23 409	41 051	1,49%
CZ	149 932	1,8%	-1,0%	1,90%	1,39%	192 993	206 784	312 875	1,62%
DE	2 495 000	3,3%	0,7%	1,03%	0,73%	2 965 206	3 075 028	3 824 847	1,05%
DK	236 334	1,1%	-0,4%	1,17%	1,59%	276 828	299 547	480 832	1,19%
EE	14 371	9,6%	3,9%	1,67%	1,40%	20 297	21 758	33 018	2,10%
ES	1 045 620	0,1%	-1,6%	1,73%	1,51%	1 287 184	1 387 346	2 174 952	1,42%
FI	178 724	2,8%	-1,0%	1,60%	1,49%	223 578	240 739	375 183	1,50%
FR	1 901 345	2,0%	0,0%	**1,36%**	**1,63%**	2 343 083	2 537 801	4 125 956	1,45%
GR	222 152	-7,1%	-6,4%	0,53%	1,20%	206 912	219 628	314 125	-0,06%
HU	96 243	1,6%	-1,7%	1,13%	1,20%	111 239	118 075	168 879	1,03%
IE	158 097	2,2%	0,2%	1,86%	2,20%	205 726	229 374	440 626	1,88%
IT	1 551 886	0,5%	-2,5%	1,00%	1,31%	1 730 646	1 847 012	2 729 225	0,87%
LT	27 710	6,0%	3,7%	1,33%	1,28%	36 167	38 542	56 447	1,66%
LU	39 303	1,9%	-0,2%	2,33%	1,74%	53 922	58 779	98 622	2,03%
LV	18 039	5,3%	5,2%	1,30%	1,10%	23 636	24 965	34 663	1,64%
MT	6 385	1,7%	0,9%	1,83%	1,30%	8 294	8 847	13 035	1,64%
NL	586 789	0,9%	-1,2%	1,30%	1,27%	691 915	736 982	1 076 171	1,15%
PL	354 616	4,5%	1,9%	2,63%	1,04%	529 194	557 291	760 120	2,29%
PT	172 860	-1,3%	-3,2%	0,90%	1,36%	185 554	198 520	297 716	0,69%
RO	124 328	2,2%	0,7%	1,57%	0,87%	156 675	163 610	212 163	1,38%
SE	349 945	2,9%	0,9%	1,87%	1,71%	462 284	503 184	836 828	1,83%
SI	35 485	0,7%	-2,5%	1,70%	1,13%	43 376	45 882	64 276	1,29%
SK	65 897	3,0%	1,8%	2,83%	1,10%	99 314	104 897	145 646	2,35%
UK	1 731 809	1,1%	0,3%	1,83%	1,84%	2 222 986	2 435 167	4 208 045	1,72%
EU15	11 310 767	**1,52%**	**-0,48%**	**1,24%**	**1,42%**	13 653 819	14 630 088	22 342 947	1,29%
EU12	946 464	**3,17%**	**0,79%**	**2,00%**	**1,13%**	1 288 560	1 362 709	1 909 719	1,84%
EU27	12 257 231	**1,65%**	**-0,38%**	**1,31%**	**1,39%**	14 942 378	15 992 797	24 252 666	1,34%
CH	414 884	1,8%	1,0%	2,23%	1,79%	568 218	620 927	1 057 289	2,04%

Table 64 : Population scenario (Europop2008, level NUTS 2) (Source: Europop 2008 (Eurostat), DG ECFIN , Estimation BG Unit (Million)

Pays	2010	2030	2050	2010-2030%
AT	8 405	8 741	8 847	0,20%
BE	10 784	11 989	12 882	0,53%
BG	7 564	6 667	5 911	-0,63%
CY	821	958	1 073	0,78%
CZ	10 394	10 728	10 494	0,16%
DE	82 145	77 635	70 230	-0,28%
DK	5 512	5 847	6 013	0,30%
EE	1 333	1 316	1 256	-0,07%
ES	46 673	50 612	52 466	0,41%
FI	5 337	5 632	5 632	0,27%
FR	62 583	67 361	69 836	**0,37%**
GR	11 307	11 580	11 419	0,12%
HU	10 023	9 679	9 096	-0,17%
IE	4 614	5 492	6 365	0,87%
IT	60 017	63 410	64 047	0,28%
LT	3 337	3 073	2 842	-0,41%
LU	494	606	661	1,02%
LV	2 247	2 078	1 843	-0,39%
MT	414	415	415	0,02%
NL	16 503	17 238	17 066	0,22%
PL	38 092	37 146	34 010	-0,13%
PT	10 723	10 868	10 525	0,07%
RO	21 334	20 035	18 088	-0,31%
SE	9 306	10 446	11 069	0,58%
SI	2 034	2 115	2 061	0,20%
SK	5 407	5 521	5 230	0,10%
UK	61 984	69 670	75 611	0,59%
EU15	396 388	417 128	422 671	**0,26%**
EU12	103 001	99 731	92 320	**-0,16%**
EU27	499 389	516 860	514 991	**0,17%**
CH	7 695	8 977	9 859	0,77%

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Appendix 10: Asia-Europe shipment prices in 2012 and 2013

Table 65 : Shipment prices for the relations Asia-Europe for different shipping companies in 2012 and 2013 (Source: Drewry Maritime Research)

	Average freight rate Asia-Europe ($/teu)	
	1Q13	**4Q12**
APL	1207	1203
OOCL	1269	1252
Coscon	974	964
Hapag-Llyoyd	1307	
Average freight rate in $/TEU	1022	
Average freight rate (€/TEU/km)	0.038	

Appendix 11: Evolution of the modal share between the reference and SMSR basic scenarios

Table 66 : Effect of the SMSR project on the modal share between the reference and SMSR scenarios

Traffic in million of tons	Reference 2030					SMSR scenario 2030					Effect of the SMSR project in millions of tons					Effect of the SMSR project in percentage				
Port	TOTAL	Road	Rail	IWW	IWW-Rail	TOTAL	Road	Rail	IWW	IWW-Rail	TOTAL	Road	Rail	IWW	IWW-Rail	TOTAL	Road	Rail	IWW	IWW-Rail
TOTAL 2030	**800.2**	**577.2**	**134.4**	**75.2**	**13.4**	**800.2**	**576.1**	**132.8**	**77.6**	**13.7**	0.0	-1.1	-1.6	2.3	0.3	0%	0%	-1%	3%	2%
Baltic	42.0	41.2	0.8	0.0	0.0	42.0	41.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	-1%	**15%**
UK & Irland	91.2	80.2	11.0	0.0	0.0	91.1	80.2	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	0%	**11%**
Germany	143.9	76.3	59.7	7.5	0.4	143.8	76.2	59.4	7.5	0.7	-0.1	-0.1	-0.3	0.0	0.2	0%	0%	0%	0%	**50%**
Hamburg	119.3	63.9	48.1	6.8	0.4	119.2	63.9	47.9	6.8	0.6	-0.1	-0.1	-0.2	0.0	0.2	0%	0%	-1%	0%	**49%**
Netherlands	129.3	61.6	18.9	42.7	6.1	129.7	61.4	18.5	43.9	5.9	0.4	-0.2	-0.4	1.2	-0.2	0%	0%	-2%	3%	-3%
Rotterdam	124.5	57.4	18.9	42.2	5.9	124.9	57.3	18.5	43.4	5.7	0.4	-0.2	-0.4	1.2	-0.2	0%	0%	-2%	3%	-3%
Belgium	126.6	81.2	18.1	20.8	6.4	126.4	81.0	17.8	21.1	6.4	-0.2	-0.2	-0.3	0.3	0.0	0%	0%	-2%	2%	0%
Antwerp	118.4	74.5	16.7	20.8	6.4	118.2	74.3	16.4	21.1	6.4	-0.2	-0.2	-0.3	0.3	0.0	0%	0%	-2%	2%	0%
France	45.7	35.7	5.3	4.2	0.4	45.7	35.1	4.9	5.0	0.6	0.0	-0.6	-0.4	0.8	0.2	0%	-2%	-7%	**19%**	**39%**
Le Havre	27.2	21.0	3.2	2.8	0.2	27.1	20.9	3.1	2.8	0.3	-0.1	-0.1	-0.1	0.0	0.1	-1%	-1%	-2%	0%	**24%**
Marseille-Fos	13.2	9.5	2.1	1.4	0.1	13.3	9.1	1.8	2.2	0.2	0.2	-0.4	-0.3	0.8	0.1	1%	**-4%**	**-15%**	**59%**	**71%**
Autres Fr	5.3	5.2	0.0	0.1	0.0	5.3	5.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	-2%	-1%	-1%
Iberia	95.0	84.6	10.3	0.0	0.1	95.0	84.6	10.2	0.0	0.2	0.0	0.0	-0.1	0.0	0.1	0%	0%	-1%	0%	**101%**
Italy	81.5	71.7	9.7	0.0	0.0	81.4	71.7	9.7	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0%	0%	0%	0%	2%
Other Mediterranean	29.1	28.7	0.4	0.0	0.0	29.1	28.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	0%	13%
Black Sea	16.0	16.0	0.0	0.0	0.0	16.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%	0%	0%	15%

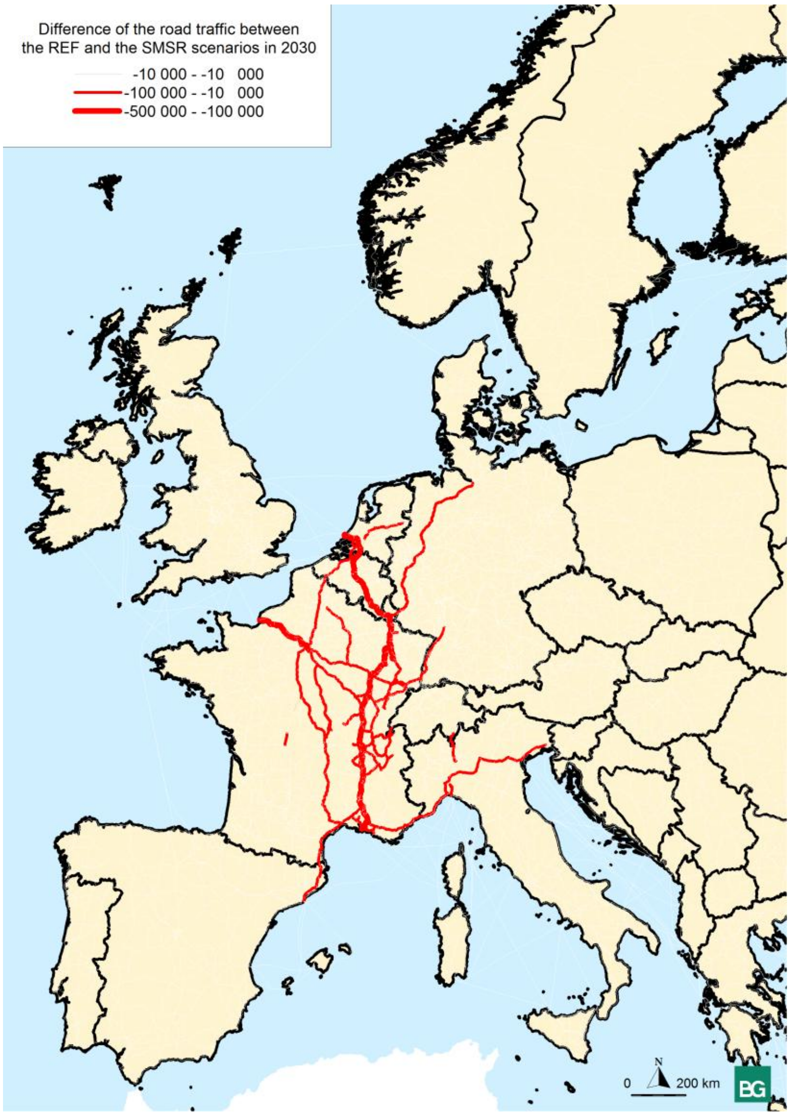

Figure 73: Difference of road traffic between the Reference and SMSR Scenarios in 2030

Appendix 12: Evolution of the trade of containers between the French regions and the ports of interest with the creation of the SMSR canal for the reduction of the border effect scenario and maritime scenario

Table 67 : Relative evolution of the trade of containers between the French regions and the ports of interest between the reference and SMSR scenario with reduction of the border effects

	Allemagne	Pays-Bas	Belgique	Reste Europe	Le Havre	Marseille	Autres FR
TOTAL	-2.4%	4.2%	-0.9%	-2.3%	-0.5%	0.1%	-0.3%
Champagne-Ardenne	-0.6%	-0.2%	-0.4%	-0.6%	-0.5%	**20.3%**	-0.4%
Centre	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	2.1%	0.0%
Bourgogne	-11.2%	**23.0%**	-6.4%	-12.7%	-9.2%	**14.6%**	-8.5%
Lorraine	-2.6%	-1.6%	-2.6%	-2.9%	-2.1%	**126.2%**	-2.5%
Alsace	-2.0%	-1.8%	-2.1%	-1.9%	2.6%	**75.3%**	-1.9%
Franche-Comté	**-15.3%**	**10.1%**	-6.5%	-13.5%	-4.3%	**38.2%**	**-13.7%**
Midi-Pyrénées	0.0%	0.7%	0.0%	-0.1%	-0.1%	-0.2%	-0.1%
Limousin	-0.1%	0.5%	-0.1%	-0.1%	-0.1%	-0.2%	-0.1%
Rhône-Alpes	-7.1%	**25.7%**	-6.3%	-6.8%	-7.3%	-1.5%	-7.0%
Auvergne	-3.6%	**17.1%**	-3.1%	-3.7%	-3.7%	-3.3%	-3.3%
Languedoc-Roussillon	2.0%	**29.2%**	2.8%	-1.4%	-1.9%	-2.0%	-1.5%
Provence-Alpes-Côte d'Azur	0.1%	**43.1%**	0.9%	-1.6%	-2.0%	-1.5%	-2.0%
Corse	-1.6%	**13.7%**	-1.7%	-1.4%	-1.8%	-1.8%	-1.8%

Table 68 : Relative evolution of the trade of containers between the French regions and the ports of interest between the maritime reference and SMSR scenario

	Allemagne	Pays-Bas	Belgique	Reste Europe	Le Havre	Marseille	Autres FR
TOTAL	-2.5%	1.7%	-1.4%	-2.3%	-0.7%	1.8%	-0.8%
Champagne-Ardenne	-1.5%	-1.2%	-1.3%	-1.5%	-1.4%	18.4%	-1.3%
Centre	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	2.0%	-0.2%
Basse-Normandie	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bourgogne	-11.4%	**13.7%**	-8.5%	-13.5%	-10.1%	**13.4%**	-10.4%
Lorraine	-7.4%	-6.9%	-7.4%	-7.6%	-7.2%	**114.2%**	-7.5%
Alsace	-5.8%	-5.6%	-5.6%	-5.8%	-2.3%	**66.8%**	-5.4%
Franche-Comté	-17.5%	1.2%	-11.5%	-15.8%	-8.5%	**36.9%**	-16.9%
Midi-Pyrénées	0.0%	0.6%	0.0%	-0.1%	-0.1%	-0.1%	0.0%
Limousin	-0.1%	0.5%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Rhône-Alpes	-5.7%	**21.7%**	-5.9%	-6.0%	-6.1%	-0.7%	-5.9%
Auvergne	-2.3%	**15.4%**	-2.6%	-2.8%	-2.7%	-2.5%	-2.6%
Languedoc-Roussillon	2.1%	**23.4%**	1.9%	-0.8%	-1.0%	-1.2%	-0.9%
Provence-Alpes-Côte d'Azu	0.8%	**35.8%**	1.0%	-0.9%	-0.9%	-0.8%	-0.9%
Corse	-1.1%	**12.5%**	-1.2%	-0.9%	-1.2%	-1.3%	-1.2%