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# Green corridors in freight logistics

**PhD thesis 7.2016**

**DTU Management Engineering**

George Panagakos
August 2016

**DTU Management Engineering**
Department of Management Engineering

# Green Corridors in Freight Logistics

**PhD thesis**

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DTU Management Engineering contributes actively to the development of management tools and optimisation of processes by using and re-thinking theoretical engineering perspectives, models and methods.

To Coralia and Christiana

# Summary (English)

The subject of this thesis is 'green corridors,' a European concept denoting a concentration of freight traffic between major hubs and by relatively long distances. Since their inception in 2007, green corridors have gained popularity as a policy tool that enhances the overall environmental sustainability of transport through improving the competitiveness of the railway and waterborne modes that exhibit better environmental characteristics than road haulage.

The thesis has three objectives, all related to green corridors. The first one aims to develop a methodology for the quantitative monitoring of the performance of a green corridor in terms of pre-specified Key Performance Indicators (KPIs). The thesis builds on previous own work under the EU-financed SuperGreen project and applies the new methodology on the GreCOR corridor extending from Oslo to Rotterdam. The scope of the two other objectives relates to environmental indicators viewed in the context of maritime corridors. The second objective seeks to develop a simple and practical framework for classifying the carbon emission reduction measures that have been proposed for the shipping industry, while the third one examines the impacts on modal split and emissions of designating the Mediterranean Sea as a Sulphur Emission Control Area (SECA), where stricter limits on the sulphur content of marine fuels apply.

In relation to the first objective, the thesis reviews the most important EU transport policy documents, discusses the available definitions of green corridors, identifies the characteristics that distinguish a green corridor from any other efficient corridor, and uses these characteristics as criteria to investigate the relation between the so-called 'core network corridors' of the trans-European transport network and the green corridor concept.

Once the rationale for a performance monitoring scheme has been established, the thesis critically reviews the SuperGreen methodology which consists of: (i) decomposing the corridor into transport chains, (ii) selecting a sample of typical chains, (iii) assessing these chains through a set of KPIs, and (iv) aggregating the chain-level KPIs to corridor-level ones using proper weights. Unlike SuperGreen that suggests a study-based approach for constructing the corridor sample, the thesis proposes founding the selection of typical chains on the outcome of specialised transport models. The periodic collection of stakeholder data on the selected 'basket' of transport services would then enable monitoring progress towards meeting the objectives that corridor management has set.

The combination of the model-based approach for the sample construction and the study-based approach for the estimation of chain-level indicators is the main contribution of the thesis towards this first objective, as it exploits the strengths of each method and avoids their weaknesses. A necessary condition, of course, is securing the stakeholder input which, as the GreCOR application shows, has proven easier said than done.

In relation to the second objective, the thesis reviews existing frameworks found in the literature for assessing transport sustainability and proposes an extended Kaya identity for decomposing carbon emissions. As the most important factors, the thesis identifies: (i) the carbon intensity of the fuels used, (ii) the energy efficiency of the vessels employed, (iii) the vessel capacity and utilisation rate, and (iv) the transport activity expressed by cargo volumes and average haul lengths. The thesis classifies a wide range of carbon emission reducing practices and policies on the basis of these factors.

The thesis contributes with a framework which is built on rigid theoretical foundations, puts available options into the right perspective, and serves as guidance in assessing their effectiveness and compatibility. In terms of policy recommendations, the framework underlines the advantages that packages of complementary instruments have over single measures, and reminds the indirect environmental benefits of many profit maximising measures that often tend to be forgotten.

With regard to SOx emissions, the thesis contributes to the discussions concerning the possible designation of the Mediterranean Sea as a SECA by examining a case study involving the transportation of consolidated cargoes between Thessaloniki, Greece and industrial hubs in northern Germany. A binomial logit model is used to predict the modal shift from a combined-transport route involving a ferry and a truck-on-train service to a road-only option in the case of increased marine fuel costs imposed by the SECA restrictions. Despite the resulting modal shift in favour of the road-only route, the overall effect on the emissions produced is, surprisingly, positive. This is because of the longer distance of the combined-transport option in comparison to the road-only one and, the poor environmental performance of the Ro-Pax vessels basically due to their relatively high speed.

A further contribution of the thesis with regard to this objective relates to the use of transport time in addition to cost as an explanatory variable in modelling modal split, as well as the application of a micro-level perspective addressing the SME subsector of the Greek logistics industry, which is convenient in securing comparable door-to-door transport chains on one hand, while it allows the delineation of an emission allocation scheme for a multi-load multi-drop operation on the other.

# Resumé (Summary in Danish)

Denne afhandling behandler begrebet ”grønne korridorer”, som er et europæisk koncept, der benyttes til at beskrive en koncentration af godstrafik mellem større knudepunkter og forholdsvis lange afstande. Siden konceptets introduktion i 2007, har grønne korridorer vundet popularitet som et politisk redskab, der medvirker til at øge den samlede miljømæssige bæredygtighed af transporten gennem forbedring af konkurrenceevnen for jernbane- og søtransporten, der udviser bedre miljømæssige egenskaber end vejtransporten.

Afhandlingen har tre mål, der alle er relateret til grønne korridorer. Det første mål har til formål at udvikle en metode til kvantitativ monitorering af performance af specifikke grønne korridorer ved hjælp af præ-specificerede Key Performance Indicators (KPI'er). Afhandlingen bygger på tidligere eget arbejde i det EU-finansierede projekt ”Supergreen” og anvender den nye metode på GreCOR-korridoren, der strækker sig fra Oslo til Rotterdam. Sigtet for de to andre mål vedrører miljøindikatorer set i forbindelse med maritime korridorer. Det andet mål søger således at udvikle en enkel og praktisk ramme for klassificering af de reduktionsforanstaltninger for kulstofemissioner, der er blevet foreslået til anvendelse inden for shippingindustrien, mens det tredje mål undersøger konsekvenserne af såvel ”modal split” som af emissioner ved udpegelse af Middelhavet som et såkaldt ”Sulphur Emission Control Area” (SECA), hvor strengere grænser for indholdet i skibsbrændstoffer er gældende.

I forbindelse med det første mål, gennemgår afhandlingen de vigtigste EU-transportpolitiske dokumenter, diskuterer de tilgængelige definitioner af grønne korridorer, identificerer de karakteristika, der adskiller en grøn korridor fra enhver anden effektiv korridor, og anvender disse egenskaber som kriterier for at undersøge relationen mellem de såkaldte

”hovednetkorridorer” i det trans-europæiske transportnet og det grønne korridor koncept.

Efter begrundelsen for monitorering af korridor-performance gennemgår afhandlingen metoden fra Supergreen, som består af: (i) nedbrydning af korridoren i transportkæder, (ii) udtagning af en stikprøve af typiske kæder, (iii) vurdering af disse kæder gennem et sæt af KPI'er, og (iv) aggregering af kæde-niveau KPI'er til korridor-niveau, ved hjælp passende vægte. I modsætning til Supergreen, der foreslår en undersøgende tilgang til konstruktion af en passende sample af korridoren, foreslår afhandlingen at basere udvælgelsen af typiske kæder på resultatet fra specialiserede transportmodeller. Den periodiske indsamling af data fra interessenterne - om den valgte "vifte" af transportydelser - vil derefter muliggøre monitorering af fremskridtene hen imod opfyldelse af de mål som ledelsen af korridoren har sat.

Kombinationen af den modelbaserede tilgang for sample-udtagningen og den undersøgende tilgang til estimering af indikatorer på kæde-niveau er det vigtigste bidrag af afhandlingen i forhold til dette første mål, da metoden udnytter de stærke sider ved hver metode og undgår deres svagheder. En nødvendig betingelse, er naturligvis at sikre interessenternes input, der, som erfaringerne fra GreCOR viser, har vist sig lettere sagt end gjort.

I forhold til det andet mål undersøger afhandlingen de eksisterende rammer, der findes i litteraturen til vurdering af bæredygtig transport og foreslår en udvidet Kaya identitet for at kunne nedbryde kulstofemissioner. Som de vigtigste faktorer, identificerer afhandlingen: (i) kulstofintensiteten af de brændstoffer der anvendes, (ii) energieffektivitet af de anvendte skibe, (iii) skibenes kapacitet og udnyttelse, og (iv) transportaktivitet udtrykt ved godsmængderne og gennemsnitlige transportafstande. Afhandlingen klassificerer en bred vifte af metoder til kulstof emissionsreduktion og politikker på grundlag af disse faktorer.

Afhandlingen bidrager med en ramme, som er bygget på et solidt teoretisk grundlag, stiller tilgængelige mulige metoder til rådighed i det rette perspektiv, og tjener som vejledning i vurdering af metodernes effektivitet og kompatibilitet. Med hensyn til politiske anbefalinger, understreger rammen de fordele, som bredden af supplerende instrumenter har over enkelte foranstaltninger, og husker de indirekte miljøfordele af mange profitmaksimerende indsatser, der ofte har tendens til at blive glemt.

Med hensyn til SOx-emissioner bidrager afhandlingen til diskussionerne om eventuel udpegning af Middelhavet som SECA ved at undersøge en case, der involverer transport af konsoliderede laster mellem Thessaloniki, Grækenland og industrielle knudepunkter i det nordlige Tyskland. En binomial-logit model anvendes til at forudsige modal shift fra en inter-modal transportrute, der involverer færge og lastbil-på-tog til den single-modale vejbaseret rute som ville være eneste mulighed i tilfælde af øgede marine brændstofomkostninger pålagt af de SECA restriktioner. Trods den resulterende omlægning til fordel for den single-modale vejbaserede rute er den samlede effekt på emissionerne overraskende positiv. Dette skyldes den længere afstand af den inter-modale transportrute set i forhold til den vejbaserede rute samt den dårlige miljømæssige performance af Ro-Pax skibene, der dybest set er forårsaget på grund af deres relativt høje hastighed.

Yderligere bidrag for afhandlingen til denne målsætning hidrører fra anvendelsen af transporttiden ud over at optræde som forklarende variabel i modelleringen af modal split, samt anvendelsen af et mikro-niveau perspektiv til at adressere SMV-delsektoren af den græske logistikindustri, som repræsenterer en håndfuld sikre sammenlignelige dør-til-dør transportkæder på den ene side, mens det på den anden side giver mulighed for afgrænsning af en emissionstildelingsordning for en multi-load multi-drop operation.

# Preface

This thesis is submitted as a partial fulfilment of the requirements for a PhD degree from the Department of Management Engineering of the Technical University of Denmark.

There are a few aspects about this thesis that, I think, the reader should be aware of. The first one is of a rather personal nature and relates to the author's perspective. When I started working on this PhD project, I already had 28 years of fruitful and enjoyable professional life behind me, mostly in the areas of consulting and manufacturing. Unlike many of my younger colleagues, the drive behind this exciting adventure was not the prospect of an academic career neither any other professional aspiration. It was merely the selfish desire – what the economists call 'utility' – of having studied a particular subject in such depth that renders someone an expert in something, however important or meaningless this subject might be. Maybe this can help explain the level of detail in covering certain topics, particularly the policy-related ones, that can be annoying to some readers and for which I sincerely apologise in advance.

Another peculiarity of this PhD project relates to the host institute. Although this is a DTU PhD project, it did not start this way. The first phase of my PhD work on 'green corridors,' covering the period Apr. 2013 – Aug. 2014, took place in Athens, Greece at the Laboratory for Maritime Transport with the National Technical University of Athens (NTUA). My PhD project, entitled '*Monitoring the performance of green corridors in European freight logistics*' was being supervised by Harilaos N. Psaraftis who, at the time, was serving at NTUA as full professor. His relocation to DTU in the summer of 2013 eventually led to my moving closer to him and, in Aug. 2014, I undertook the 2-year PhD project '*Green corridors in freight* *logistics*' under his supervision with the assistance of Professor MSO Allan Larsen as co-supervisor. Formally, the period in NTUA was considered as 'stay abroad' and this period's output forms part of the overall results achieved by the PhD study.

This relocation has also affected the sponsorship of the project. The Athens period was funded by The Lloyd's Register Foundation (LRF) in the context of the project '*Centre of Excellence in Ship Total Energy-Emissions-Economy*' running at NTUA during the years 2010 to 2015. LRF, a UK registered charity and sole shareholder of Lloyd's Register Group Ltd, invests in science, engineering and technology for public benefit, worldwide. The Lyngby period was co-financed by three projects: (i) a start-up fund granted by the President of DTU to Prof. Harilaos N. Psaraftis, (ii) the EU Interreg project '*GreCOR - Green corridor in the North Sea Region*' project (2012-2015), which provided a suitable field for testing the corridor benchmarking methodology, and (iii) another internal grant by the DTU administration. In turn, work on the PhD thesis provided partial co-financing for two new EU Interreg projects: (a) the '*TENTacle – Capitalising on TEN-T core network corridors for prosperity, growth and cohesion*' project (2016-2019), which will use the PhD project results to improve the effectiveness of the governing structures of the TEN-T core network corridors in the Baltic region, and (b) the '*Scandria®2Act - Sustainable and multimodal transport actions in the Scandinavian-Adriatic corridor*' project (2016-2019), which will apply the methodology presented here to assess the implications of the recent stricter sulphur limits for marine fuel on the environmental and financial sustainability of the Ro-Ro connections along the Scandinavian-Mediterranean TEN-T core network corridor.

Another project that deserves special reference here is the EU FP7 project '*SuperGreen - Supporting EU's Freight Transport Logistics Action Plan on green corridors issues*' (2010-2013). Although the PhD project started a few months after SuperGreen's termination and in this sense there is no overlap, it is this project that provided the scene where, among others, the ground work was laid down and the corridor benchmarking methodology was initially conceived and applied. A deliberate effort has been made in the thesis to define what was done when. However, the frequent references to SuperGreen can possibly obscure these boundaries. For this occasion, it is good to remember that the SuperGreen methodology was developed by the same individuals: me under the supervision of Prof. Harilaos N. Psaraftis who was the SuperGreen's Project Manager.

The SuperGreen roots have certainly influenced the scope of this PhD project. As such, the study deals exclusively with surface freight transport. Aviation is outside the scope of the analysis, as is the use of pipelines for liquid cargoes. SuperGreen has also bequeathed a European focus to the study, although a more global perspective is taken on selected topics like maritime transport. A third boundary in terms of scope relates to the environmental attributes examined. In line with SuperGreen, coverage is limited to greenhouse gas (GHG) and SOx emissions.

In an effort to put emphasis on the greening of transport corridors, each of these two types of emissions is allocated a separate chapter in this thesis. I have selected a maritime context for these two chapters mainly because of the importance of maritime transport in terms of global freight volumes and its significant share in global SOx emissions. I have to admit, though, that given my background in naval architecture and marine engineering, my personal interests on the topic might have influenced this decision.

A final comment before turning to the content of the thesis relates to its structure. In planning it, I had to select among the paper-based and the monograph options. I decided to take advantage of both forms by delivering a paper-based document, where the papers have been slightly modified to improve reader friendliness. More specifically, the numbering of figures, tables and equations has been unified, the references of the constituent papers have been integrated into a single list at the end of the thesis, overlapping material has been dropped, and cross references have been added. Furthermore and unlike the typical paper-based structure, conclusions have been moved into a separate chapter (Chapter 9) in the last part of the thesis.

Content wise, the thesis is based on three book chapters and three papers. Despite dealing with (duly updated) SuperGreen-related work, the book chapters were drafted during the DTU phase of the PhD project when the book '*Green Transportation Logistics: the Quest for Win-Win Solutions*' was being assembled by Prof. Harilaos N. Psaraftis. They are:

- Panagakos G. (2016). *The policy context*, Chapter 1 in Green Transportation Logistics: the Quest for Win-Win Solutions, H.N.Psaraftis (ed.) Springer, Heidelberg.
- Panagakos G. (2016). *Green corridors basics*, Chapter 3 in Green Transportation Logistics: the Quest for Win-Win Solutions, H.N.Psaraftis (ed.) Springer, Heidelberg.
- Panagakos G. (2016). *Green corridors and network design*, Chapter 4 in Green Transportation Logistics: the Quest for Win-Win Solutions, H.N.Psaraftis (ed.) Springer, Heidelberg.

As for the papers, the first one in the list below was prepared at NTUA, while the others were drafted at DTU:

- Panagakos G., Stamatopoulou E., Psaraftis H. (2014). *The possible designation of the Mediterranean Sea as a SECA: A case study*. Transportation Research Part D: Transport and Environment 28 (2014) 74–90.
- Panagakos G. and Psaraftis H. (2016). *Using transport model results in freight corridor performance monitoring – A European case study*, submitted to the European Journal of Transport and Infrastructure Research (currently under revision).
- Panagakos G. and Psaraftis H. (2016). *A taxonomy of carbon emission reduction measures in waterborne freight transportation*, submitted to Maritime Policy & Management (currently under review).

Furthermore, the output of the PhD project includes four additional publications, two book chapters and two conference papers which, however, have been excluded from the thesis as the relevant material is more or less incorporated in the abovementioned documents. These additional publications are:

- Panagakos G., Psaraftis H., Minsaas A., Ilves I., Salanne I. (2013). *The SuperGreen project and green corridor benchmarking*, Chapter 1 in European Corridor Projects – Trends, Strategies and Practices in freight transport and logistics, Herbert Sonntag (ed.) Wildauer Schriftenreihe, Technische Hochschule Wildau.

- Panagakos G. and Psaraftis H. (2014). *How green are the TEN-T core network corridors?* Paper presented at the TRA2014 Conference, Paris, France, 16.4.2014.
- Panagakos G., Psaraftis H., and Holte E.A. (2015). *Green corridors and their possible impact on the European supply chain*, Chapter 18 in Handbook of Ocean Container Transport Logistics: Making Global Supply Chains Effective, C.Y. Lee and Q. Meng (ed.) Springer, Heidelberg.
- Panagakos G. and Psaraftis H. (2016). *Performance assessment of a freight corridor on the basis of transport model results*. Paper presented at the TRA 2016 Conference, Warsaw, Poland, 19.4.2016.

Material contained in this thesis has also been presented in the following conferences, workshops or invited lectures outside DTU:

- Panagakos G. (2013). *Green Corridors in the EU Transport Policy*, European Maritime Week Conference, Athens, Greece, 24/5/2013.
- Panagakos G., Psaraftis H. (2013). *Implementing green corridors: What can be learned from SuperGreen?* BESTFACT International Workshop on Co-modality and Green Logistics, Vienna, Austria, 20/9/2013.
- Panagakos G., Psaraftis H. (2013). *Implementing green corridors: What can be learned from SuperGreen?* SWIFTLY Green Kick-off Conference, Gothenburg, Sweden, 28/11/2013.
- Panagakos G. (2014). *Green corridor assessment – Example from the GreCOR project*, Mid-term Conference SWIFTLY Green, Brussels, Belgium, 4/11/2014.
- Panagakos G. (2014). *Green Corridor assessment – Application of the SuperGreen method to GreCOR*, GreCOR Final Conference, Gothenburg, Sweden, 26/11/2014.
- Panagakos G., Psaraftis H. (2015). *SuperGreen: Mapping Sustainability and Emissions of Trans-European Trade Corridors*, TRB – Transportation for Sustainability Conference, Washington, DC, USA, 7/5/2015.
- Panagakos G., Psaraftis H. (2015). *An overview of implementing Green Corridors in Europe*, International Workshop on Green Corridors: European Experience and Brazilian Perspectives, São

Paulo, Brazil, 15/9/2015.

- Panagakos G., Psaraftis H. (2015). *Green Corridors: Concepts, benchmarking and their application in Europe*, Invited lecture at the University of São Paulo, São Paulo, Brazil, 17/9/2015.
- Panagakos G. (2016). *A taxonomy of $CO_2$ reduction for transport*, 3rd LRF-NTUA Centre of Excellence Workshop, Piraeus, Greece, 15/2/2016.

The work performed in the framework of the SuperGreen and GreCOR projects has been rewarded with the second place in the TRAVISIONS 2016 senior researcher contest on innovative transport ideas in the area of cross-modality.

Have a good read.

Kgs. Lyngby, Denmark
August, 2016

George Panagakos

# Acknowledgements

Notwithstanding the advantages that a 25-year educational and a 30-year professional record might have, they certainly complicate matters when it comes to acknowledging other people's contributions to one's PhD thesis. The reason is that an intellectual product like this basically reflects the author's scientific thinking and his/her ability to keep the reasoning clear of personal beliefs, preferences and biases of any kind. In the search for individual influences on one's thinking such a long educational and professional track record becomes an obstacle. Not only because it widens the range of candidates but also because it comes with age which inevitably weakens memory.

Fairness suggests that my first thanks go to this invisible hand that has arranged all these fantastic formal and informal teachers I've had, all these exciting people I've met and exchanged views with, all these wonderful authors whose books I've read, all those who collectively have formed me as an individual and a member of this society. If I had to name one individual as a mentor, this would be Stavros Apergis, whom I had the fortune to meet on my second day in my professional life as a young employee of the World Bank. His crystal clear thinking, his astonishing ability to focus on the substance, and his disarming candour have left their mark on the way I think. Since then, he has been a dear colleague, a reliable business partner, a dependable best man and god father, and a long lasting friend.

Closer to my research subject, I would like to thank my supervisory team, Harilaos and Allan, for their guidance in scientific and administrative matters, their trust on me, and their encouragement when I needed it. But most of all, I thank them for the kind and discrete way they have offered their advice, making me feel as if it were my own thinking. Special thanks are extended to Prof. Harilaos N. Psaraftis who, in addition to being my supervisor in both NTUA and DTU, was a professor of mine at MIT in 1984-85, an employer of mine for numerous research projects since 1993, the Project Manager of SuperGreen, my co-author in almost all my writings, and a reliable companion for almost every academic activity of mine including travels to places like Kuopio, Finland in the middle of the winter. Thank you for being there for me, Harilae.

I, hereby, express my indebtedness to the following institutions that have supported my work financially, as otherwise I would have never been able to materialise my dream:

(i) The Lloyd's Register Foundation through the NTUA project '*Centre of Excellence in Ship Total Energy-Emissions-Economy*,' which financed my PhD work during the period Apr. 2013 – Aug. 2014. The output of this period includes Chapter 8 and parts of Chapter 4 of this thesis. In relation to this project, I would like to thank the Project Manager, Prof. Christos Frangopoulos, for his trust and comments on my writings, Eirini Stamatopoulou for her input in the paper of Chapter 8, as well as Elisavet Vasiliadou and Mary Georgiou for their administrative support.

(ii) The EU Interreg North Sea Region Programme through the project '*GreCOR - Green corridor in the North Sea Region*,' which partly financed my PhD work during the period Aug. 2014 – June 2015. Chapter 5 of this thesis is based on output of this project. My appreciation is extended to Anna Hansson, Annelie Nylander, Pernilla Ngo and Nicklas Hansson of the Swedish Transport Administration, as well as Jerker Sjögren, Sofie Vennersten and Gustav Malmqvist of the Lindholmen Science Park in Gothenburg, Sweden.

(iii) The EU Interreg Baltic Region Programme through the projects '*TENTacle – Capitalising on TEN-T core network corridors for prosperity, growth and cohesion*' and '*Scandria®2Act - Sustainable and multimodal transport actions in the Scandinavian-Adriatic corridor*,' which were partly co-financed by my PhD work during the period Nov. 2015 – Aug. 2016. Work on these projects is on-going and results will be reported in future documents. The trust of Wiktor Szydarowski of the Swedish Blekinge Region, and Horst Sauer of the

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(iv) The DTU Transport and DTU Management Engineering Departments that partly financed my PhD work during the periods Aug. 2014 – Apr. 2016 and May 2016 – Aug. 2016 respectively,[1] including the drafting of all chapters of this thesis.

It is my duty to acknowledge several people who contributed to the SuperGreen project, which has played a critical role in my PhD study. The assistance of Rein Jüriado and Fleur Breuillin, both Project Officers at the European Commission (DG-MOVE), is gratefully acknowledged for their technical and administrative support and for their advice in general. The members of the project's Advisory Committee are also thanked for their input. Among the numerous colleagues in the project, I would like to acknowledge here only my co-authors in a number of papers (in alphabetical order): Alkis Corres, Andreas Bäck, Atle Minsaas, Aud Marit Wahl, Chara Georgopoulou, Dimitris Lyridis, Eero Vanaale, Even Ambros Holte, Francesca Vio, Humberto Moyano, Ilkka Salanne, Indrek Ilves, Juha Schweighofer, Konrad Pütz, Panagiotis Zacharioudakis, Sanni Rönkkö, and Sara Fozza.

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[1] On 1 May 2016 DTU Transport was merged with DTU Management Engineering.

McLaughlin of Maritime Policy & Management for having published or considering publication of the papers presented in this thesis. Many thanks also deserve the anonymous reviewers of these papers for their constructive comments, as well as all individuals who have provided information on the transport chains examined here but who cannot be named explicitly due to confidentiality restrictions. Valuable comments on the final version of this thesis have also received from the members of my Examination Committee Jeppe Rich, Kevin Cullinane and Lauri Ojala, who are thanked for their contribution.

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I am grateful to my father and mother for their love and support. I was rather surprised to realise how comforting the awareness of their positive thinking can be even at this age. I am sure that they will enjoy my PhD degree as much as I will.

The same applies to my wife, Coralia. But in her case, it is not only the joy of my degree that she deserves; it is half of the degree itself. Isn’t she the one who gave up her comfortable life in Greece to escort me here, who took care of all other family matters to let me focus on my work unobstructed, who coped with my long office hours, who supported me through the ups and downs of this challenging endeavour, who anticipated and catered for all my needs, who created this warm and friendly atmosphere around me with her unique social skills? After all, we have learned to share everything in our long common life; why not a degree?

But the most valuable treasure we share with Coralia is our daughter Christiana. Her thought brings smile, and her existence adds meaning to everything we do. This thesis is not an exception. But she’s more than a wonderful daughter. On several occasions the struggle she’s giving all alone towards a demanding degree in Geneva has been an inspiration for me, and our internal race of who is going to graduate first has been a lot of fun. Thank you.

"Not everything that can be counted counts, and
not everything that counts can be counted"

(William Bruce Cameron, 1963; although the quote is often attributed to Albert Einstein)

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# Glossary of acronyms and abbreviations

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|---|---|
| ADB | Asian Development Bank |
| API | Aggregate Performance Indicator |
| ATM | Air Traffic Management |
| BGLC | Bothnian Green Logistics Corridor |
| CARE | Community Road Accident Database |
| CAREC | Central Asia Regional Economic Cooperation |
| CEF | Connecting Europe Facility |
| CIAM | Criterion-Influences-Actions-Measures (for sustainability frameworks) |
| CMS | Corridor Management System |
| CNC | Core Network Corridor |
| CNG | Compressed Natural Gas |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| $CO_2$-eq | Carbon dioxide equivalent unit |
| CPI | Consumer Price Index |
| CPMM | Corridor Performance Measurement and Monitoring |
| CRT | Carbon dioxide Reducing Technology |
| CUR | Capacity Utilisation Rate |
| DEFRA | Department for Environment, Food and Rural Affairs (UK) |
| DG MOVE | Directorate-General for Mobility and Transport, European Commission |
| DWT | Deadweight (of a ship) |
| EC | European Commission |
| ECA | Emission Control Area |
| ECSA | European Community Shipowners’ Association |
| EDI | Electronic Data Interchange |

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|---|---|
| EDU | Equivalent Delivery Unit |
| EEDI | Energy Efficiency Design Index |
| EEIG | European Economic Interest Group |
| EEOI | Energy Efficiency Operational Indicator |
| EFTA | European Free Trade Association |
| EIB | European Investment Bank |
| EMSA | European Maritime Safety Agency |
| EP&C | European Parliament & Council |
| ERA | European Railway Agency |
| ERDF | European Regional Development Fund |
| ERTMS | European Rail Traffic Management System |
| ET | Empty Trip factor |
| ETCR | Regulation in Energy, Transport and Communications (OECD) |
| ETCS | European Train Control System |
| ETS | Emissions Trading System |
| EU | European Union |
| EWTC | East-West Transport Corridor |
| FMCG | Fast Moving Consumer Goods |
| FTLAP | Freight Transport Logistics Action Plan |
| FUTRE | Future prospects on Transport evolution and innovation challenges for the competitiveness of Europe (7th Framework Programme) |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| GIS | Geographic Information System |
| GreCOR | Green Corridor in the North Sea Region |
| GRT | Gross Registered Tonnage |
| HC | Non-methane Hydrocarbon |
| HDV | Heavy Duty Vehicle |
| HES | Household Expenditure Survey |
| HFO | Heavy Fuel Oil |
| ICS | International Chamber of Shipping |
| ICT | Information and Communication Technology |
| IMO | International Maritime Organization |
| INEA | Innovation and Networks Executive Agency |

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|---|---|
| IPCC | Intergovernmental Panel on Climate Change |
| IQ-C | International Group for Improving the Quality of Rail Transport in the North-South-Corridor (Rotterdam-Genoa) |
| ITS | Intelligent Transport Systems |
| IWT | Inland Waterway Transport |
| JRC | Joint Research Centre, European Commission |
| KPI | Key Performance Indicator |
| LCA | Life Cycle Assessment |
| LF | Load Factor |
| LNG | Liquefied Natural Gas |
| LPG | Liquefied Petroleum Gas |
| LPI | Logistics Performance Index, the World Bank |
| LRF | The Lloyd's Register Foundation |
| LRIT | Long Range Identification and Tracking |
| LTM | Lands Trafik Modellen (Danish National Transport Model) |
| MARPOL | International Convention for the Prevention of Pollution from ships |
| MAUT | Multi-Attribute Utility Theory |
| MBM | Market Based Measure |
| MCDA | Multi-Criteria Decision Analysis |
| MDO | Marine Diesel Oil |
| MEPC | Marine Environment Protection Committee, IMO |
| MGO | Marine Gas Oil |
| MJ | Megajoule (energy unit) |
| MoS | Motorway of the Sea |
| MoU | Memorandum of Understanding |
| MRV | Monitoring, Reporting and Verification (of $CO_2$ emissions) |
| MTMS | Multimodal Transport Market Study |
| NECL | North East Cargo Link |
| NOx | Nitrogen oxides (NO and $NO_2$) |
| NTM | Network for Transport Measures |
| NTUA | National Technical University of Athens |
| OD | Origin-Destination |
| OECD | Organisation for Economic Co-operation and Development |
| OR | Operational Research |
| PM | Particulate Matter |

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| PSC | Public Service Contract |
| PSR | Pressure-State-Response (for sustainability frameworks) |
| RDS-TMC | Radio Data System - Traffic Message Channel |
| RFC | Rail Freight Corridor |
| RIS | River Information Services |
| RMMS | Rail Market Monitoring Scheme |
| RNE | RailNetEurope |
| Ro-Pax | Roll on – Roll off / Passenger (for ships) |
| Ro-Ro | Roll on – Roll off (for ships) |
| RTD | Research and Technological Development |
| SCANDRIA | Scandinavian-Adriatic corridor for innovation and growth |
| SDS | Sustainable Development Strategy |
| SECA | SOx Emission Control Area |
| SEEMP | Ship Energy Efficiency Management Plan |
| SESAR | Single European Sky ATM Research |
| SGCI | Swedish Green Corridors Initiative |
| SME | Small and Medium-sized Enterprise |
| SoNorA | South-North-Axis corridor in central Europe |
| $SO_2$ | Sulphur dioxide (also referred to as SOx) |
| SSN | SafeSeaNet (a VTMIS) |
| SSS | Short-Sea Shipping |
| STEEP | Socio-cultural, Technological, Economic, Ecological, and Political |
| TCD | Time-Cost-Distance |
| TEN | Trans-European Networks |
| TEN-T | Trans-European Transport Network |
| TEN-T EA | Trans-European Transport Network Executive Agency |
| TEU | Twenty-foot Equivalent Unit (for containers) |
| TMS | Transport Market Study |
| TOE | Tonne of Oil Equivalent |
| UIC | International Union of Railways |
| ULSFO | Ultra-Low Sulphur Fuel Oil |
| UN | United Nations |
| UNECE | United Nations Economic Commission for Europe |
| VAT | Value Added Tax |
| VECTO | Vehicle Energy Consumption Calculation Tool |

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| VMT | Vehicle Miles Travelled |
| VTMIS | Vessel Traffic Monitoring and Information System |
| VRP | Vehicle Routing Problem |
| WEF | World Economic Forum |
| WTO | World Trade Organization |

# PART I. SETTING THE SCENE

# 1. Introduction

## 1.1 Challenges in freight transport logistics

Although undisputed, the vital role of transport in economic growth, territorial cohesion and social development is not free of problems. A number of challenges impede its effectiveness, the most important of which are briefly presented in this section. It is noted that while a European perspective is adopted here, many of the same issues are also encountered in other parts of the world and hence may have a broader applicability.

The quest for **efficiency** is not new. Removing barriers to fair competition is a European pursuit as old as the 1957 Treaty of Rome that established the European Economic Community (EEC, 1957). Since then, a lot of ground has been covered in all modes. However, gaps in **market opening** still exist, particularly in the rail sector where state monopolies were the rule until quite recently. In many Member States, the implementation of legislation prescribing market opening in rail freight transport as of 2007 has been slow and incomplete and enforcement has been inadequate (EC, 2011b). Complex and diversified **administrative formalities** applicable to intra-EU maritime transport still deprive short sea shipping from its competitive advantages in terms of cost and emissions by excessively lowering its overall speed (EC, 2009b). Little progress has been made in **internalising transport externalities** that can rationalise user behaviour despite having developed a common methodology for this purpose since 2008 (EC, 2008c).

Transport **safety** has been the object of successive legislation in Europe for many years with good tangible results in all modes. There is room for improvement, though, as the loss of lives on the pavement is becoming less tolerable. The latest White Paper on transport that describes the EC's vision of future transport and the corresponding strategy for the next decade has set the aim of halving road casualties by 2020, and moving close to zero fatalities in road transport by 2050 (EC, 2011a).

**Security** of transport that became an issue after 11 September 2001 is attracting increasing attention due to the unstable geopolitical situation in our neighbourhood. Nowadays there are EU legislative measures on transport security for most transport modes and for critical infrastructures, while EU naval operations have been launched to fight the global problem of piracy (EC, 2009a). Secure transport is seen by the new White Paper as an important feature of an efficient and integrated mobility system, and 9 out of the 131 initiatives of the document relate to this issue (EC, 2011a).

**Congestion** was a problem in Europe already during the 1990s. As early as in 1993, the White Paper on Growth, Competitiveness and Employment warned: "*Traffic jams are not only exasperating; they also cost Europe dear in terms of productivity*" (EC, 2001a). The trend of increasing congestion is expected to exert more pressure towards its containment which, however, is not foreseen in the near future.

Environmental issues are gaining importance. Sustainability became a strategic issue in the EU only in 2001 (EU, 2001b) and it was with its 2006 review of the 2001 White Paper that the Commission pointed to the need to use a broad range of policy tools to achieve sustainable mobility (EU, 2006). **GHG emissions** from the transport sector attract the attention of both transport and climate change policymakers because of their significant share in total emissions and their persistently strong growth (Petersen et al., 2009). The substantial improvements of the past years in the energy efficiency of vehicles are not sufficient to cope with the boosting transport demand. The result is rising GHG emissions from transport unlike what happens in many other sectors of the European economy.

When it comes to **air pollutants**, emissions from transport are also a very high percentage of the total. Once again, progress has been made during the last two decades basically through setting stringent emission standards on vehicles/vessels and fuel quality. However, air quality in areas of dense transport activity, particularly in urban areas, is still a serious problem (Petersen et al., 2009).

The emission problem is exacerbated by an emerging **environmental consciousness** culture. Motivated by the visible deterioration of the global environment, consumers acknowledge the dependency of human existence on the natural environment and are more sensitive to the need to protect it from the negative impacts of human activity. This trend may generate pressures to companies to decrease their emission footprints and use more environmentally-friendly transport modes (where possible), such as rail, inland waterway transport and short sea shipping (BE LOGIC, 2009). Along these lines, on the basis of a Delphi survey mainly among academics, Ojala et al. (2013) have concluded that the demand for environmentally accountable logistics services in the Baltic Sea Region will significantly grow until 2025. Similarly, the World Bank '*Connecting to Compete*' report that delivers insights into the importance and the state of logistics globally sees the demand for green logistics gradually becoming a common feature among the logistics friendlier countries (Arvis et al. 2016).

Furthermore, European transport remains highly **dependent on oil** and other fossil fuels. In 2010, oil counted for 94% of the transport energy needs in Europe and 84% of it was imported. This fact, combined with the growing concerns about **energy security**, increases the need to move towards a low-carbon economy basically through a greater supply of renewable energy (EC, 2013a).

**Large investments** are required to modernise the EU infrastructure so it can match transport demand. An estimated cost of over € 1.5 trillion for the period 2010-2030 is cited in EC (2011b). In the present environment of budgetary consolidation, caused by the recent economic crisis and the higher social security expenditures due to the ageing population, such amounts appear unrealistic.

On top of these rather general issues, a number of more specific challenges burden freight transport logistics. Current trends demonstrate a shift of competition from among enterprises to among supply chains. In view of this, supply chain partners need to remove barriers inhibiting the flow of materials/products, financial resources and information so as to optimise their overall performance (BE LOGIC, 2009). **Supply chain integration** appears as the most effective way to manage these complex flows among the participating actors, which sometimes have their own agendas and conflicting interests. Recent research, however, suggests that increased collaboration in the supply chain is associated with lower logistics costs and better financial performance of the participating firms (Solakivi et al., 2015).

This trend, further enhanced by the increasing levels of congestion and transport related emissions mentioned above, places more pressure on the service providers to develop comprehensive business models that support innovative practices and extensive cooperation among the actors involved. **Information sharing** having a positive effect on demand and capacity planning as well as on performance and inventory management is considered as the basic pillar of such supply chain integration. Cui et al. (2015) have estimated for a leading producer in the US beverage industry that incorporating downstream retail sales data improves the company's forecast accuracy by more than 40%.

As competition among supply chains is gradually strengthened, the end customer satisfaction becomes the major determinant of supply chain success or failure. In such an environment, supply chains tend to adopt organisational and managerial structures that enable not only **reliability** which continues to be a major concern for both shippers and consignees (Arvis et al. 2016) but also **responsiveness** to short lead times, highly customised variety of products/services and direct deliveries. **Agility**, the ability to react quickly to rapid shifts in supply and demand, is an equally important requirement. According to a KPMG survey among the supply chain directors of 80 companies across the UK, US, Portugal and Germany, 'developing more effective responses to demand volatility' was one of the three main themes that they focused on in 2012 (KPMG, 2012). The **shortage of skilled labour**, which is expected to become a serious concern for the logistics industry in the future, does not help in any respect (EC, 2011a; Ojala et al., 2013; Arvis et al. 2016).

Finally, as regards people like us who devote most of our time researching logistics-related issues, the **lack of data** or data of questionable quality is a long-standing problem, especially when it comes to multimodal freight flows. Although the use of Information and Communication Technology (ICT) applications might prove fruitful in alleviating this problem, this has not materialised in any substantial way thus far (Psaraftis, 2016a). This is the reason for including 'observation of logistics' (measurement of its economic, environmental and social performances) as one of the six themes to be developed in the next 10 years according to '*France Logistique 2025*,' the French strategic plan for logistics (Savy, 2016).

## 1.2 Objectives and research questions

My PhD study plan explicitly states only one objective: "A quantitative analysis of freight transport corridor performance in terms of specified KPIs." However in order to expand the policy content of the project, which also appears in the expected output of the study plan, it was decided to add two more objectives concerning the environmental indicators (GHG and SOx emissions) of the assessment methodology. A maritime corridor context has been selected for these objectives mainly because:

(i) shipping is the principal carrier of world trade, carrying as much as 90% by volume (IMO, 2015) and
(ii) despite its lowest relative[2] energy consumption among all modes, shipping produces a share of 5 – 10% of global SOx emissions (ITF, 2014) due to the poor quality of marine fuels.

Each of the resulting three general objectives of the PhD study occupies a separate heading below. The corresponding specific objectives and research questions have been itemised in order to simplify the assessment of the project contribution later on (Chapter 9).

### 1.2.1 Objective 1: Green corridors and their assessment

Faced with the problems mentioned above, the European Commission proposed in 2007 the 'green corridor' concept, denoting a concentration of freight traffic between major hubs and by relatively long distances. The immediate effect would be improved competitiveness of rail and waterborne transport that exhibit better

[2] Expressed on a per-unit-of-transport-work basis, which in the case of freight becomes per tonne-km.

environmental characteristics than road haulage, thus, enhancing the overall environmental sustainability of the sector (EC, 2007b).

The introduction of the Rail Freight Corridors in 2010 (EP&C, 2010a) and the TEN-T core network corridors more recently (EP&C, 2013a) indicate that the corridor approach is gaining popularity as an implementation tool in EU transport policy. It is worth mentioning that the latest EU White Paper on transport considers green corridors as a tool for meeting the ambitious goal of shifting 30% of road freight over 300 km to other modes by 2030, and more than 50% by 2050 (EC, 2011a).

Numerous green corridor applications also exist at the regional level. In Scandinavia, where the concept has been very popular, such applications include the East West Transport Corridor (EWTC) (Fastén and Clemedtson, 2012), the Swedish Green Corridor Initiative (SGCI) (Wålhberg et al., 2012) and the related GreCOR (Pettersson et al., 2012) and Bothnian Green Logistic (Södergren et al., 2012) corridors, the TransBaltic (TransBaltic, 2012), the Scandria (Friedrich, 2012), the Midnordic Green Transport Corridor (Kokki, 2013) and the Green STRING Corridor (Stenbæk et al., 2014). Outside Scandinavia, examples of important green corridor projects include the Rotterdam-Genoa corridor (Corridor A, 2011) and the Munich-Verona Brenner corridor (Mertel and Sondermann, 2007).

A common feature of all these projects relates to the need for monitoring the performance of the relevant transport corridors in terms of pre-specified qualities. Most of these projects define a set of indicators to be used for performance monitoring; either explicitly (Mertel and Sondermann, 2007; Corridor A, 2011; Fastén and Clemedtson, 2012; Wålhberg et al., 2012; Pettersson et al., 2012 and Södergren et al., 2012) or implicitly (TransBaltic, 2012; Friedrich, 2012; and Stenbæk et al., 2014). Very few, however, propose a performance monitoring methodology.

SGCI (2012) provides a more analytical set of guidelines for monitoring the performance of individual transport services, covering both links and nodes, but the aggregation at corridor level is unclear and the scope of the project is limited to the environmental aspects of green corridors. A more comprehensive methodology has been proposed by SuperGreen (Ilves et al., 2011), an EU-financed project aiming at further defining the green corridor concept, and the EWTC project (Fastén and Clemedtson, 2012). Both these documents cover all aspects of sustainability (i.e. economic, environmental and social efficiency) and describe a corridor through a set of typical transport chains. However, EWTC never applied the proposed methodology on a full scale corridor, while the SuperGreen selection of typical chains was based on the ill-conceived idea of 'critical link,' the segment involving the greatest geographical barrier of the corridor. Both projects ran into serious data availability problems.

In view of these difficulties, Panagakos (2012) proposed the construction of a 'basket' of typical transport chains for each corridor on the basis of the 'Transport Market Study' foreseen by Reg. No 913/2010 for the Rail Freight Corridors and, through them, for the TEN-T core network corridors, too. The Key Performance Indicators (KPIs) estimated for the basket chains would, then, be aggregated at corridor level through proper weights, also specified by the Transport Market Study.

However, having been conceived only at the end of the SuperGreen project, this methodology never had the chance to be tested on a real corridor. Addressing this gap by examining the effectiveness of this methodology and its subsequent refinement on the basis of problems encountered along the way is one of the aims of this PhD study. The first objective of the study, then, becomes:

***OB1:*** ***Quantitative analysis of the performance of a green freight transport corridor in terms of pre-specified key performance indicators (KPIs)***

The corresponding specific objectives include:

***SO1.1:*** ***Define a green freight transport corridor***

***SO1.2:*** ***Develop and refine a methodology for corridor performance benchmarking, placing emphasis on the:***
- ***construction of the sample of representative transport chains,***
- ***estimation of chain-level KPI values on the basis of available data, and***
- ***developing the methods for aggregating chain-level***

***indicators to corridor-level KPIs.***

***SO1.3: Collect and process relevant data from various databases and other sources***

***SO1.4: Apply the above methodology to a specific corridor.***

The research questions in relation to OB1 are:

***Q1.1: Which are the specific characteristics that distinguish a green corridor from any other efficient transport corridor?***

***Q1.2: Are the TEN-T core network corridors green according to the criteria of Q1.1?***

***Q1.3: Is it possible to assess the performance of a green corridor?***

***Q1.4: Which assessment approach (study- or model-based) is recommended?***

***Q1.5: What policy recommendations can be drawn from the application of this methodology on a green corridor?***

***Q1.6: Is it possible to develop a more quantitative definition of a green corridor on the basis of the results achieved in the case study?***

The output of the study is expected to provide guidance and support to all green corridor projects that are currently in their implementation phase, particularly in relation to methodological issues.

### 1.2.2 Objective 2: Green maritime corridors – $CO_2$

A wide range of measures have been proposed to improve vessel efficiency, reduce fuel consumption and lower emissions (Eide et al., 2011; ABS, 2012). The classification of such measures is the subject of several publications. The detailed review of these publications results in two broad groups. The first one classifies carbon emission reduction options in three fundamental categories: energy efficiency improvements, renewable energy sources, and fuels with lower lifecycle emissions per unit of work. The Second GHG Study of the International Maritime Organization (IMO, 2009) is a good example of such document, as are Balland et al. (2010) and Calleya, Pawling, and Greig (2015). These classification schemes are simple and practical but lack rigid theoretical foundations.

The second group consists of documents that attempt to capture the multiplicity of interrelations among all factors affecting emission volumes. IMO (2009) is once again a good example, as is McKinnon, Browne, and Whiteing (2012). Such schemes tend to be of limited practical value, however, due to their high level of complexity.

The PhD study aims to close the gap between these two groups by developing a simple and practical framework for classifying emission reduction measures in the shipping industry which, however, is sufficiently supported by theory. The second objective, then, becomes:

***OB2: Simple theoretical framework for classifying carbon emission reduction measures in the shipping industry***

The corresponding specific objectives include:

***SO2.1: Review existing sustainability frameworks and select the most appropriate one for the intended use***

***SO2.2: Decompose carbon emissions into a number of factors***

***SO2.3: Classify carbon emission reduction measures in waterborne transport according to the factors identified in SO2.2.***

The research questions in relation to OB2 are:

***Q2.1: Which is the most suitable sustainability framework for classifying carbon emission reduction measures in the shipping industry?***

***Q2.2: Which are the most important factors influencing carbon emissions in waterborne transport?***

***Q2.3: Which are the most important practices and policies in the field that address the factors identified in Q2.2?***

***Q2.4: What policy recommendations can be drawn from this taxonomy?***

It should be stated at the outset that the above questions will be answered on the basis of a literature survey and the study does not intend to provide an exhaustive list of potential carbon emission reduction measures in waterborne transport. The contribution of the study relates to the formulation of the framework itself. Such a framework would put available options into a better perspective and serve as guidance in assessing their effectiveness and compatibility.

### 1.2.3 Objective 3: Green maritime corridors – SOx

The stricter standards on the sulphur content of marine fuels as introduced by IMO in 2008, particularly the 0.1% limit applicable to the SOx Emission Control Areas (SECAs) as of 1 January 2015, caused serious concerns within the shipping industry in northern Europe. A negative impact on the competitiveness of shipping operations was expected, potentially leading to a shift to other less environmentally friendly modes of transport. A number of studies were undertaken to examine the impact of these stricter requirements. Hader et al. (2010), Notteboom et al. (2010), and EMSA (2010) are only a few examples.

During the debate that preceded the transposition of these standards into European law, a discussion took place on possible designation of the Mediterranean Sea as a SECA (Bosch et al., 2009; Delhaye et al., 2010; Kehoe and Woxenius, 2010; Schinas and Bani, 2012).

In this framework, the PhD study aims to examine the impact of designating the Mediterranean Sea as a SECA on a typical transport of consolidated cargoes between Thessaloniki, Greece and industrial hubs of northern Germany. This will be done by assessing a road-only option against a combined-transport route involving a ferry service for crossing the Ionian/Adriatic Seas and a truck-on-train service for crossing the Alps. The modal shift resulting from a Mediterranean SECA will be calculated by a binomial logit model, considering transport cost and time as determinants of modal choices. Thus, the third objective of the PhD study is:

***OB3:*** ***A case study examining the impacts on modal split and emissions of designating the Mediterranean Sea as a SECA***

The corresponding specific objectives include:

***SO3.1:*** ***Collect detailed cost and time data for the two alternative door-to-door options examined in the case study***

***SO3.2:*** ***Develop and calibrate a binomial logit model for the calculation of modal split***

***SO3.3:*** ***Use the model developed in SO3.2 to calculate the modal***

***shift resulting from the designation of the Mediterranean Sea as a SECA***

***SO3.4: Estimate CO2-eq, SOx, NOx and PM10 emissions on the basis of the results of SO3.3***

***SO3.5: Run sensitivity analyses on the basic parameters entering the calculations.***

The research questions in relation to OB3 are:

***Q3.1: Which are the available options of the maritime industry to comply with the stricter standards on the sulphur content of marine fuel in SECAs?***

***Q3.2: What is the impact of a costlier marine fuel on the modal split along the routes examined in the case study?***

***Q3.3: What are the implications of the expected modal shift on the average emissions along the corridor?***

***Q3.4: Which are the most important parameters entering the modal split calculations and how sensitive the results are in relation to these parameters?***

***Q3.5: What policy recommendations can be drawn from this case study?***

In addition to complementing the literature on the subject, which happens to be much thinner for the Mediterranean Sea in comparison to the Baltic and North Seas, the study is expected to contribute by developing a methodology that takes transport time into consideration in addition to costs. Furthermore, the study will apply a micro-level perspective, which is handful in securing comparable door-to-door transport chains on one hand, while it allows the delineation of an emission allocation scheme for a multi-load multi-drop operation on the other.

## 1.3 Outline of the thesis

The thesis consists of nine chapters organised in five parts. In addition to the present one, the first introductory part contains a chapter on the policy framework of the 'green' freight logistics, thus, setting the scene for the more focused subjects of the following chapters. The most important EU transport policy documents are reviewed and briefly presented by transport mode. Horizontal documents covering all modes are reviewed first. The material spans a 15-year period, from the Sustainable Development Strategy of May 2001 to the Directive 2014/94/EU of 22 October 2014 on the deployment of alternative fuels infrastructure. Presenting a subject as wide and complex as the EU transport policy in the limited space of a thesis chapter is not an easy task. Although there is no guarantee that the author's personal biases have been left out entirely, every effort has been made to cover as many aspects of policy making as possible, always in the context of green freight logistics.

The second part of the thesis is devoted to the concept of 'green corridors' and consists of two chapters. The purpose of Chapter 3 is to introduce this concept as a means to develop integrated, efficient and environmentally friendly transportation of freight between major hubs and by relative long distances. The basis of this material is work conducted in the context of the EU SuperGreen project, which aimed at advancing the green corridor concept through a benchmarking exercise involving KPIs. The chapter discusses the available definitions of green corridors and identifies the characteristics that distinguish a green corridor from any other efficient surface transport corridor (Q1.1). After providing examples of green corridor projects in Europe, it focuses on the KPIs that have been proposed by various projects for monitoring the performance of a freight corridor. Emphasis is given to the SuperGreen KPIs, covering the economic, technical, environmental, social and spatial planning aspects of freight logistics, as they have been scrutinised extensively by stakeholders in order to keep their number within practical and operable limits. In addition, the chapter presents the performance monitoring methodology that was developed by SuperGreen in an effort to close the gap of earlier works. The lessons learned from SuperGreen led to a revised methodology suitable for monitoring the performance of a corridor.

Chapter 4 aims to investigate the relation between the trans-European transport network (TEN-T) and the green corridor concept (Q1.2). First, the need is established for a corridor governance structure that enables the close cooperation among the numerous public- and private-sector stakeholders engaged in issues ranging from network design to the provision of integrated logistical solutions. The governance scheme of the recently introduced TEN-T core network corridors is also examined. Following a brief history of TEN-T development, the 2013 major overhaul of the EU transport infrastructure policy is outlined and the basic differences with the past are pinpointed. The provisions of the new TEN-T Guidelines are scrutinised so as to check whether the TEN-T core network corridors exhibit the characteristics of a green corridor, as they have been identified in the previous chapter. Based on the results of this analysis, it is concluded that the TEN-T core network is, as far as its freight dimension is concerned, a network of green corridors.

Part III deals with assessing the performance of a freight corridor (Q1.3 to Q1.6). It consists of two chapters. Chapter 5 proposes a new methodology for assessing the 'greenness' of a corridor. The earlier assessment method, proposed by SuperGreen, consists of decomposing the corridor into transport chains, selecting a sample of typical chains, assessing these chains through a set of KPIs, and then aggregating the chain-level KPIs to corridor-level ones using proper weights. It suggests a study-based approach for constructing the corridor sample using specialised transport studies like those prepared for the TEN-T Core Network Corridors and the corresponding Rail Freight Corridors. Corridor studies, however, tend to focus on the most trafficked and/or problematic areas of the corridor and fail to provide the balanced coverage needed for selecting a representative sample of transport chains. The proposed methodology addresses this problem by relying on transport model results instead. It was tested on GreCOR, a green corridor project in the North Sea Region, while the Danish National Traffic Model was used as the principal source of information for both sample construction and KPI estimation. The results show that the methodology can effectively assess the performance of a freight transport corridor. Combining the model-based approach for the sample construction and the study-based approach for the estimation of chain-level indicators exploits the strengths of each method and avoids their weaknesses. Possible improvements are also suggested by the chapter.

Chapter 6 aims to improve the method proposed in the previous chapter by incorporating stakeholder input. After revising the sample of corridor chains as constructed in Chapter 5 to eliminate atypical and insignificant chains, the data solicitation effort is described. No KPIs and indices are calculated, however, as the feedback received is still not sufficient to support a meaningful statistical analysis. It is for this reason that this chapter is the only one in the thesis that is based on a technical report rather than a paper. As the work is still on-going, the results will be presented in future publications.

Part IV seeks to enhance the policy content of the thesis by concentrating on the environmental implications of maritime corridors. Each of the two chapters of this part addresses one the two environmental KPIs examined in the thesis; $CO_2$ and SOx. Chapter 7 aims at developing a simple and practical framework for classifying carbon emission reduction measures in the shipping industry. The main types of frameworks found in assessing transport sustainability are reviewed and a 'Criterion-Influences-Actions-Measures' structure is suggested as the most suitable one for the intended use (Q2.1). The waterborne transport related carbon emissions are decomposed into a number of drivers through an extended Kaya identity (Q2.2). The carbon intensity of the fuels used, the energy efficiency of the vessels employed, the vessel capacity and utilisation rate, and the transport activity expressed by cargo volumes and average haul lengths are identified as the most important factors affecting emissions. A wide range of carbon emission reducing practices and policies, albeit by no means exhaustive, are examined and classified on the basis of these factors (Q2.3). The proposed framework, built on rigid theoretical foundations, puts available options into the right perspective and serves as guidance in assessing their effectiveness and compatibility. It also helps acknowledging: (i) the advantages that packages of complementary instruments have over single measures, and (ii) the environmental benefits derived indirectly by many profit maximising measures (Q2.4).

Taking part in the discussions concerning the possible designation of the Mediterranean Sea as a Sulphur Emission Control Area (SECA), Chapter 8 applies a modal split model to a case involving the transportation of consolidated cargoes between Thessaloniki, Greece and industrial hubs in northern Germany. A road-only option is assessed against a combined-transport route involving a ferry (Greece–Italy) and a truck-on-train (Italy–Austria) service. A binomial logit model is used to answer the relevant research questions. The data are derived from interviews with a small transport service provider, typical for Greece, and are based on actual trips made (revealed preferences). The results predict that the designation of the Mediterranean as a SECA will cause a modal shift in favour of the road-only route by 5.2%, which under certain assumptions can reach 17.1%. However, the environmental implications of the resulting modal choices, calculated through the EcoTransIT World web based tool, are positive in relation to all emissions examined. This is attributed to the longer distance of the combined-transport option in comparison to the road-only one and, the poor environmental performance of the Ro-Pax vessels basically due to their relatively high speed.

The last part of the thesis consists of a single chapter that summarises the project results and conclusions of the previous chapters. The research questions set in Section 1.2 form the basis for this discussion. The contributions of the PhD study are identified and suggestions for future research are proposed.

# 2. The policy context[3]

## 2.1 Introduction

The purpose of this chapter is to delineate the term 'green' when used in the context of freight transportation logistics. This will be done by reviewing a number of relevant policy documents. At the same time, this review will set the scene for presenting the subjects of the following chapters.

The material presented here is based on work performed under the 'SuperGreen' project financed by the EC's 7th Framework Programme of Research and Technological Development. This is the reason for the almost exclusively European coverage of this chapter. Sporadic references to documents issued by institutions like the International Maritime Organization (IMO) are only exceptions to the general picture. By the same token, coverage is limited to the regional scope of the EU, which usually reflects a negotiated compromise between the national views of the Member States.

Very often the term 'green' is used to refer to merely environmental protection features. In this thesis, 'green' means 'sustainable,' thus, adding economic and social attributes to the usual environmental ones (Figure 1).

3 With the exception of some minor editorial changes basically concerning cross-references, this chapter is identical to the homonymous Chapter 1 of the book *Green Transportation Logistics: the Quest for Win-Win Solutions*, edited by H.N.Psaraftis (Panagakos, 2016a).

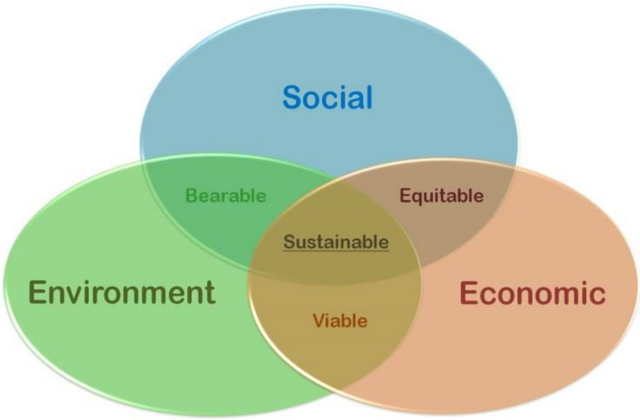


**Figure 1. The three dimensions of sustainable development**

(Source: The Sustainable Leader, 2014)

This broader perspective creates the need for reviewing a much wider range of EU policies. It is, then, necessary to be very selective in those presented and focus only on these documents that have a direct relevance to the subjects of the following chapters.

The present chapter basically follows a modal structure. Road, rail and waterborne transport are each covered in a separate section. Aviation and pipelines are outside the scope of the thesis. Within each mode (section), the documents reviewed are presented in chronological order.

Section 2.2 covers basic material published before 2010. After a brief discussion on the sustainability concept, the section presents the EU action plan on freight logistics and the so-called 'Greening transport package.' Section 2.3 is devoted to more recent documents but still horizontal in nature. It outlines the transport strategy of the EU for the next decade, its new transport infrastructure policy, its initiatives on alternative fuels and the newly introduced transport scoreboard. Section 2.4 relates to road transport and presents the EC policy on ITS deployment and its proposals on vehicle dimensions and strategy formulation for reducing fuel consumption and $CO_2$ emissions from trucks. Section 2.5 deals with the EC efforts to liberalise rail transport and increase the priority of international freight trains. The last section of the chapter concerns the waterborne transport and more specifically the IMO and EU initiatives addressing greenhouse gas (GHG) and SOx emissions of ships.

## 2.2 Background

The first appearance of the term 'green' in the context of EU policy on transport logistics took place in 2007, when the Freight Transport Logistics Action Plan introduced the 'green corridors.' Therefore, this document can serve as our point of departure. But before departing, it is necessary to look briefly into the way the European policy makers view the concept of sustainability with emphasis placed on sustainable transport.

In relation to the external costs of transport, the European Parliament asked the Commission in 2006 to present "*a generally applicable, transparent and comprehensible model for the assessment of all external costs… and a strategy for a stepwise implementation of the model for all modes of transport*". In response to this request, the Commission prepared the 'Greening transport package,' which was adopted in July 2008 (EC, 2008a). It basically consists of:

- the *Greening Transport Inventory* that describes the actions already taken by the EU to make transport greener, and
- the *Strategy to Internalise the External Costs of Transport* accompanied by a proposal for introducing road tolls for lorries and track access charges for rail differentiated according to the environmental impact of train operation.

Both these documents will be briefly reviewed in this section, too.

### 2.2.1 The European Sustainable Development Strategy

Building on the traditional 'Brundtland Commission' definition of sustainable development, i.e. *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs,"* the EU developed its own Sustainable Development Strategy (SDS) in 2001. The SDS called for a society where **economic growth**, **social cohesion** and **environmental protection** go hand in hand, and laid down long-term objectives and priority actions in six policy areas (EC, 2001b):

- climate change and clean energy,
- public health,
- social exclusion, demography and migration,
- management of natural resources,
- sustainable transport, and
- global poverty and development challenges.

In terms of sustainable transport, SDS set the headline objectives of:

- decoupling transport growth from GDP growth in order to reduce congestion and other negative side-effects of transport[4], and
- bringing about a shift in transport use from road to rail, water and public passenger transport,

and identified a number of priority actions, two of which found their way to the conclusions of the subsequent Gothenburg Council of June 2001 (Council, 2001):

- adopt revised guidelines for trans-European transport networks with a view to giving priority, where appropriate, to infrastructure investment for public transport and for railways, inland waterways, short sea shipping, intermodal operations and effective interconnection, and
- propose a framework to ensure that by 2004 the price of using different modes of transport better reflects costs to society.

A revised SDS was adopted at the Brussels European Council of June 2006 (Council, 2006). The renewed SDS now rests on four separate pillars – **economic prosperity**; **social equity and cohesion**; **environmental protection**; and **global governance** – and is based on a long list of guiding principles: promotion and protection of fundamental rights, solidarity within and between generations, the guarantee of an open and democratic society, involvement of citizens, involvement of businesses and social partners, policy coherence and

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4 The indicator adopted for monitoring SDS implementation in terms of sustainable transport is: Energy consumption of transport relative to GDP.

governance, policy integration, use of best available knowledge, the precautionary principle and the polluter-pays principle. Furthermore, a seventh policy area – sustainable consumption and production – is added to the previous six.

The overall objective of sustainable transport is now:

- ensuring that our transport systems meet society's needs whilst minimising their undesirable impacts on the economy, society and the environment,

while the corresponding operational targets for freight transport are:

- decoupling economic growth and the demand for transport,
- achieving sustainable levels of transport energy use and reducing GHGs,
- reducing pollutant emissions,
- achieving a balanced shift towards environment friendly transport modes, and
- reducing transport noise both at source and through mitigation measures.

Talking about sustainability, it should be mentioned that **sustainable growth**, i.e. promoting a more resource efficient, greener and more competitive economy, comprises one of the three mutually reinforcing priorities of *Europe 2020*, the strategy aimed at dragging Europe out of the 2008-09 economic crisis (EC, 2010b); the other two being **smart growth** (developing an economy based on knowledge and innovation) and **inclusive growth** (fostering a high-employment economy delivering social and territorial cohesion). The relevant targets set for 2020 by this document are:

- reduce GHG emissions by at least 20% compared to 1990 levels or by 30%, if the conditions are right,
- increase the share of renewable energy sources in EU's final energy consumption to 20%, and
- increase energy efficiency by 20%.

Moreover and in order to catalyse progress, *Europe 2020* has put forward seven flagship initiatives among which, the most relevant to the subject of this thesis is 'Resource efficient Europe' helping to:

decouple economic growth from the use of resources, support the shift towards a low carbon economy, increase the use of renewable energy sources, modernise our transport sector and promote energy efficiency.

### 2.2.2 Freight Transport Logistics Action Plan

In 2007, the Freight Transport Agenda (EC, 2007a) was launched by the EC to broaden the focus on freight transport policy through a set of policy initiatives. The first one among them was the Freight Transport Logistics Action Plan (FTLAP), which introduced a number of short- to medium-term actions aimed at integrating transport modes (EC, 2007b). The most important among these actions were:

- **Measuring performance of integrated systems:** The plan suggested the identification and monitoring of operational, infrastructural and administrative bottlenecks, the establishment of a core set of generic indicators that would measure and record performance (e.g. sustainability, efficiency etc.) in freight transport logistics chains, and the elaboration of a set of generic (dynamic and static) benchmarks for multimodal terminals.
- **Exchange of information through interoperable ICT systems:** The plan introduced the concept of e-Freight denoting the vision of a seamless electronic flow of information associating the physical flow of goods with a paperless trail built by Information and Communication Technology (ICT) regardless of transport mode, and called for the development of an Action Plan for deploying Intelligent Transport Systems (ITS) in road transport.
- **Easing regulatory requirements for the exchange of information between modes:** The plan called for the assessment of establishing a single transport document for all carriage of goods, irrespective of mode, of introducing within the EU of a standard (fall-back) liability clause and of establishing a single window (single access point) and one stop-administrative shopping for administrative procedures in all modes.
- **Introducing 'green corridors':** The plan introduced the concept of 'green corridors,' denoting corridors of highly

dense freight traffic and of relatively long transport distances equipped with adequate transhipment facilities at strategic locations. Industry should be encouraged along these corridors to rely on co-modality and on advanced technology in order to accommodate rising traffic volumes, while promoting environmental sustainability and energy efficiency.

- **Enhancing the urban dimension of integrated transport solutions:** The plan introduced a holistic vision paying attention to aspects of land use planning, environmental considerations and traffic management.

It is interesting to note that an action plan on transport logistics concentrated solely on mode integration issues. In fact, two of the five actions listed above (green corridors and urban distribution) relate to cargo flows, two (exchange of information and administrative procedures) concern information flows, while the fifth one (performance indicators) applies to both.

The green corridors introduced by the FTLAP play a key role in this thesis not only because *"... [they] are ideal environments for the development and introduction of solutions that help promote environmental sustainability and energy efficiency, so that they may become showcases of 'green' freight transport,"* as stated by the Impact Assessment document accompanying the FTLAP (EC, 2007c), but because they comprise a vehicle that can address wider policy objectives of the EU, including modal integration, simplification of administrative formalities, internalisation of external costs, and harmonisation of safety, security and social legislation (Panagakos et al., 2013). Green corridors are studied in detail in Part II of this thesis.

The e-Freight concept introduced by FTLAP also deserves special attention, as the exchange of information is a basic pillar of supply chain integration. It has a positive effect on, among others, demand planning, capacity and production planning, performance management, and inventory control. It is also vital in applications related to international safety and security. Information integration is considered as one of the most prominent future trends in supply chain management. Along this line, the e-Freight initiative of the EU aims at:

- enhancing interoperability between freight transport information systems,
- enabling operators to enter information only once in the whole multimodal supply chain for planning, execution, monitoring and reporting purposes,
- developing interoperable information and booking tools (such as multimodal journey planners for freight) for an optimised use of multimodal transport possibilities, and
- developing a structure for the use of information coming from tracking and tracing technologies as well as from intelligent cargo applications.

More specifically, the reference framework for ICT in transport logistics that e-Freight seeks to establish would enable the provision of services like:

- a single transport document, as an electronic waybill across modes,
- a single window for information sharing across modes, for business-to-administration, administration-to-administration and administration-to-business purposes at national, between national and at EU level,
- a standard description of transport services and the issuing of transport instructions.

### 2.2.3 Greening Transport Inventory

This document (EC, 2008b) compiles a list of measures that were in place in 2008 to reduce the negative impacts of transport and more specifically those related to climate change, regional and local pollution, noise pollution, congestion and accidents. The most important of them are mentioned below:

*Multiple-impact measures*

- Motor fuel taxation: Minimum rates are set depending on the type of fuel. Alternative fuels, such as LPG and natural gas, are treated favourably, as are biofuels.
- State aids (subsidies, tax breaks etc.): Can be allowed for environmental purposes in specific cases. Transport projects with clear environmental benefits can be funded through the

TEN-T, the Cohesion and European Regional Development Funds. Special financing (Marco Polo programme) is available for projects that stimulate traffic avoidance or modal shift from road to rail, short-sea shipping and inland waterway transport.[5]

- Environmental assessment: Required for projects over a certain size in all transport modes, as well as for policy plans and programmes setting the framework for future infrastructure projects.
- Research and technology: Actions on transport, the environment and energy, as well as ICTs which have an impact on all of these areas are funded through the 7th Framework Research Programme.[6]

*Climate change*

- Commercial aviation to be included in the EU Emissions Trading System (ETS).
- Limitation or reduction of GHG emissions from ships is to be achieved through the IMO. In the absence of sufficient progress at the IMO, the Commission will propose EU measures.
- A strategy to reduce the $CO_2$ emissions from light duty road vehicles (i.e. cars and vans) was adopted in 2007.[7]
- Minimum energy performance measures to be put in place when buildings with a useful floor area of more than 1,000 $m^2$ (including airports, port terminals, stations and car parks) are renovated or constructed.

*Local pollution*

- EU rules set maximum levels for sulphur in both diesel fuel

[5] The last Marco Polo II call of the 2007-2013 financial period was launched in March 2013.

[6] The 7th Framework Programme was the EU's research and innovation funding programme for the period 2007-2013. The current programme is Horizon 2020 but at the time of drafting this text (2014) there were many projects funded under the 7th Framework Programme that were still running.

[7] This strategy led to Regulation (EU) No 510/2011, which sets emission performance standards for new light commercial vehicles.

and gas oil and for polycyclic aromatic hydrocarbons in diesel fuel.

- International rules establish a maximum worldwide level of sulphur content in fuel oil burned by ships. They also set up SOx Emission Control Areas (SECAs) where more stringent limits apply (refer to Chapter 8).
- EU rules set limits on the sulphur content of gas oil and marine gas oil, which are commonly used for inland navigation to 0.1%.
- International rules limit the NOx emissions from new marine diesel engines over a certain size.
- EU rules set limit values for emissions of CO, HC, NOx and PM from new engines for locomotives and inland waterway vessels sold in the EU.
- EU measures limit emissions of various pollutants including CO, HC, NOx, PM, smoke and ammonia (the 'EURO' standards) from road vehicles.
- EU rules exist to limit the emissions of volatile organic compounds during the storage, loading, distribution and unloading of petrol.
- Specific EU rules exist for the collection and disposal of waste oils, used and shredded tyres, batteries and accumulators from automotive sources etc.
- International rules on the discharge of ballast water from ships have been adopted, aiming to prevent the transfer of harmful aquatic organisms and pathogens.

*Noise pollution*

- Member States are required to monitor and map noise, as well as draw up action plans to prevent and reduce noise.
- EU rules require all non-passenger vessels with a deadweight of more than 350 tonnes which travel on inland waterways to not exceed 75 dB(A) when moving and 65 dB(A) when stationary.
- EU rules limit noise emissions from both conventional and high-speed rail. New rolling stock for conventional rail should have low-noise brake blocks which reduce noise emissions by 50%.

- EU rules set the maximum permissible noise emission levels for all new motor vehicles except tractors. There are separate EU requirements for noise from passenger car tyres and from van, bus and lorry tyres.
- Limits also exist for aircraft, and more stringent restrictions can be put in place at certain EU airports.

*Congestion*

- EU measures have helped financing increased and alternative infrastructure capacity.
- Since March 2003, all new high speed lines and, since September 2006, all new sections of conventional priority projects must be equipped with ERTMS (the European Rail Traffic Monitoring System). ERTMS will allow increased capacity on the railways reducing congestion.
- All sectors will benefit from the possibilities that Galileo (Global Navigation Satellite System) will offer for congestion avoidance through optimising transport routes.

*Accidents*

- There are numerous international and EU safety requirements concerning the design, construction and maintenance of road and rail vehicles, inland waterway vessels, ships and aircrafts.
- EU rules set out the maximum dimensions (height, width and length) and minimum turning circles for lorries in international and national traffic, as well as the maximum weights for lorries in international traffic.
- All lorries must have speed limiters fitted to be used on the road; they must be set at 90 km/h.
- EU rules exist aiming to improve safety of the transport of dangerous goods by all transport means.
- EU rules on tunnel safety require all tunnels longer than 500 meters and belonging to the TEN-T road network to meet minimum safety requirements.

### 2.2.4 The strategy to internalise the external costs of transport

The aim of this document was to propose a common methodology for the internalisation of transport-related external costs (EC, 2008c). Internalisation intends to give the right price signal; so that users bear the costs they create and thus have an incentive to change their behaviour in order to reduce these costs.

In theory, the ‘social marginal cost charging,’ i.e. the additional short-term cost created by one extra person using the infrastructure, is the appropriate price setting mechanism that does not lead to overexploitation of resources (through under-pricing), and at the same time does not damage the transport sector or ultimately the economy (through over-pricing). However in practice, marginal costs cannot be calculated easily, as they vary according to time and place. Furthermore, for some costs, such as those relating to noise, the method for estimating the marginal costs is very complex, and average cost pricing is used instead.

It should be mentioned that external costs, which are internalised according to the ‘polluter pays’ principle, should not be confused with infrastructure costs that are funded according to the ‘user pays’ principle.

After setting the principles, the document proposed a methodology adapting the overall strategy of external cost internalisation to the characteristics of each mode of transport.

For the **road sector**, Directive 1999/62/EC on the charging of Heavy Duty Vehicles (HDVs) precluded incorporating any of the external costs when calculating tolls. It was amended by Directive 2006/38/EC to allow different tariffs to be applied depending on vehicles’ environmental characteristics. However, with the exception of mountainous regions, and then only in certain circumstances, toll revenues could not exceed infrastructure costs. This was the case even in more congested regions or regions with higher levels of pollution. The Commission, therefore, proposed to revise Directive 1999/62/EC in order to enable Member States to integrate in tolls levied on HDVs an amount which reflects the cost of air pollution and noise pollution caused by traffic. During peak periods, it would also allow tolls to be calculated on the basis of the cost of congestion imposed upon other vehicles. The amounts would vary with the travelled distance, location and time of use of roads to better reflect these external costs (EC, 2008d).

An interesting feature of the proposed revision was that the proceeds would have to be used by Member States for making transport more sustainable through projects such as research and development on cleaner and more energy efficient vehicles, mitigating the effect of road transport pollution or providing alternative infrastructure capacity for users. The charge would have to be collected through electronic systems which do not impede the free flow of traffic and which can be extended to other part of the network at a later stage without significant additional investments.

In addition, the proposal extended the scope of the current Directive beyond the TEN-T network to avoid inconsistent pricing schemes between major corridors and other interurban roads.[8] The same charging principles could also be extended to private cars.

For the **rail sector**, Community action was suggested to reduce the exposure of citizens to rail noise by retrofitting freight wagons with low-noise brakes. To overcome the financial burden of retrofitting, the Commission analysed different measures and concluded that a combination of noise-differentiated track access charges, noise emission ceilings and voluntary commitments is the most appropriate solution (EC, 2008e).

- In the framework of a revised Directive 2001/14/EC12, which harmonises charging principles including noise, a system of **noise-differentiated track access charges** could be introduced. Three basic models could be used as an incentive:
  - ✓ a cost-neutral bonus-malus system with reduced charges for silent wagons and higher charges for noisy ones,
  - ✓ a bonus system in the form of economic incentives for the wagon owners to retrofit their wagons in the start-up

[8] The proposal was adopted in 2011 as Directive 2011/76/EU amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures.

phase, and

- ✓ a malus system consisting of increased charges for noisy wagons.

Infrastructure managers would be in charge of the installation of identification systems and the necessary ICT tools.[9]

- The **noise emission ceiling** limits the average emissions within a determined period at a certain location along the line. Such schemes leave it to the rail sector to find optimal solutions and can comprise the second step after the initial retrofitting programmes have been completed.
- **Voluntary commitments** by the rail sector can guarantee the effectiveness of differentiated track access charges and help to speed up their implementation even before legal requirements enter into force.

As for the **maritime transport**, the Commission expressed its wish to include it in the post-2012 agreement on preventing climate change. If IMO would not make sufficient progress, the Commission suggested taking action at European level; with one of the possible options being to include the maritime sector in the EU ETS.

Before changing subject, it should be mentioned that in order for internalisation to be effective, the transport user must be price sensitive. As such, internalisation often has to be accompanied by other measures intended to create greater elasticity of demand, i.e. the provision of credible alternatives, enhanced competition with regard to a particular mode of transport, sufficient incentive to innovate and switch to clean practices, etc. In order to reduce the external costs, we therefore need a strategy that includes various other elements in addition to internalisation, elements such as providing infrastructure, encouraging technological innovation, competition policy and setting standards.

[9] Directive 2012/34/EU establishing a single European railway area (recast of the first railway package) was adopted on 21 November 2012. A provision for non-mandatory noise-differentiated track access charges is included as Art. 31(5). In addition, the Commission shall adopt implementing measures by 2015 setting out the charging modalities for the cost of noise effects enabling the differentiation of infrastructure charges to take into account, among others, the sensitivity of the area affected.

## 2.3 Horizontal policies

This section presents more recent policy documents which, due to their horizontal nature, cannot be allocated to one of the modal sections that comprise the remainder of this chapter.

The highest-level strategic document presenting the EC's vision for the future of the EU transport system and defining the policy agenda for the following decade is usually contained in a White Paper issued at the beginning of each decade, followed by its mid-term revision. The 2011 White Paper on transport, which is fully compatible with the Europe 2020 strategy and its 'Resource efficient Europe' flagship initiative, presented in Section 2.2.1, is the latest such document and will be briefly presented here.

The section will also present the EU policies in relation to transport infrastructure and the deployment of alternative fuels in the transport sector. The recently introduced EU transport scoreboard, comparing the performance of the Member States in a number of transport-related issues completes the section.

### 2.3.1 The White Paper on transport

The 2011 White Paper on transport (EC, 2011a) is the single most important document in the EU transport policy, as it describes the EC's vision of future transport and the corresponding strategy for the next decade. More specifically, it takes a global look at developments in the transport sector, at its future challenges and at the policy initiatives that need to be considered in the period until 2020 in order to meet the long-term requirement for limiting climate change to 2 °C. This general objective is translated into the following specific objectives:

(a) a reduction of transport-related GHG emissions by approximately 60% by 2050 compared to 1990,
(b) a drastic decrease in the oil dependency of transport-related activities by 2050, and
(c) limiting the growth of congestion.

According to the document, the Commission's vision of future transport is:

*"a system that underpins European economic progress, enhances competitiveness and offers high quality mobility services while using resources more efficiently. Curbing mobility is not an option. New transport patterns must emerge, according to which larger volumes of freight are carried jointly to their destination by the most efficient (combination of) modes. Individual transport is preferably used for the final miles of the journey and performed with clean vehicles. Information technology provides for simpler and more reliable transfers. Transport users pay for the full costs of transport in exchange for less congestion, more information, better service and more safety."*

Alternatively, this vision is expressed through three strands, which are listed below together with 10 related benchmarks for achieving the GHG emissions reduction target:

- Improving the energy efficiency performance of vehicles across all modes; developing and deploying sustainable fuels and propulsion systems.
  - (1) Halve the use of 'conventionally-fuelled' cars in urban transport by 2030; phase them out in cities by 2050; achieve essentially $CO_2$-free city logistics in major urban centres by 2030.
  - (2) Low-carbon sustainable fuels in aviation to reach 40% by 2050; also by 2050 reduce EU $CO_2$ emissions from maritime bunker fuels by 40% (if feasible 50%).
- Optimising the performance of multimodal logistic chains, including by making greater use of inherently more resource-efficient modes, where other technological innovations may be insufficient (e.g. long distance freight).
  - (3) 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors. To meet this goal will also require appropriate infrastructure to be developed.
  - (4) By 2050, complete a European high-speed rail network. Triple the length of the existing high-speed rail network by 2030 and maintain a dense railway network in all

Member States. By 2050 the majority of medium-distance passenger transport should go by rail.

(5) A fully functional and EU-wide multimodal TEN-T 'core network' by 2030, with a high quality and capacity network by 2050 and a corresponding set of information services.

(6) By 2050, connect all core network airports to the rail network, preferably high-speed; ensure that all core seaports are sufficiently connected to the rail freight and, where possible, inland waterway system.

- Using transport and infrastructure more efficiently through use of improved traffic management and information systems, and advanced logistics and market measures.

(7) Deployment of the modernised air traffic management infrastructure (SESAR) in Europe by 2020 and completion of the European Common Aviation Area. Deployment of equivalent land and waterborne transport management systems (ERTMS, ITS, SSN and LRIT, RIS). Deployment of the European Global Navigation Satellite System (Galileo).

(8) By 2020, establish the framework for a European multimodal transport information, management and payment system.

(9) By 2050, move close to zero fatalities in road transport. In line with this goal, the EU aims at halving road casualties by 2020. Make sure that the EU is a world leader in safety and security of transport in all modes of transport.

(10) Move towards full application of 'user pays' and 'polluter pays' principles and private sector engagement to eliminate distortions, including harmful subsidies, generate revenues and ensure financing for future transport investments.

The above mentioned targets shall be met through the following 4-tier strategy:

- **Internal market:** Create a genuine single European transport area by eliminating all residual barriers between modes and national systems, easing the process of integration and facilitating the emergence of multinational and multimodal operators.

- **Innovation:** EU research needs to address the full cycle of research, innovation and deployment in an integrated way through focusing on the most promising technologies and bringing together all actors involved.
- **Infrastructure:** The EU transport infrastructure policy needs a common vision and sufficient resources. The costs of transport should be reflected in its price in an undistorted way.
- **International:** Opening up third country markets in transport services, products and investments continues to have high priority. Transport is included in all trade negotiations with European participation (WTO, regional and bilateral).

Furthermore, a total of 131 actions, organised in 40 concrete initiatives, are proposed by the document for the materialisation of this strategy.

### 2.3.2 The new TEN-T policy

In line with the 2011 White Paper of the previous section and in view of persisting obstacles at EU level, like:

- missing links, in particular at cross-border sections,
- considerable and enduring infrastructural bottlenecks, in particular with respect to the east-west connections,
- fragmented transport infrastructure between transport modes,
- significant investments in transport infrastructure needed in order to achieve the GHG emission reduction target, and
- interoperability problems due to different operational rules and requirements by the Member States, adding to the transport infrastructure barriers and bottlenecks,

the Commission has redefined its long-term transport infrastructure policy up to 2030/2050 through revising the so-called 'TEN-T guidelines' (EP&C, 2013a), which set out priorities and provide implementation measures for the trans-European transport network (TEN-T).

The main objective, i.e. the establishment and development of a complete TEN-T, consisting of infrastructure for railways, inland waterways, roads, maritime and air transport, is pursued through two fields of action.

The first one concerns the 'conceptual planning' of the network for which a dual-layer approach has been selected, consisting of a comprehensive and a core network. The comprehensive network constitutes the basic layer of the TEN-T and is, in large part, derived from the corresponding national networks. It should be in place by 2050 at the latest. The core network overlays the comprehensive network and consists of its strategically most important parts. It constitutes the backbone of the multimodal mobility network and concentrates on those components of TEN-T with the highest European added value: cross border missing links, key bottlenecks and multimodal nodes. The core network is to be in place by 2030 at the latest.

It is worth mentioning that the guidelines (Article 39) lay down specific requirements for the core network, in addition to the requirements for the comprehensive network. The most prominent among them is the necessity to provide 'alternative clean fuels' for all transport modes. This term includes fuels such as electricity, hydrogen, biofuels (liquids), synthetic fuels, methane (CNG, LNG and biomethane) and LPG, which serve, at least partly, as a substitute for fossil oil sources in the supply of energy to transport and contribute to its decarbonisation. For rail transport, this requirement is further defined as full electrification of the line tracks and sidings. Furthermore, new railway lines should have a nominal track gauge of 1,435 mm (with certain exceptions), while ERTMS should be fully deployed on all new and existing lines. In addition, the freight lines of the core network should be able to accommodate at least 22.5t axle loads, 100 km/h line speeds and running trains with a length of 740 m. For motorways, emphasis is placed on the development of rest areas approximately every 100 km.

The second field of action concerns the implementation instruments. The Commission has developed the concept of 'core network corridors', taking due account of the rail freight corridors introduced with Regulation No 913/2010 (refer to Section 2.5.2), as an instrument for the coordinated implementation of the core network. Core network corridors (Article 43):

- cover the most important cross-border long-distance flows in the core network,
- are multimodal in nature and involve at least three transport modes,
- cross at least two borders, and
- include Motorways of the Sea[10] (MoS), where appropriate.

Annex I to Regulation No 1316/2013 (EP&C, 2013b), establishing the Connecting Europe Facility, which finances EU priority infrastructure in transport, energy and digital broadband, lists nine core network corridors. They are shown in Figure 2.

In terms of governance, the new TEN-T guidelines provide for European Coordinators to be designated by the EC in agreement with the Member States concerned. A European Coordinator shall be assigned to each and every core network corridor, while two additional Coordinators shall be designated for implementing the horizontal ERTMS and MoS respectively. Acting in the name and on behalf of the EC, the European Coordinators shall facilitate the coordinated implementation of the core network corridors. They will be assisted in this task by a secretariat and by a consultative forum (the Corridor Forum), established for each corridor. The European Coordinators shall chair the Corridor Fora, the composition of which shall be agreed with the relevant Member States.

A central task of the European Coordinator is drawing up a corridor work plan and monitoring its implementation, in consultation with the Corridor Forum and the relevant Member States. The work plan shall include (Article 47):

- a description of the characteristics of the core network corridor including its cross-border sections,
- a list of objectives and priorities to be pursued,
- a plan for the removal of physical, technical, operational and administrative barriers between and within transport modes,

[10] MoS represent the maritime dimension of the TEN-T and consist of maritime links between maritime ports of the comprehensive network including the related facilities and infrastructure for direct land and sea access (Article 21).

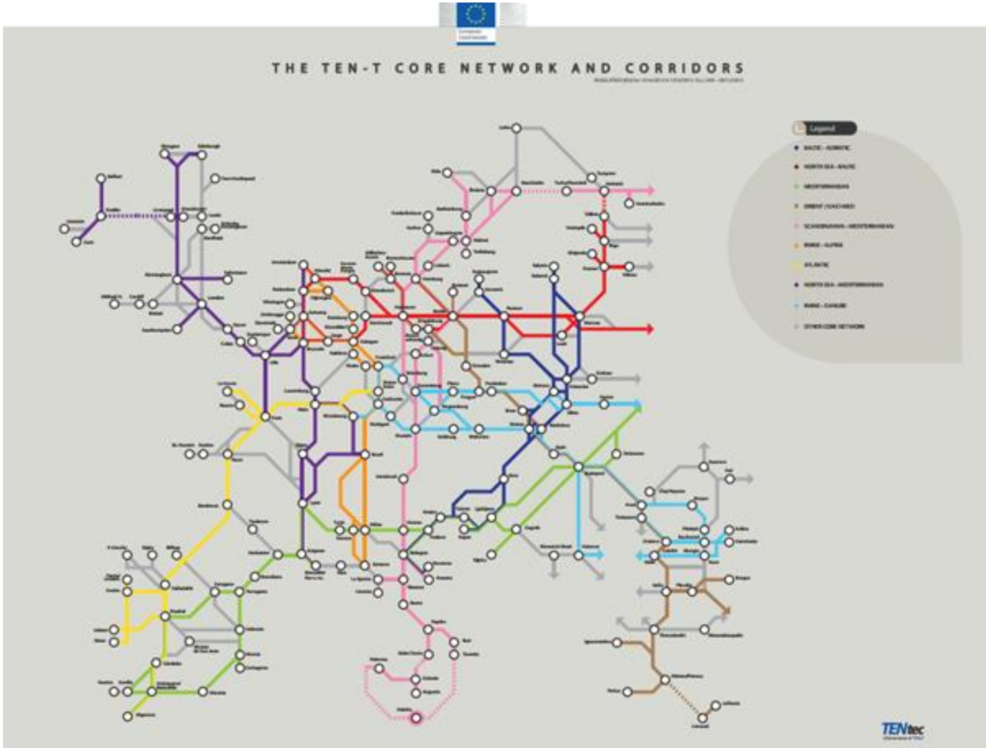


**Figure 2. The nine TEN-T core network corridors and other connections**

(Source: EC, 2014a)

- a deployment plan of interoperable traffic management systems,
- proposed measures to enhance resilience to climate change,
- proposed measures to mitigate GHG emissions, noise and, as appropriate, other negative environmental impacts,
- a list of projects for the extension, renewal or redeployment of transport infrastructure,
- an analysis of the investment required, including the various funding sources envisaged, at international, national, regional, local and Union levels,
- where appropriate, measures to improve the capacity to design, plan, implement and monitor major transport projects, and
- details of public consultations supporting the development of the work plan and its implementation.

Based on this information the Commission will adopt implementing acts (decisions) for each corridor.

### 2.3.3 Clean Power for Transport Initiative

Transport in Europe is heavily dependent on oil, which counted for 94% of the sector's energy needs in 2010 (EC, 2013a). The fact that 84% of it is imported, in combination with the recent political instability of major exporting regions, raises genuine security of supply concerns. The cost of oil imports for transport was close to € 1 billion a day in 2011 and this figure should be viewed in conjunction with increasing volatility and uncertainty (crude oil prices have left their historic range of $10–30 per barrel, and rose to nearly $150 per barrel before the global downturn in 2008). Furthermore, mitigating the environmental impact of transport has already been documented in the previous sections as a primary objective of the EU transport policy. Alternative fuels are, therefore, urgently needed to switch to a post-oil economy.

Research has led to the successful development of alternative fuel solutions for all transport modes. However, their market uptake is slower than usual, mainly due to the fact that the use of alternative fuels requires the gradual build-up of charging and refuelling infrastructures and, thus, significant investments. The relationship between vehicles capable of running on alternative fuels and the appropriate refuelling infrastructure is often described as a 'chicken and egg' problem, requiring state intervention.

Faced with this challenge, the EC adopted in January 2013 the so-called 'Clean Power for Transport' package aiming to facilitate the development of a single market for alternative fuels for transport in Europe. The package consisted of:

- a comprehensive European alternative fuels strategy for the long-term substitution of oil as energy source in all modes of transport (EC, 2013a),
- an action plan for a broad market uptake of LNG in the shipping sector (EC, 2013b), and
- a proposal for a Directive on the deployment of alternative fuels recharging and refuelling infrastructure, accompanied by its impact assessment.

Following the inter-institutional negotiations, the above proposal led to Directive 2014/94/EU of 22 October 2014 (EP&C, 2014), which:

- requires Member States to adopt national policy frameworks for the market development of alternative fuels and the deployment of the relevant infrastructure,
- sets minimum coverage and timetable for each use of alternative fuels in accordance with Table 1 below,
- ensures the use or common technical specifications for recharging and refuelling stations, and
- paves the way for setting up appropriate labelling of alternative fuels, as well as for providing information that enables sound price comparisons by the end users.

Member States have to submit their national policy frameworks to the Commission within two years and report on their implementation on 3-year intervals thereafter. The Commission will assess and report on those national policy frameworks in order to ensure coherence at Union level.

**Table 1. Coverage and timetable of alternative fuel uses (Directive 2014/94/EU)**

| Alternative fuel | Coverage | Timing |
|---|---|---|
| Electricity for motor vehicles in urban/suburban and other densely populated areas | Appropriate number of publically accessible recharging points | by end 2020 |
| CNG for motor vehicles in urban/suburban and other densely populated areas | Appropriate number of refuelling points | by end 2020 |
| CNG for motor vehicles along the TEN-T core network | Appropriate number of refuelling points | by end 2025 |
| Shore-side electricity supply for seagoing and IWT vessels | Ports of the TEN-T core network and other ports | by end 2025 |
| Hydrogen for motor vehicles in the Member States which choose to develop it | Appropriate number of refuelling points | by end 2025 |
| LNG at maritime ports | Ports of the TEN-T core network | by end 2025 |
| LNG at inland ports | Ports of the TEN-T core network | by end 2030 |
| LNG for heavy-duty vehicles | Appropriate number of refuelling points along the TEN-T core network | by end 2025 |

## 2.3.4 The EU transport scoreboard

In April 2014, the European Commission published for the first time a scoreboard on transport in the EU. It compares the performance of the Member States in 21 transport-related categories and highlights the five top and bottom performers for most of these categories. It aims at helping Member States identify shortcomings and define priorities for investment and policies.

The scoreboard builds on the World Bank's Logistics Performance Index (LPI) which, since 2007, assists countries benchmark their performance on trade logistics. It draws data from a variety of sources (Eurostat, the

European Environment Agency, the World Bank and the OECD) and can be consulted either by mode of transport (road, rail, waterborne, air) or by one of the following categories:

- **Single market:** It assesses the level of market integration for each mode of transport:
  - ✓ *Regulation of road freight transport*, based on the OECD indicator of regulation in energy, transport and communications (ETCR), which considers entry barriers and price control by authorities.
  - ✓ *Market share of all but the principal railway undertakings*, separately for freight and passenger transport, on the basis of RMMS (Rail Market Monitoring Scheme) data.
  - ✓ *Maritime cabotage transport of goods*, based on Eurostat data (no ranking is provided for this indicator, which simply exhibits the volume of national transport of goods by sea).
  - ✓ *Regulation of air passenger transport*, based on OECD's ETCR which, for air passenger transport, considers entry barriers and public ownership.
- **Infrastructure:** It assesses the quality of infrastructure for each mode of transport:
  - ✓ *Motorway density*, expressed by the ratio between the total length of motorways and the population (in millions), on the basis of data from Eurostat, UNECE and national sources.
  - ✓ *Quality of rail infrastructure*, rating based on a survey by the World Economic Forum (WEF).
  - ✓ *Quality of port infrastructure*, rating based on a WEF survey of business executives' perception of their country's port facilities.
  - ✓ *Quality of air transport infrastructure*, rating based on a WEF survey.
- **Environmental impact:** Indicators are provided only for road and rail transport:
  - ✓ *Average $CO_2$ emissions from new passenger cars*, on the basis of European Environment Agency data (in $gCO_2/km$).
  - ✓ *Electrified railway lines*, expressed as a percentage of electrified railway lines over total lines in use, on the basis of data from the International Union of Railways (UIC) and

national sources.

- **Safety:** Once again only road and rail transport indicators are provided:
  - ✓ *Road fatalities*, defined as persons deceased within 30 days of a road accident per million inhabitants, on the basis of information from the CARE database of DG MOVE.
  - ✓ *Railway victims*, defined as persons (including workers, passengers, crossing users and unauthorised persons) deceased or seriously injured in railway accidents in relation to the overall rail transport activity (in million train-km), calculated using Eurostat and ERA data.
- **Transposition of EU law:** Percentage of EU transport directives for which Member States have notified transposition measures to the Commission by 31 December 2013, even with delays (total number of directives to be transposed: 115).
- **Infringements of EU law:** According to DG MOVE, on 31 December 2013, the Commission was dealing with a total of 202 infringement proceedings in the area of transport (cases of a Member State not applying an EU law properly). The scoreboard presents the number of cases separately for each mode of transport, while an additional category deals with cases that are not mode-specific, in particular concerning passenger rights.
- **Research and innovation:** This horizontal category covers two aspects:
  - ✓ *Private investment in transport research and development*, defined as investment by transport companies in research and development, as percentage of GDP. It includes manufacturing of motor vehicles, other transport equipment, air/spacecraft, railway locomotives and rolling stock, transportation and storage. It is based on information from FUTRE project.
  - ✓ *Innovative transport companies*, defined as the percentage of companies that replied positively to the question 'do you innovate?' of the 2010 Community Innovation Survey of Eurostat.
- **Logistics:** The World Bank's Logistics Performance Index, rating the relative ease and efficiency with which products can be moved into and inside a country (refer to Figure 3).

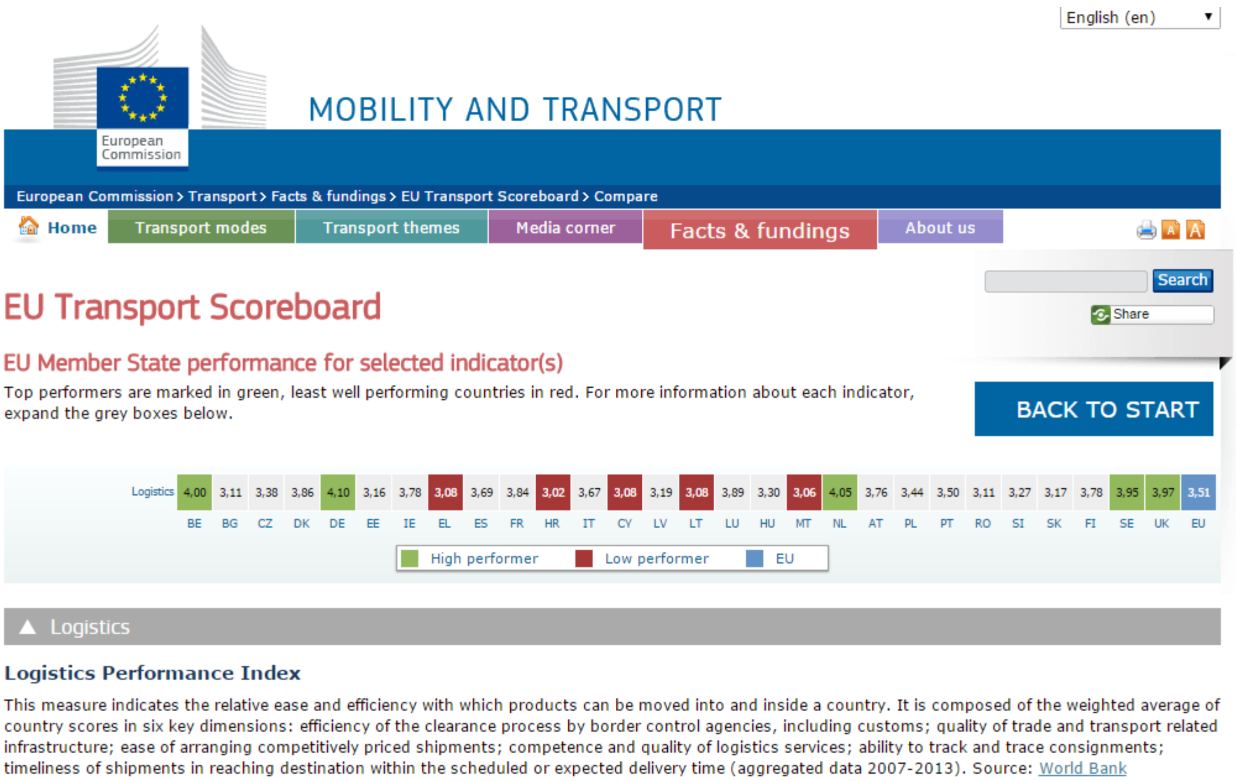


**Figure 3. Indicative Scoreboard screen exhibiting the performance of EU Member States in relation to Logistics**

(Source: EU Scoreboard, 2014)

The Commission intends to further refine the above indicators, in dialogue with Member States, industry and other stakeholders.

## 2.4 Road transport

Among the challenges facing the transport sector today, the following are the most important ones that pertain to road transport:

- High congestion levels already seriously affect road transport in several Member States, while by 2030 it is expected to obstruct the inter-urban network as well.
- The share of $CO_2$ emissions from EU transport as a proportion of all EU emissions continues increasing and road transport accounts for 82% of the energy consumption of the transport sector.
- Whilst road fatalities are in regression their number is still unacceptably high.

A number of initiatives have been taken by the EC to address them. The deployment of ITS, the revision of the maximum authorised dimensions and weights for HDVs and the recently adopted strategy for reducing fuel consumption and $CO_2$ emissions are the most interesting among them.

### 2.4.1 Deployment of Intelligent Transport Systems

ICT systems play a key role in the development and evolution of transport operations, as they identify and alleviate bottlenecks and release latent demand and supply for transport services exploiting in full the capacity of infrastructure, vehicles and equipment. In this respect, they improve the efficiency of using the transport infrastructure and equipment, reduce transport costs, improve the quality of transport services, and enhance the environmental sustainability of the sector through improved traffic management, reduced congestion and emissions, optimised operations, lower externalities etc.

In 2008, the EC adopted its Action plan for the deployment of Intelligent Transport Systems in Europe to create the momentum necessary to speed up market penetration of rather mature ITS applications and services in Europe. It was prepared on the basis of input provided by a wide consultation of stakeholders. Traffic management, congestion relief on freight corridors and in cities, promotion of co-modality, in-vehicle safety systems, real time traffic and travel information and an open in-vehicle platform to integrate applications were among the priority issues identified.

The Action Plan outlined the following six priority areas for action:

| | |
|---|---|
| Action Area 1: | Optimal use of road, traffic and travel data |
| Action Area 2: | Continuity of traffic and freight management ITS services on European transport corridors and in conurbations |
| Action Area 3: | Road safety and security |
| Action Area 4: | Integration of the vehicle into the transport infrastructure |
| Action Area 5: | Data security and protection, and liability issues |
| Action Area 6: | European ITS cooperation and coordination. |

As a result of this Action Plan, Directive 2010/40/EU establishing a framework for the deployment of ITS in the field of road transport (the 'ITS Directive') was adopted on 7 July 2010 to accelerate the deployment of these innovative applications across Europe (EP&C, 2010b). Aiming to establish interoperable and seamless ITS services while leaving Member States the freedom to decide which systems to invest in, it is an important instrument for the coordinated implementation of ITS in Europe.

Under the ITS Directive, the EC has to adopt within seven years specifications (i.e. functional, technical, organisational or services provisions) to address the compatibility, interoperability and continuity of ITS solutions across the EU. The first priorities are traffic and travel information, the e-Call emergency system and intelligent truck parking.

### 2.4.2 New dimensions and weights

In April 2013, the EC communicated its proposal to amend the maximum authorised dimensions and weights for heavy duty road vehicles, which have been in force since 1996, in order to allow more energy efficient vehicles to be put on the market (EC, 2013d). The proposal intends to:

- Grant derogations from the maximum dimensions of vehicles for the addition of aerodynamic devices to the rear of vehicles or to redefine the geometry of the cabs for tractors. While ensuring compliance with road safety rules and the constraints imposed by infrastructure and traffic flow, these derogations aim to open up new prospects for manufacturers of tractors, trucks and trailers, provided that the load capacity of the vehicles is not increased. In addition to reducing fuel consumption and GHG emissions, the new designs of tractor cabs are expected to improve the drivers' field of vision, increasing the drivers' comfort and safety and reducing road accidents.

- Authorise a weight increase of one tonne for vehicles with an electric or hybrid propulsion, to take account of the weight of batteries or the dual motorisation, without prejudice to the load capacity of the vehicle.
- Facilitate the development of intermodal transport by allowing a derogation of 15 cm in the length of trucks carrying 45-foot containers, which are increasingly used in intercontinental and European transport. This minor adjustment is sufficient to permit an extra EUR-pallet to fit in a 45-foot palletwide container (8½-foot wide), adding about 3% load efficiency to the usual 32 EUR-pallet arrangement, while improving safety by reducing empty spaces.
- Confirm that cross-border use of longer vehicles is lawful for journeys that only cross one border, if the two Member States concerned already allow it and if the existing infrastructure and the road safety situation allow it.
- Enable the inspection authorities to better detect infringements through the use of either weighing systems built into the road or by means of onboard sensors in vehicles which communicate remotely with roadside inspectors. These technologies will allow a better filtering of the vehicles, so that only vehicles strongly suspected of infringement are stopped for manual inspection. Furthermore and in order to encourage the spread of such devices, the Commission plans to define the technical standards for onboard weighing devices, particularly the standards for the electromagnetic communication interface. Such systems offer the additional advantage of enabling drivers to better control the weight of their vehicles.

### 2.4.3 Strategy for reducing fuel consumption and $CO_2$ emissions

Despite the existence of several technical solutions that improve the fuel efficiency of a Heavy Duty Vehicle (HDV), their market uptake is very slow. Even solutions that can be implemented at a net profit are often not adopted. Aarnink et al. (2012) have identified a number of market barriers that hamper the implementation of such measures, including split incentives (i.e. the owner of a vehicle does not benefit from fuel savings when this is operated by a separate entity), limited access to finance and the practice of manufacturers offering fuel saving technologies as optional rather than standard features of a new vehicle. However, the most important barrier found was the lack of information on the fuel savings associated with individual technical measures. It appears that the transport freight industry is more focused on operational improvements for fuel savings than on new technologies, which are perceived as more costly. This knowledge gap results from the fact that HDV $CO_2$ emissions are not measured, certified and recorded when new vehicles are registered.

In May 2014, the EC issued its strategy to improve HDV performance and cut $CO_2$ emissions through measures that address the knowledge gap and unlock a large part of the existing potential (EC, 2014c).

With the exception of transport demand, which is linked to economic activity and lies outside the scope of this policy document, the proposed strategy is built around the other main drivers of HDV fuel consumption and $CO_2$ emissions: modal split, fuel GHG intensity, vehicle energy efficiency and operation of HDV fleets.

In terms of modal split, the new TEN-T policy (refer to Section 2.3.2) aims to reverse the trend of increasing share of road transport. The development of multimodal freight corridors enhanced by the e-freight initiative (refer to Section 2.2.2) is also expected to influence modal split.

The revised TEN-T guidelines are expected to have a positive impact in reducing the fuel GHG intensity, too, through the requirement for alternative fuel availability along the core network corridors for all modes, including road transport. The Clean Power for Transport Initiative of Section 2.3.3 will further support this development. The proposed inclusion of a $CO_2$ element in fuel taxation can further enhance the share (~ 6% in 2010) of alternative fuels in the energy use of road transport.

In the area of HDV fleet operation, the on-going review of road user charging legislation aims to take measures improving load factors, accelerating the renewal of fleets and creating conditions for greater co-modality (refer to Section 2.2.4 on internalisation of external costs). The ITS Directory of Section 2.4.1 will further improve the efficiency of using the road infrastructure and vehicles, as well as the interfaces with other modes of transport. The review of the remaining restrictions on road cabotage and the inclusion of eco-driving requirements in the truck drivers' examinations can also help make road transport more efficient.

As for supporting the deployment of more energy efficient vehicles, the proposed revision of the maximum authorised dimensions of HDVs to improve their aerodynamics (refer to Section 2.4.2) is one of the measures foreseen. Others include the funding of research under the ‘Green Car Initiative’ and the ‘Horizon 2020’ programmes, as well as the EU legislation on the procurement of more environment friendly vehicles by public entities.

However, no standards have been set at EU level in relation to the fuel consumption and $CO_2$ emissions of HDVs. A prerequisite to address these issues is to measure and monitor them. This is exactly the focus of the short-term actions of the proposed strategy. Unlike the approach selected for the waterborne transport (refer to Section 2.6.3), the actions foreseen for road transport are:

- **Completion of the VECTO simulation tool.** The Vehicle Energy Consumption Calculation Tool (VECTO) is a simulation tool that is being developed by the EC in cooperation with industry stakeholders since 2009. It is used for measuring total vehicle emissions including emissions due to the vehicle's motor and transmission, aerodynamics, rolling resistance, and auxiliaries. The simulation approach has been selected for addressing the identified knowledge gap because $CO_2$ testing on the basis of a testing cycle (as is the case with cars and vans) is not appropriate for HDVs due to the diversity of existing models and tasks.
- **Legislative action for certifying and reporting $CO_2$ emissions.** The methodology for determining fuel consumption and $CO_2$ emissions (VECTO calculations) needs to be included in the relevant type approval legislation.

On the basis of the findings of these short-term actions, medium-term policy options, including the setting of mandatory $CO_2$ emission standards for newly registered HDVs would be considered in order to assist meeting the environmental targets of the EU transport policy.

## 2.5 Rail transport

In its effort to strengthen the position of railways vis-à-vis other transport modes, the EC has been very active during the last 25 years in restructuring the rail transport market, basically through interventions in three areas:

- **Opening of the rail transport market to competition**, addressing the structure of state monopolies that characterised European railways until not very long ago.
- **Improving the interoperability and safety of national networks**, addressing the patchwork of different rail systems that exist (differences range across a wide spectrum, including at least 4 different rail gauges, at least 4 different electricity systems, at least a dozen different signalling systems, various clearance profiles, various technical specifications of locomotives and other rolling stock, and many other differences, not the least of which is that trains in some countries run on the left and in some other countries on the right side).
- **Developing rail transport infrastructure**, addressing bottlenecks due to insufficient capacity and/or poor quality of existing rail networks.

The latter point is dealt with the new TEN-T policy that offers preferential treatment to railway infrastructure, which features persistently in all TEN-T core network corridors (refer to Section 2.3.2). Furthermore, ERTMS, the European approach to handling interoperability problems in the rail transport, is prescribed as a requirement for all TEN-T core network corridors, which to a large extent supersede the so-called ‘ERTMS corridors,’ introduced by the relevant deployment plan[11]. That leaves the liberalisation of rail transport as the only topic that needs to be discussed further in this section. Special attention will also be given to the Rail Freight Corridor concept, which was introduced together with the green corridors and paved the way for the TEN-T core network corridors that were adopted later on.

### 2.5.1 Liberalisation of railway markets

Community involvement in the sector came in 1991 with a Directive requiring separate accounts to be kept for railway infrastructure

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[11] Commission Decision of 22.7.2009 amending Decision 2006/679/EC as regards the implementation of the technical specification for interoperability relating to the control-command and signalling subsystem of the trans-European conventional rail system, C(2009) 5607, Brussels, 22.7.2009.

management and the provision of railway transport services. Ten years later, in February 2001, the ‘first railway package’ was adopted aiming to enable rail operators to have access to the trans-European network on a non-discriminatory basis. The Commission underlined the need to improve the distribution of train paths, establish a tariff structure that reflects relevant costs, reduce delays at borders and introduce quality criteria.

The ‘second railway package’ of 2004 accelerated the liberalisation of rail freight services by fully opening the rail freight market to competition as from 1 January 2007. In addition, the package created the European Railway Agency situated in Valenciennes (France), introduced common procedures for accident investigation and established Safety Authorities in each Member State.

In October 2007, the ‘third railway package’ was adopted opening up the international passenger transport market including cabotage by 2010. Since then, operators may pick up and set down passengers at any station on an international route, including at stations located in the same Member State. Furthermore, the third railway package regulated the rail passenger rights and the certification of train crews.

In 2012, Directive 2012/34/EU (a recast of the first railway package) establishing a single European railway area, reinforced existing provisions on competition, regulatory oversight and the financial architecture of the rail sector (EP&C, 2012a). However, a number of remaining regulatory and market failures have been identified basically related to the full implementation and enforcement of EU legislation by Member States. In many cases infrastructure managers and operators are not fully independent and the effectiveness of the regulatory oversight of market functioning remains problematic.

In view of these problems, the EC adopted in January 2013 the ‘fourth railway package’ comprising of legislative proposals in the following four areas:

<u>*Market access*</u>

- Open by 2019 the domestic rail passengers market to competition either by offering competing commercial services (open access) or through bidding for public service contracts (PSCs), which account for some 90% of EU rail journeys and will now be subject to mandatory tendering.

- Introduce an obligation for competent authorities to take the financial risk of the residual value of rolling stock at the end of a PSC by appropriate means (i.e. assume ownership of the rolling stock, provide a bank guarantee for the purchase of new, set up a leasing company).
- Establish national integrated ticketing systems on a voluntary basis, subject to non-discrimination requirements.

*Market structure*

- Separate infrastructure managers from any transport operator running the trains (albeit vertically integrated 'holding structures,' formed prior to the current legislation's entry into force, may be accepted provided that all safeguards ensuring the legal, financial and operational independence are in place).
- Strengthen infrastructure managers so that they perform all functions related to the development, operation and maintenance of the infrastructure, including traffic management (albeit subcontracting of specific renewal or maintenance works to railway undertakings is still possible).
- Establish a Coordination Committee which will allow all infrastructure users to express their needs and ensure that the difficulties they encounter are properly addressed.
- Create a Network of Infrastructure Managers to ensure that issues of cross-border and pan-European nature are properly addressed in a coordinated manner.

*Harmonised standards and approvals*

- Reinforce the role of the European Railway Agency (ERA) to become a 'one stop shop,' issuing EU wide vehicle authorisations in the form of 'vehicle passports' as well as EU wide safety certificates for operators.

*Rail workforce*

- Allow Member States to protect rail workers beyond the general EU requirements by requiring new contractors to take them on when PSCs are transferred.
- Oblige pan-European railway undertakings to create European Works Councils and to take part in the Railway Social Sectoral Dialogue Committee.

## 2.5.2 Rail Freight Corridors

As part of the 2007 Freight Transport Agenda (EC, 2007a), which also included the Freight Transport Logistics Action Plan of Section 2.2.2, the Commission issued a Communication on a freight-oriented rail network (EC, 2007d), which aimed at making rail freight more competitive, in particular by ensuring lower transit times and increasing rail's reliability and responsiveness to customer requirements. The following actions were proposed:

- Creation of freight-oriented corridors
- Measures on improving service quality along a corridor
- Increasing the infrastructure capacity of a corridor
- More coordination and more priority to international freight trains
- Priority rules applying in the case of traffic disturbance
- Improving ancillary rail services (especially terminals and marshalling yards)
- Monitoring of the measures proposed.

This initiative eventually led to the adoption of Regulation No 913/2010 (EP&C, 2010a), which lays down rules for the establishment, organisation and management of international rail corridors with a view to developing a European rail network for competitive freight.

The nine initially designated Rail Freight Corridors (RFCs) appear in Figure 4. A process of capacity allocation to freight trains with better coordination of priority rules and prioritising, among freight trains, those that cross at least one border is described in the Regulation for the RFCs.

It further sets up detailed rules for the governance of each RFC through:

- an executive board composed of representatives of the authorities of the Member States concerned,
- a management board composed of the infrastructure managers concerned and, where relevant, the allocation bodies,
- an advisory group made up of managers and owners of the terminals of the RFC including, where necessary, sea and inland waterway ports, and
- a further advisory group made up of railway undertakings interested in the use of the freight corridor.

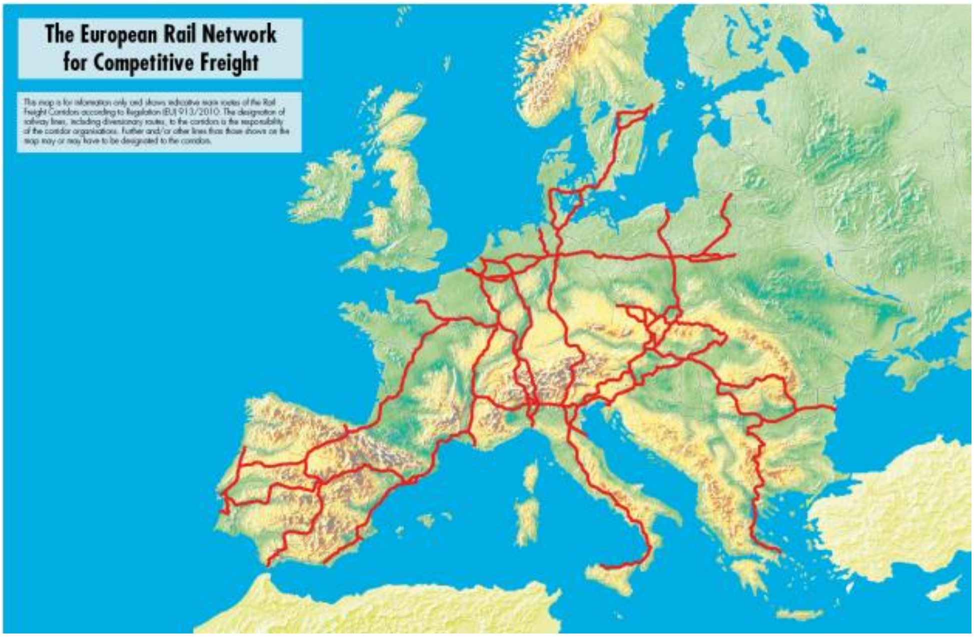


**Figure 4. The European Rail Network for Competitive Freight**

(Source: EC, 2011c)

The measures for implementing the RFC, described by the Regulation, include:

- drafting and periodically updating a transport market study relating to the existing and expected traffic conditions on the RFC,
- drawing up an implementation plan describing:
  - ✓ the characteristics of the freight corridor (including bottlenecks),
  - ✓ the programme of measures necessary for creating the freight corridor,
  - ✓ the objectives for the RFC, in particular in terms of the quality of service and the capacity of the corridor,
- drawing up and periodically reviewing an investment plan providing details of:
  - ✓ indicative medium- and long-term investment for infrastructure and its equipment along the corridor,
  - ✓ the relevant financial requirements and sources of finance,
  - ✓ a deployment plan relating to the interoperable systems along

  the freight corridor, and
  - ✓ a plan for the management of the capacity of freight trains which may run on the freight corridor,
- setting up an one-stop-shop for application for infrastructure capacity, which would also display infrastructure capacity available at the time of request and its characteristics in accordance with pre-defined parameters,
- monitoring the performance of rail freight services on the freight corridor and publishing the results of this monitoring once a year, and
- organising a satisfaction survey of the users of the freight corridor and publishing the results of it once a year.

The governance structures of transport corridors are further discussed in Chapter 4.

## 2.6 Waterborne transport

The international character of shipping makes the regulatory environment of this sector more efficient if agreed, adopted and implemented on a global basis. The International Maritime Organization (IMO), the standard-setting UN agency for the safety, security and environmental performance of international shipping, is the forum at which this process takes place. The promotion of sustainable shipping and sustainable maritime development is one of the major priorities of IMO in recent years.

IMO's drive to reduce GHG emissions from ships has followed thus far two quasi-parallel tracks. One track relates to setting energy efficiency standards for new ships and has led to the adoption of the Energy Efficiency Design Index (EEDI) in July 2011 at the 62nd session of IMO's Marine Environment Protection Committee (MEPC 62). The EEDI is discussed in Section 2.6.1 below.

The other track concerns Market Based Measures (MBMs), of which more in Psaraftis (2016b). However, the proposed in June 2013 EU Regulation on monitoring, reporting and verification of $CO_2$ emissions, constituting a first step towards an MBM, is presented in Section 2.6.3.

Meanwhile, in November 2012 the EU adopted Directive 2012/33/EU transposing into European law the IMO standards on maximum sulphur content of marine fuels adopted in 2008. This is the subject of Section 2.6.2.

### 2.6.1 The adoption of EEDI and SEEMP

The IMO's Energy Efficiency Design Index (EEDI) is a benchmarking scheme aiming to provide an indication of a merchant ship's $CO_2$ output in relation to its transport work. The adoption of EEDI is the first step of IMO's drive to reduce $CO_2$ emissions from shipping. The EEDI compares design-level $CO_2$ emissions and transport work of a vessel and benchmarks this ratio against an IMO-set requirement.

For a given ship, the EEDI is provided by the following formula:

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}{*}\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

There is no need to explain all these symbols here. The numerator in the formula is $CO_2$ emissions expressed as a function of all power generated by the ship (main engine and auxiliaries), and the denominator is a product of the ship's deadweight and the ship's 'reference speed,' appropriately defined as the speed corresponding to 75% of the Maximum Continuous Rating of the ship's main engine. The units of EEDI are grams of $CO_2$ per tonne mile.

The EEDI of a new ship is to be compared with the so-called 'EEDI (reference line),' which is defined as:

$$EEDI\ (reference\ line) = a \times DWT^{-c} \qquad (1)$$

where DWT is the deadweight of the ship and $a$ and $c$ are positive coefficients determined by regression from the world fleet database, per major ship category.

For a given new ship, the attained EEDI value should be equal or less than the required EEDI value which is provided by the following formula:

$$Attained\ EEDI \leq Required\ EEDI = (1 - X/100) \times a \times DWT^{-c} \qquad (2)$$

where $X$ is a 'reduction factor' specified for the required EEDI compared to the EEDI (reference line).

The values of $X$ specified by the IMO are as follows:

- $X = 0\%$ for ships built from 2013-2015
- $X = 10\%$ for ships built from 2016-2020
- $X = 20\%$ for ships built from 2020-2025 and
- $X = 30\%$ for ships built from 2025-2030.

This means that it will be more stringent to be EEDI-compliant in the years ahead. If a ship's attained EEDI is above the required value, the ship is not allowed to operate until and unless measures to fix the problem are taken.

The reference line parameters $a$ and $c$ in Eq. (1) and (2), which have been finalised by regression analyses after a long debate within the IMO are presented in Table 2 below, although they are subject to revision.

**Table 2. EEDI reference line parameters a and c for various ship types**

| Ship type | a | c |
|---|---|---|
| Bulk carrier | 961.79 | 0.477 |
| Gas carrier | 1120.00 | 0.456 |
| Tanker | 1218.80 | 0.488 |
| Container ship | 174.22 | 0.201 |
| General cargo ship | 107.48 | 0.216 |
| Reefer | 227.01 | 0.244 |
| Combination carrier | 1219.00 | 0.488 |

(Source: IMO, 2011)

For Ro-Ro ferries the basic concept seems the same at first glance, but the EEDI (reference line) formula is more complex in that its various coefficients are not constant.

The basic philosophy of EEDI, which applies to all ships of 400 GRT and above, is to build ships that are more energy efficient, that is, reduce emissions (numerator) per unit of transport work (denominator). Measures to achieve this end are intended to be mostly technological.

In contrast to EEDI, which relates to the design of new ships, IMO adopted in July 2011 the Ship Energy Efficiency Management Plan (SEEMP), which addresses energy saving at the operational stage and applies to all (existing and new) ships above 400 GRT. SEEMPT takes the form of a mandatory management plan and aims to establish a mechanism for a shipping company and/or a ship to improve the energy efficiency of ship operations through four steps: planning, implementation, monitoring, and self-evaluation and improvement.

The Energy Efficiency Operational Indicator (EEOI) has been proposed by the IMO as a monitoring tool in the SEEMP. The EEOI is calculated by the following formula, in which a smaller EEOI value means a more energy efficient ship:

$$EEOI = \frac{actual\ CO2\ emissions}{performed\ transport\ work} \quad (3)$$

The intention was to develop a formula enabling the continuous monitoring of individual ships in operation and thereby quantifying the impact of any change made to the ship or its operation. However, it should be clarified that ships operate under a broad variety of different conditions, some of which are beyond the control of their operators. As such, although EEOI has been adopted as an indicator to be used for assessing the performance of individual ships in the framework of SEEMP, the IMO considers its use for comparisons between ships to be flawed (ICS, 2013).

### 2.6.2 The sulphur directive

In addition to GHG, IMO regulates the emission of air pollutants from ship exhausts, including NOx and SOx emissions. These regulations are contained in the MARPOL Annex VI protocol which, in addition, designates specific geographic areas as Emission Control Areas (ECAs), where more stringent requirements apply. An ECA can be designated for NOx and PM, or SOx, or all three types of emissions from ships (the term SECA is used for a SOx ECA). The existing ECAs appear in Figure 5, while their entry into force date is shown in Table 3.


**Figure 5. The Emission Control Areas**

(Source: CIW, 2014)

**Table 3. The adoption, entry into force and effective dates of ECAs**

| Adoption, entry into force & date of taking effect of Special Areas | | | |
|---|---|---|---|
| **Special Areas** | **Adopted #** | **Date of Entry into Force** | **In Effect From** |
| Baltic Sea (SOx) | 26 Sept 1997 | 19 May 2005 | 19 May 2006 |
| North Sea (SOx) | 22 Jul 2005 | 22 Nov 2006 | 22 Nov 2007 |
| North American (SOx, and NOx and PM) | 26 Mar 2010 | 1 Aug 2011 | 1 Aug 2012 |
| United States Caribbean Sea ECA (SOx, NOx and PM) | 26 Jul 2011 | 1 Jan 2013 | 1 Jan 2014 |

(Source: IMO, 2014)

The latest revision of MARPOL Annex VI was adopted in October 2008. Its basic provisions that relate to SOx emissions include:

- a reduction in the global limit of sulphur content in fuel to 3.5% by mass (from 4.5%) effective from 1 January 2012; then to 0.5%, effective from 1 January 2020 subject to a feasibility review to be completed no later than 2018 (it can be postponed to 1 January 2025 if the review reveals that not enough fuel with a sulphur content of 0.5% is available for global shipping in 2020),
- a reduction in sulphur limits for fuels in SECAs to 1%, beginning on 1 July 2010 (from 1.5%); being further reduced to 0.1%, effective

from 1 January 2015,

- the possibility of using suitable abatement equipment as an alternative to fuel switching requirements on the basis that equivalent SOx emissions are achieved on a continuous basis.

The timing of the above sulphur content limits are represented graphically in Figure 6.

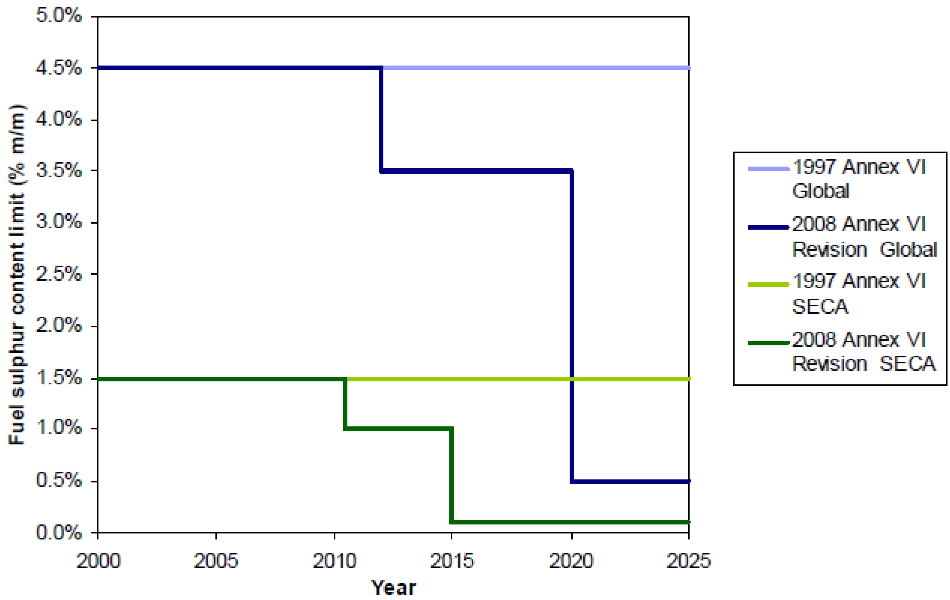


**Figure 6. Revised MARPOL Annex VI – Fuel sulphur limits**

(Source: Entec, 2010)

At European level, these provisions were not transposed into European law until November 2012, when Directive 2012/33/EU was adopted (EP&C, 2012b)[12]. The Directive aligns to the IMO regulations and brings the 0.5% limit into force on 1 January 2020 for all EU sea territory, even if on global scale this limit gets postponed to 2025. Furthermore, the Commission's proposal for passenger ships to follow the SECA limits of 0.1% also outside

[12] The previous IMO limits were applied by Directive 2005/33/EC which, in addition, imposed a 1.5% sulphur limit for fuels used by passenger vessels on regular services between EU ports from 11 August 2006, and a 0.1% sulphur limit on fuel used by inland waterway vessels and by seagoing ships at berth in EU ports, from 1 January 2010.

the SECA area from 2020 onwards was not approved, and the current 1.5% limit will be lowered to 0.5% in 2020 as for all shipping within the EU.

The 0.1% limit, effective as of 1 January 2015 within SECAs, can only be achieved by fitting expensive exhaust scrubbers, consuming LNG, or burning Marine Gas Oil, which is currently around $300 per tonne more expensive that Heavy Fuel Oil 1.0%S. This is expected to have adverse effects on shipping and ports in SECAs, as well as the industries that depend on their services (refer to Chapter 8 for a more detailed discussion on this issue). However, the focus of the shipping industry has now moved to concerns about the effective enforcement of these rules, which is far from trivial.

### 2.6.3 Monitoring, reporting and verification of $CO_2$ emissions

The IMO work on Market Based Measures (MBMs) was suspended in May 2013 in the wake of a clash between developed and developing Member States at MEPC 65. One month later the European Commission issued its proposal for a Regulation on monitoring, reporting and verification of $CO_2$ emissions, the so-called MRV proposal, as a first step towards setting GHG reduction targets and taking further measures, including an MBM (EC, 2013c).

The immediate objective of the MRV proposal is to produce accurate information on the $CO_2$ emissions of large ships using EU ports and incentivise energy efficiency improvements by making this information publicly available. In this way, the Commission sets the ground for possible future MBMs or efficiency standards, while at the same time attempts to address one of the market barriers found to prevent the implementation of cost-effective abatement measures by the industry, namely the lack of reliable information on fuel efficiency of ships.[13] Yet, another stated objective of introducing an MRV system is the securing of more time to discuss emission reduction targets and relevant measures, particularly at global level in IMO.

The proposed MRV system applies to ships above 5,000 GRT, regardless of

[13] The other market barriers relate to: (a) the split incentives between ship owners who invest into efficiency improvements and ship operators who reap the benefits of such investments through lower fuel bills, and (b) the lack of access to finance for these investments.

flag, and covers intra-EU, incoming (from the last non-EU port to the first EU port of call) and outgoing (from an EU port to the next non-EU port of call) voyages. It concerns the $CO_2$ emissions only.

Following the preparation of an emission monitoring plan by the ship-owning company and its approval by an accredited verifier, information on fuel consumption, distance travelled, time at sea and cargo carried is collected by the company for each ship and each journey falling under the Regulation. Actual fuel consumption for each voyage can be calculated using one of the following methods, provided that the method selected is pre-defined in the monitoring plan and, once chosen, is applied consistently:

- Bunker Fuel Delivery Notes and periodic stocktakes of fuel tanks,
- Bunker fuel tank monitoring on board,
- Flow meters and applicable combustion processes, and
- Direct emissions measurements.

Based on these parameters, a number of energy efficiency/emissions indicators are calculated and reported on an annual basis. The annual reports are submitted to the Commission and the flag state after their approval by the verifiers, who issue conformity documents that need to be kept on board the ships covered by the system. Conformity is to be checked by the flag state and through the port state control system. Sanctions are foreseen for the failure to comply, including in certain cases the expulsion of a ship, i.e. banning its entry to EU ports until the compliance problem has been resolved. The energy efficiency performance of the ships falling within the scope of the Regulation is made publicly available by the Commission every year.

As is usually the case, the proposal has attracted criticism from both directions. The environmental groups consider the proposal exceptionally mild, while the shipping interests argue that it imposes unnecessary obligations to an industry that suffers already from excessive administrative burdens.

In November 2014, an informal agreement by the EU legislators on the MRV proposal was announced according to which, no major modifications on the final text should be expected. Both the European Community Shipowners Association (ECSA) and the International Chamber of Shipping (ICS) expressed their concern that with the MRV proposal, which is expected to be fully operational by 2018, the EU may pre-empt negotiations taking place at IMO. Furthermore, ICS drew attention to the need to handle data on cargo carried by ships with particular sensitivity because of the suspicion that this could lead to the development of a mandatory operational efficiency index, like the EEOI of Section 2.6.1, whose mandatory application for benchmarking different vessels was considered inappropriate by IMO on technical grounds (GreenPort, 2014).

# PART II. GREEN FREIGHT CORRIDORS

# 3. Green corridors basics[14]

## 3.1 Introduction

The purpose of this chapter is to introduce the concept of green corridors and present a method for monitoring the performance of a freight transport corridor in order to:

(i) obtain a better understanding of its present status,
(ii) identify areas for improvements,
(iii) observe changes over time, and
(iv) compare with benchmarks.

The basis of this material is work conducted in the context of the EU SuperGreen project and therefore the geographical setting of the chapter is Europe. Much of the material of the chapter is an expanded version of the so-called *Green Corridors Handbook – Vol. I* (Moyano et al., 2012) and *Vol. II* (Panagakos, 2012) published by SuperGreen.

The general objective of the SuperGreen project has been to support the development of sustainable transport networks by fulfilling requirements covering environmental, technical, economic, social and spatial planning aspects. More specifically the project aimed at:

- giving overall support and recommendations on green corridors to the EU's *Freight Transport Logistics Action Plan*,

[14] With the exception of some minor editorial changes basically concerning cross-references, this chapter is identical to the homonymous Chapter 3 of the book *Green Transportation Logistics: the Quest for Win-Win Solutions*, edited by H.N.Psaraftis (Panagakos, 2016b). The chapter draws in part from the *Green Corridors handbook – Vol. II* (Panagakos, 2012).

- encouraging co-modality for sustainable solutions,
- benchmarking green corridors based on selected Key Performance Indicators (KPIs) covering all aspects of transport operations and infrastructure (emissions, internal and external costs),
- conducting a programme of networking activities between stakeholders (public and private),
- delivering policy recommendations at a European level for advancing the development of green corridors, and
- providing recommendations concerning new calls for R&D proposals to support the development of green corridors.

It should be clarified that this chapter does not seek to present all the work performed under SuperGreen, not even a summary of it. For more information on SuperGreen, the reader should be referred to the project's web site (www.supergreenproject.eu) featuring all project reports. The basic identity of the project appears also in Appendix I to this thesis. Instead, this chapter attempts to clarify the concept of a green corridor as much as possible and present a methodology for monitoring its performance through a set of selected KPIs.

In terms of scope, it has to be mentioned that the chapter deals only with surface freight transport, noting however that the quality of transport and logistics services is also affected by passenger transport competing for route capacity. Aviation is outside the scope of this analysis, as is the use of pipelines for liquid cargoes.

The rest of this chapter is structured as follows. Section 3.2 discusses the physical and functional elements of a transport corridor. Section 3.3 presents the available definitions of a green transport corridor and explains the benefits associated with this concept in the search for win-win solutions. Section 3.4 provides a brief presentation of the most important green corridor projects in Europe. Sections 3.5 and 3.6 are devoted to monitoring a corridor's performance. The former presents the KPIs that SuperGreen and other projects have suggested, while the latter focuses on the relevant benchmarking methodology. The chapter ends with a set of guidelines for corridor benchmarking.

## 3.2 Transport corridors

Despite being used for years as a concept, there is no precise definition for a 'transport corridor.' The World Bank publication *Best Practices in Management of International Trade Corridors* (Arnold, 2006) provides a descriptive definition that suits the way this term is used here. According to this definition, transport corridors have both physical and functional elements. In terms of their physical dimension:

- Transport corridors include one or more routes that connect centres of economic activity.
- The routes have different alignments but common transfer points and common end points, which are gateways that allow traffic to enter or exit the corridor.
- The routes are composed of the links over which the transport services travel and the nodes that interconnect the transport services.
- Some corridors are unimodal, but most involve multiple modes.
- Some corridors are relatively short and defined by a principal gateway like a port; others are defined by the region they serve; still others are defined as part of a network serving a larger region.

As for their functional dimension:

- Transport corridors provide transport and other logistics services that promote trade among the cities and countries along the corridor. In fact, most transport corridors are developed to support regional economic growth. It is for this reason that many transport corridors are associated with corresponding trade and economic corridors.
- Transport corridors can be domestic or international.
- A domestic corridor is a designated set of routes within the national transport network that is used to distribute goods within the country. It includes links and nodes for the various modes as well as nodes that connect different modes and different service areas.
- An international transport corridor may serve the foreign trade of a single country or several neighbouring countries. It may also connect countries that are separated by one or more transit countries or provide a landlocked country with access to the sea.

In relation to this last distinction, it should be mentioned that the international transport corridors consist of a number of national ones. As such, they are often characterised by competing functions, conflicting objectives, multiple jurisdictions and different funding schemes for their development and maintenance. On the other hand, they are usually associated with larger volumes of cargo and greater impact on the economies involved.

Corridor A, the corridor from Rotterdam to Genoa is a good example of an international transport corridor in the European context (refer to Figure 7). It stretches from the sea ports of Rotterdam, Zeebrugge and Antwerp to the port of Genoa, right through the heart of the EU along the so-called 'Blue Banana.' This is the most heavily industrialised North-South route in Central Europe and connects Europe's prime economic regions.


**Figure 7. Rail Corridor A serving the 'Blue Banana' region**

(Source: Corridor Rhine-Alpine, 2014)

The 'Blue Banana' includes economically strong urban centres such as Rotterdam, Amsterdam, Duisburg, Cologne, Frankfurt, Mannheim, Basle, Zurich, Milan and Genoa. All these centres are served and connected by the corridor, also indirectly including London and Brussels. The countries directly involved are The Netherlands, Belgium, Germany, Switzerland and Italy.

This outstanding position together with the resulting fact that this corridor carries by far the greatest transport volume in Europe, makes the Rotterdam-

Genoa route with its branch to Zeebrugge and Antwerp the pioneer for international rail freight transport in Europe.

## 3.3 The ‘green corridor’ concept

Neither a ‘green corridor’ is defined precisely in a strict sense. In fact one of the most important contributions of ongoing research on the topic would be to develop an explicit and workable definition of the term.

The concept was introduced in 2007 by the *Freight Transport Logistics Action Plan* of the European Commission (EC, 2007b). According to this document:

> *“... [green] transport corridors are marked by a concentration of freight traffic between major hubs and by relatively long distances...*
>
> *... Industry will be encouraged along these corridors to rely on co-modality*[15] *and on advanced technology in order to accommodate rising traffic volumes, while promoting environmental sustainability and energy efficiency...*
>
> *... Green transport corridors will ... be equipped with adequate transhipment facilities at strategic locations ... and with supply points initially for bio-fuels and, later, for other forms of green propulsion...*
>
> *... Green corridors could be used to experiment with environmentally-friendly, innovative transport units, and with advanced Intelligent Transport Systems (ITS) applications ...*
>
> *... Fair and non-discriminatory access to corridors and transhipment facilities should be ensured in accordance with the rules of the Treaty.”*

Some years later, the Swedish Logistics Forum worked out a more structured definition (Fastén and Clemedtson, 2012). According to them:

---

[15] In the EU transport policy documents, the term co-modality is used to refer to the "use of different transport modes on their own and in combination" in the aim of obtaining "an optimal and sustainable utilisation of resources."

*"Green Corridors aim at reducing environmental and climate impact while increasing safety and efficiency. Characteristics of a green corridor include:*

- *sustainable logistics solutions with documented reductions of environmental and climate impact, high safety, high quality and strong efficiency,*
- *integrated logistics concepts with optimal utilisation of all transport modes, so called co-modality,*
- *harmonised regulations with openness for all actors,*
- *a concentration of national and international freight traffic on relatively long transport routes,*
- *efficient and strategically placed transhipment points, as well as an adapted, supportive infrastructure, and*
- *a platform for development and demonstration of innovative logistics solutions, including information systems, collaborative models and technology*."

A direct comparison between the two definitions reveals the following differences:

- The Swedish definition includes 'high safety' in the list of characteristics, referring to social acceptance, the third pillar of sustainability as it appears in the strategic document *Europe 2020* (EC, 2010b). On the contrary, the EU definition confines itself to the other two dimensions of sustainability; those of economic and environmental efficiency.
- The Swedish definition makes reference also to harmonised regulations as a necessary feature of a green corridor.
- Although both definitions mention technology as a green corridor element, only the EU one makes direct reference to alternative fuels and green propulsion.

Despite their differences, the two definitions share an important aspect of green corridors: these corridors are more than just economically efficient and they are more than just environmentally sustainable; they are both economically efficient and environmentally sustainable. It is for this reason that green corridors enjoy a central position in green freight logistics and also a central role in this thesis.

If, for simplicity purposes, we consider safety as a pre-condition constraining economic efficiency, then green corridors comprise a subset of the efficient ones. Figure 8 depicts this notion schematically.

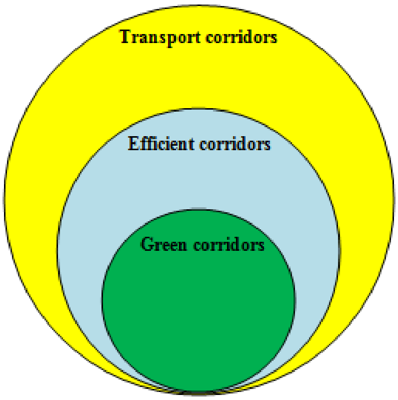


**Figure 8. Green corridors as a subset of efficient corridors**

(Source: Panagakos and Psaraftis, 2014)

What are, then, the specific characteristics that distinguish a green corridor from an otherwise efficient one? To answer this question, one has to merge the two lists of characteristics presented above into a single one and exclude the features that pertain to any efficient corridor. The following green characteristics result from this exercise:

a) Reliance on co-modality, i.e. the efficient use of different modes on their own and in combination, which in turn requires:
   - adequate transhipment facilities at strategic locations; and
   - integrated logistics concepts.

b) Reliance on advanced technology allowing use of alternative clean fuels (in addition to energy efficiency that can be viewed as a characteristic of an efficient corridor anyway).

c) Development and demonstration capabilities of environmentally-friendly and innovative transport solutions, including advanced telematics applications.

d) Collaborative business models.

The last question to address in this section relates to the expected benefits of this new concept. What is it that makes the green corridors so special?

The basic principle relates to the consolidation of large volumes of freight for transport over long distances, in between the so-called first and last miles. This is a prerequisite for improving the competitiveness of modes like rail and waterborne transport, which are environmentally friendlier than trucks, on the one hand, and exhibit spare capacity, on the other. Increased competitiveness leads to higher possibilities of engaging trains and ships in freight logistics. In turn, the shift of cargoes away from European roads is expected to alleviate the serious congestion problem that this transport mode faces, producing positive externalities to the other users of the road network through improvements in reliability and reduction of transport time.

Furthermore, the scale and length of such freight corridors enable further optimisation in terms of energy use and emissions for these long-hauls, resulting in additional environmental and financial (due to lower operating costs) gains. The feasibility of investments associated with establishing a network of refuelling stations for alternative fuels (biofuels, electricity, LNG, etc.) along such corridors would be improved, while the use of more energy efficient vehicles/vessels (trucks with better aerodynamic performance and new engines, longer trains, LNG-fuelled vessels, etc.) would be boosted.

Advanced ICT applications like automatic guidance systems would further improve the utilisation and performance of existing infrastructure through minimising congestion and accidents. ICT would also help integrating regular rail, sea and inland waterway services with road transport which will maintain the predominant role over short and medium distances. Applications would include cargo tracking and tracing, schedule optimisation and simplification of formalities related to multimodal freight transport.

In addition, the international character of the corridors (involve at least three Member States) addresses the fragmented nature of transport networks, especially rail, dealing with the haunting interoperability issues in geographical terms. At the same time, focusing on a subset of the network improves the chances of identifying workable solutions by limiting the overwhelming scale of the problem.

The realisation of international multimodal corridors cannot be implemented without appropriate corridor structures. These structures will bring together the Commission, Member States, the regions, the local authorities, but also the infrastructure owners and managers, transport operators, shippers, financiers and, when appropriate, neighbouring countries. The involvement of such structures is absolutely necessary in promoting multimodal logistics, where lack of coordination comprises probably the most persisting problem.

The systematic exchange of information between national authorities would further enable the uniform enforcement of common safety, security, environmental and social legislation which, in turn, would benefit the users of transport services and their providers through full market opening and the provision of a level playing field.

Last but not least, the establishment of corridors that enhance the efficiency of transport modes (alone and in combination) through better utilisation of resources is expected to limit the considerable investments needed for expanding the capacity of the transport networks in an environment of budgetary consolidation and increasing public opposition to major transport infrastructure projects especially in the vicinity of urban areas.

## 3.4 Green corridor projects in Europe

Those who follow the evolution of the EU transport policy cannot escape noticing that the corridor approach gains more and more importance as a response to the new and old challenges that the common transport policy faces in Europe (refer to Section 1.1 for a discussion on these challenges).

- In March 2005, the European Commission and the railway sector agreed on a MoU referring to the implementation of the European Rail Traffic Management System (ERTMS - a signalling system that will replace all those currently in use throughout Europe) on six corridors to define a European migration strategy for the deployment of ERTMS (refer to Figure 9).

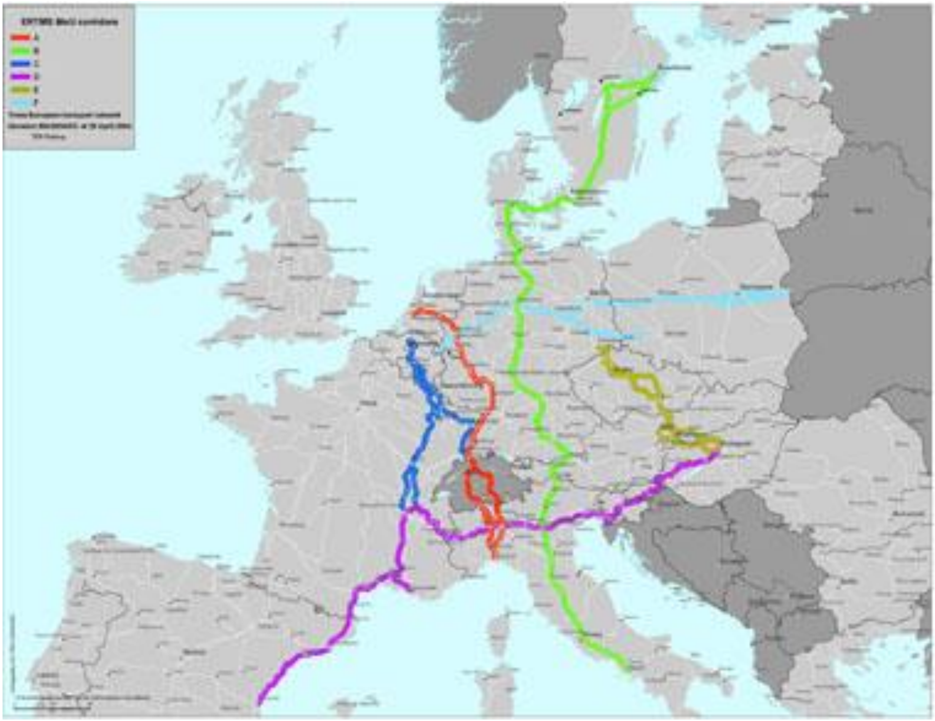

**Figure 9. The six ERTMS corridors**
(Source: RFF, 2014)

- In October 2007, The European Commission published its Freight Transport Logistics Action Plan, which introduced the concept of ‘green corridors’ as a means to improve the efficiency and sustainability of freight transport in Europe.
- In November 2010, the European Parliament and the Council adopted the EU Regulation No 913/2010 concerning a European rail network for competitive freight (EP&C, 2010a). This Regulation defines nine initial Rail Freight Corridors (RFCs) along which, sufficient priority among freight trains, is given to those crossing at least one border (refer to Figure 10).

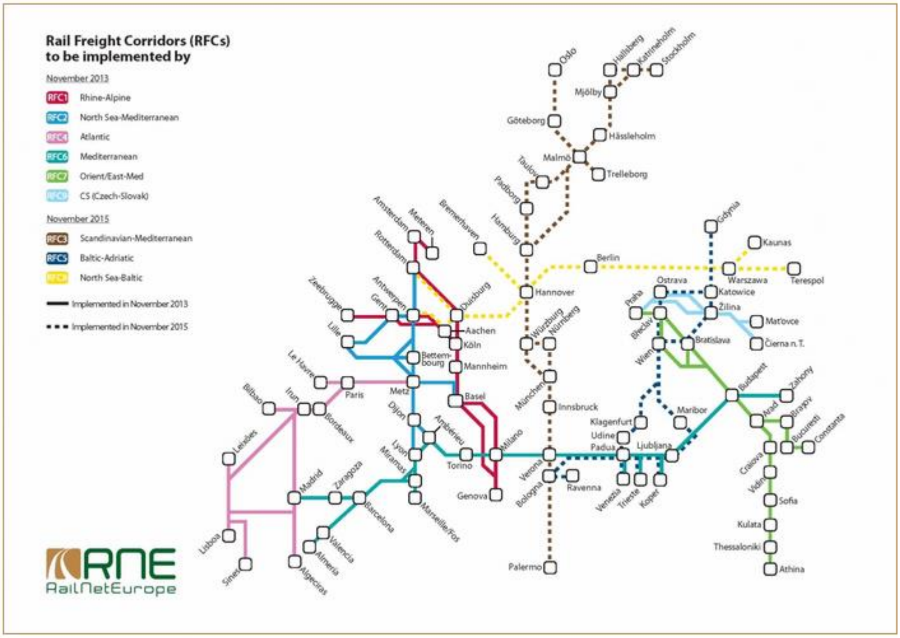


**Figure 10. The nine Rail Freight Corridors**

(Source: RNE, 2014)

- In March 2011, the European Commission in describing its vision of future transport and the corresponding strategy for the next decade, included in the latest White Paper on transport ‘multimodal freight corridors’ as a means to improve governance and to support pilot projects for innovative and clean transport services (EC, 2011a).
- In December 2013, the European Parliament and the Council adopted the EU Regulation No 1315/2013 on Union guidelines for the development of the Trans-European Transport Network (TEN-T), which introduced the concept of ‘core network corridors’ as an instrument to facilitate the coordinated implementation of the parts of the TEN-T with the highest strategic importance (EP&C, 2013a). The nine TEN-T core network corridors are shown in Figure 11.

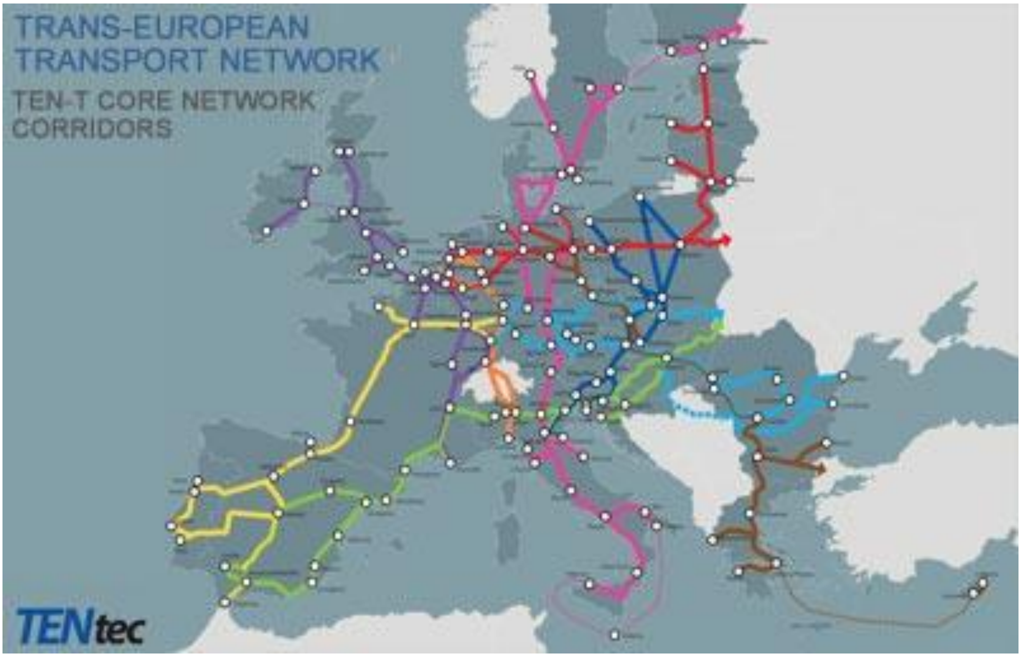


**Figure 11. The nine TEN-T core network corridors**
(Source: EC, 2014b)

At a lower level, the initiatives listed below comprise a selection of the most important among a wide range of corridor applications in Europe:

- In December 2002, Germany, Austria and Italy adopted the Brenner Action Plan aiming at a significant and sustainable increase in intermodal volume along the Brenner corridor, one of the most trafficked international transit corridors, where - on a length of only 448 km between Munich and Verona - three countries and thus railway infrastructures and the Alps are being bridged (Mertel and Sondermann, 2007).
- In January 2003, the Ministries of Transport of The Netherlands, Germany, Switzerland and Italy agreed on a MoU establishing an international working group to develop a comprehensive action plan aiming at bringing about numerous quantitative and qualitative improvements on the rail corridor from Rotterdam to Genoa (Corridor A, 2011). The so-called Corridor A was born (refer also to Section 3.2).

- In 2006, 42 partners (local, regional and national authorities, universities, harbours and private stakeholders) from Denmark, Lithuania, Russia and Sweden joined forces to strengthen transport development along the so-called 'East-West Transport Corridor – EWTC' through infrastructure improvements, new solutions for business, logistics and cooperation between researchers (refer to Figure 12). The success of EWTC led to the follow up project EWTC II, which aims at transforming the EWTC into a green corridor in line with the EU policy.

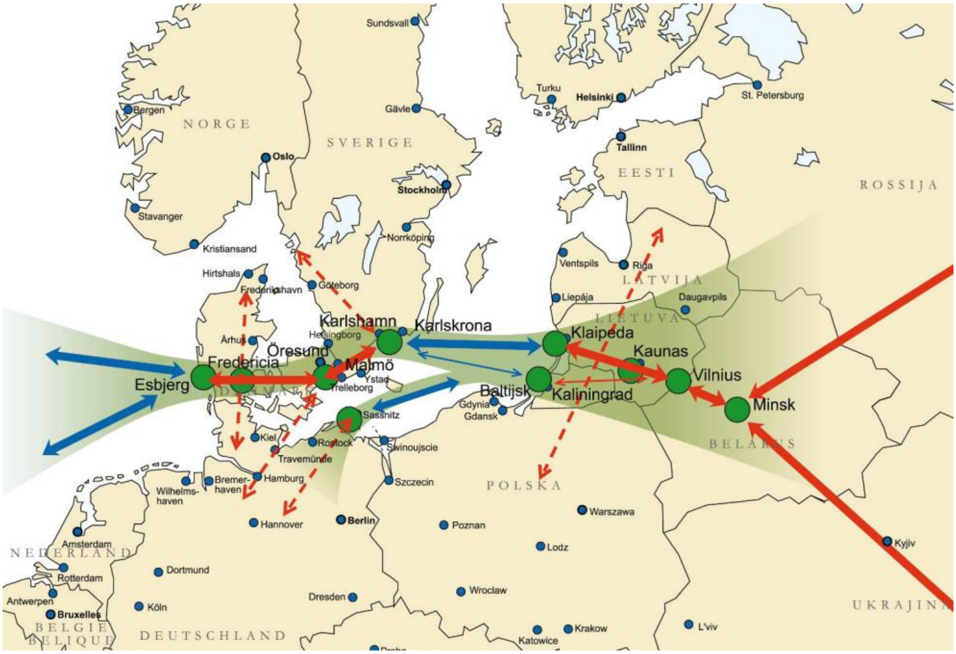


**Figure 12. The East-West Transport Corridor**

(Source: Fastén and Clemedtson, 2012)

- In 2008, the Swedish Green Corridors Initiative (SGCI) was introduced focusing on transport routes and collaboration among shippers, forwarders, industry and haulers in order to optimise the use of available transport capacity (Wålhberg et al., 2012). Two green corridors were established by this initiative:
  - ✓ The Oslo–Randstad corridor that follows one of Northern Europe's most important freight routes (Figure 13). GreCOR, an Interreg IVB

project running in the period 2012-15, aims to: (i) improve knowledge about the logistic needs and conditions along this corridor, and (ii) implement the first green corridor in the North Sea Region (Hansson and Hansson, 2014). The project uses a collaborative approach to enhance co-modality and influence infrastructural development in the region, including the hinterland of the corridor's hubs. Among other results, GreCOR will develop a methodology for assessing the environmental performance of a corridor and a web-based market place for route planning.


**Figure 13. The GreCOR corridor**

(Source: Hansson and Hansson, 2014)

- ✓ The Bothnian Green Logistic Corridor (BGLC). Twenty-nine partners across five countries – Sweden, Finland, Norway, Germany and Poland – were working during 2012-14 within different fields to develop BGLC (Figure 14) into an efficient, reliable and green transport corridor, connecting northern Scandinavia's raw materials with the markets in Europe (Södergren et al., 2012). Project activities involved: mapping cargo flows and future needs, elimination of bottlenecks, introduction of new intermodal solutions for increased flexibility, examination of the regional and economic effects of corridor development, identification of strategically important nodes, and the design of innovative business models and pilot projects enhancing collaboration between private and public stakeholders.


**Figure 14. The BGLC corridor**

(Source: Södergren et al., 2012)

- In 2009, the Scandria project was introduced, covering the corridor from Region of Halland (Sweden), via Zealand (Denmark) to Mecklenburg-Vorpommern and Berlin (Germany). During three years, 19 partners and 16 associated partners from business, national, regional and local administration, and research institutions fostered green and innovative development between Scandinavia and Eastern Germany. The project also cooperated with SoNorA (South-North-Axis corridor in central Europe), extending coverage from Berlin to the Adriatic Sea (Friedrich, 2012).

- In 2009, the TransBaltic project was also introduced covering corridors across the Baltic Sea. The overall objective of this 3-year project was to provide regional level incentives for the creation of a sustainable multimodal transport system in the Baltic Sea Region, through joint transport development measures and jointly implemented business concepts (Transbaltic, 2012).
- In 2010, the Midnordic Green Transport Corridor project of NECL (North East Cargo Link) was initiated with the aim to address obstacles along the transport corridor that stretches through the middle parts of Norway, Sweden and Finland (Kokki, 2013). Other objectives included carrying out pre-investment studies, developing transport solutions, marketing of the corridor on a macro region level and developing an ICT application (portal) in close cooperation with the national transport authorities and industry over the national borders (Figure 15).

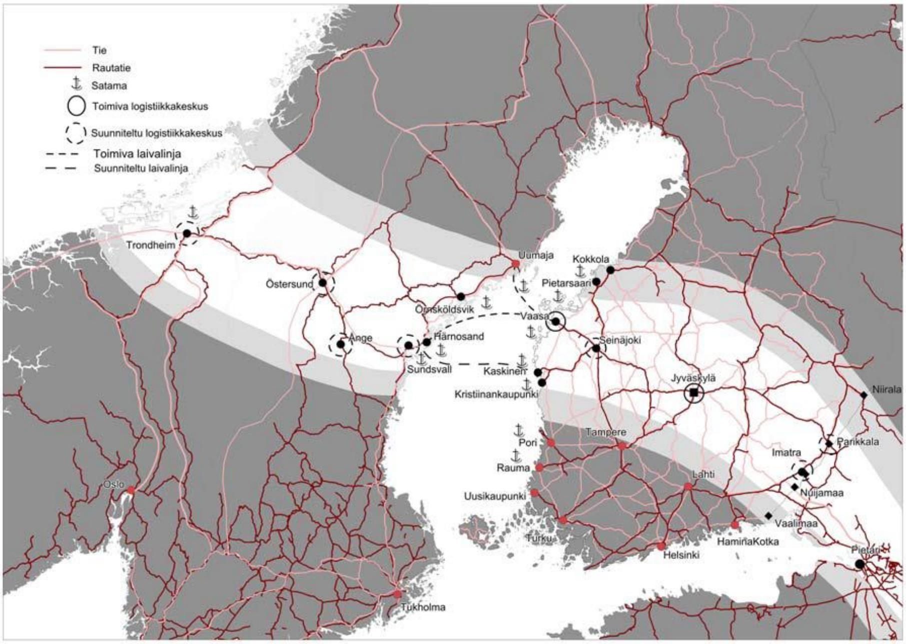


**Figure 15. The Midnordic transport network**

(Source: Kokki, 2013)

- In 2010, SuperGreen, a Coordination and Support Action co-financed by the EC's 7th Framework Programme of Research and Technological Development (RTD), was launched. The main objective of this 3-year project was to assist in further defining and developing the green corridor concept. Basic information on this project can be found in Appendix I to this thesis. Its central activity was the development of a corridor benchmarking methodology using a set of Key Performance Indicators (KPIs) that are suitable for monitoring the sustainable development goals of the European Union. The results of this activity will be presented in the following sections of this chapter; the discussion here will be confined to the SuperGreen corridors selected for applying the proposed methodology.

  The project compiled an initial list of 60 potential corridors on the basis of the TEN-T priority projects, the pan-European transport network and proposals made by the project's industrial partners. After two consolidation rounds, the number of candidate corridors was reduced to 30. A survey was carried out to gather information on these 30 corridors. Based on the information gathered and criteria like corridor length, population affected, freight volume, types of goods transported, number and seriousness of bottlenecks, transport and information technology used, and assessment of the supply chain management, a pre-selection of 15 corridors was made. A geographic and modal balance was ensured among these pre-selected corridors. The aim at this stage was to select the ones with the highest 'greening potential' rate.

  Further information was collected on these 15 pre-selected corridors and a deeper analysis was performed taking into consideration land use aspects like the percentage of corridor surface comprising urban and environmentally sensitive areas. The analysis resulted in a recommendation of 9 corridors for final selection, which was presented to a stakeholder workshop especially arranged for this purpose. In line with comments received during the workshop, the selected corridors were modified by adding segments that exhibit advanced 'greening' characteristics.

  These 9 corridors were given nicknames and are described in

  Table 4, while Figure 16 presents this set of corridors in metro format.

**Table 4. The nine SuperGreen corridors**

| Nicknames | Acronym | Corridor Description |
|---|---|---|
| **Brenner** | **BerPal** | Malmö-Trelleborg-Rostock/Sassnitz-Berlin-Munich-Salzburg-Verona-Bologna-Naples-Messina-Palermo<br>Branch A: Salzburg-Villach-Trieste (Tauern axis)<br>Branch B: Bologna-Ancona/Bari/Brindisi-Igoumenitsa/Patras-Athens |
| **Finis Terrae** | **MadPar** | Madrid-Gijon-Saint Nazaire-Paris<br>Branch A: Madrid-Lisboa |
| **Cloverleaf** | **CorMun** | Cork-Dublin-Belfast-Stranraer<br>Branch A: Munchen-Friedewald-Nuneaton Branch B: West Coast Main line |
| **Edelweiss** | **HelGen** | Helsinki-Turku-Stockholm-Oslo-Göteborg-Malmö-Copenhagen (Nordic triangle including the Oresund fixed link)- Fehmarnbelt - Milan - Genoa |
| **Nureyev** | **RotMos** | Motorway of Baltic sea<br>Branch: St. Petersburg-Moscow-Minsk-Klapeida |
| **Strauss** | **RhiDan** | Rhine/Meuse-Main-Danube inland waterway axis<br>Branch A: Betuwe line<br>Branch B: Frankfurt-Paris |
| **Two Seas** | **AthDre** | Igoumenitsa/Patras-Athens-Sofia-Budapest-Vienna-Prague-Nurnberg/Dresden-Hamburg |
| **Mare Nostrum** | **SinOde** | Odessa-Constanta-Bourgas-Istanbul-Piraeus-Gioia Tauro-Cagliari-La Spezia-Marseille-(Barcelona/Valencia)-Sines<br>Branch A: Algeciras-Valencia-Barcelona-Marseille-Lyon |
| **Silk Way** | **CNHam** | Shanghai-Le Havre/Rotterdam-Hamburg/Gothenburg-Gdansk-Baltic ports-Russia<br>Branch:Xiangtang-Beijing-Mongolia-Russia-Belarus-Poland-Hamburg |

(Source: Salanne et al., 2010)

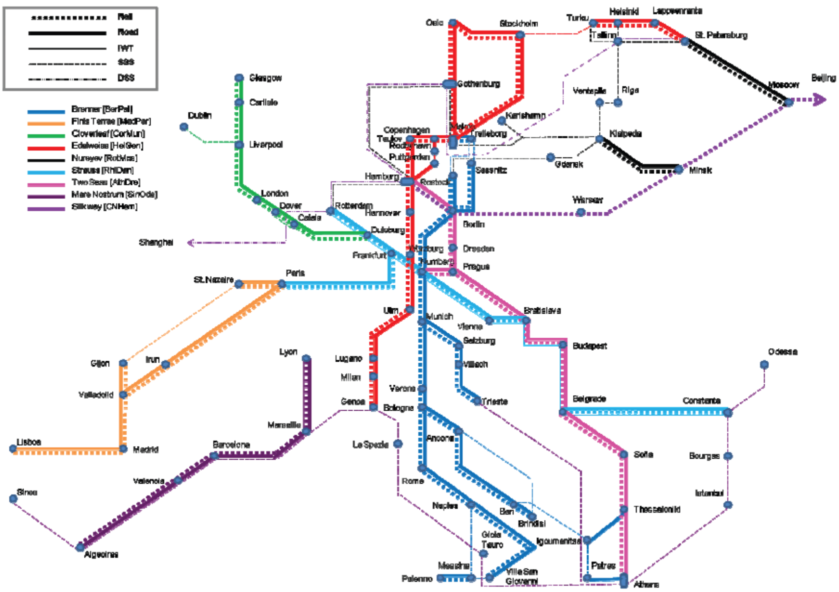


**Figure 16. The SuperGreen corridors in metro format**

(Source: Ilves et al., 2011)

In addition to being geography- and mode-wise balanced, the resulting set of corridors comprised a mix of environmentally advanced ones on one hand, and those exhibiting a high 'greening potential' on the other, thus constituting a suitable field for testing the benchmarking methodology and KPIs.[16] More details on SuperGreen corridor selection can be found at Salanne et al. (2010).

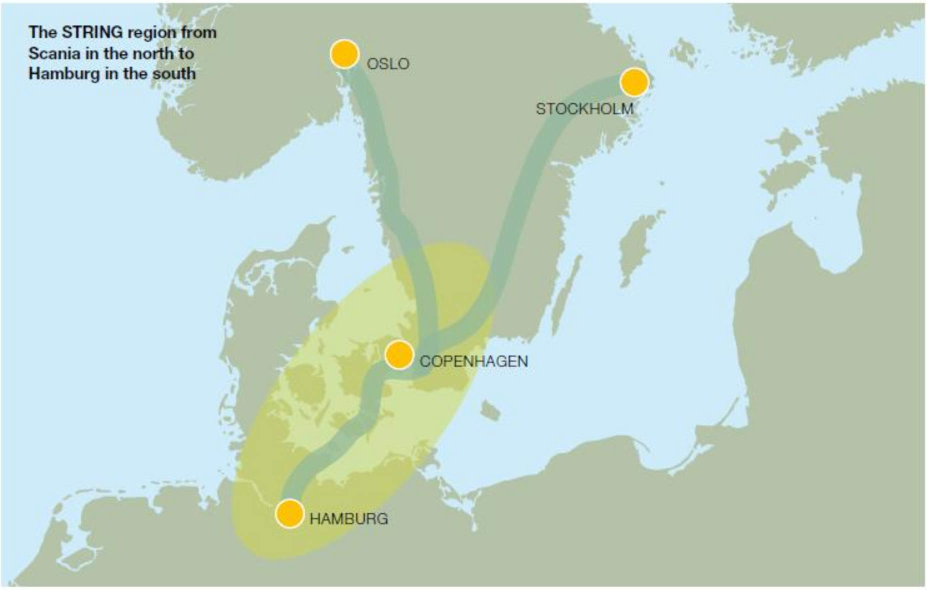


**Figure 17. The STRING green corridor**

(Source: Stenbæk et al., 2014)

- In 2011, the Green STRING Corridor project was launched, scheduled to run for three years. Its aim was to promote the potential of innovative transport and logistics solutions for developing a green transport corridor between the Öresund Region and Hamburg, capitalising on the benefits of the forthcoming fixed Fehmarn Belt link (Figure 17). The project identified the conditions and challenges that a green transport corridor sets for the distribution and logistics strategies of private companies, as

[16] It should be clarified that the selection of these corridors was made only for the purposes of the SuperGreen project and by no means has this implied any direct or indirect endorsement, either by the SuperGreen consortium or by the European Commission, of these corridors vis-à-vis any other corridor, with respect to any criteria, environmental, economic, or other.

well for cross-border planning among public authorities at a local, regional and national level (Stenbæk et al., 2014).

## 3.5 Key performance indicators

Monitoring the performance of the relevant transport corridors is a common need of all the projects of Section 3.4. Their performance needs to be assessed in terms of pre-specified qualities that correspond to the objectives pursued by the corridor management. Monitoring is achieved through a set of indicators which is defined either explicitly (Brenner corridor, Corridor A, EWTC, SGCI, GreCOR, BGLC, SuperGreen) or implicitly (Scandria, TransBaltic, STRING).

For example, the quality objectives of the BRAVO project (Brenner corridor) were punctuality, reliability, flexibility, customer information, employment rate of rolling stock, and reliability of transport documents. The management of Corridor A (Rotterdam-Genoa) has selected indicators concerning traffic volume, modal split, punctuality and commercial speed. On a more theoretical basis, the World Bank proposes the use of cost, time, reliability and flexibility as corridor performance indicators (Arnold, 2006).

When discussing indicators, it should be kept in mind that KPIs need to be:

- relevant (there should be a clear link between indicators and objectives),
- quantifiable[17] (assessed by certain units that have a numerical value attached),
- clear (defined in a way that precludes misinterpretations and enables meaningful comparisons),
- simple (easy to use and compute in terms of data availability and cost),
- robust (resistant to manipulation by those responsible),
- sensitive to classified information,
- mutually exclusive and, to the extent possible, collectively exhaustive.

The three sets of indicators presented below are indicative of the different

[17] In cases of policy- and process-benchmarking, quantifiable indicators might need to be complemented by qualitative ones.

perspectives and level of detail employed.

### 3.5.1 The SGCI criteria

The Swedish Green Corridors Initiative compiled a list of criteria for selecting, comparing and evaluating green corridor projects (SGCI, 2012). The document identifies two distinct aspects affecting a corridor's performance: (i) the framework that enables the provision of transport services (policies and regulations, infrastructure, ICT applications, organisational issues, etc.) and (ii) the operational characteristics of the transport services. It selects, however, to focus on the second one on the assumption that a sufficiently good framework is provided. Furthermore, the term 'green' is seen from a purely ecological perspective and the selected criteria cover the environmental dimension only.

It is interesting to note that all environmental criteria are described in both absolute and relative terms (refer to Table 5). The absolute measurement indicates actual emissions caused by a transport activity and reflect the volume of transport work, while relative data describes the environmental efficiency of the transport activity.

### 3.5.2 The EWTC KPIs

In relation to SGCI, the East-West Transport Corridor (EWTC) project has advanced the KPI selection in two important ways: Firstly, the term 'green' now combines all three sustainability dimensions (economic, environmental and social efficiency). Secondly, the grouping of indicators into operational and enabling ones, which was only touched upon by SGCI, has now been strengthened. Operational indicators aim at optimising cargo flows in the short run with regard to their overall sustainability and address the perspectives of transport service providers, shippers and the corridor managers. On the other hand, enabling indicators aim to optimise long term development of the corridor framework and are relevant to infrastructure managers, policy makers and the corridor managers.

**Table 5. The SGCI indicators**

| **Transport service/technique** | | | |
|---|---|---|---|
| | | *Max performance levels* | |
| *Performance area* | *Performance indicator* | *Year 2010* | *Year 2014* |
| **Environment** | | | |
| GHG emissions$_{tot}$ | CO2e [ton/year] | -x tonne CO2e/year | -y tonne CO2e/year |
| GHG productivity | CO2e [g/tkm] | x gram CO2e/tkm | y gram CO2e/tkm |
| NOx emissions$_{tot}$ (e.g. regulated) | NOx emissions[kg/year] | -x kg NOx/year | -y gram NOx/year |
| NOx emission productivity | NOx emissions [g/tkm] | x gram NOx/tkm | y gram NOx/tkm |
| $SO_2$ emissions$_{tot}$ (e.g. regulated) | $SO_2$ emissions[kg/year] | -x kg $SO_2$/year | -y gram $SO_2$/year |
| $SO_2$ emission productivity | $SO_2$ emissions [g/tkm] | x gram $SO_2$/tkm | y gram $SO_2$/tkm |
| HC emissions$_{tot}$ (e.g. regulated) | HC emissions[kg/year] | -x kg HC/year | -x kg HC/year |
| HC emission productivity | HC emissions [g/tkm] | x gram HC/tkm | x gram HC/tkm |
| PM emissions$_{tot}$ (e.g. regulated) | PM emissions[kg/year] | -x kg CO2e/year | -y gram CO2e/year |
| PM emission productivity | PM emissions [g/tkm] | x gram CO2e/tkm | y gram CO2e/tkm |
| | | | |
| **Resources** | | | |
| Energy use$_{tot}$ | Energy use [kWh/year] | x kWh/year | Y kWh/year |
| Energy use productivity | Energy use [kWh/tkm] | x kWh/tkm | Y kWh/tkm |
| **Requisite criteria´s** | | | |
| Follow-up systems | Systematic plan | According to guidelines | According to guidelines |
| Vulnerability/ redundancy plans | Systematic plan | According to guidelines | According to guidelines |
| Maintenance plans | Systematic plan | According to guidelines | According to guidelines |
| **Corridor service** (sum of total transport services included in the corridor) | | | |
| | | *Max performance levels* | |
| *Performance area* | *Performance indicator* | *Year 2010* | *Year 2014* |
| **Environment** | | | |
| ∑GHG emissions$_{tot}$ | CO2e [ton/year] | -x tonne CO2e/year | -y tonne CO2e/year |
| ∑GHG productivity | CO2e [g/tkm] | x gram CO2e/tkm | y gram CO2e/tkm |
| ∑NOx emissions$_{tot}$ (e.g. regulated) | Emissions[kg/year] | -x kg CO2e/year | -y gram CO2e/year |
| ∑NOx emissions productivity | Emissions [g/tkm] | x gram CO2e/tkm | y gram CO2e/tkm |
| ∑SOx emissions$_{tot}$ (e.g. regulated) | SOx emissions[kg/year] | -x kg $SO_2$/year | -y gram $SO_2$/year |
| ∑SOx emission productivity | SOx emissions [g/tkm] | x gram $SO_2$/tkm | y gram $SO_2$/tkm |
| ∑HC emissions$_{tot}$ (e.g. regulated) | HC emissions[kg/year] | -x kg HC/year | -x kg HC/year |
| ∑HC emission productivity | HC emissions [g/tkm] | x gram HC/tkm | x gram HC/tkm |
| ∑PM emissions$_{tot}$ (e.g. regulated) | PM emissions[kg/year] | -x kg PM/year | -y gram PM/year |
| ∑PM emission productivity | PM emissions [g/tkm] | x gram PM/tkm | y gram PM/tkm |
| **Resources** | | | |
| ∑Energy use$_{tot}$ | Energy use [kWh/year] | x kWh/year | Y kWh/year |
| ∑Energy use productivity | Energy use [kWh/tkm] | x kWh/tkm | Y kWh/tkm |
| **Requisite criteria´s** | | | |
| Follow-up systems | Systematic plan | According to guidelines | According to guidelines |
| Vulnerability/ redundancy plans | Systematic plan | According to guidelines | According to guidelines |
| Maintenance plans | Systematic plan | According to guidelines | According to guidelines |

(Source: SGCI, 2012)

The EWTC scheme of KPIs appears in Table 6. It needs to be mentioned that, unlike the operational ones, the enabling indicators are monitored through a corridor dashboard. The dashboard highlights the need to eliminate bottlenecks that may occur either within or outside the immediate corridor region.

**Table 6. The EWTC indicators**

| Performance areas | Operational indicators | Enabling indicators |
|---|---|---|
| *Economic efficiency* | Total cargo volumes<br>On time delivery | Corridor capacity |
| *Environmental efficiency* | Total energy use<br>Greenhouse gases, CO2e<br>Engine standards<br>ISO 9001 dangerous goods | Alternative fuels filling stations |
| *Social efficiency* | ISO 31 000<br>ISO 39 000 | Safe truck parking<br>Common safety rating<br>Fenced terminals |

(Source: Fastén and Clemedtson, 2012)

### 3.5.3 The SuperGreen KPIs

The KPI selection part of the SuperGreen project was a cumbersome procedure that drew heavily on stakeholder input. It was performed in two distinct phases. During the first phase, a process involving the compilation of a gross list of performance indicators, their categorisation into five different groups and their filtering during detailed discussions among project partners resulted in an initial set of KPIs. The five KPI groups (efficiency, service quality, environmental sustainability, infrastructural sufficiency, and social issues) were formed so as to combine all three sustainability dimensions with the adequacy of the capacity, condition and administrative framework of the corridor infrastructure (the so-called 'enabling indicators' of SGCI and EWTC). These initial KPIs are presented in Table 7 along with their respective definition.

**Table 7. Initial set of SuperGreen KPIs**

| KPIs | Units |
|---|---|
| **Efficiency** | |
| Absolute cost | €/tonne |
| Relative cost | €/tonne-km |
| **Service quality** | |
| Transport time | hours |
| Reliability (time precision) | % of shipments delivered on time (within acceptable window) |
| Frequency of service | Number of services per year |
| ICT applications<br>- cargo tracking, availability<br>- cargo tracking, integr. & functionality<br>- other ICT serv., availability<br>- other ICT serv., integr. & functionality | graded scale (1-5)<br>graded scale (1-5)<br>graded scale (1-5)<br>graded scale (1-5)<br>graded scale (1-5) |
| Cargo security | Number of incidents per total number of shipments |
| Cargo safety | Number of incidents per total number of shipments |
| **Environmental sustainability (*)** | |
| $CO_2$-eq | g/tonne-km |
| $SO_2$ | g/1000 tonne-km |
| NOx | g/1000 tonne-km |
| $PM_{10}$ | g/1000 tonne-km |
| **Infrastructural sufficiency** | |
| Congestion | average delay (hours) per tonne-km |
| Bottlenecks<br>- geography<br>- infrastructure capacity<br>- infrastructure condition<br>- administration | graded scale (1-5) based on list of bottlenecks per category, accompanied by list of projects aiming at their removal/mitigation |
| **Social issues** | |
| Corridor land use<br>- urban areas<br>- sensitive areas | <br>% of buffer zone (**) covered by urban areas<br>% of buffer zone (**) covered by environmentally sensitive areas |
| Traffic safety | sum of fatalities and serious injuries per year per million ton-km |
| Noise | % of corridor length above 50/55 dB |
| (*) well-to-wheel approach<br>(**) shaped by a radius of 20 km around the median line of the corridor | |

(Source: Moyano et al., 2012)

With the aim of soliciting feedback, this initial set (together with the proposed benchmarking methodology that will be presented in the following section) was presented in three events: two regional stakeholder workshops (in Napoli, Italy and in Antwerp, Belgium) and a meeting of the project's Advisory Committee. The general consensus was that in broad terms the proposed KPIs cover all basic facets of the problem. However, there was also a general sense that the indicators were too ambitious and there was a need to simplify them so that the set be practical. In that sense, reducing the set of KPIs to a more manageable one was considered as a desirable outcome.

Following an internal round of KPI screening, a revised set was presented to a third regional SuperGreen workshop, organised in Malmö, Sweden and hosted by the Swedish Transport Administration.  The aim was to set a basis for collaboration with the numerous green corridor initiatives in the Baltic region and take advantage of an audience directly or indirectly exposed to the green corridor concept. The KPI set that resulted from this process is the one of Table 8. This set was reaffirmed at a fourth regional stakeholder workshop of the project in Sines, Portugal.

**Table 8. Revised set of SuperGreen KPIs**

| Indicator | Unit |
|---|---|
| Out-of-pocket costs (excluding VAT) | €/tonne-km |
| Transport time (or average speed) | hours (or km/h) |
| Reliability of service (in terms of time precision) | % of shipments delivered within acceptable window |
| Frequency of service | Number of services per year |
| $CO_2$-eq emissions | g/tonne-km |
| SOx emissions | g/tonne-km |

(Source: Ilves et al., 2011)

It is worth noting that four of the six indicators concern economic efficiency (transport costs accompanied by three KPIs related to quality of service – time, reliability and frequency), while the remaining two reflect environmental concerns (GHG and sulphur emissions). The social aspects are absent, probably signifying a secondary role that stakeholders attach to them when it comes to freight logistics.

## 3.6 Corridor benchmarking

### 3.6.1 Early works

Unlike KPIs, corridor benchmarking is not a very popular topic in the literature. Most benchmarking work stops at the transport chain level. The few exceptions found in the bibliography are presented below.

The World Bank's *Best Practices in Management of International Trade Corridors* contains a first attempt in assessing the performance of a corridor (Arnold, 2006). On the basis that a corridor is generally composed of several alternative routes, the method focuses on measuring the performance of each route. Refer to Figure 18 for a schematic depiction of the methodology.

In the event that no information on market segments, commodity groups, shipment types and modal split is available (which is normally the case), the analysis starts with the construction of a sample. The paper does not specify the sample's configuration. However, the need to compute cost, time and reliability indicators for the sample, which comprises the next step of the methodology, makes one infer that the sample is composed of transport chains[18]. After considering trends, the comparison with benchmarks leads to the identification of problems on a route basis. No details are given on how the chain-level indicators are transformed into route-level ones; a reference to supply chain analysis might be relevant. As a next step, route problems are translated into performance deficiencies at the links and nodes. No attempt is made to compute indicators at the corridor level. The absence of environmental considerations from the analysis is also noticeable.

[18] It is worth noting that the flexibility indicator that has been proposed as a KPI earlier in the paper does not enter the methodology, presumably due to its rather qualitative nature.

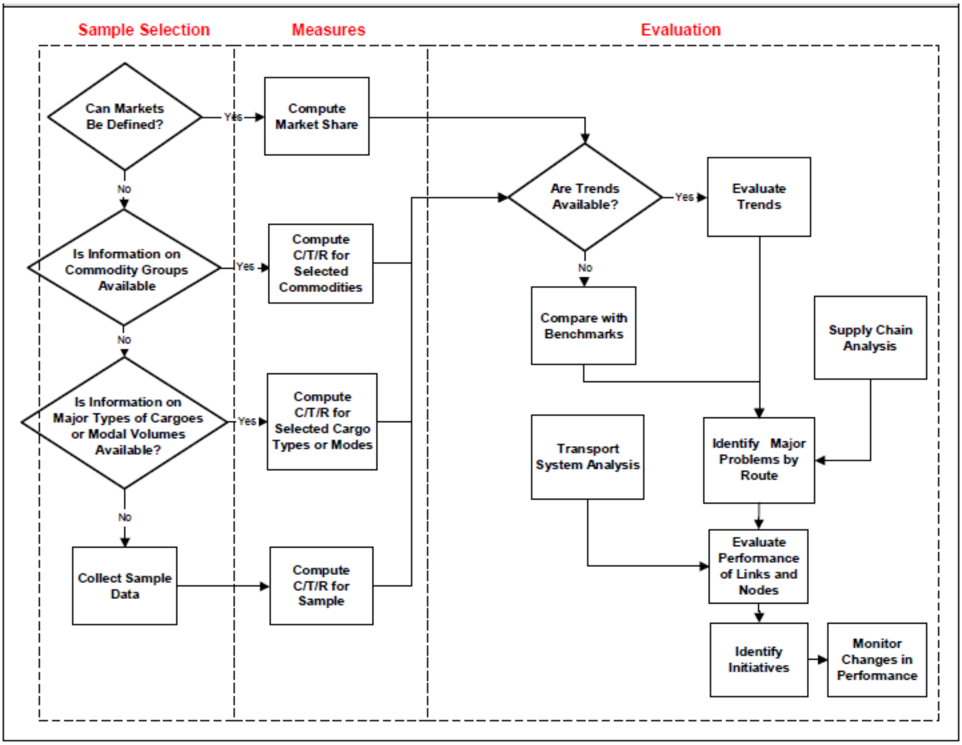


**Figure 18. Evaluation of corridor performance**

(Source: Arnold, 2006)

An interesting contribution of this World Bank publication relates to the way cost and time figures of links and nodes are combined to form chain- and corridor-level indicators. The cost of a transport chain consists of all out-of-pocket costs plus either the insurance costs or any loss or damage to cargo while en route. The costs incurred in a transport link can be described as a combination of a fixed cost and a variable cost that depends on the distance travelled. The average transit cost for a transport chain consisting of three links can then be depicted as in Figure 19. The vertical lines represent the costs incurred at the nodes plus any fixed costs associated with using the subsequent link. The sloping lines represent the costs incurred while transiting a link with the slope proportional to the average variable cost.

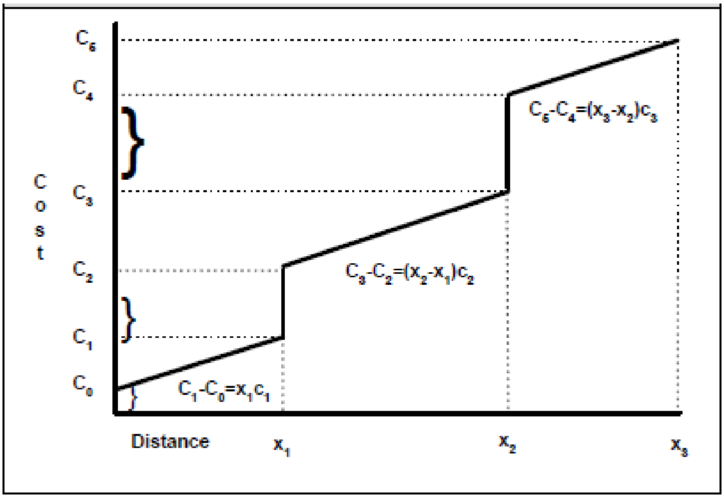


**Figure 19. Transport cost for a 3-leg chain**

(Source: Arnold, 2006)

Similarly, time can be shown in the form of the graph of Figure 20, as a function of distance along the chain. The average transport time of a chain is defined as the time needed to complete all activities essential for moving from the origin to the destination of the chain. The sloping lines represent the time spent moving along a link; the slope is inversely proportional to the average link speed. The vertical lines represent the time spent at the nodes and include the delays associated with the frequency of services, with congestion at the nodes and with other required activities like cargo handling, transhipment, vehicle/cargo inspection, etc.

Each transport chain, then, can be represented by its average cost and time for transit. A corridor, consisting of different combinations of routes, modes, and chains can be represented by either the average time and cost for transiting the corridor or by a curve like the graph of Figure 21, which combines the time-cost pairs of all transport chains that are available in the corridor. It is conceivable that an intervention in the corridor that improves both time and cost shifts the corridor frontier down and to the left.

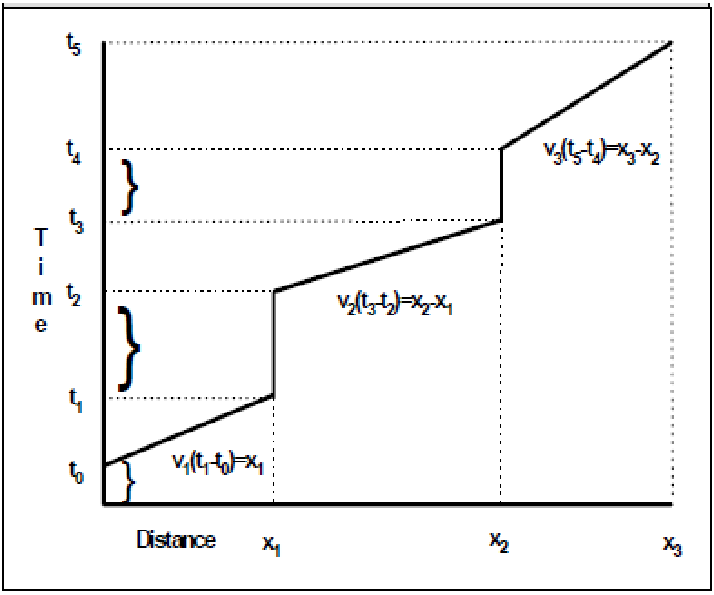


**Figure 20. Transport time for a 3-leg chain**

(Source: Arnold, 2006)

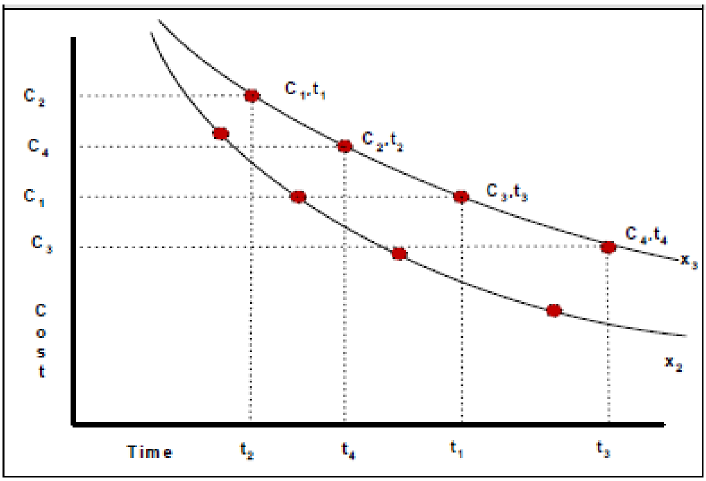


**Figure 21. Corridor time-cost options**

(Source: Arnold, 2006)

A different approach was followed by the BE LOGIC project a few years later. In addition to developing a methodology for benchmarking transport chains through KPIs (Kramer et al. 2009), BE LOGIC went one step further by attempting to assess the performance of the freight transport system at a strategic level through a set of Aggregate Performance Indicators (APIs). They are higher-level characteristics than the KPIs and are expressed at a modal level, as opposed to the company/terminal/transport chain level of the KPIs. A STEEP (Socio-cultural, Technological, Economic, Ecological, and Political) analysis was used for their assessment, which was purely qualitative (BE LOGIC, 2009). The APIs proposed by BE LOGIC for the transport services were:

- operating cost per unit of transport activity (e.g. €/tonne-km),
- energy consumed per unit of transport activity (e.g. toe/tonne-km),
- emissions produced per unit of transport activity (e.g. kg of $CO_2$/tonne-km),
- reliability (ability of mode to offer services punctual and according to the published schedule or promised delivery date and time),
- flexibility (ability of mode to adapt to changes in demand/volume/size/timetable and to cope with serious disruptions like cancellations, strikes, etc.),
- frequency (ability of mode to offer frequent services in line with the respective demand).

Although the BE LOGIC's APIs can be modified to address all desired criteria in monitoring the performance of a corridor, they would be suitable for benchmarking purposes only if estimated on a quantitative basis which, however, was not the case.

A quantitative but equally infeasible suggestion comes from the Swedish Green Corridors Initiative presented in Section 3.5.1. In the lower part of Table 5, the chain-level SGCI indicators are summed over all transport chains that use the corridor to form the corridor-level KPIs. However, as can be seen from Section 3.4, corridors are usually defined along broad lines making it difficult to identify the flows and services that need to be examined. Even if the corridors were more precisely defined, it is certain that the necessary data does not exist or if it did, the cost of extraction and manipulation would soon exceed the expected benefits of such undertaking.

This problem was spotted by the East-West Transport Corridor project, which suggests that the KPI analysis should be limited to a number of services along the corridor that need to be wisely selected[19] (Fastén and Clemedtson, 2012). In fact, EWTC went on to offer the following advice concerning this selection:

- Always keep in mind the purpose of the analysis.
- Select corridor sections with few parallel operations enabling effective monitoring.
- Identify large and stable flows, usually connected to large industries.
- Select operations run by organisations that are willing to share information.
- Take advantage of existing systems for data collection including relevant ICT applications like fleet monitoring systems, electronic toll systems, etc.
- Focus on known difficulties in meeting sustainability criteria, e.g. trade imbalances, old vintage engines etc.

The methodology proposed by EWCT includes the following steps:

Step 1. Produce a clear goal statement defining the purpose of the analysis. It should also describe the intended use of the results in meeting the stated goal.

Step 2. Define the scope on the analysis in terms of the objects to be monitored. These objects need to be described in detail in order to ensure consistency.

Step 3. Select a set of KPIs that reflect the purpose of the study and serve the monitoring needs of the selected objects.

Step 4. Set system boundaries in relation to: (i) the geographical coverage and physical boundaries of the system under examination, (ii) the activities of the transport services that comprise the sample, (iii) the activities accounted for when calculating energy consumption (e.g. life cycle), and (iv) the time period covered.

Step 5. Collect data including through secondary data sources and expert judgments in case of missing information.

Step 6. Calculate KPIs.

[19] The East-West Transport Corridor II project ran in parallel with SuperGreen and a certain degree of cross-fertilisation took place between them.

The approach suggested by EWTC is sensible and practical. Its only weakness relates to the fact that, as explicitly stated by Fastén and Clemedtson (2012), the proposed methodology aims to assess selected corridor components (services) rather than the corridor as such.

### 3.6.2 Benchmarking of the SuperGreen corridors

A methodology aiming at benchmarking a corridor in its entirety was suggested by SuperGreen (Ilves et al., 2010; Ilves et al., 2011). It was built around the concept of:

- decomposing the corridor into transport chains,
- benchmarking these chains using a set of KPIs, and then
- aggregating the chain-level KPIs to corridor-level ones using proper weights for the averaging.

Initially, the methodology included the following steps:

Step 1. Select one of the 9 SuperGreen corridors to be used as pilot case for testing the methodology. The corridor with the best coverage in terms of data availability should be selected.

Step 2. Identify the ‘critical’ segment of the corridor involving a major link that cannot be bypassed due to geographical constraints. Examples are the Brenner passage of the Brenner corridor (link between Munich and Verona), the channel crossing of the Cloverleaf corridor (link between Calais and Dover) or the Pyrenees crossing of the Finis Terrae corridor (link between Valladolid and Irun). The rationale was that these segments are usually better studied than others improving the probability of securing the necessary data.

Step 3. Analyse cargo flows along the critical segment in terms of:
- origin/destination,
- types of cargoes moved,
- modes used,
- routes taken,
- trade imbalances (empties), etc.

Step 4. Select 4-5 typical cargoes being transported along the critical segment of the corridor. Unitised (containerised) cargoes should be given emphasis due to the importance of co-modality in green corridor projects. Part load break bulk is also suggested due to the special logistics requirements imposed by this type of cargo. Dry bulk and liquid bulk commodities can be selected due to their high volume and different supply chain organisation. In general, the selection should be based on the relevant importance of each type of cargo and the special requirements that it imposes on the transport means and the supply chains.

Step 5. Select 1-2 typical transport chains for each selected type of cargo. The origin/destination of the cargo could be any pair of nodes within or outside the corridor, provided that the routes/modes used are among those defined for the corridor. At this point the analysis moves away from the critical segment to cover the entire corridor. All branches of the corridor and all modes involved should be covered. Transport chains involving more than one mode are highly desirable. For sea-based corridors, transport chains should be selected based on:

- typical cargoes using each port in the corridor (use of port statistics),
- existing connections between ports in the corridor,
- relative importance of connections in terms of volumes of cargo,
- connections to land-based corridor segments,
- types of vessels used,
- ‘best practice’ cases identified in literature.

The output of Step 5 is a set of 10-15 transport chains that need to be analysed in terms of the selected KPIs.

Step 6. Locate the proper data sources for estimating the KPI values. Take into consideration that KPI estimation requires detailed information on the types of vehicles used, the technologies applied and other operational characteristics of the chains under examination.

Step 7. Estimate one set of KPIs for each chain selected under Step 5. Due to the length of the SuperGreen corridors, it is probable to have segments with different ‘green’ qualities along a single corridor. It is thus preferable to do the analysis in segments to the extent possible.

Step 8. Identify obstacles in KPI estimation. A KPI re-engineering process might be needed for obstacles that can be addressed. KPIs running into unsolvable obstacles should be dropped. It is conceivable at this stage that segments of the corridor for which sufficient data is not available need to be dropped from further examination.

Step 9. Transform the KPI values estimated at the chain level to a single set of KPI values at the corridor level. Most probably weighted averages would have to be employed, using appropriate weights like cargo volumes, transport work, number of shipments, etc. It is, thus, important to come up with reliable information enabling calculation of the respective weights.

Step 10. Transform the set of KPI values derived under Step 9 to a single corridor rating. Relative weights should be assigned to each KPI. It is expected that different stakeholders would propose different weights for this calculation. A flexible approach of user specified weights should be considered as an alternative.

Step 11. Once the methodology suggested above has passed the applicability test successfully, it can be applied for the remaining SuperGreen corridors.

In applying this methodology, the Brenner corridor, extending from Malmö (SE) to Palermo (IT) with branches from Salzburg (AT) to Trieste (IT) through the Tauern axis, and from Bologna (IT) to Athens/Thessaloniki (GR) through the Italian and Greek Adriatic ports, was selected to be examined as a pilot case. The following steps were followed:

- the Brenner pass (Munich – Verona) was selected as the corridor's critical segment;
- the cargo flows along this critical segment were identified in literature;
- a small number (15) of typical transport chains concerning typical cargoes were selected;
- detailed information concerning these transport chains (type of vehicles used, load factors, etc.) was collected from studies and interviews with transport service providers; and
- the selected KPIs were evaluated for each one of these transport chains (emissions were estimated through the EcoTransIT World web based tool).

The chains examined for the Brenner corridor and the corresponding KPI values are presented in Table 9. It is noted that the KPIs on ICT tools, cargo security, cargo safety, $NO_x$ and $PM_{10}$ emissions were later on dropped from the analysis.

**Table 9. The Brenner corridor chains**

| Transport chain identity | | | | Key Performance Indicators (KPIs) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Origin-Destination | Mode | Annual vol. (t) | Cost (€/tkm) | Time (h) | Reliab. (%) | Freq. (no/year) | ICT (%) | Sec. (%) | Saf. (%) | Emissions (g/tkm) $CO_2$ | NOx | SOx | $PM_{10}$ |
| 1 | Verona-Naples | Train | 61.000 | - | 12 | 92 | 260 | 100 | 0 | 0 | 17.61 | 0.02 | 0.09 | 0.006 |
| 2 | Verona-Nurnberg | Train | 500.000 | 0.80 | 9 | 50 | 260 | 100 | 0 | 0 | 14.87 | 0.01 | 0.05 | 0.004 |
| 3 | Verona-Nurnberg | Train | 2.700.000 | 0.05 | 9 | 100 | 572 | 100 | 0 | 0 | 14.87 | 0.01 | 0.05 | 0.004 |
| 4 | Verona-Berlin | Road | 1.100 | 0.07 | 25 | 50 | 2.600 | 0 | 0 | 0 | 71.86 | 0.51 | 0.08 | 0.013 |
| 5 | Rome-Nurnberg | Road | 32.000 | 0.05 | 48 | 80 | 104 | 100 | 0 | 0 | 62.08 | 0.47 | 0.07 | 0.013 |
| 6 | Rome-Palermo | SSS | 1.500 | 0.04 | 24 | 100 | 52 | 100 | 0 | 0 | 16.99 | 0.25 | 0.12 | 0.018 |
| 7 | Verona-Trelleborg | Interm. | 13.000 | 0.04 | 50 | 98.8 | 624 | 100 | 0.5 | 2 | 10.62 | 0.01 | 0.02 | 0.002 |
| 8 | Bari-Athens | Interm. | 10.000 | 0.04 | 72-96 | 95 | 52 | 100 | < 0.5 | 0 | 27.28 | 0.18 | 0.08 | 0.008 |
| 9 | Bari-Thessaloniki | Interm. | 3.000 | 0.03 | 72-96 | 95 | 26 | 100 | < 0.5 | 0 | 42.11 | 0.29 | 0.10 | 0.011 |
| 10 | Trieste-Munich | Train | 81.000 | - | 12 | 85 | 416 | 100 | 1 | 1 | 12.53 | 0.01 | 0.04 | 0.003 |
| 11 | Trieste-Salzburg | Train | 652.500 | - | 8 | 90 | 208 | 100 | 1 | 1 | 9.49 | 0.01 | 0.05 | 0.003 |
| 12 | Trieste-Villach | Train | 135.600 | - | 4 | 95 | 364 | 100 | 1 | 1 | 16.36 | 0.02 | 0.09 | 0.006 |
| 13 | Berlin-Thessaloniki | Interm. | 437 | 0.09 | 76 | 99 | 104 | 0 | < 1 | 1 | 27.11 | 0.19 | 0.06 | 0.006 |
| 14 | Bari-Berlin | Road | 24.000 | 0.05 | 72 | 99 | 1.040 | 100 | 0 | 0 | 46.51 | 0.11 | 0.05 | 0.004 |
| 15 | Bari-Athens | Interm. | 8.500 | 0.05 | 24 | 99 | 520 | 100 | 0 | 0 | 25.41 | 0.25 | 0.14 | 0.024 |

(Source: Ilves et al., 2011)

It soon became evident that the aggregation of Step 9, i.e. from chain-level KPIs to corridor-level ones for each and every segment of the corridor, would be problematic due to limited reliability on the grounds that:

- the sample was very thin (for some segments there was only one observation) and the resulting figure would have limited statistical value, if any;
- not all of the chains reflected the entire door-to-door transport as needed to ensure comparability; some of them covered only terminal-to-terminal operations; and
- most data was collected through interviews and reflected personal assessments without strict validation.

It was, thus, decided to express corridor benchmarks as ranges of values that resulted from the transport chain data, i.e. minimum and maximum values of all chain-level KPIs. Table 10 summarises the KPI values of the Brenner corridor presented by transport mode.

**Table 10. KPI values for the Brenner corridor**

| KPIs | Intermodal | Road | Rail | SSS |
|---|---|---|---|---|
| Cost (€/tkm) | 0.03 – 0.09 | 0.05 – 0.07 | 0.05 – 0.80 | 0.04 |
| Av. speed (km/h) | 9 – 41 | 19 – 40 | 44 – 98 | 23 |
| Reliability (%) | 95 – 99 | 50 – 99 | 50 – 100 | 100 |
| Frequency (no/year) | 26 – 624 | 104 – 2600 | 208 – 572 | 52 |
| $CO_2$ (g/tkm) | 10.62 – 42.11 | 46.51 – 71.86 | 9.49 – 17.61 | 16.99 |
| SOx (g/tkm) | 0.02 – 0.14 | 0.05 – 0.08 | 0.04 – 0.09 | 0.12 |

(Source: Ilves et al., 2011)

The most important conclusion of this exercise is the width of the fluctuation range of some KPIs. Even after taking into consideration the drawbacks mentioned above, one would expect more concise estimates.

Furthermore, the aggregation of Step 10 of the initial methodology involving the transformation of all KPIs into a single corridor rating proved overoptimistic. The rationale for such a rating was to cope with interactions between different KPI groups, as is for example the case where measures introduced to improve performance in relation to one area might have adverse effects on another. However, this approach was later considered as an unnecessary complication given that:

- the weights needed for such calculation very much depend on the user (different users will propose different weights),
- it is a political issue best left for policy makers to decide,
- weights, if assigned, might lead to wrong interpretations,
- weights change over time (e.g. social issues might become more significant in the future), and
- weights would not reflect country specific characteristics of transport operations.

The issue was discussed extensively in a SuperGreen workshop organised in Napoli, Italy and a decision was reached to exclude such attempt from the methodology. The decision was later confirmed by the project's Advisory Committee.

The methodology, as it resulted from the pilot exercise, was applied for benchmarking five other corridors (Cloverleaf, Nureyev, Strauss, Mare Nostrum and Silk Way). Lack of data combined with time and resource restrictions did not permit the examination of the remaining three corridors (Finis Terrae, Two Seas and Edelweiss). The results are summarised in Table 11.

It is important to note that the emission KPIs of Table 11 were produced by the EcoTransIT World web emission calculator (EcoTransIT, 2014), while the remaining indicators are based on self-reported figures from interviewees and literature review. As such, they are only indicative. Using other tools and methods might have led to different results. The accuracy problem identified in the Brenner corridor was confirmed.

Table 11 leads to the following observations:

- The comparison of rail transport attributes across corridors shows very high variance of cost and reliability for the Brenner corridor, which requires further investigation.
- The very low speed and high emissions of the trans-Siberian service is also noticeable, albeit expected due to the diesel traction and the gauge incompatibility problem along this route.

**Table 11. Benchmarking results (all corridors)**

| Corridor | Mode | Cost (€/tkm) | Av. speed (km/h) | Reliability (%) | Frequency (no/year) | $CO_2$ (g/tkm) | SOx (g/tkm) |
|---|---|---|---|---|---|---|---|
| Brenner | Intermodal | 0.03-0.09 | 9-41 | 95-99 | 26-624 | 10.62-42.11 | 0.02-0.14 |
| | Road | 0.05-0.07 | 19-40 | 50-99 | 104-2.600 | 46.51-71.86 | 0.05-0.08 |
| | Rail | 0.05-0.80 | 44-98 | 50-100 | 208-572 | 9.49-17.61 | 0.04-0.09 |
| | SSS | 0.04 | 23 | 100 | 52 | 16.99 | 0.12 |
| Cloverleaf | Road | 0.06 | 40-60 | 80-90 | 4.680 | 68.81 | 0.09 |
| | Rail | 0.05-0.09 | 45-65 | 90-98 | 156-364 | 13.14-18.46 | 0.01-0.02 |
| Nureyev | Intermodal | 0.10-0.18 | 13-42 | 80-90 | 156-360 | 13.43-33.36 | 0.03-0.15 |
| | SSS | 0.05-0.06 | 15-28 | 90-99 | 52-360 | 5.65-15.60 | 0.07-0.14 |
| Strauss | IWT | 0.02-0.44 | - | - | - | 9.86-22.80 | 0.01-0.03 |
| Mare Nostrum | SSS | 0.003-0.20 | 17 | 90-95 | 52-416 | 6.44-27.26 | 0.09-0.40 |
| | DSS | - | - | - | - | 15.22 | 0.22 |
| Silk Way | Rail | 0.05 | 26 | - | - | 41.00 | - |
| | DSS | 0.004 | 20-23 | - | - | 12.50 | - |

(Source: Ilves et al., 2011)

- The wide fluctuation of intermodal transport attributes is also impressive and can be explained by the different nature of schemes examined in each case.

The more general conclusions stemming from the SuperGreen benchmarking work are summarised below:

- Corridor benchmarking is possible but we need to standardise both the process and the KPIs, if we want to make it operational.
- Even then, comparisons across corridors are problematic due to the fact that no consideration is given to corridor specific characteristics. It is certain that the attributes of the logistical solutions employed in crossing the Baltic Sea are much different than those used for crossing the Alps. This type of risk is eliminated when comparing a time series of KPI values for the same corridor.
- The construction of sample chains on the basis of the 'critical segment' flows proved difficult in some cases, and in any event the characteristics of the critical segment might be totally irrelevant for other remote segments of the same corridor. Another solution should be conceived.
- Data collection proves to be a serious problem. Relevant obligations imposed by the corridor management might be a solution. The formation of corridor specific stakeholder groups can be helpful in this regard. Automated ICT applications, able to provide cargo flow data without causing physical disruptions of the vehicle flows or other administrative bottlenecks, can also be of particular importance.
- Aggregating chain-level KPIs to a single set of corridor- or segment-level ones is possible provided that an adequate sample of transport chains is examined under the same conditions. Otherwise, the use of value ranges is suggested.
- Aggregating corridor-level KPIs to an overall corridor rating should be omitted because there are problems associated with the weights needed for such calculation and the issue is a political one best left for policy makers to decide.

### 3.6.3 Guidelines for corridor benchmarking

In place of the usual concluding remarks, this section provides a set of guidelines for effective corridor benchmarking that takes into consideration the experiences of SuperGreen and other projects in this field.

**Benchmarking goal:** Monitoring the performance of a transport corridor can serve several purposes. Obtaining a better understanding of the present conditions, identifying problems to be addressed, observing developments over time and comparing with benchmarks are some of them. Also important is the perspective of the analysis. A multiplicity of actors is involved in a corridor and their priorities do not always coincide. A corridor consists of various types of services offered by competing operators through organised supply chains over a multimodal infrastructural network within an international regulatory and administrative framework. In a complex system like this, setting the exact purpose of the analysis and its intended use is essential. A clear goal statement will assist decision making throughout the analysis and will affect all subsequent tasks. In general, it should be kept in mind that due to resource limitations, there is a trade-off between the width and the depth of analyses of this sort.

**Corridor description:** The next task cannot be different than defining the corridor under investigation. As can be inferred from Section 3.4, corridors tend to be described by locations that represent rather broad geographical areas/places where the corridors start, end or pass through. This has to be translated into a more detailed definition that includes the modes to be examined and the routes comprising the corridor. Each route should be described as a set of designated links, terminals and supporting facilities. Only existing major links should be designated to a route. Parallel secondary links or by-passes should be mentioned only as enhancing the resilience of a corridor. As for terminals, all uni- and/or multi-modal terminals should be designated to a route, except if irrelevant to the corridor traffic or unwilling to take part in it.

**KPI selection:** After extended consultation with stakeholders, the SuperGreen project proposes the following set of KPIs for corridor benchmarking applications:

- Out-of-pocket costs (excluding VAT), measured in €/tonne-km,
- Transport time, measured in hours (or average speed, measured in km/h, depending on the application),

- Reliability of service (in terms of timely deliveries), measured in percentage of consignments delivered within a pre-defined acceptable time window,
- Frequency of service, measured in number of services per year,
- $CO_2$-eq emissions, measured in g/tonne-km, and
- $SO_x$ emissions, measured in g/tonne-km.

Among them, the cost indicator is the most difficult one to calculate due to scarcity of relevant data. In such cases, the volume of cargo moved along the corridor can serve as a proxy for describing its efficiency.

Other projects suggest different indicators. It needs to be emphasised that KPIs should be selected by the corridor management on the basis of the objectives being pursued.

**Methodological principles:** The methodology is built around the principle described by the following four steps:

Step 1. Disintegrate the corridor into transport chains.

Step 2. Select a representative set of typical transport chains.

Step 3. Estimate KPI values for each and every chain selected in Step 2.

Step 4. Aggregate these values into corridor level KPIs by using appropriate weights and methods.

**Sample construction:** In view of the problems encountered with the ‘critical segment’ notion applied in SuperGreen, it is suggested to construct a ‘basket’ of typical transport chains on the basis of traffic model results. Alternatively, the information of the ‘Transport Market Study’ foreseen by Reg. No 913/2010 for the Rail Freight Corridors and, through them, for the TEN-T core network corridors can be used for the sample construction (Panagakos, 2012). The proposed methodology resembles the functionalities of the Consumer Price Index (CPI) calculated by the statistical bureaus around the world. In the CPI context, the basket of goods and services used for CPI calculations is selected on the basis of the so-called Household Expenditure Survey (HES) that provides information on the spending habits of the population. In the context of green corridors, the traffic model will play the HES role.

The international character of a green corridor calls for a model covering effectively all of its routes. The European TRANS-TOOLS model (Ibánez-

Rivas, 2010) is an ideal source of information, provided that its updating is successfully completed. Until then, national transport models can be used, but care should be taken to ensure compatibility.[20]

In selecting typical chains, coverage of:

- all segments of the corridor,
- all modes of transport participating in the analysis,
- all possible types of transport chains examined by the model, and
- all types of vehicles examined by the model

should be ensured.

**Data collection:** The task relates to the information needed for calculating KPI values for each and every transport chain of the basket. Readily available information from official statistics and other sources should be exploited to the extent possible. More detailed information should be solicited directly from stakeholders willing to take part in such an effort. To this end:

- a sample of transport providers and major shippers should be formed for soliciting information,
- a questionnaire should be prepared for gathering the necessary information,
- follow-up actions should be foreseen for data collection including interviews if necessary, and
- a procedure addressing missing observations and quality adjustments should be designed.

As a general rule, the reported values should be:

- **Consistent:** The methodology employed should be consistent to allow for meaningful comparisons over time. Any changes to data, system boundaries, methods or any other relevant factor in the time series has to be clearly documented.
- **Transparent:** All relevant issues need to be addressed in a factual and coherent manner. The underline assumptions, calculation methodologies and data sources used have to be disclosed.

[20] The author of this chapter has used the Danish National Transport Model (LTM-Lands Trafik Modellen) for applying this methodology to the GreCOR corridor. The relative work is presented in Section 5.3 of this thesis.

- **Accurate:** Ensure that uncertainties are reduced as far as practicable. Values reported should be of sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information.

**Emission estimation:** When it comes to emissions, the definition of system boundaries is crucial in fulfilling all three criteria mentioned above (consistency, transparency and accuracy). Swahn (2010) defines four system boundaries (refer to Figure 22):

- System boundary A includes traffic and transport related activities regarding engine operation for the propulsion and equipment for climate control of goods, as well as losses in fuel tanks and batteries. This includes the traffic-related terminal handling, i.e. when goods do not leave their vehicle/vessel.
- System boundary B includes in addition the supply of energy from energy source to the tank, battery and electric motor (trains). This is the minimum required system boundary for performance of comparisons between different modes of transport.
- System boundary C includes in addition traffic infrastructure operation and maintenance.
- System boundary D includes in addition vehicle, vessel, load units production and scrapping (life cycle approach).

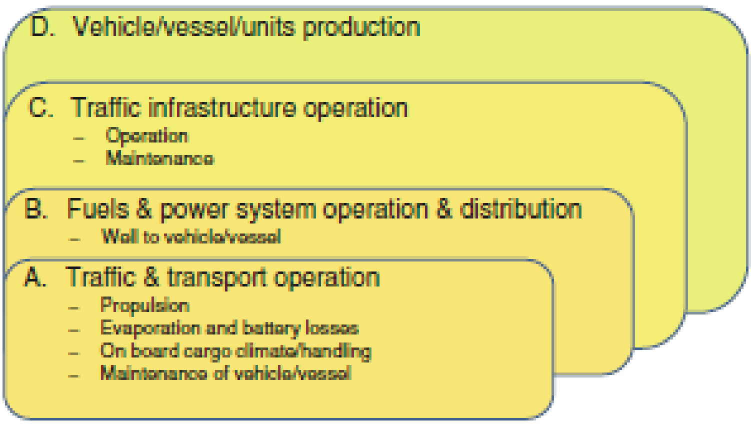


**Figure 22. Definition of system boundaries**

(Source: Swahn, 2010)

Although the introduction of the Life Cycle Assessment (LCA) methodology in decision making happens to be one of the policy recommendations that resulted from the SuperGreen project, it is essential to keep things as simple as possible in the early stages of a green corridor development. It is for this reason that the system boundary B is recommended to begin with. Later on, the boundary can be expanded to reach level D.

Another comment relates to the type of carbon emissions measured. In discussing emissions, lots of terms are used – carbon emissions, carbon dioxide, greenhouse gases (GHGs). In fact, climate change is caused by a range of gases, known collectively as 'greenhouse gases.' Of these, the most common is carbon dioxide ($CO_2$). However, other GHGs are emitted from vehicle exhausts (i.e. nitrous oxide and methane), and their reporting is also valuable. This is done through $CO_2$-equivalent ($CO_2$-eq) units expressing GHGs as if they had the same climate change effects as $CO_2$. The choice between $CO_2$ and $CO_2$-eq depends on the availability of data and/or the capabilities of the emissions calculator used. $CO_2$-eq, if available, is preferable to $CO_2$.

In general, a specialised emission calculator is needed for estimating the emission KPIs. In SuperGreen, the web-based tool EcoTransIT World has been used but, as long as certified footprint calculators are not available, any other model could be used in its position, provided that a relevant qualification escorts the results. In the framework of the BGLC project, Öberg (2013) compared EcoTransIT World with NTM, a Swedish emission calculator, with inconclusive results. The announced cooperation between the two models towards creating synergies in their methodological expertise on carbon accounting is welcomed (EcoTransIT, 2014).

In relation to emission calculators, it should be mentioned that user specified inputs are preferred to any model's default values, only when they are adequately verified and there is consistency across all chains examined. Otherwise, it is safer to use the default values of the selected model.

Finally, it is important to note that in a multi-load multi-drop vehicle trip the allocation of emissions to specific loads becomes quickly almost unworkably complex, requiring far more data than is likely to be available. A simplification is suggested by DEFRA (UK) according to which, emissions are allocated on the basis of the number of EDUs (Equivalent Delivery Units) transported for each customer. Generally speaking, the choice of EDU should reflect the limiting factor on the loading of the vehicle. If the load is typically limited by volume, then a volume-based EDU such as pallets or cube should be used. If the load is more often limited by weight, then a weight-based EDU such as tonnes will be more appropriate and provide more accurate results.

**KPI aggregation:** The weights needed for aggregating chain-level KPIs into corridor-level ones depend on the relative significance of each chain in the route it belongs and in the entire corridor. As such, they have to be determined by using the model results that were considered in constructing the chain basket. These weights should be relatively fixed to permit historical comparisons.

It is noted that normally the weights for aggregating unit costs, $CO_2$ and $SO_x$ emissions should be in tonne-km units. Transport time can only be aggregated if expressed as average speed, unless all chains examined concern a single origin-destination pair. The volume of cargo is probably the most suitable weight for aggregating transport time (or speed) and reliability. As for frequencies, one needs to be careful to avoid adding pears with apples. As a general rule of thumb, in serial services it is the least frequent one that determines the frequency of the chain.

**Data verification:** Before closing, it is necessary to alert the reader on the data verification issue. Verification is an independent assessment of the accuracy and completeness of data. Confidence in the quality and integrity of the data supports internal operations and decision making by revealing existing problems or points for potential improvement. It can, thus, lead to improved performance, reliability and quality of operations. Another common reason for verifying data is to increase external stakeholder confidence. For example it may reassure a transport operator that they can include the green corridor data in what they report about their services, by demonstrating:

- credibility and reliability of the corridor data,
- consistency and accuracy of performance monitoring approach, and
- completeness of assessment.

Furthermore, verification can provide confidence that the data reported is fit for the purpose for which it is intended, for example, target setting or service benchmarking.

In general, it is not always necessary to get an external party to verify the reported data if reasonable and transparent processes are established. However, in the case of monitoring a complex system such as a transport corridor, the engagement of an external verifier seems unavoidable. In such cases it is particularly important to be sure that the reported information is genuine and based on a consistent and accurate approach to measurement over time.

It is, thus, suggested the verification to be undertaken by a third party accredited by an internationally recognised body. Especially for GHG emission reporting, there are a number of internationally recognised standards and protocols that can be applied, like:

- ISO14064 – Greenhouse gas accounting
- ISO14065 – Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition.
- EN 16258 – Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers).

**Benchmarking frequency:** The frequency of monitoring the performance of a corridor depends on the objectives set by the corridor management. As far as transport services are concerned, an annual benchmarking is both feasible and practical, especially if customer satisfaction needs to be reported which happens to be the case with Rail Freight Corridors (Reg. 913/2010). Infrastructural developments can be reported on a less frequent basis.

A relevant issue relates to the periodical adjustments needed to account for changes in the composition of cargoes and transport chains using the corridor. As such changes would affect the model results (and the corresponding chain basket and weights), they can only be accounted for whenever the model is updated. In the CPI context, the HES is usually updated every 5-7 years.

**General qualification:** The method outlined above permits monitoring of the performance of a single corridor over time. It is not suitable for comparisons between corridors, as it does not consider differences in corridor characteristics that can be decisive in the overall performance of a corridor. This statement excludes the parameters determined by the

Handbook on Reg. 913/2010 concerning railway transport (EC, 2011c), as they have been aligned with the reports on train performance management of RNE in order to ensure a consistent quality of performance monitoring reports.

# 4. Green corridors and network design[21]

## 4.1 Introduction

The purpose of this chapter is to explore possibilities for green freight transport in relation to network features. Once again, the geographical scope of the analysis is Europe and its transport network.

This task will be performed in three parts that directly correspond to the three main sections of the chapter. The first one deals with the development and governance of green corridors. Following the description of a green corridor and its basic characteristics in the previous chapter, here the issues of more practical nature pertaining to the implementation of this concept are discussed. Those who study or practice logistics know very well that cooperation among all actors involved lies at the core of this business. The international nature of green corridors makes this necessity even more critical. It follows that the governance structure should enable and facilitate the cooperation among public and private sector stakeholders who play a significant role in all facets of green freight transport; from network design to the provision of integrated logistical solutions. An effective and enabling governance scheme is, thus, a prerequisite for a successful implementation.

The second part of the analysis looks into the trans-European transport network (TEN-T). Comprising one of the basic dimensions of the Common Transport Policy in Europe, it aims to provide the infrastructure needed for the internal market to function smoothly and for the objectives of the Lisbon

[21] With the exception of some minor editorial changes basically concerning cross-references, this chapter is identical to the homonymous Chapter 4 of the book *Green Transportation Logistics: the Quest for Win-Win Solutions*, edited by H.N.Psaraftis (Panagakos, 2016c). The chapter incorporates the conclusions of the paper *How green are the TEN-T core network corridors?* presented at the TRA 2014 Conference in Paris (Panagakos and Psaraftis, 2014).

Agenda on growth and jobs to be achieved. It also helps ensure accessibility and boost economic, social and territorial cohesion. TEN-T supports the EU citizen's right to move freely within the territory of the Member States and it integrates environmental protection requirements with a view to promoting sustainable development. Of particular importance to the subject of this thesis are the TEN-T Guidelines, the documents containing the EU transport infrastructure policy. Both the previous one that supported the development of the network as it exists today and the current one that places emphasis on the corridor approach will be reviewed.

The third part of the chapter investigates whether the green characteristics of a corridor, as have been identified in the previous chapter, are exhibited by the TEN-T core network corridors introduced with the new TEN-T Guidelines. Based on the results of this analysis, the chapter concludes that, as of the end of 2013, a network of green corridors has been established in Europe.

## 4.2 Green corridor governance

The purpose of this section is to present issues related to the governance and operation of green corridors. Both these issues are linked to the management of the corridor structures. The term management, of course, implies some form of control but, given the diversity of stakeholders involved, this is easier said than done. The problem is further complicated by the fact that, despite the recent establishment of numerous corridors with such a self-claimed label, in practice green corridors have not yet moved far beyond the stage of inception. In this respect, the present section handles practical matters but in a rather visionary context.

The activities of a transport corridor involve a number of government agencies and a diverse set of transport and logistics service providers carrying a wide variety of operations. As a result, the management of a corridor is generally performed by organisations established by government, the private sector, or jointly to plan development, disseminate information and coordinate stakeholder efforts. The appropriate structure for corridor management depends on the nature of the corridor and the specific functions to be managed.

### 4.2.1 Corridor functions

Having examined a number of international transport corridors in the framework of a World Bank project, Arnold (2006) identifies a number of general functions requiring management oversight. They can be grouped in the following categories:

- **Infrastructure and facilities**, including links and nodes along the routes, are developed and funded primarily by the public sector but increasingly constructed and maintained by the private sector. The role of management is to guide the planning and procurement of these assets. Its goal is to ensure that these assets are:
  - ✓ of sufficient capacity to meet projected demand,
  - ✓ designed to provide efficient movement of cargo along the infrastructure and through the facilities,
  - ✓ constructed and maintained so as meet required standards,
  - ✓ used efficiently, and
  - ✓ fully utilised.
- **Transport and logistics services.** Increasingly these activities are undertaken by the private sector in a competitive market with costs recovered through user charges. The objective of the managers of individual services is to capture significant market share by offering a competitive combination of cost, time and reliability. To the extent that corridor management is responsible for overseeing these services, its objective should be to promote more efficient services, usually by encouraging competition but often by allowing vertical and horizontal integration. Addressing security concerns and encouraging the use of ICT and risk management are additional objectives.
- **Regulatory procedures** that affect the movement of goods in the corridor and the transport and logistics providers operating in the corridor. Rarely is corridor management involved in the enforcement of the regulations or even in the enactment of these regulations. Instead it performs an advocacy role discouraging excessive regulation and reforming regulation that leads to inefficiencies. The management can encourage reform by supporting efforts to harmonise procedures across borders, to simplify documentation and procedures, and to enhance transparency. In cases involving trade

and transit agreements, corridor management can be engaged in their periodic revisions and in defining the regulations ensuring their proper implementation.

- **Monitoring corridor performance.** Corridor management is the appropriate entity for monitoring and coordination efforts aiming at improving its performance. The subject has been discussed in Chapter 3 and will be the focus of Part III of this thesis.

These corridor functions require different management approaches. They can involve the public sector, the private sector or both. The public sector usually provides assets in a market with limited competition and partial cost recovery, the private sector provides services in a competitive market with full cost recovery, while both are engaged in the enforcement of laws/regulations and tax collection.

More recently, Engström (2011) reports that the Swedish Transport Administration views green corridors projects/initiatives as being divided into three main categories that interact and complement each other. These categories promote the view of logistics/transports as a system of integrated services and properties aiming at increased efficiency and a reduced negative ecologic impact. The three parts, shown in Figure 23, are:

- **Corridors (links and nodes):** A corridor project is a geographic subset of a designated main European Green Corridor. It is based on the needs of an efficient transport infrastructure in a physical and/or communicative aspect. A corridor project promotes optimal use of transport modes including transhipment nodes (hubs, cross docks etc.). It can be of either a national or international character.
- **Transport techniques:** Projects related to transport techniques encompass features and properties of various types of equipment used in transport operation. The main focus is on the different transport modes, transport/load units and transfer/reloading of goods between different modes. Examples are techniques related to trucks, trailers, railway engines, rail wagons, ships, port handling, containers, packaging, cranes, stackers etc.
- **Transport/logistics solutions:** Refers to complete solutions which integrate different partners and stakeholders mutually forming a business case that promotes efficiency and lowers environmental impact. In general terms, it is a complete freight logistic/transport setup that meets a shipper’s demand often linked to a new business

model.

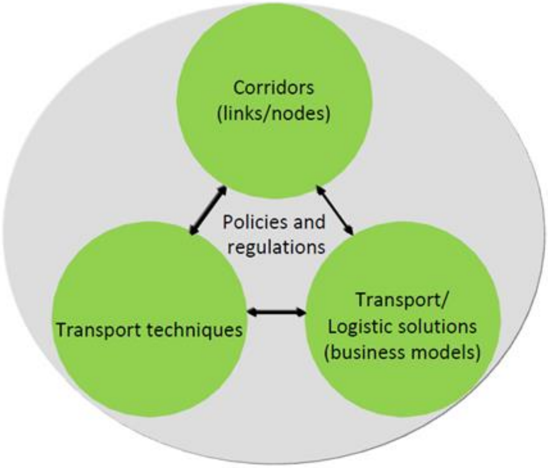


**Figure 23. The three pillars of green corridors**
(Source: Engström, 2011)

Although not seen as a ‘pillar’ in the Swedish schematic, the underlying policies and regulations are also recognised as a prerequisite for the implementation of green corridors.

### 4.2.2 Corridor development models

Based on the functions of the previous section, Arnold (2006) distinguishes between three general models that have been applied in corridor development.[22] The first is named **project coordination** and is viewed as part of a general development model. This approach is characterised by a project focus. Governments undertake improvements in the corridor infrastructure based on local requirements and problems. Growth in trade combined with liberalisation of the transport and logistics sector offers a steady improvement in the variety, quality and competitiveness of the transport services. An evolving consensus on the concept of the corridor

[22] A fourth model relates to an institution responsible for developing public-private partnerships for improving the operation of facilities and services in the corridor. However, this model is dropped from the present analysis, as it is effective only at the domestic level.

allows stand-alone projects to be related to the development of the corridor. This model has been most effective in providing improvements in infrastructure, but is less suitable for addressing legal or operational issues. Neither is it particularly useful for tackling bilateral and multilateral issues. Moreover, it lacks a formal corridor organisation or other mechanism to identify and prioritise initiatives, as it relies on committees or similar structures.

The second is the so-called **legislative** model. This is characterised by the use of legislation to provide formal recognition of the importance of corridors, designation of specific routes, harmonisation of standards, simplification of cross-border movements and funding for corridor infrastructure. Implementation is left to individual jurisdictions and government agencies. Coordination is undertaken at the regional or ministerial level and is characterised by formal meetings to review progress made by others. Development of services on the corridor is left to private sector competition. Improvements in infrastructure are undertaken by government agencies responsible for transport. This approach is effective in targeting funding infrastructure and reducing formal impediments to movement of goods on these corridors. It is less effective for improving interconnections through modifications of regulatory constraints on cross-border and transit movements.

The third is the **consensus-building** model. This approach uses a regional institution to mobilise stakeholder support for improvements in the corridor and to push for trade facilitation reforms including improving border-crossing procedures. Its primary function is to provide information to stakeholders, including government agencies, concerning current performance, needs for improvement, and success of previous initiatives. The success of this model depends on the active participation of public and private sector stakeholders in addressing issues related to regulation, investment and quality of service. The ability to maintain a professional staff is also a critical success factor for such a model.

Bringing this taxonomy into the current European environment, one could distinguish between two models. The first is the **top-down** model that corresponds to Arnold's legislative one. It has been followed in all corridor development initiatives of the European Commission, such as the RNE corridors, the ERTMS corridors, the rail freight corridors of Regulation No 913/2010 and, more recently, the TEN-T core network corridors. In a smaller scale, the Brenner corridor is a good example of a top-down model application.

The second is the **bottom-up** model, corresponding to Arnold's consensus-building one. All Scandinavian projects such as the EWTC II, SCANDRIA, TransBaltic, and BGLC corridors comprise applications of this type of model.

No European equivalent to Arnold's project coordination model is necessary, as activities such as priority setting and project identification under this model are more or less undertaken at national or local level which, nowadays in Europe, concerns only infrastructure projects of minor importance.

How do these models compare? Their distinction basically relates to the origin of the initiative. In the top-down model the initiative comes from a powerful central entity like the European Commission or a modal association. On the contrary, it is the transport and logistics companies themselves who take the initiative in the bottom-up model.

Nevertheless, as the corridor structures mature, their success will depend on whether they exhibit features like:

- the cooperation between public and private sectors; and
- the active participation of stakeholders.

In this respect, in the long run the two models will have to converge.

If the idea of a green corridor is more popular among private businesses, the bottom-up approach should be followed. The idea is cultivated among all types of stakeholders and once sufficient support is secured, the public sector is engaged. In any event, its involvement is necessary for signing the necessary bilateral or multilateral agreements.

If, on the other hand, the idea is originated in the ministerial offices or among infrastructure managers closely related to national governments, the top-down model seems to be more appropriate. Intensive information campaigns are needed to engage the private sector in the process as early as possible.

### 4.2.3 Corridor governance structures

Regardless of the functions it serves or the development model it has followed, a corridor needs an organisation engaged in the promotion and coordination of its development and operation. Where corridors have been successful, there has been strong political and market support for their development. A corridor organisation provides a point of coordination for stakeholder efforts and a forum for identifying major impediments. It also provides coordination for the financing schemes. As a promoter, this organisation must have the support of the private sector but be able to work closely with government agencies to improve procedures and policies. As a coordinator, it must have some form of public-private partnership as well as linkages with a regional ministerial committee that is tasked to address issues of regional harmonisation.

A first attempt of the European research community to formulate an open Corridor Management System (CMS), linking the actors of an intermodal chain of transport, was done by the BRAVO project and concerned the Brenner Corridor (Galonske, 2004).

The project succeeded in describing in detail both the role of all actors involved (Infrastructure Managers, Railway Undertakings, Intermodal Operators and Terminal Operators) and the procedures that need to be followed in order to plan an intermodal transport, which as shown in Figure 24, takes about 12 months.

In relation to corridor management, the project first assessed the ‘Full integrator model,’ which gives all parties free access to all components of the CMS. After rejecting this model due to legal and institutional considerations and the existing competition between actors, the project suggested as the most suitable management structure a combination of an ‘open platform’ integrating all actors in a non-discriminating way (e.g. guided ‘Round table’) for the strategic and long-term tasks and a ‘restricted platform’ for operational and commercial tasks (Figure 25).

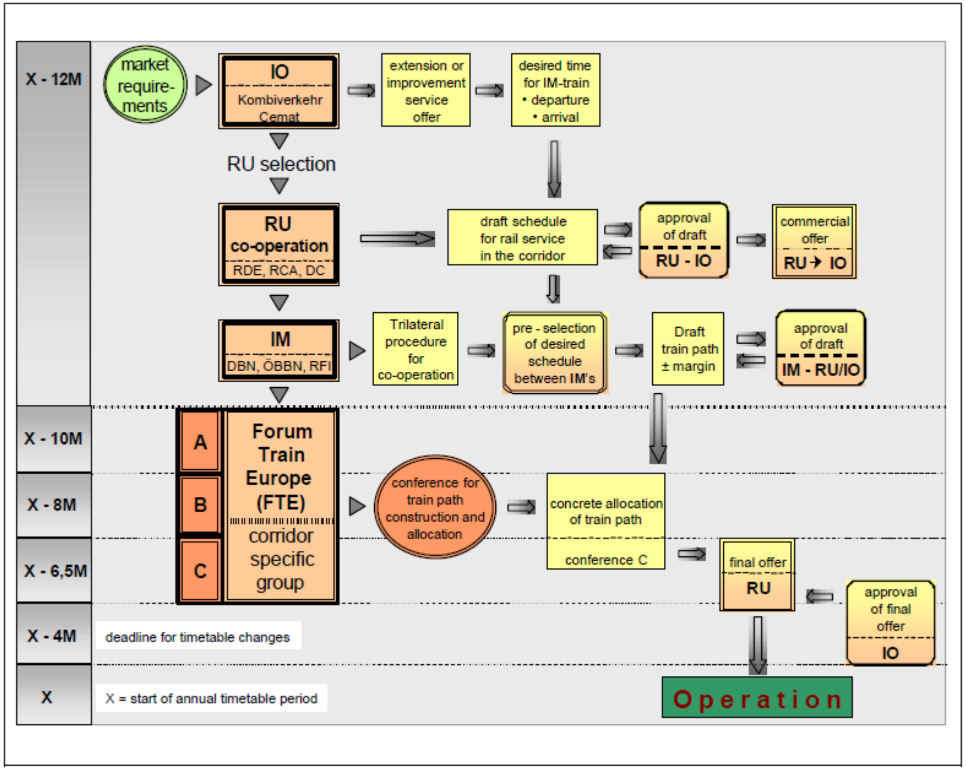


**Figure 24. Planning procedure for intermodal Brenner transports**

(Source: Galonske, 2004)

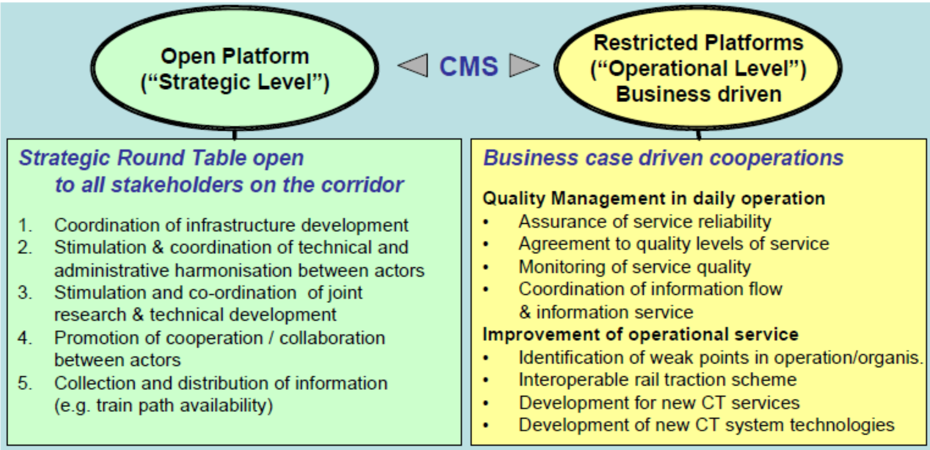


**Figure 25. BRAVO Corridor Management Scheme**

(Source: Mertel and Sondermann, 2007)

The management organisation of ERTMS Corridor A (Rotterdam-Genoa) is more structured. On 9 January 2003 the transport ministers of Germany, Italy, the Netherlands and Switzerland signed a joint MoU in Lugano aimed at enhancing the quality of cross-border freight transport by rail on the Rotterdam-Genoa corridor. The ministers entrusted the International Group for Improving the Quality of Rail Transport in the North-South-Corridor or Corridor A (IQ-C) with the task of implementing a package of specific measures that were defined following a prior analysis of the main problems hampering rail freight transport along the North-South-Corridor.

In 2006, the organisation for the deployment of ERTMS/ETCS in the corridor was established. As shown in Figure 26, the Infrastructure Managers set up the Management Committee to steer the overall improvement programme integrating all ERTMS and other activities of IQ-C, whereas the Ministries created the Executive Board supervising the ERTMS implementation on the corridor. Since 2008, the IQ-C Working Group of the Ministries of Transport and the ERTMS Executive Board are working together in very close cooperation and coordinate their actions and time schedules. The same year, the Infrastructure Managers of the corridor founded the EEIG 'Corridor Rotterdam-Genoa EWIV,' which enabled them to act as a legal entity, financially borne by its members and associates.

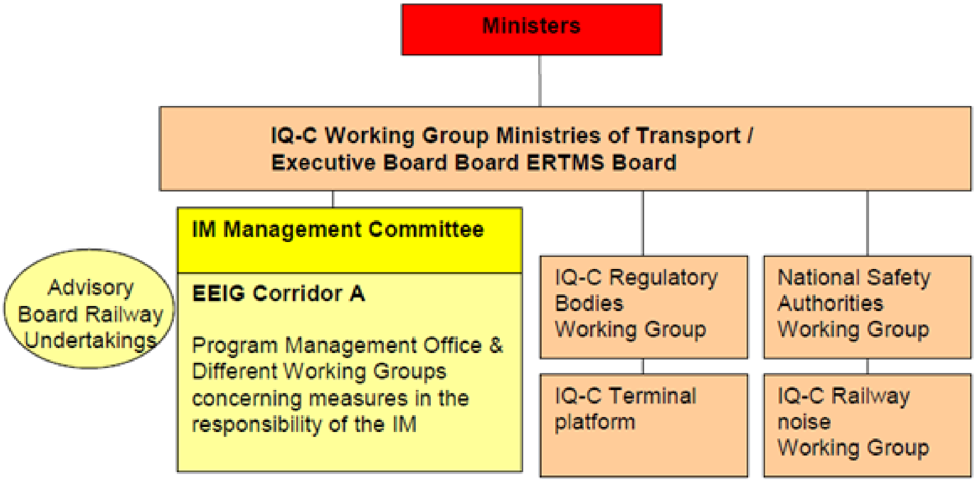


**Figure 26. The management structure of Corridor A**

(Source: Corridor A / IQ-C, 2011)

On the side of Infrastructure Managers, the Programme Management Office is implemented and works as one common corridor management board, which develops, steers, monitors and reports all corridor activities as an integrated action. Since 2009, the corridor organisation includes a ‘Terminal platform’ and a Working Group on Railway noise as additional parts of the organisation (Corridor A / IQ-C, 2011).

This structure is basically identical to the one stipulated by Regulation EU 913/2010 establishing the Rail Freight Corridors (Figure 27).

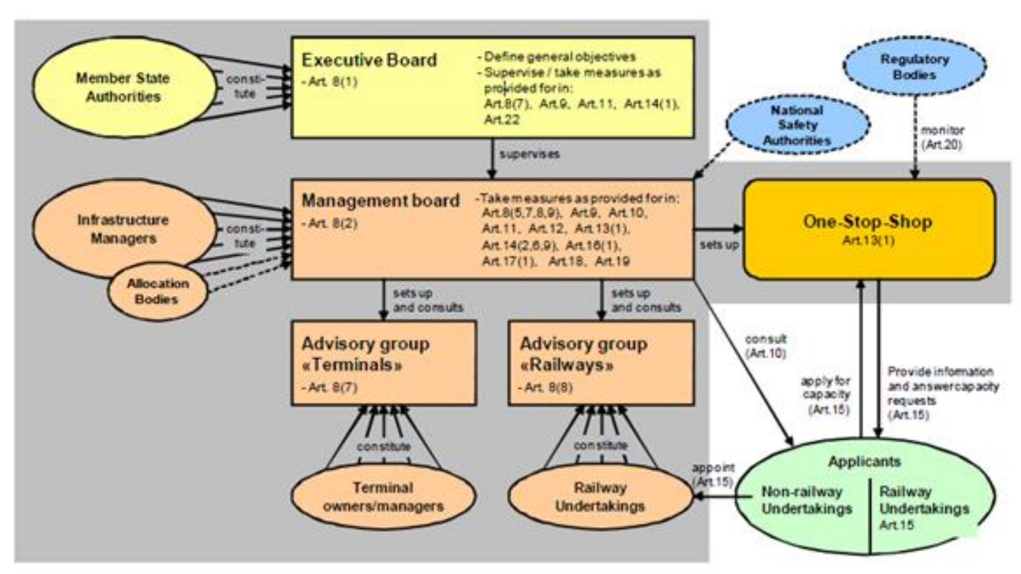


**Figure 27. Governance structure of a Rail Freight Corridor**

(Source: EC, 2011c)

The Executive Board is composed of representatives of Member States. The Management Board is formed by the Infrastructure Managers and where relevant the Allocation Bodies. It is clearly stated that Railway Undertakings cannot be members of the Management Board, which can be an independent legal entity such as an EEIG. The Management Board has to set up two Advisory Groups, one consisting of managers and owners of the terminals of the freight corridors, the other representing Railway Undertakings using or interested in using the corridor. To simplify communication with applicants and other interested parties, the Regulation provides for the establishment of a corridor one-stop-shop. More details on the governance structure specified by the Regulation can be found in the relevant handbook (EC, 2011c).

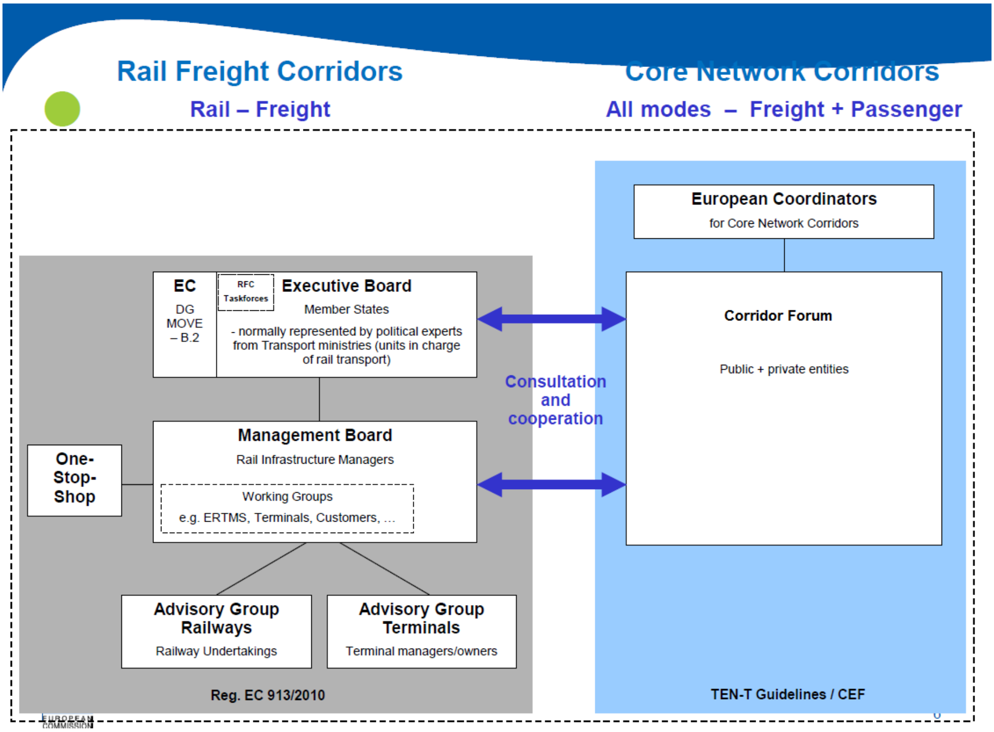


**Figure 28. Governance structure of the TEN-T core network corridors**

(Source: Based on Rousseaux, 2012)

More recently, Regulation EU 1315/2013 on the 'new TEN-T guidelines' established the core network corridors. In terms of governance, this Regulation foresees European Coordinators, acting in the name and on behalf of the Commission, to facilitate the coordinated implementation of the core network corridors. Furthermore, for each core network corridor, the Member States concerned shall establish a Corridor Forum responsible for defining the general objectives of the corridor and for preparing and supervising the relevant measures. The Corridor Forum shall be composed of the Member State representatives and other appropriate public and private entities, and shall be chaired by the European Coordinator. The relation of this structure to the one foreseen for the Rail Freight Corridors appears schematically in Figure 28. Although the Corridor Forum is expected to include representatives of all parties involved, its structure intentionally has been left open to be decided on a corridor level enabling consideration of corridor specific conditions.

## 4.3 The trans-European transport network

The purpose of this section is to present the TEN-T with emphasis placed on its design aspects. Following a brief piece on network development prior to the involvement of the EU, the TEN-T is presented as it looked until very recently, that is a combination of an extensive comprehensive network and a set of priority projects. The section ends with a reference to the 'new TEN-T guidelines,' representing a major overhaul of the European transport infrastructure policy. The network design aspects of this attempt are given special attention.

### 4.3.1 The pre-EU era

The point of this brief heading is to underline that cross-border transport networks were being developed for well over a century prior to the EU's influence on infrastructural integration.

The European cross-border infrastructure is being discussed since the early nineteenth century. During negotiations about the European order after the Napoleonic Wars at the Vienna Congress in 1814–15, the French philosopher Claude-Henri de Saint Simon suggested the establishment of a European Parliament to take on matters of common European interest such as large trans-border waterway projects.

Although Saint Simon's idea of a European Parliament did not materialise for a long time, transnational networks did. Schipper and Van der Vleuten (2008) distinguish between existing and new transport networks. Navigation and road networks were already in place. However, they were greatly improved in terms of length, density, quality and usage. Waterways were always considered as long-distance arteries. Roads, by contrast, were rediscovered as such only after the introduction of the automobile. At the dawn of the 20th century, France was the owner of the most advanced technology in car manufacturing. A number of well-advertised road races, introducing transnational road use, were organised between Paris and other European capitals like Amsterdam, Berlin, Vienna and Madrid, before the trend was stopped abruptly following the disastrous Paris-Madrid race of

1903.[23]

**Figure 29. The 1903 Paris-Madrid race**

(Source: Jarrott Charles, 2015)

The United Nations Economic Commission for Europe (UNECE) Declaration on Main International Traffic Arteries of 1950 was the first post-war international treaty concerning road traffic in Europe. The signatory parties *"... considered it essential, in order to establish closer relations between European countries, to lay-down a coordinated plan for the construction or reconstruction of roads suitable for international traffic*." So, they adopted the road network of Table 12 as a concerted plan, which they intended to undertake in accordance with agreed upon technical specifications within the framework of their national programmes for public works or within the possibilities of international financing.

[23] The race was declared officially over at the end of its first leg Versailles – Bordeaux (552 km), after half of the 224 participating vehicles (170 cars and 54 motorcycles) had crashed or retired, eight people had died (three spectators and five racers) and over 100 had been wounded. No other races on public streets were allowed until 1927 (Mille Miglia).

**Table 12. The main international traffic arteries**

| Number | Description[24] |
|---|---|
| E1 | London-Paris-Nice-Roma-Palermo |
| E2 | London-Lausanne-Milano-Brindisi |
| E3 | Lisboa-Paris-Stockholm |
| E4 | Lisboa-Bern-Köbenhavn-Stockholm-Helsinki |
| E5 | London-Wien-Budapest-Beograd-Alexandroupolis-Istanbul-Ankara-Turkish/Syrian frontier |
| E6 | Roma-Berlin-Oslo-Stjördal |
| E7 | Roma-Wien-Warszawa |
| E8 | London-Den Haag-Berlin-Warszawa-USSR |
| E9 | Amsterdam-Basel-Genova |
| E10 | Paris-Bruxelles-Den Haag-Amsterdam |
| E11 | Paris-Salzburg |
| E12 | (Paris)-Praha-Warszawa-(Leningrad and Moskva) |
| E13 | Lyon-Venezia |
| E14 | Trieste-Praha-Szczecin |
| E15 | Hamburg-Berlin-Praha-(Budapest) |
| E16 | Bratislava-Gdynia |
| E17 | Chagny-Salzburg |
| E18 | Stavanger-Oslo-Stockholm |
| E19 | (Greek/Albanian frontier)-Ioannina-Korinthos |
| E20 | Koritza-Sofia |
| E21<br>E21a<br>E21b | Aosta-Torino-Savona<br>Martigny-Grand Saint Bernard-Aosta<br>Genève-Bonneville-Mont Blanc-Aosta |
| E22 | Berlin-Wroclaw-Opole-Bytom-Krakow-Rzeszow-Przemysl-(USSR) |
| E23 | Ankara-Kirsehir-Kayseri-Sivas-Erzincan-Erzurum-Agri-(Turkish/Iranian frontier) |
| E24 | Kömürler-Gasiantep-Urfa-Mardin-Cizre-Hakkari-Bajirge-(Turkish/Iranian frontier) |
| E25 | Burgos-Madrid-Bailén-Sevilla-Cádiz-Algeciras |
| E26 | Barcelona-Tarragona-Castellón de la Plana-Valencia-Granada-Málaga-Algeciras |

(Source: UNECE, 1950)

[24] Names of cities/countries appear as listed in the original document.

In terms of new infrastructure, railways attracted most popular attention in the nineteenth century. The highly transnational character of these networks resulted from the extensive effort of governments to re-position their countries in the European economic and military geography. Starting from the 1830s, Dutch and Belgian rail projects connected the major ports of the region to the Central-European hinterland. The Italian network was developed with the same purpose soon after the Suez Canal was opened in 1869. Alpine countries built hugely expensive railway tunnels to improve their accessibility, while Prussian and Austria-Hungarian interests promoted connection to the Balkan Peninsula and ultimately Turkey and Iraq. Russia's Trans-Siberian railway was operational by 1901 and soon travelling from the Channel to Vladivostok, an unthinkable endeavour some years ago, became a reality (Schipper and Van der Vleuten, 2008).

In the twentieth century, a fourth transport network, aviation, further strengthened transportation across the globe, as maritime shipping had done earlier.

### 4.3.2 Early EU efforts in network development

Transport was one of the two sectors of economic activity for which a common policy is pursued by the 1957 Treaty of Rome; agriculture being the other one. In establishing the European Economic Community, the founding parties considered the creation of a common market as their primary objective. In this regard, the provisions of Title IV (Transport: Articles 74-84) were dealing exclusively with the removal of barriers to fair competition that were not uncommon in this period.

It is interesting to note that the relevant provisions were applicable only to transport by rail, road and inland waterway (Article 84). Apparently, access to the market of international maritime services was even back then much less inhibited by protective measures.

No reference to infrastructure investments was contained in the Treaty of Rome. However, the role of infrastructure in the growth of regional economies, especially in the peripheral areas, as well as in the integration of the transport services and the EU itself soon became evident. In February 1966, the Council of Ministers introduced a consultation procedure for infrastructure investment, albeit with minimum results due to circumstantial exchange of information (Stasinopoulos, 1995).

A second consultation procedure on transport infrastructure programmes was adopted by the Council of Ministers in 1978 and a special committee was set up to coordinate national infrastructure policies. In 1979 the European Commission argued that the European transport policy would not achieve the objectives set out in the 1957 Treaty of Rome unless it related more to the infrastructure. However the Commission's early attempts to promote a European approach to investment in transport infrastructure met with only limited success (Butcher, 2012).

In terms of financing, the European Investment Bank (EIB) had started in the 1960s to grant loans to infrastructure projects of Community interest. Since 1975, the European Regional Development Fund (ERDF) further supported transport infrastructure in lagging regions. In general, however, the financial assistance was inadequate and the arrangements to determine Europe-wide intervention were based solely on national plans.

During the preparations for the European Single Market throughout the second half of the 1980s, the European Round Table of Industrialists expressed its concern that, because of infrastructure bottlenecks, a further development of transport could be hampered, and that this would result in a loss of productivity gains that could otherwise be brought about by a more sophisticated division of labour (Sichelschmidt, 1999).

The European Commission (1990) expressed the view that the European infrastructure networks were still segmented and that *"... the lack of interoperability between them makes it impossible for them to link up with each other beyond national frontiers and for them to be operated simultaneously or consecutively so that they offer a coherent and satisfactory service at a reasonable cost to the user. These difficulties are linked not only to the facilities and installations concerned but also to the services provided..."*

The same document identified the following criteria that the Community infrastructure needs to meet:

- ability to cope with the predicted increase in the intra-Community trade unimpeded by physical, technical and, "...in the near future, tax barriers" (volume effect),
- need for existing infrastructure and services to be interconnected so that they will match the new dimensions of the market (interoperability requirement),

- taking the Community dimension into account in the design and development of future networks (dimension effect – subsidiarity principle),
- provision of adequate service quality throughout Europe (quality requirement), and
- need to draw closer all the elements of the Community space (cohesion effect).

Furthermore, the document drew the framework of an action programme for Community infrastructure in the sectors of transport, energy and telecommunications, containing indicative priority projects. In terms of transport, only the road and rail sub-sectors are covered. The following road links are mentioned:

- Toulouse-Madrid and Bordeaux-Valencia via a tunnel under the Somport,
- Toulouse-Barcelona via the Puymorens tunnel,
- The Brenner axis,
- Road link to Ireland: A5/A55 Crewe-Holyhead link in the UK,
- Brindisi-Patras-Athens,
- Lisbon-Madrid,
- Aalborg-Frederikshaven motorway,
- Fehmarn links, and
- Athens-Evzoni-Yugoslavia.

With respect to rail transport, the indicative projects included:

- The North high speed axis: Paris-London-Brussels-Amsterdam-Cologne,
- The South high speed axis: Seville-Madrid-Barcelona-Lyon-Turin-Milan-Venice, and hence to Tarvisio and Trieste, Oporto-Lisbon-Madrid,
- The Dublin-Holyhead-Crewe and Dublin-Belfast axes, and
- The Brenner axis.

On 7 February 1992, the Trans-European Networks (TENs) were officially introduced with the Maastricht Treaty (EC, 1992):

> *"...to enable citizens of the Union, economic operators and regional and local communities to derive full benefit from the*

> *setting up of an area without internal frontiers, the Community shall contribute to the establishment and development of trans-European networks in the areas of transport, telecommunications and energy infrastructures."* (Article 129b)

The stated objective of this Community action was *"... within the framework of a system of open and competitive markets, ... to promote the interconnection and interoperability of national networks as well as access to such networks. It shall take account in particular of the need to link island, landlocked and peripheral regions with the central regions of the Community."*

To meet these objectives, the Community (Article 129c):

- shall establish a series of guidelines, which would identify projects of common interest,
- shall implement any measures necessary to ensure the interoperability of the networks, in particular in the field of technical standardisation,
- may support the financial efforts of the Member States for projects included in the guidelines, particularly through feasibility studies, loan guarantees, interest rate subsidies or through the Cohesion Fund to be set up no later than 31 December 1993,
- may take, in close cooperation with the Member States, any useful initiative promoting coordination among the Member States in relation to policies pursued at national level which may have a significant impact on the stated objectives, and
- may decide to cooperate with third (i.e. non-EU) countries to promote projects of mutual interest and to ensure the interoperability of networks.

The political impetus was subsequently given by the European Council (1993) in Copenhagen: it called on the Commission and the Council to speed up the adoption of master plans in the field of transport, energy and telecommunication.

In December of the same year, the White Paper on "*Growth, Competitiveness and Employment*" (EC, 1993) was published. In this paper, the Commission presented the TENs as "...the arteries of the single market." In a true Keynesian line of thinking, the Commission claimed that the malfunction of the networks reflected lost opportunities to create new markets and hence jobs.

An important finding of this document relates to the massive investment required for the implementation of the TENs, particularly for transport infrastructures. Given the shortage of available public financing at both the Community and Member State level, new types of partnerships between private and public financing were needed, backed by financial engineering encompassing all different sources and types of financing. In order to effectively launch the process of this partnership, an initial list of 26 projects which were both of Community interest and had the potential to mobilise private economic operators was drawn up by the Commission. These candidate projects formed the basis on which discussions were initiated with the relevant authorities and economic circles.

In the framework of these discussions, a "group of personal representatives of the Heads of State or Government", called the 'Christophersen Group' for short, was set up in December 1993 at the request of the Council to identify priority projects in transport and energy. It proposed 35 projects to be granted priority. In its interim report to the Corfu European Council in June 1994, the Group identified a first list of 11 projects in the transport sector as special priorities because they were either in the stage of realisation or prepared for a start of realisation before the end of 1996. A final report was presented to the Council meeting in Essen in December 1994 including three additional projects. This proposal (some 8,000 km of rail lines, thereof nearly 4,500 km for high speed traffic, an ample 4,000 km of motorways and one airport project) was finally endorsed by the European Council meeting in Essen (Sichelschmidt, 1999).

In addition to the top 14 projects, the Group produced a list of traffic management projects and a list of other projects which were important but which were not yet ready for work to begin. The Commission proposed in 2001 to add six further schemes, including the global navigation and positioning satellite system, Galileo. Finally, the High Level Group, chaired by Karel Van Miert, recommended in total 16 additional priority projects. These were added to TEN-T in 2003, bringing the total number of priority projects to 30 (Butcher, 2012).

### 4.3.3 The 2010 TEN-T Guidelines

The objectives, priorities and broad lines of measures envisaged in the area of the trans-European transport network are contained in a document called 'TEN-T Guidelines.' The same document indicates the routes of Union importance that may be considered for EC financial support. The first set of Union guidelines for the development of the TEN-T was published in 1996. It was revised in 2001 and 2004 and recast in 2010. Although the guidelines currently in force are those of 2013 (refer to Section 4.3.4), the existing infrastructure of the TEN-Ts has been formed on the basis of the provisions of the 2010 Guidelines (Decision 661/2010/EU). The main features of this document are briefly presented below.

*Objectives*

The single objective of the EU transport infrastructure policy is the gradual (by 2020) establishment of the TEN-T by integrating land, sea and air transport infrastructure networks throughout the Union in accordance with a set of outline plans and specifications.

In terms of requirements, the network must:

- ensure the sustainable mobility of persons and goods within an area without internal frontiers under the best possible social and safety conditions, while helping to achieve the Union's objectives, particularly in regard to the environment and competition, and contribute to strengthening economic and social cohesion,
- offer users high-quality infrastructure on acceptable economic terms,
- include all modes of transport, taking account of their comparative advantages,
- allow the optimal use of existing capacities,
- be, insofar as possible, interoperable within modes of transport and encourage intermodality,
- be, insofar as possible, economically viable,
- cover the whole territory of the Member States so as to facilitate access in general, link island, landlocked and peripheral regions to the central regions and interlink without bottlenecks the major conurbations and regions of the Union,
- be capable of connecting to the networks of the European Free Trade Association (EFTA) States, the countries of Central and Eastern Europe and the Mediterranean countries, while at the same time promoting interoperability and access to these networks, insofar as this proves to be in the Union's interest.

The comparison between these requirements and those of 1990 (refer to Section 4.3.2) shows that during the last 20 years the European society has become more sensitive in issues relating to the environmental and social sustainability, safety, economic viability, optimal use of existing capacities, and the external dimension of EU policies. It is believed that the European dimension (subsidiarity principle) is missing from the recent list only because it has been taken into consideration inherently in drawing up the outline plans (see below).

*Scope and priorities of the network*

In terms of scope, the trans-European network consists of transport infrastructure, traffic management systems and positioning and navigation systems. The transport infrastructure includes road, rail and inland waterway networks, motorways of the sea, seaports and inland waterway ports, airports and other interconnection points between modal networks.

The following priorities are mentioned in the guidelines:

- the establishment and development of the key links and interconnections needed to eliminate bottlenecks, fill in missing sections and complete the main routes, especially their cross-border sections, cross natural barriers, and improve interoperability on major routes,
- the establishment and development of infrastructure which promotes the interconnection of national networks in order to facilitate the linkage of islands, or areas similar to islands, and landlocked, peripheral and outermost regions on the one hand and the central regions of the Union on the other, in particular to reduce the high transport costs in these areas,
- the necessary measures for the gradual achievement of an interoperable rail network, including, where feasible, routes adapted for freight transport,
- the necessary measures to promote long-distance, short sea and inland shipping,
- the necessary measures to integrate rail and air transport, especially through rail access to airports, whenever appropriate, and the infrastructures and installations needed,
- the optimisation of the capacity and efficiency of existing and new infrastructure, promotion of intermodality and improvement of the

safety and reliability of the network by establishing and improving intermodal terminals and their access infrastructure and/or by developing intelligent systems,
- the integration of safety and environmental concerns in the design and implementation of the trans-European transport network,
- the development of sustainable mobility of persons and goods in accordance with the objectives of the Union on sustainable development.

*The outline plans and specifications by sector*

The **road network** comprises motorways and high-quality roads, as well as infrastructure for traffic management, user information, dealing with incidents, emergencies and electronic fee collection. The network should guarantee its users a high, uniform and continuous level of services, comfort and safety.

The outline plan of the road network for a 2020 horizon appears in Figure 30. In addition to those shown on the plan, projects of common interest[25] could concern:

- development of the network, and in particular:
  - ✓ widening of motorways or upgrading of roads,
  - ✓ construction or improvement of bypasses or ring roads,
  - ✓ increasing the interoperability of national networks.
- development of traffic management and user information systems, and in particular:
  - ✓ establishment of telematics infrastructures for collecting traffic data,
  - ✓ developing traffic information centres and traffic control centres, as well as exchanges of data between traffic information centres in different countries,
  - ✓ establishing road information services, in particular the RDS-TMC system,
  - ✓ technical interoperability of telematics infrastructures.

[25] According to the terminology of the TEN-T Guidelines, a ‘project of common interest’ is one that pursues the set objectives of the guidelines, corresponds to one or more of the set priorities of the guidelines, is economically viable on the basis of a socio-economic cost/benefit analysis, relates to the routes of the outline plans and meets the specifications set by the guidelines.


**Figure 30. The road TEN-T outline plan for 2020**

(Source: EP&C, 2010c)

The **rail network** comprises both high-speed and conventional rail networks, as well as facilities that enable the integration of rail and road and, where appropriate, maritime and air transport services. Technical harmonisation and the gradual implementation of the ERTMS harmonised command and control system ensures the interoperability of national networks. The users should benefit from a high level of quality and safety, by virtue of its continuity and the gradual realisation of its interoperability.

The outline plan of the rail network appears in Figure 31. In addition to those of the plan, projects of common interest could concern:

- interoperability between trans-European railway systems,
- interconnection with networks of other modes of transport.

The **inland waterway network** comprises rivers, canals, and inland ports. The network also includes traffic management infrastructure, and in particular an interoperable, intelligent traffic and transport system (RIS - River Information Services), intended to optimise the existing capacity and safety of the inland waterway network as well as improve its interoperability with other modes of transport. The minimum technical characteristics for waterways forming part of the network are those of class IV, which allows the passage of a vessel or a pushed train of craft 80 to 85 m long and 9.50 m wide.

The outline plan of the inland waterway network appears in Figure 32. In addition to those presented on the plan, projects of common interest, which must relate solely to infrastructure open to any user on a non-discriminatory basis, could concern:

- inland ports, and in particular:
  - ✓ access to the port from waterways,
  - ✓ port infrastructure inside the port area,
  - ✓ other transport infrastructure inside the port area,
  - ✓ other transport infrastructures linking the port to other elements of the trans-European transport network.
- traffic management, and in particular:
  - ✓ a signalling and guidance system for vessels, in particular those carrying dangerous or polluting goods,
  - ✓ communication systems for emergencies and inland waterway safety.


**Figure 31. The rail TEN-T outline plan for 2020**

(Source: EP&C, 2010c)

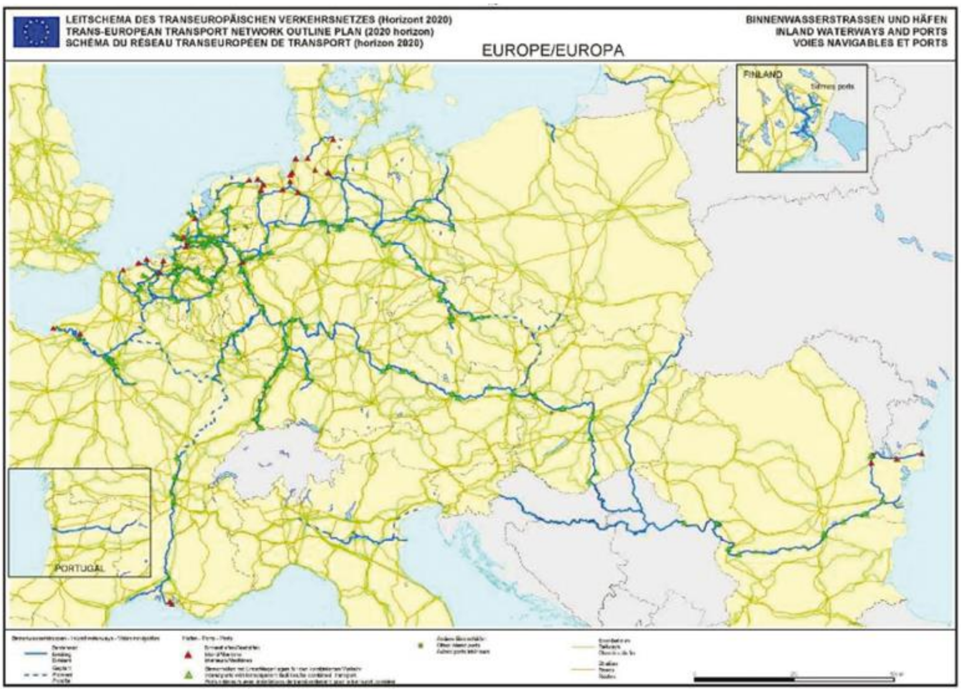


**Figure 32. The inland waterway TEN-T outline plan for 2020**

(Source: EP&C, 2010c)

The **seaport network** permits the development of sea transport and constitutes shipping links for islands and the points of interconnection between sea transport and other modes of transport. Seaports provide equipment and services to transport operators. Their infrastructure provides a range of services for passenger and goods transport, including ferry services and short- and long-distance shipping services, including coastal shipping, within the Union and between the latter and third countries.

Although the outline plan of seaports (refer to Figure 33) includes only ports of class A, meaning ports with a total annual traffic volume of not less than 1.5 million tonnes of freight or 200,000 passengers, certain project types are open for class B (with a total annual traffic volume of not less than 0.5 million tonnes of freight or between 100,000 and 199,999 passengers) or class C (do not meet the criteria of categories A and B but are situated in island, peripheral or outermost regions, interconnecting such regions by sea and/or connecting them with the central regions of the Union) ports.


**Figure 33. The seaport (Class A) TEN-T outline plan for 2020**

(Source: EP&C, 2010c)

Projects of common interest, relating solely to infrastructure open to any user on a non-discriminatory basis, may concern:

- Infrastructure necessary for the development of short-sea and sea-river shipping (class A).
- Access to ports, and in particular:
  - ✓ Access to ports from sea or inland waterway (classes A and B)
  - ✓ Permanent accessibility of ports in the Baltic Sea situated at approximately latitude 60° north and beyond, including capital costs for ice-breaking works during winter (classes A, B and C)
  - ✓ Creation or improvement of hinterland access linking the port to other elements of the TEN-T through rail, road and inland-waterway connections (class A)
  - ✓ Development of existing hinterland access linking the port to other elements of the TEN-T through rail, road and inland-waterway connections (classes A and B).
- Port infrastructure within the port area, and in particular:
  - ✓ Development of port infrastructure in order to increase intermodal efficiency (classes A and B)
  - ✓ Upgrading of the port infrastructure, in particular in ports on islands and in peripheral and outermost regions (class C)
  - ✓ Development and installation of management and information systems such as EDI (Electronic Data Interchange) or other systems of intelligent management of goods and passenger traffic using integrated technologies (classes A, B and C)
  - ✓ Development of port installations to receive waste (classes A, B and C).

The **Motorways of the Sea (MoS)** network concentrates flows of freight on sea-based logistical routes so as to improve existing maritime links and establish new viable, regular and frequent links for the transport of goods between Member States. The concept builds on EU’s goal of transforming shipping into a genuine alternative to overcrowded land transport, and aims at introducing new intermodal maritime-based logistics chains in Europe.

The MoS network consists of facilities and infrastructure concerning at least two ports in two different Member States, one maritime operator and ideally hinterland transport operators. The projects can include elements, such as port facilities, electronic logistics management systems, safety, security, administrative and customs procedures, as well as infrastructure for direct land and sea access, including dredging and icebreaking facilities. The projects of common interest of the MoS network should be proposed by at least two Member States and adhere to a tendering process.

Through Priority Project 21 of the TEN-T (see below), the following four corridors (refer to Figure 34) have been designated for setting up projects of European interest:

- Motorway of the Baltic Sea,
- Motorway of the Sea of western Europe,
- Motorway of the Sea of south-east Europe, and
- Motorway of the Sea of south-west Europe.


**Figure 34. The Motorways of the Sea**

(Source: INEA, 2015)

The **airport network** comprises airports situated within the EU which are open to commercial air traffic (refer to Figure 35). They should permit the development of air links, both within the EU and between the EU and the rest of the world, as well as the interconnection with other modes of transport.

Airports are classified into international, Union and regional connecting points according to a set of criteria. The international and Union connecting points form the core of the TEN-T airport network. Airport projects can qualify as projects of common interest provided that they meet the following specifications:

- Optimisation of existing airport capacity, and in particular:
  - ✓ Optimisation of the existing capacity in terms of aircraft, passenger or freight movements, including the airport's air navigation equipment (all classes)
  - ✓ Improvement of airport security and safety (all classes)
  - ✓ Adaptation of existing infrastructures made necessary by completion of the internal market and in particular by the measures governing the free movement of persons within the Union (all classes)
- Development of new airport capacities, and in particular:
  - ✓ Development of the infrastructure and equipment which determine airport capacity in terms of aircraft, passenger or freight movements, including the airport's air navigation equipment (international and Union classes)
  - ✓ Construction of new airport to replace an existing airport or airport system which cannot be developed further on its site (international and Union classes)
- Improvement of environmental compatibility in terms of noise and the treatment of airport effluent (international and Union classes)
- Improvement or development of airport access, and in particular:


**Figure 35. The airport TEN-T outline plan for 2020**

(Source: EP&C, 2010c)

- ✓ Improvement or development of interfaces between the airport and access infrastructures (international and Union classes)
- ✓ Improvement and development of interconnections with other transport networks, and more specifically the rail network (international and Union classes).

The **combined transport network** comprises railways and inland waterways which, together with the shortest possible road haulage in relation to the first and last miles, permit long-distance combined transport of goods. It also comprises intermodal terminals equipped with installations permitting transhipment between railways, inland waterways, shipping routes and roads, as well as suitable rolling stock as required.

The outline plan of the combined transport network for a 2020 horizon appears in Figure 36. In addition to those shown on the plan, projects of common interest could concern:

- construction or upgrading of railway or inland waterway infrastructures in order to make the transport of intermodal loading units technically possible and economically viable,
- construction or development of centres for transfers between inland types of transport, including the setting up within the terminal of transhipment equipment with the corresponding infrastructure,
- adaptation of port areas, making it possible to develop or improve combined transport between sea transport and rail, inland waterway or road transport,
- railway transport equipment specially adapted to combined transport where so required by the nature of the infrastructure.

Furthermore, the TEN-T Guidelines include the shipping management and information network, the air traffic management network and the positioning and navigation network.


**Figure 36. The combined transport TEN-T outline plan for 2020**

(Source: EP&C, 2010c)

*The priority projects*

The provisions of the guidelines concerning the so-called 'priority projects' is the part of the document that attracts the highest attention due to special financing possibilities offered to these projects. They are projects of common interest, where examination confirms that they:

- are intended to eliminate a bottleneck or complete a missing link on a major route of the TEN-T, in particular projects which are of cross-border or cross-natural-barrier nature,
- are on such a scale that long-term planning at European level contributes significant added value,
- present, overall, potential socio-economic net benefits and other socio-economic advantages,
- significantly improve the mobility of goods and persons between Member States and thus also contribute to the interoperability of national networks,
- contribute to the territorial cohesion of the Union by integrating the networks of the new Member States and improving connections with the peripheral and island regions,
- contribute to the sustainable development of transport by improving safety and reducing environmental damage caused by transport, in particular by promoting a modal shift towards railways, intermodal transport, inland waterways and maritime transport,
- demonstrate commitment on the part of the Member States concerned to carrying out studies and evaluation procedures in time to complete the work in accordance with a date agreed in advance, based upon national plans or any other equivalent document relating to the project in question.

The Guidelines provide in annex a list of 30 priority projects, on which work was due to start before 2010, together with the agreed date of completion. This list is presented in Table 13 below.

**Table 13. The priority projects of the 2010 TEN-T Guidelines**

| Number | Description |
|---|---|
| PP1 | Railway axis Berlin-Verona/Milan-Bologna-Naples-Messina-Palermo |
| PP2 | High-speed railway axis Paris-Brussels-Cologne-Amsterdam-London |
| PP3 | High-speed railway axis of south-west Europe |
| PP4 | High-speed railway axis east |
| PP5 | Betuwe line |
| PP6 | Railway axis Lyon-Trieste-Divača/Koper-Divača-Ljubljana-Budapest-Ukrainian border |
| PP7 | Motorway axis Igoumenitsa/Patra-Athens-Sofia-Budapest |
| PP8 | Multimodal axis Portugal/Spain-rest of Europe |
| PP9 | Railway axis Cork-Dublin-Belfast-Stranraer |
| PP10 | Malpensa airport |
| PP11 | Öresund fixed link |
| PP12 | Nordic triangle railway/road axis |
| PP13 | Road axis UK/Ireland/Benelux |
| PP14 | West coast main line |
| PP15 | Galileo |
| PP16 | Freight railway axis Sines/Algeciras-Madrid-Paris |
| PP17 | Railway axis Paris-Strasbourg-Stuttgart-Vienna-Bratislava |
| PP18 | Inland waterway axis Rhine/Meuse-Main-Danube |
| PP19 | High-speed rail interoperability in the Iberian peninsula |
| PP20 | Railway axis Fehmarn Belt |
| PP21 | Motorways of the Sea |
| PP22 | Railway axis Athens-Sofia-Budapest-Vienna-Prague-Nuremberg/ Dresden |
| PP23 | Railway axis Gdańsk-Warsaw-Brno/Bratislava-Vienna |
| PP24 | Railway axis Lyon/Genova-Basel-Duisburg-Rotterdam/Antwerp |
| PP25 | Motorway axis Gdańsk-Brno/Bratislava-Vienna |
| PP26 | Railway/road axis Ireland/United Kingdom/continental Europe |
| PP27 | 'Rail Baltica' axis Warsaw-Kaunas-Riga-Tallinn-Helsinki |
| PP28 | 'Eurocaprail' on the Brussels-Luxembourg-Strasbourg railway axis |
| PP29 | Railway axis of the Ionian/Adriatic intermodal corridor |
| PP30 | Inland waterway Seine-Scheldt |

(Source: EP&C, 2010c)

But what makes these projects so special? Article 24 of the Guidelines declares these priority projects to be of 'European interest,' while Article 25 forces Member States to give appropriate priority to the projects declared to be of European interest when submitting their projects under the Cohesion Fund and the budget for the trans-European networks. The implications are straightforward in an environment of restricted budgets at both the Union and the Member State level.

It is worth noticing that the selected projects show a clear tendency for a preferential treatment of the railway sector. The high share of rail projects in the TEN-T program reflects the EC's long-standing intention to bring about a modal shift in intra-European cargo transport from road to rail (and/or sea), in order to improve the environmental effects of transport (EP&C 2010c, preamble, recital [14]).

*Implementation of the Priority Projects*

The financing of infrastructure projects in the EU is supported by various instruments, including the TEN-T budget, the Structural and Cohesion Funds, and loans from the EIB. The Structural and Cohesion Funds have been a major source of finance for the investment needed to reduce imbalances in transport endowment in lagging regions across the EU. The TEN-T budget currently co-finances projects on the TEN-T network.

Nevertheless, Community financial instruments have so far not been able to bring about a full and timely completion of all projects involved. Insufficient finance – both public and private – is probably the most important obstacle in infrastructure development. This has also been identified as one of the main reasons for delays in the implementation of certain TEN-T priority projects.

According to the 2010 annual progress report of the TEN-T Executive Agency[26] (TEN-T EA), the status of the 30 TEN-T priority projects is graphically depicted in Figure 37. Five of these 30 projects have been completed:

[26] The TEN-T EA was established in 2006 to follow the technical and financial implementation of all TEN-T projects throughout their entire lifecycle, to provide support to the beneficiaries of TEN-T financing and to coordinate with other institutional partners. It became autonomous in 2008 and was succeeded by the Innovation and Networks Executive Agency (INEA) as of 1 January 2014.

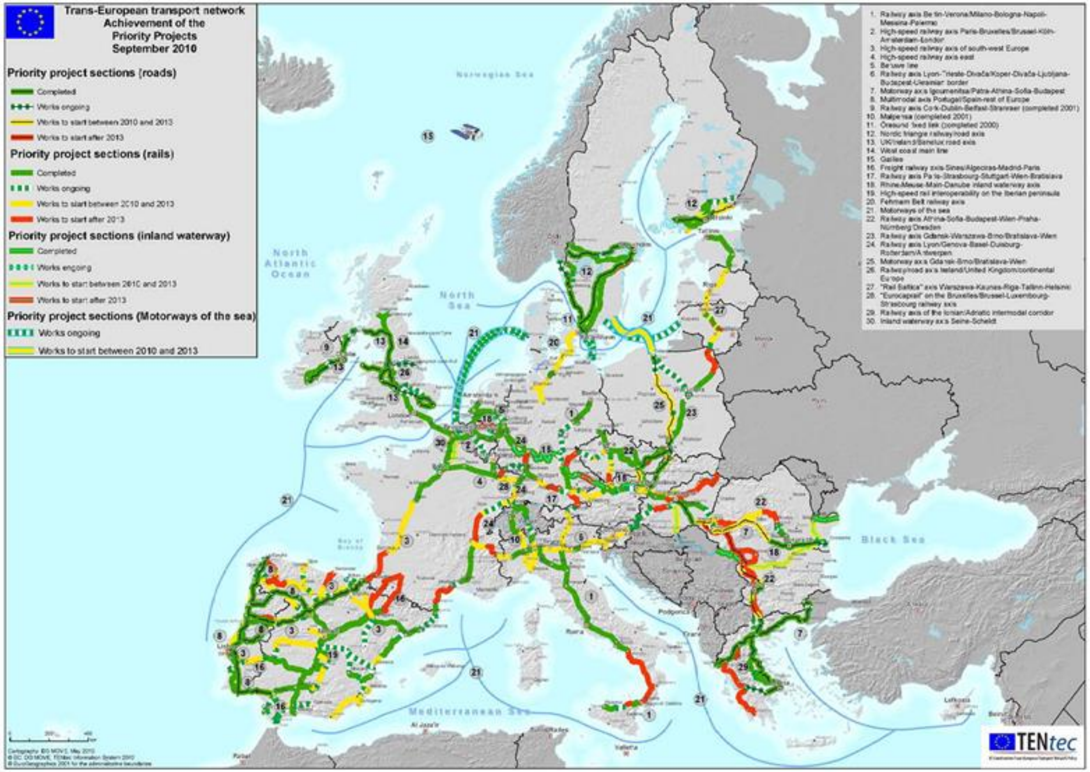


**Figure 37. Status of the 30 TEN-T priority projects as of September 2010**

(Source: EC, 2010a)

PP5: Betuwe Line
PP9: Railway axis Cork-Dublin-Belfast-Stranraer
PP10: Malpensa airport
PP11: Öresund fixed link
PP14: West coast main line,

while significant progress has been made in some other projects. The opening of high-speed lines in Germany, Italy, Spain, France and the Benelux countries has considerably improved accessibility and brought people closer together. Rail has already captured market shares from aviation and from the passenger car. However, other projects have not been as successful: a couple of projects such as the trans-Alpine rail tunnels on Brenner and Fréjus have been designated as a ‘priority’ for about 20 years but they remain critical bottlenecks since then.

### 4.3.4 The recent reform of the TEN-T

As already mentioned in Section 2.3.2, in December 2013, the European Parliament and the Council adopted a legislative package defining a new policy framework for the TEN-T, which was proposed by the European Commission back in October 2011. The package includes a Regulation on the new Union guidelines for the TEN-T development with a time horizon extending to 2050 (EP&C, 2013a) and a Regulation for establishing the Connecting Europe Facility (CEF), which will govern EU funding until 2020 (EP&C, 2013b).

The TEN-T Guidelines, as the first component of the package, establish the policy basis by defining network plans including infrastructure standards, objectives and priorities for action. A dual layer network structure has been introduced, consisting of a comprehensive and a core network. The comprehensive network constitutes the basic layer of the TEN-T and is, in large part, derived from the corresponding national networks. The core network, on the other hand, overlays the comprehensive network and contains its strategically most important parts.

The core network is the result of a genuine European network planning methodology that combines geographical and economic criteria. It builds on the key nodes of political, economic, cultural and transport-related importance and links them through all available transport modes (EC, 2011d). More specifically, the design of the core network involved the following steps:

Step 1: Identification of the main nodes of the Core Network. These are the nodes of the highest strategic importance in the EU, which are identified in the first step of the planning procedure:
- main nodes for passengers and freight,
- main nodes for freight only,
- main nodes for passengers only.

Step 2: Identification of the links between the main nodes. Multimodal links were selected from the comprehensive network to connect the main nodes, following the corresponding (potential) main traffic flows.

Applying this methodology on inland waterways showed that almost all of them would become part of the core network. For this reason, the entire inland waterway network which complies with UNECE category IV is considered part of the core network.

The 'Motorways of the Sea' are the maritime dimension of the TEN-T. As far as they fulfil the function of core network links or of sections thereof (e.g. linking core network main nodes across the sea), they are considered part of the core network, as well.

Step 3: Merging the modal network parts to the multimodal core network.

The functions of the comprehensive and the core network complement each other: whereas the purpose of the comprehensive network is to serve accessibility functions and ensure a balanced infrastructure endowment throughout the Union, the core network pioneers the development of a sustainable mobility network. It shall be completed as a priority, by 2030. The new policy basis provides more clarity with regard to the identification of a broad range of 'projects of common interest' (including the closing of missing physical links, infrastructure upgrading to target standards, ITS or innovative equipment).

To facilitate implementation of the core network, the Guidelines introduce the instrument of 'core network corridors' – a coordination tool aiming at coherent project implementation and at promoting technological, operational and governance-related innovation. The core network corridors also aim to strengthen a 'systems' approach that links transport infrastructure development with related transport policy measures. Eventually, this approach seeks to promote higher resource efficiency to achieve the EU objectives of reduced carbon emissions in the transport sector.

Due to the broad range of measures addressed with the new Guidelines, many different actors will have to contribute to their implementation. The proposed corridor governance structures (see Section 4.2.3) intend to foster cooperation of the various actors. Existing activities such as the rail freight corridors introduced with Regulation No 913/2010 will form an integral part of core network corridor developments.

Vis-à-vis the TEN-T guidelines, the CEF, as the financing instrument, sets out funding priorities in transport, energy and digital broadband for the period 2014 – 2020, as well as the corresponding rules. Regarding transport, it defines a geographical basis for the corridor approach and pre-identifies the most mature projects along those corridors. Annex I to the CEF Regulation (EP&C, 2013b) lists the 9 core network corridors that form the basic part of the TEN-T core network. They appear in Figure 38 and, in metro format, in Figure 2 of Chapter 2.

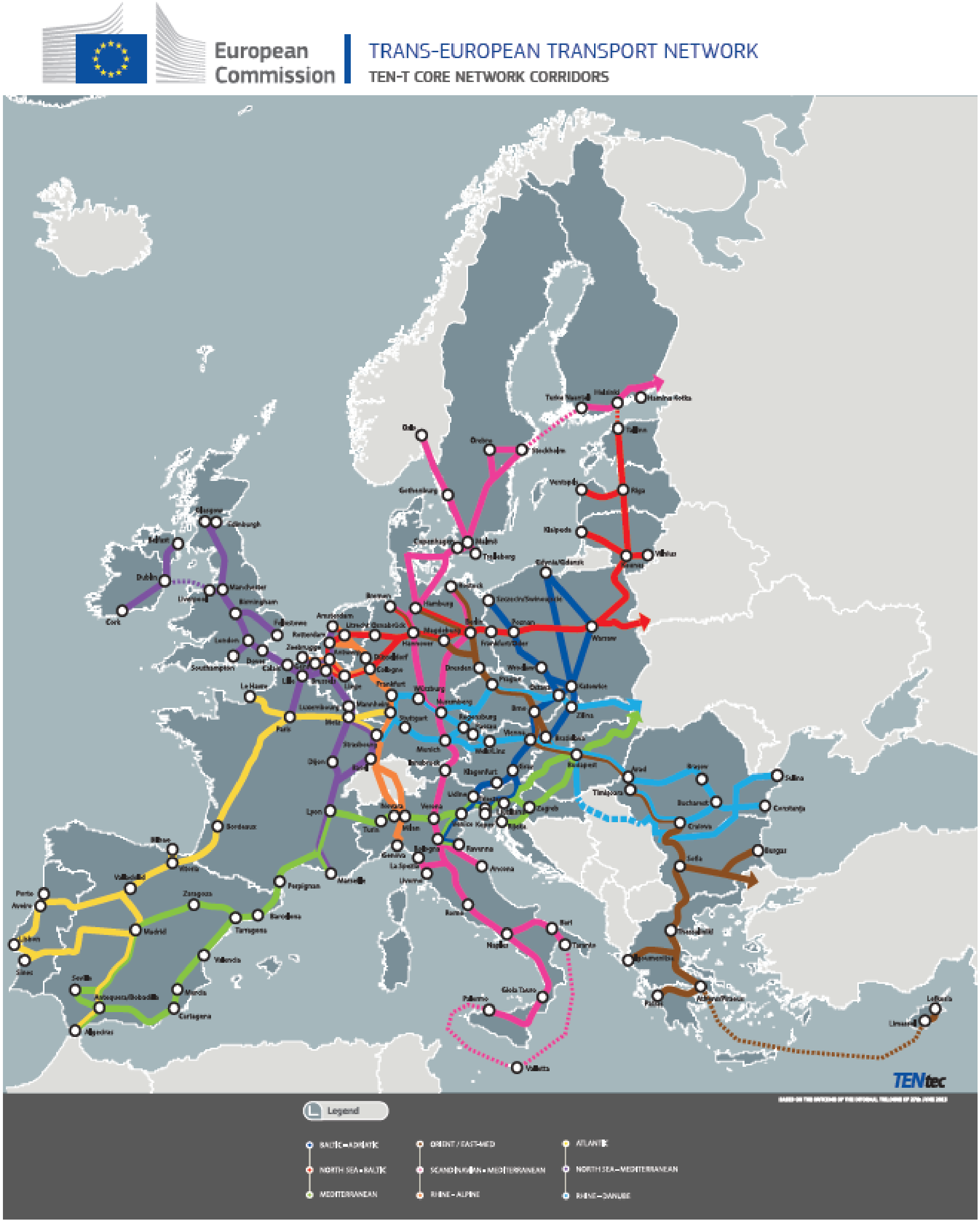


**Figure 38. The TEN-T core network corridors**

(Source: EC, 2015)

## 4.4 How do green corridors relate to the TEN-T?

Figure 39 depicts the land part of the core network plotted against the nine SuperGreen corridors (refer to Section 3.4). The geographic overlap is impressive, even after accounting for the fact that the priority projects of the TEN-T were taken into consideration, among several other criteria, when selecting the SuperGreen corridors in June 2010.

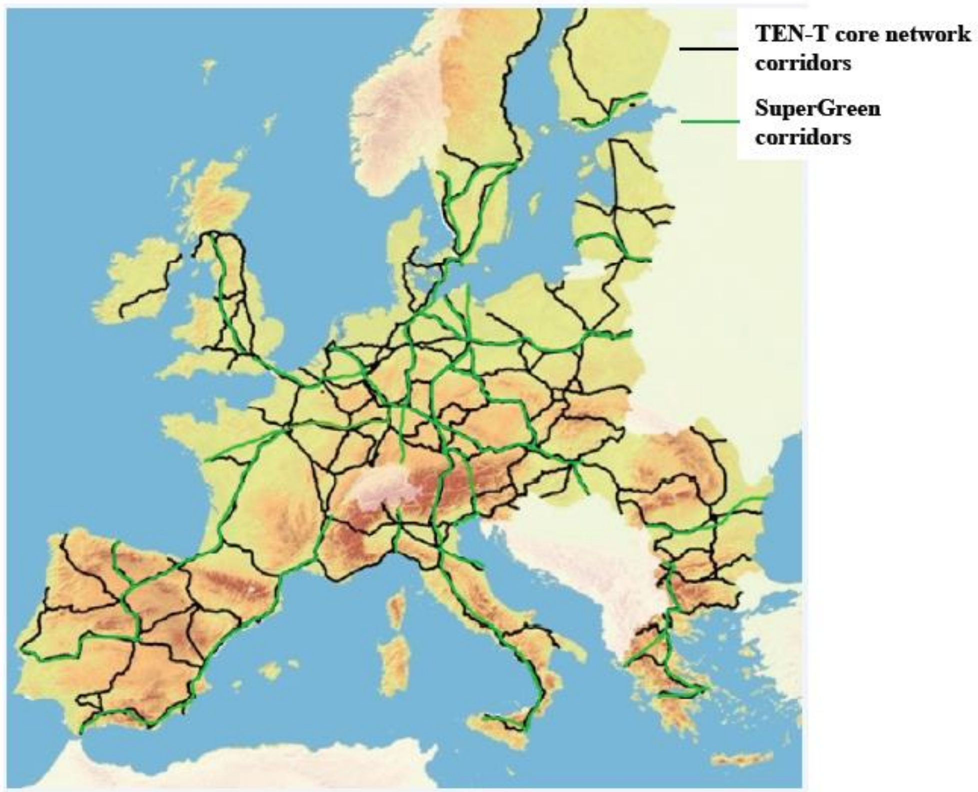


**Figure 39. The SuperGreen and TEN-T core network corridors**

(Source: Panagakos, 2012)

How about the conceptual relation though? Do these corridors exhibit the green characteristics identified in Section 3.3? To refresh your memory, these characteristics are:

a) Reliance on co-modality, which in turn requires:
   - adequate transhipment facilities at strategic locations, and

- integrated logistics concepts.

b) Reliance on advanced technology leading to:
   - improved energy efficiency, and
   - use of alternative clean fuels.

c) Development and demonstration capabilities of environmentally-friendly and innovative transport solutions, including advanced telematics applications.

d) Collaborative business models.

The provisions of the new TEN-T Guidelines in relation to these characteristics are presented below:

<u>Reliance on co-modality</u>

Although the term co-modality is not mentioned, the Guidelines include several references to multimodality. In fact, there is an entire section (Section 6) devoted to the 'infrastructure for multimodal transport' that refers to the comprehensive network and includes logistic platforms. When it comes to the core network, Article 42 is crystal clear:

> *"… In order to lead to resource-efficient multimodal transport, ... core network corridors shall be focused on modal integration, interoperability, and a coordinated development of infrastructure."*

<u>Adequate transhipment facilities</u>

The TEN-T Guidelines provide for:

- the connection of rail freight terminals with the road infrastructure or, where possible, the inland waterway infrastructure of the comprehensive network (Article 12),
- the connection of inland ports with the road or rail infrastructure (Article 15),
- the connection of maritime ports with railway lines or roads and, where possible, inland waterways of the comprehensive network, except where physical constraints prevent such connection (Article 22),
- multimodal interconnections between airports and infrastructure of other transport modes (Article 26),

- seamless connection between the infrastructure of the comprehensive network and the infrastructure for regional and local traffic and urban freight delivery, including logistic consolidation and distribution centres (Article 30).

Integrated logistics concepts

It is worth mentioning that the general objective of the TEN-T is to *"... strengthen the social, economic and territorial cohesion of the Union and contribute to the creation of a* ***single European transport area*** *which is efficient and sustainable, increases the benefits for its users and supports inclusive growth"* (Article 4).

Furthermore, one of the criteria for identifying 'projects of common interest,' which comprise the building blocks of the TEN-T, is the demonstration of 'European added value' (Article 7) which, in turn, is defined as *"... the value of a project which, in addition to the potential value for the respective Member State alone, leads to a significant improvement of either transport connections or transport flows between the Member States which can be demonstrated by reference to improvements in efficiency, sustainability, competitiveness or cohesion ..."* (Article 3).

Reliance on advanced technology

There are numerous references to advanced technology applications including ICT. The following is an indicative list:

- *"[TEN-T contributes to efficiency through] ... cost-efficient application of innovative technological and operational concepts"* (Article 4),
- *"The TEN-T shall be planned, developed and operated in a resource-efficient way, through ... the deployment of new technologies and telematics applications, where such deployment is economically justified"* (Article 5),
- *"In the development of the comprehensive network, general priority shall be given to measures that are necessary for ... implementing and deploying telematics applications and promoting innovative technological development"* (Article 10),
- *"Telematics applications shall, for the respective transport modes, include in particular ERTMS (for railways), RIS (for inland waterways), ITS (for road transport), VTMIS and e-Maritime services (for maritime transport) and the SESAR system (for air*

*transport)"* (Article 31),

- *"In order for the comprehensive network to keep up with innovative technological developments and deployments, the aim shall be in particular to support and promote the decarbonisation of transport through transition to innovative and sustainable transport technologies"* (Article 33),
- *"The core network corridors shall support the comprehensive deployment of interoperable traffic management systems and, where appropriate, the use of innovation and new technologies"* (Article 42).

Energy efficiency

Relevant references include:

- *"In the development of the comprehensive network, … particular consideration shall be given to measures that are necessary for ... ensuring fuel security through increased energy efficiency, and promoting the use of alternative and, in particular, low or zero carbon energy sources and propulsion systems"* (Article10),
- *"Member States shall pay particular attention to projects of common interest which both provide efficient freight transport services that use the infrastructure of the comprehensive network and contribute to reducing carbon dioxide emissions and other negative environmental impacts, and which aim to stimulate resource and carbon efficiency, in particular in the fields of vehicle traction, driving/steaming, systems and operations planning"* (Article 32).

Use of alternative clean fuels

The TEN-T Guidelines provide direct references to alternative fuels for all transport modes:

- *"Member States shall ensure that the railway infrastructure, save in the case of isolated networks, is fully electrified as regards line tracks and, to the extent necessary for electric train operations, as regards sidings"* (Article 12),
- *"Projects of common interest for motorways of the sea ... may also include activities ... for improving environmental performance, such as the provision of shore-side electricity ... and alternative fuelling facilities ..."* (Article 21),

- *"In order for the comprehensive network to keep up with innovative technological developments and deployments, the aim shall be in particular to make possible the decarbonisation of all transport modes by stimulating energy efficiency, introduce alternative propulsion systems, including electricity supply systems, and provide corresponding infrastructure"* (Article 33),
- As for the core network, Article 39 stipulates full electrification of the line tracks and selective sidings for the railways, while alternative clean fuels should be available for the road, inland waterway and maritime transport infrastructures. For air transport, the relevant requirements are reduced to the *"... capacity to make alternative clean fuels available."*

<u>Development of innovative logistics solutions</u>

The promotion of innovative solutions is mentioned several times in the guidelines:

- *"In the development of the comprehensive network, general priority shall be given to measures that are necessary for ... promoting the efficient and sustainable use of the infrastructure ..."* (Article 10),
- *"When developing the comprehensive network in urban nodes, Member States shall, where feasible, aim to ensure promotion of efficient low-noise and low-carbon urban freight delivery"* (Article 30),
- *"Member States shall pay particular attention to projects of common interest which ... aim to promote the deployment of innovative transport services ..."* (Article 32),
- *"Projects of common interest relate to all directly concerned stakeholders, ... [who may contribute to] ... the promotion of sustainable transport solutions, such as enhanced accessibility by public transport, telematics applications, intermodal terminals/multimodal transport chains, low-carbon and other innovative transport solutions and environmental improvements"* (Article 50).

<u>Collaborative business models</u>

Although no direct reference to business models can be found in the guidelines, there are several ones relating to the need for enhanced cooperation among stakeholders including provision of information:

- *"The ... core network corridors, is a strong means of realising the respective potential of stakeholders, of promoting cooperation between them and of strengthening complementarity with actions by Member States"* [Preamble (50)],
- *"Member States shall ensure ... that freight terminals and logistic platforms, inland and maritime ports and airports handling cargo are equipped for the provision of information flows within this infrastructure and between the transport modes along the logistic chain"* (Article 28),
- *"Telematics applications shall be such as to enable traffic management and the exchange of information within and between transport modes for multimodal transport operations and value-added transport-related services, improvements in safety, security and environmental performance, and simplified administrative procedures"* (Article 31),
- *"Member States shall pay particular attention to projects of common interest which ... aim to promote the deployment of innovative transport services ... through ... the establishment of relevant governance structures"* (Article 32),
- *"Member States shall pay particular attention to projects of common interest which ... aim to facilitate multimodal transport service operations, including the necessary accompanying information flows, and improve cooperation between transport service providers"* (Article 32).

The above references lead to the conclusion that all green characteristics of a corridor that have been identified in Section 3.3 are shared more or less by the TEN-T core network corridors, as they have been introduced in the new Guidelines. In conjunction with the enabling governance structure of Section 4.2.3, we can conclude that, through the freight dimension of the TEN-T core network, the new TEN-T Guidelines have established a network of green corridors in Europe.

# PART III. ASSESSMENT OF CORRIDOR PERFORMANCE

# 5. Model-based corridor performance analysis[27]

## 5.1 Introduction

Despite voices suggesting that modal shifts away from truck may be neither easy to achieve nor significantly effective in reducing total transportation emissions (Nealer et al., 2012), the general view considers shifts from road to intermodal chains as a means for improved environmental performance of freight transportation with regard to greenhouse gas (GHG) emissions (e.g. Janic, 2007; Patterson et al., 2008; Regmi and Hanaoka, 2015). The latest EU White Paper on transport has set the goal of shifting 30% of road freight over 300 km to other modes by 2030, and more than 50% by 2050 (EC, 2011a). The green corridors, presented in Part II of this thesis, are a basic tool for meeting this target. Green corridors aim at improving the competitiveness of rail and waterborne transport which, in turn, would enable exploitation of the superior GHG-emission characteristics of these modes in comparison to road haulage. The introduction of the related Rail Freight Corridors (RFCs) in 2010 (EP&C, 2010a) and the TEN-T Core Network Corridors (CNCs) more recently (EP&C, 2013a) indicates that the corridor approach is gaining popularity as an implementation tool in EU transport policy. In addition, numerous green corridor applications have

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[27] This chapter is based on the Panagakos and Psaraftis paper *Using transport model results in freight corridor performance monitoring – A European case study*, as submitted to the European Journal of Transport and Infrastructure Research (and currently under revision). The minor changes made aim at avoiding repetition of material presented in the previous chapters, although a certain degree of overlap should be expected. A shorter version of this article by the same authors was presented at the TRA 2016 in Warsaw under the title *Performance assessment of a freight corridor on the basis of transport model results* (Panagakos and Psaraftis, 2016). On the basis of this work, the author won the second place in the TRAVISIONS 2016 senior researcher contest on innovative transport ideas in the area of cross-modality. The relative certificate is attached as Appendix II.

popped up at the regional level, especially in the Baltic Sea Region, where this concept has been very popular. Examples have been presented in Section 3.4.

A common feature of all these initiatives relates to the need for monitoring the performance of the relevant transport corridors in terms of pre-specified qualities. Although most of these projects define a set of indicators to be used for monitoring performance either explicitly (Mertel and Sondermann, 2007; Corridor A, 2011; Fastén and Clemedtson, 2012; Wålhberg et al., 2012; Pettersson et al., 2012; and Öberg, 2013) or implicitly (TransBaltic, 2012; Friedrich, 2012; and Stenbæk et al., 2014), very few propose a performance monitoring methodology.

Given that the monitoring method is unrelated to the 'greenness' of the corridor, which only affects the indicators being observed, the search for monitoring methodologies can be extended to all kinds of transport corridors. Although the literature on corridor assessment and evaluation is quite extensive, very few articles can be found in the area of continuous monitoring of a multimodal transport corridor. They are either unimodal (road) in scope (Ramani et al., 2011a; Dehghanisanij et al., 2012; Muench et al., 2012) or multimodal but focusing on specific transport chains with no aggregation at corridor level (Regmi and Hanaoka, 2012). This kind of aggregation is only attempted in specialised reports produced by international financial institutions like the World Bank and the Asian Development Bank. These studies, however, are rather limited in scope mainly being designed to address bottlenecks related to transport infrastructure and operations between developing countries such as excessive delays in nodes, customs clearance, etc. (Raballand et al., 2008; ADB, 2013).

With regard to green corridors per se, the EU-funded project SuperGreen developed a methodology that consists of decomposing the corridor into transport chains, selecting a sample of typical chains, benchmarking these chains through a set of Key Performance Indicators (KPIs), and then aggregating the chain-level KPIs to corridor-level ones using proper weights for the averaging (refer to Section 3.6.2). The early results of applying this methodology on six of the selected SuperGreen corridors were presented in Psaraftis and Panagakos (2012). Later on, Panagakos (2012) proposed selecting the sample chains on the basis of specialised studies similar in nature to those foreseen by the EU legislators for the rail freight corridors and, by extension, for the TEN-T core network corridors. It proved, however, that these studies either focus on existing and planned infrastructural issues or provide an unbalanced coverage of the corridor in terms of the traffic figures per mode (Herrero, 2015). A new methodology was in need. The proposed solution calls for constructing the corridor sample on the basis of transport model results that usually provide a coherent picture of all flows along the corridor irrespective of mode. It was decided to pilot-test this methodology along the GreCOR corridor, a road, rail and maritime transport corridor extending from Oslo to Randstad. Output of the Danish National Traffic Model was used for selecting the sample chains. The presentation of the methodology employed and the results achieved in the GreCOR case study is the general aim of this chapter.

The specific objectives of the chapter are:

(i) to briefly present the methodological approaches identified in the literature for monitoring the performance of a transport corridor,
(ii) to propose a new method using transport model results for the construction of a representative chain sample that forms the basis for assessing the performance of a freight corridor on regular intervals and,
(iii) to present the results of applying this method on the GreCOR case study.

The main contribution of this work is a new freight corridor assessing methodology that combines the merits of a model-based approach in selecting typical transport chains and a study-based approach in estimating the KPI values. The insights provided here can be useful to practitioners who are engaged in implementing corridor schemes as a means of improving the sustainability of freight logistics. They can also benefit researchers interested in advancing policy instruments, as well as educators interested in addressing sustainability in transport related infrastructure and operations.

The rest of this chapter is organised as follows. The following section is devoted to methodological issues. In order to set the scene, it starts with a brief review of previous research and practices on corridor performance monitoring. It discusses the difficulties encountered when applying the study-based approach and closes with the proposed model-based approach for selecting the typical corridor chains. Section 5.3 covers the application of the proposed method on the GreCOR case. After providing an overview of the GreCOR corridor itself, the section presents the construction of the chain sample, the estimation of the KPI values and their aggregation. The chapter closes with a summary of the main conclusions reached and suggestions for possible future improvements.

# 5.2 Methodological considerations

## 5.2.1 Literature review

Albeit mainly a transportation theme, the corridor concept is a multidimensional affair striving to integrate diverse sectoral policies in transport, housing, economic development and environmental protection (Priemus and Zonneveld, 2003; Witte et al., 2013). As such, assessing a transport corridor is not an easy task. The relevant literature is extensive and covers a range of perspectives. In terms of principal focus, an assessment can be policy-related (Yang et al., 2009; Boarnet, 2010), a macro-level examination (Regmi and Hanaoka, 2012) or a micro-level one (Ramani et al., 2011a). In terms of scope, it can be unimodal (Woroniuk et al., 2013; Loro et al., 2014) or multimodal (Janic, 2008; Beresford et al., 2011). In terms of subject, it can study the effects of infrastructural (EC, 2014d) or operational (Nair et al., 2008) parameters on service performance. In terms of timing, it can be a pre-feasibility (Bejleri et al., 2002), ex ante (Patterson et al., 2008; Regmi and Hanaoka, 2015), on-going (refer to Table 14) or ex post (Forkenbrock and Foster, 1990; Lein and Day, 2008) evaluation. Yet in terms of specialisation, a corridor assessment may concern spatial planning and land use (Witte et al., 2013), the design of infrastructure and components (Ballis and Golias, 2002), demand modelling and forecasting (Cullinane and Toy, 2000; Feo-Valero et al., 2011; Brooks et al., 2012), sustainability issues (Jeon and Amekudzi, 2005; Bueno et al., 2015), safety (Chen et al., 2011; Bagheri et al., 2014), security and resilience (Miller-Hooks et al., 2009; Turnquist and Rawls, 2010; Masiero and Maggi, 2012), effects on wildlife (Alexander and Waters, 2000) or even business models and logistics arrangements (Groothedde et al., 2005; Kuo et al., 2008; Lethinen and Bask, 2012; Poulsen et al., 2016).

**Table 14. Main features of selected bibliography**

| Author (Year) | Road | Rail | Sea | Focus | Infr. | Oper. | Corr. | Chain | Aggr. | Approach | Data source | Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A. Articles** | | | | | | | | | | | | |
| Ramani et al. (2011a) | √ | | | Micro | √ | √ | 1 | | √ | Multi-attribute utility theory | Data of the Texas DoT | US |
| Dehghanisanij et al. (2012) | √ | | | Micro | √ | | 1 | | √ | Assessment framework | Data of the Virginia DoT | US |
| Muench et al. (2012) | √ | | | Macro | √ | √ | 7 | | √ | Greenroads framework | Site visits, survey of studies | US |
| Regmi & Hanaoka (2012) | √ | √ | √ | Macro | √ | √ | 2 | | | Cost-time-distance | Site visits, studies, questionnaire | Asia |
| **B. Reports** | | | | | | | | | | | | |
| Arnold (2006) | √ | √ | √ | Macro | √ | √ | | √ | √ | Cost-time-distance | | |
| Raballand et al. (2008) | √ | | | Macro | √ | √ | 1 | √ | | Cost-time-distance | Drivers' forms, studies, interviews | Africa |
| ICF International (2009) | √ | √ | | Micro | | √ | 23 | | | Specialised model results | Official statistics | US |
| ADB (2013) | √ | √ | | Macro | √ | √ | 6 | √ | √ | Cost-time-distance | Drivers' forms | Asia |
| ETC (2014) | √ | √ | √ | Macro | √ | √ | 1 | √ | | PESTL analysis, Cost-time-distance | Official statistics, studies, interviews | EU |
| EC (2014d) | √ | √ | √ | Macro | √ | | 1 | | | Gap analysis, bottleneck identification | Official statistics, studies | EU |
| **C. Research works** | | | | | | | | | | | | |
| Fastén & Clemedtson (2012) | √ | √ | √ | Macro | | | 1 | √ | | Assessment framework | Interviews | EU |
| Panagakos (2016b) | √ | √ | √ | Macro | √ | √ | 6 | √ | √ | Assessment framework | Studies, interviews | EU |
| Herrero (2015) | √ | √ | √ | Macro | √ | √ | 1 | √ | √ | Assessment framework | Studies | EU |

(Source: Own compilation)

For the purposes of the present chapter, coverage will be restricted to performance monitoring methods which are suitable for sustainability assessments and have been published during the last ten years. For the sake of simplicity, they are listed in Table 14 grouped by document type (journal articles, reports or research studies). In addition to their modal scope, principal focus and subject (infrastructure/operations), Table 14 indicates the number of corridors examined, whether the corridor is decomposed into transport chains, whether a KPI aggregation method is provided, as well as other areas of interest like the approach, data sources used and geographical coverage.

Ramani et al. (2011a) present a performance measurement methodology for the evaluation of sustainable transportation. It is designed for highway corridor planning and addresses the five goals of the Texas Department of Transportation (reduce congestion; enhance safety; expand economic opportunity; preserve the value of transportation assets; and improve air quality). Performance against these goals is measured through 12 indicators. The multi-attribute utility theory (MAUT) approach is used for normalising KPI values and aggregating them into a sustainability index using weights developed through a Delphi process in a workshop setting. The methodology is of a micro-level focus as it was applied on a 15-mile section of US-281 in San Antonio, Texas, which was further divided into 4 shorter links. The methodology exhibits a number of interesting features in relation to the indicators selected, such as:

- the definition of 'travel-time index' as the ratio between peak-period travel times and off-peak travel times for a given road section,
- the definition of the reliability indicator as the extent to which the 95th percentile travel time for a road section exceeds the mean travel time,
- the inclusion of a land-use balance indicator having its highest value when all three categories of land use – residential, commercial/industrial, and institutional/public – are equally distributed and its lowest value when all land uses are concentrated into any one category,
- the inclusion of a truck throughput efficiency indicator that combines truck volumes and speeds as an output,
- the inclusion of an indicator expressing the possibility of adding lanes within the land already acquired solely for the purpose of

highway construction (right-of-way), and

- the calculation of the emission and accident indicators per lane-mile of infrastructure rather than per vehicle miles travelled (VMT) in order to penalise excess VMT.

Dehghanisanij et al. (2012) also have a micro-level focus and further restrict their examination in condition indicators for different highway infrastructure assets. They propose a method for translating performance indicators like pavement cracking or rutting into corridor 'health' indicators. Instead of aggregating the health indicators of the assets comprising a corridor (e.g. pavement, bridges, facilities, etc.) into a health rating for each asset and then combining them into a corridor health rating, the method aggregates similar health indicators of different assets into the associated corridor health indicators (e.g. for structure, function, safety, etc.) before developing the corridor health rating.

Muench et al. (2012) follow a different approach to assess the sustainability of 7 road projects funded by the US Federal Lands Highway Program. They apply the Greenroads rating system for roadway design and construction. This is a collection of sustainability best practices, divided into two sets: required and voluntary. Each voluntary practice is assigned a point value (1 to 5 points), depending on its impact on sustainability. Depending on the sum of points a project scores against the voluntary practices, it earns a certification level (evergreen, gold, silver, certified or none).

Regmi and Hanaoka (2012) assess the infrastructure and operational status of two corridors in North-East and Central Asia that offer maritime, road and rail freight services. A time-cost-distance (TCD) approach[28] is used for identifying infrastructural and administrative bottlenecks and for assessing and comparing the performance of the corridors. The paper is based on an extensive data collection effort involving three field visits and a questionnaire survey among transport officials, transport service providers and freight forwarders. However, it treats each corridor as a single transport chain consisting of a series of consecutive legs performed by different modes. No aggregation is required for such a setting.

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[28] The TCD approach consists of composing a chart that displays the changes of time or cost over distance. Distance occupies the horizontal axis, while time or cost occupies the vertical axis.

Arnold (2006) outlines the methodology used by the World Bank for assessing the performance of a transport corridor. On the basis that a corridor is generally composed of several alternative routes, the method focuses on measuring the performance of each route. In the absence of more aggregate information, which is usually the case, a sample needs to be constructed. Although the document does not specify the composition of the sample, one can infer from the subsequent steps of the methodology that the sample is composed of transport chains. The indicators suggested are cost, time and reliability, while the time-cost-distance approach is proposed and described in detail (refer to Section 3.6.1). A reference to supply chain analysis leads to the assumption that this is how the chain-level indicators are transformed into route-level ones. Route problems identified through benchmarking are translated into performance deficiencies at the link and node level. The environmental dimension is absent and no attempt is made to compute indicators at the corridor level.

Although Raballand et al. (2008) is a World Bank report, it applies a much simpler version of the methodology proposed by Arnold (2006). The report examines the Northern Corridor connecting the port of Mombasa, Kenya with a number of countries in Sub-Saharan Africa. The analysis is restricted to the transit time and reliability of two road connections (chains), Mombasa (KE) to Kampala (UG) and Mombasa (KE) to Kigali (RW), as well as the cargo dwell time in the port of Mombasa. The report highlights the serious difficulties encountered in data collection.

The objective of ICF International (2009) is the comparison of the fuel efficiency of rail and truck on specific corridors. As such, it lies outside the core interest of this chapter. However, it is included in this review because of the approach it follows in selecting the corridors examined. Each corridor is associated with an origin-destination (OD) pair, a route, a commodity, and a service offering, from which rail and truck equipment is configured. The criteria used in the selection of corridors include:

- Corridors that had comparable rail and truck mode shares;
- Corridors that were representative in terms of freight activity (measured in ton-miles);
- A mix of short, medium, and long-distance corridors;
- A mix of different commodities (and thus different equipment types);
- A mix of geographic regions.

The Corridor Performance Measurement and Monitoring (CPMM) methodology applied by the Asian Development Bank in the framework of its Central Asia Regional Economic Cooperation (CAREC) Program is the most advanced and complete one found in the literature (ADB, 2013). The methodology, applied on 6 corridors, is based on the TCD approach. The indicators followed are: (i) the cost incurred to travel a corridor section, (ii) the speed to travel along a corridor, (iii) the time it takes to cross a border crossing point, and (iv) the cost incurred at border crossing clearance. Data are collected through CAREC's partnership with 13 national road carrier associations directly from drivers and freight forwarders using actual commercial shipments as samples. Each partner association randomly selects 20-30 drivers per month, who fill up an especially designed driver's form for cargoes passing through one of the 6 CAREC corridors. These data are entered by the relevant association into TCD Excel sheets, which are transmitted to ADB for analysis after being validated by field consultants. In order to be aggregated at the sub-corridor and corridor level, the TCD data need to be normalised. Normalisation is done at the level of a 20-tonne truck in the case of road transport or a twenty-foot equivalent unit (TEU) in the case of rail traveling 500 kilometres. Average cost and speed of transport are calculated through the use of cargo tonnage or number of TEUs as weights.

The ETC (2014) and EC (2014d) reports for the Scandinavian-Mediterranean (ScanMed) RFC and CNC respectively are exemplary of the specialised Transport Market Studies undertaken for all such European corridors. Refer to Section 5.2.2 for a brief description of these reports.

In addition to proposing a set of KPIs to be followed, the East-West Transport Corridor (EWTC) project suggests limiting the analysis to a number of services along the corridor that need to be wisely selected (Fastén and Clemedtson, 2012). The methodology proposed by EWCT has been described in Section 3.6.1. Albeit sensible and practical, it aims to assess selected corridor components (services) rather than the corridor as such.

The SuperGreen methodology for corridor benchmarking has evolved through several improvements since its inception in 2011. The original scheme, presented in Section 3.6.2, was built around the concept of decomposing the corridor into transport chains, selecting a sample of typical chains, benchmarking these chains using a set of KPIs, aggregating the chain-level KPIs to corridor-level ones, and aggregating the corridor-level KPIs into a single corridor rating using proper weights for the averaging.

This second level of aggregation was soon abolished on the grounds that the weights needed are very much user-dependent constituting a political issue best left for policy makers to decide. Initially the selection of the typical chains was based on the so-called ‘critical segment’ of the corridor, the link containing the major geographical barrier of the corridor, on the hope that such a link would have been studied better than other parts of the corridor leading to more detailed data. Based on the early results of SuperGreen, Panagakos (2012) suggested replacing the critical segment as the basis for the sample construction with a corridor study similar in nature to the Transport Market Study foreseen by the RFC Regulation of the EU. He also suggested considering this sample as the ‘basket’ of transport chains that would be used for monitoring the performance of the corridor on an annual basis, in the same way the Consumer Price Index is calculated around the world on the basis of a ‘basket’ of goods and services. This study-based approach was applied by Herrero (2015) on the ScanMed corridor. Refer to Section 5.2.2 for more details.

### 5.2.2 The study-based approach

Two documents were reviewed by Herrero (2015) to identify the information needed for constructing the sample of typical chains along the ScanMed corridor. The first one is the Transport Market Study (TMS) of the ScanMed Rail Freight Corridor (ETC, 2014). Its main objective is to provide the corridor’s Infrastructure Managers with a detailed analysis of freight market development and an estimate of future customer demand. It also provides recommendations for operational and organisational improvements of the rail freight traffic along the corridor.

The TMS covers all three modes (road, rail, sea), albeit at varying degrees of detail. In terms of rail freight transport, it distinguishes between the so-called ‘corridor trains,’ which start and end in the corridor catchment area and cross at minimum one corridor border, and the ‘additional trains,’ which start or end within the corridor area, cross at least one corridor border and enter/exit the corridor area. It further identifies the most important OD pairs of corridor trains in 2012. The yearly trains were calculated by extrapolating the number of trains observed during two weeks of the year, as provided by the Infrastructure Managers along the corridor. For the Oslo – Hannover segment that overlaps with the GreCOR corridor of Section 5.3, the TMS suggests 7 connections: Alnabru – Trelleborg; Alnabru – Älmhult; Malmö – Taulov; Malmö – Maschen; Gothenburg – Hannover; Fredericia – Maschen and Taulov – Hamburg. The only information provided on these connections is the sum of the trains between each OD pair in both directions.

In relation to road freight traffic, the TMS analyses the ETISPLUS 2010 database and identifies for each pair of corridor countries and each direction the 3 OD pairs within the RFC catchment area with the highest volume. A total of 34 connections are suggested for the Oslo – Hannover segment. It turns out that all these connections are combinations between two cities from each country (Oslo and Sarpsborg from NO; Gothenburg and Malmö from SE; Kolding and Aarhus from DK; Hamburg and Lübeck from DE). The freight volume in tonnes is the only information provided. No maritime connections are suggested by the TMS.

The second study examined is the Multimodal Transport Market Study (MTMS) of the ScanMed Core Network Corridor (EC, 2014d). The objective of this study is to evaluate the future requirements towards the transport infrastructure of the ScanMed CNC. The MTMS examines the capacity of the future infrastructure along the corridor in light of the expected traffic volume in 2030. In order to avoid overlaps with the RFC TMS which focuses on interoperability improvements and other operational aspects, the MTMS concentrates on infrastructural issues. In this respect it goes into great detail in relation to infrastructural bottlenecks which, however, are of limited use for the application at hand.

It follows that the data provided by these two studies is rather scarce and incoherent for the intended use of creating a comprehensive chain sample for monitoring the performance of a corridor. The main difficulties encountered by Herrero (2015) relate to: (i) serious incompatibility problems when combining data from different databases, and (ii) the complete absence of information on maritime chains, for which the author had no option but using model results. Although he managed to estimate KPI values for the ScanMed corridor, it became clear that a higher level of consistency would require a different approach.

### 5.2.3 The model-based approach

The selection of a sample of typical chains along a corridor requires detailed information on the actual volumes and types of goods transported as well as the vehicles using the corridor facilities. In general, this type of information can either be extracted from existing studies (study-based approach) or sourced in the flow results of a transport model (model-based approach).

In the study-based approach, the sample selection is based on the analysis of existing transport plans and feasibility studies of single infrastructure projects or operational/regulatory measures undertaken mostly at national and sometimes at regional level. The main advantage of this approach is that very often such studies are based on actual data rather than on model assumptions or other analytic relations. Furthermore, in most cases these studies have been approved by the contracting authorities and the contained information is consistent with the national plans.

On the other hand, as the Herrero (2015) analysis has confirmed, the study-based approach suffers from fragmented and incomplete coverage of the corridor. Particularly segments lying outside the 'hot spots' of the corridor are often missing or covered only superficially. In some cases the relevant material might be unavailable due to confidentiality restrictions. The most frequent problem, though, is the lack of coherence and harmonisation among corridor segments, particularly when it comes to forecasts of future traffic conditions that need to be based on a set of assumptions that might differ from case to case.

In the model-based approach, the sample is constructed on the basis of traffic flows that result from a transport model. Models are deliberately simplified representations of reality enabling the quick and low-cost exploration of the consequences of a particular intervention by avoiding unnecessary details while (hopefully) capturing the determining features of the system under investigation (Bonsall, 1997). The strengths and weaknesses of this approach derive from the nature of modelling. On the positive side, they provide insight into complex systems by understanding simpler settings that resemble them, thus, offering a platform for testing challenging ideas. Their main advantage for the present application relates to their ability to estimate traffic even in the absence of data, which leads to a comprehensive and coherent picture of all flows on the corridor for each segment.

On the negative side, their simplified character may lead to estimates that differ from reality. Of course accuracy improves with a better calibration of the model but this requires extensive use of observed traffic load data which, in turn, suffers from problems similar to those of the study-based approach. Land use aspects, for example, are often not well integrated in demand forecasting models. In addition, model results may differ from approved national plans, which might lead to resistance from certain stakeholders.

The new methodology proposed by this thesis combines these two approaches. More specifically, it calls for:

(i) decomposing the corridor into transport chains,
(ii) selecting a sample of typical chains on the basis of cargo flows and other characteristics resulting from a transport model,
(iii) calculating the values of a number of pre-determined KPIs for each and every chain of the sample on the basis of specialised studies and/or information retrieved directly from the stakeholders involved, and
(iv) aggregating the chain-level KPIs to corridor-level ones through a set of weights also determined by the model results.

## 5.3 Method implementation on the GreCOR case

### 5.3.1 The GreCOR corridor

GreCOR – Green Corridor in the North Sea Region – is an Interreg IVB project that during the period 1/1/2012 – 30/6/2015 promoted the development of a co-modal transport corridor in the North Sea Region. The road, rail and maritime networks comprising the GreCOR corridor appear in Figure 40. However, this initial intension had to be revised in view of two other considerations.

The first one relates to the specific model that is selected to provide the necessary information. The international character of GreCOR calls for a model covering effectively all corridor segments. In this respect, the European TRANS-TOOLS model (Ibánez-Rivas, 2010) would have been an ideal source of information. However TRANS-TOOLS was being updated at the time and its completion schedule was not compatible with the time plan of the GreCOR project. The Danish National Traffic Model (LTM) was the second best option. By definition, the accuracy of the results of a country's national model drops with the distance from this country. In 2010, the base year of LTM, the share of Denmark in the external trade of the UK was in the order of 1% for both imports and exports. In addition, all Scandinavian countries (DK, SE, NO, FI) represented less than 9% of the imports[29] and

[29] About 60% of this figure concern exports of energy products from Norway to the UK, which are not captured by LTM anyway.

5% of the exports of the UK (Eurostat, 2011). It was, thus, decided to exclude the UK from the analysis. By the same token, the Norwegian part Stavanger-Oslo was also excluded limiting the analysis to the Oslo-Randstad segment.


**Figure 40. GreCOR corridor - Intended coverage by mode**

(Source: GreCOR, 2014)

Secondly, in December 2013, almost two years after the commencement of GreCOR, the TEN-T CNCs were adopted as part of a major overhaul of the EU transport infrastructure policy. The central role of the CNCs in the European transport network necessitated the reviewing of all extant corridor schemes. In fact, the Connecting Europe Facility (CEF) Regulation (EP&C, 2013b) demands the re-alignment of the RFCs in line with the corresponding CNCs. In view of this development, the Oslo-Randstad segment of the corridor was split into two parts: Oslo-Hannover and Hannover-Randstad. The former was compared to the ScanMed CNC linking the major urban centres in Germany to Scandinavia and the Mediterranean, while the latter was related to the North Sea-Baltic corridor joining the Baltic Sea Region in northeast with the four largest European ports (Rotterdam, Antwerp, Hamburg and Amsterdam) in the low countries of the North Sea Region.

When the GreCOR routes, modified to reflect the alignment of the ScanMed and North Sea–Baltic CNCs, were introduced into the zonal system of LTM, the GreCOR catchment area of Figure 41 was produced. The disproportionate coverage of German, Dutch and Belgian regions in comparison to the Scandinavian areas is due to the much broader definition of LTM zones outside Scandinavia.

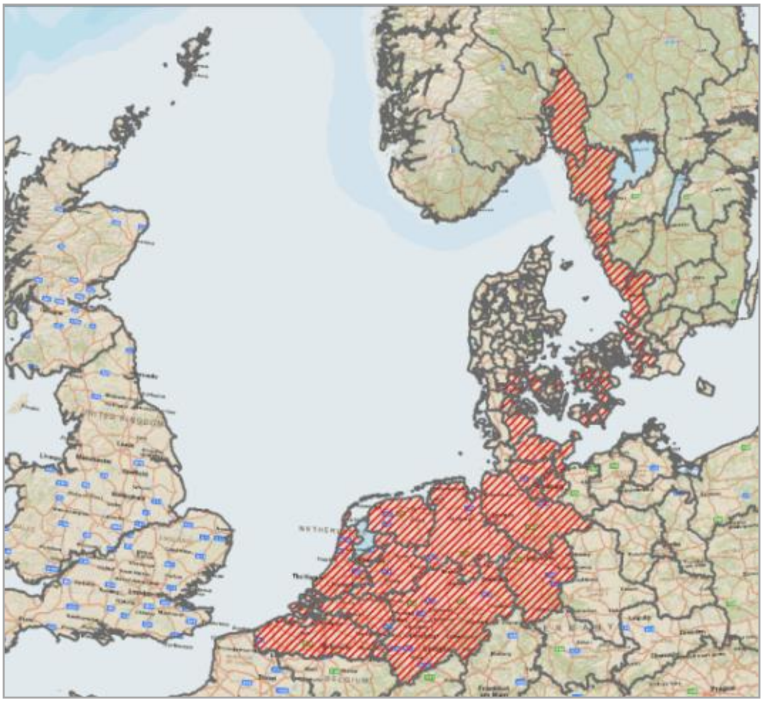

**Figure 41. GreCOR corridor - Catchment area after adjustments (marked in red)**

(Source: Own compilation)

It is worth mentioning, however, that the exclusion of a node from the catchment area does not preclude its use by a corridor chain. For example, this would allow Belgian cargoes to Oslo by rail to be routed via Hallsberg (SE) or Dutch cargoes to Copenhagen by ship to be routed via Esbjerg (DK).

## 5.3.2 Data structure

The LTM model handles all types of goods movement related to Denmark, i.e. national transports within Denmark; international transports to and from Denmark; transit transports through Denmark; and transport which may be transferred to transit through Denmark, for example by a new fixed link across the Fehmarn Belt. This last feature is important as it extends coverage to flows between Scandinavia and Europe that presently bypass Denmark. The world is divided in 351 zones, of which 176 are located in Denmark (at sub-municipality level), 119 in Europe, and 56 in the rest of the world.

**Table 15. Composition of the chain matrix by commodity, 2010**

| ID | Commodity | Original matrix | | Final matrix | |
|---|---|---|---|---|---|
| | | Tonnes | Chains | Tonnes | Chains |
| 1 | Products of agriculture, fish, etc. | 40,574,668 | 245,831 | 1,475,663 | 2,760 |
| 2 | Coal and lignite | 19,571,829 | 7,646 | 130,093 | 84 |
| 3 | Iron ores and non-ferrous metal ores | 13,199,566 | 76,006 | 336,673 | 1,339 |
| 4 | Food products, beverages and tobacco | 30,190,571 | 236,557 | 2,009,451 | 3,134 |
| 5 | Textiles and leather products | 3,650,520 | 200,150 | 270,242 | 3,096 |
| 6 | Wood and products of wood and cork | 45,488,712 | 223,744 | 1,466,753 | 2,811 |
| 7 | Coke and refined petroleum products | 62,995,960 | 27,862 | 3,449,555 | 486 |
| 8 | Chemicals, chemical products, etc. | 36,868,486 | 184,906 | 2,596,137 | 2,751 |
| 9 | Other non-metallic mineral products | 15,560,549 | 203,555 | 789,124 | 2,616 |
| 10 | Basic metals, fabricated metal products | 23,458,563 | 215,847 | 1,034,014 | 3,501 |
| 11 | Machinery and equipment | 18,305,567 | 156,526 | 130,175 | 964 |
| 12 | Transport equipment | 4,744,573 | 125,491 | 323,634 | 815 |
| 13 | Furniture; other manufactured goods | 19,993,166 | 233,532 | 373,480 | 3,114 |
| 14 | Secondary raw materials and other wastes | 11,924,412 | 194,735 | 526,522 | 2,454 |
| 15 | Mail, parcels | 6,759,979 | 176,535 | 376,253 | 2,077 |
| 16 | Equipment utilised in the transport of goods | 249,571 | 16,093 | 26,621 | 123 |
| 17 | Household and office removal goods | 1,050,634 | 74,221 | 891 | 59 |
| 18 | Grouped goods | 2,862,862 | 99,080 | 392,971 | 2,198 |
| 19 | Unidentifiable goods | 0 | 0 | 0 | 0 |
| 20 | Other goods | 0 | 0 | 0 | 0 |
| 21 | Crude petroleum and natural gas | 99,275,548 | 7,945 | 1,201,714 | 101 |
| 22 | Fertilizer, chemical and natural | 8,581,166 | 95,220 | 53,964 | 1,116 |
| 23 | Stone, sand, gravel & other quarry products | 41,382,172 | 133,235 | 273,223 | 1,847 |
| | Total | 506,689,075 | 2,934,717 | 17,237,155 | 37,446 |

(Source: Own compilation)

The commodities covered by LTM appear in Table 15 according to the nomenclature of the standard goods classification for transport statistics (NST 2007). In terms of modes, the model is designed to handle road, rail and maritime transport. For road transport, it distinguishes among 7 vehicle types ranging from light goods vehicles to articulated trucks. Three configurations are used for rail transport (conventional train, short wagon train and a combined truck-on-train arrangement) and three more for maritime transport (conventional dry/liquid bulk carrier, containership and a Ro/Ro – ferry – ship).

LTM produces three types of freight flows: (i) between the producer (P) and consumer (C) in the so-called PC-matrix, (ii) the above PC flows broken down into combinations of up to three OD (origin-destination) legs in the so-called chain matrix, and (iii) the separate OD legs in the so-called OD-matrix. The chain matrix is the output type best suited to the present application. Each entry of the chain matrix database corresponds to a transport chain. There are 25 different types of transport chains featuring 1, 2 or 3 legs each. Five of them are 1-leg chain types, all concerning road transport:

Type 1: ‘No crossing’ refers to road chains between Denmark and other Scandinavian countries, irrelevant to a future Fehmarn Belt fixed link;

Type 2: ‘Land border’ refers to road chains crossing the land border between Denmark and Germany;

Type 3: ‘Ferry’ refers to road chains connecting Denmark to locations south of the Fehmarn Belt, which involve the use of a ferry;

Type 5: ‘Transit DK’ refers to road chains between origins/destinations outside Denmark that cross the country in transit;[30] and

Type 6: ‘Direct ferry’ refers to road chains between origins/destinations outside Denmark that use a direct Ro/Ro connection bypassing Denmark.

[30] Chain type 4 of LTM refers to the Fehmarn fixed link. It is purposely omitted from this analysis as it consists of chains that have been counted for already in the other types.

Twelve chain types consist of 2 legs but they all refer to domestic flows within Denmark which are excluded from the analysis (refer to Section 5.3.3). The remaining 8 types relate to 3-leg chains, where the first and third legs are always road feeder services (coded as ‘1’ in the corresponding 3-digit chain type codes). The middle leg can be either one of the 5 road types listed above (111, 121, 131, 151 and 161) or one of rail (171), conventional ship (181) and Ro-Ro ship (191).

The results produced for each chain concern general information (commodity type, production zone, consumption zone, annual volume in tonnes, chain type, containerisation) and information pertaining to each of the legs comprising the chain (destination zone, destination terminal, mode, consolidation/deconsolidation, vehicle type and number of vehicles required to carry the annual flow).

The results used in this application are those of Year 2010, which is the latest base (model calibration) year. The composition of the chain matrix by commodity appears in Table 15, together with the corresponding cargo volumes and number of chains (under the ‘original matrix’ columns; the ‘final matrix’ ones are defined in Section 5.3.3 below). The database contains more than 2.9 million chains that conveyed almost 507 million tonnes in 2010.

### 5.3.3 Boundaries of the analysis

The analysis starts with setting boundaries that either reduce the size of the database or exclude irrelevant entries. The first restraint relates to the annual volumes of the cargo flows. A closer look at the records reveals a considerable number of chains with annual volumes very close to zero. Apparently this is due to the rounding specifications of the model (or lack of). In fact, about 60% of the entries concern chains with annual volumes below 1 tonne. Therefore, the introduction of a 1-tonne threshold in the annual volumes of freight flows can have a dramatic effect on the size of the database (reduces the number of chains to 1.2 million) without affecting the tonnage, which remains at about 507 million tonnes.

The second intervention relates to border crossing. Although not explicitly stated in the definition of green corridors, their international character is revealed in all projects of Section 3.4. In fact, both ScanMed and North Sea–Baltic CNCs that relate to GreCOR cross up to six borders in their full length. Aiming, once again, to a minimal intervention impact, the limit of at least one border crossing has been selected. The number of chains now drops to 635 thousand (47% reduction in relation to the latest size) and the total volume now sums to 396 million tonnes, reflecting a 22% drop.

The last restriction imposed concerns the relation of the chains under examination to the catchment area of the corridor. So far, the matrix contains chains of the following types:

(i) Totally irrelevant to GreCOR, e.g. Helsinki-Kaliningrad by ship;
(ii) Originating and ending outside the catchment area of GreCOR but touching the corridor, e.g. Aalborg-Vienna by truck;
(iii) Originating or ending within the GreCOR catchment area, e.g. Kolding-Verona by train; and
(iv) Originating and ending within the GreCOR catchment area, e.g. Gothenburg-Ghent by Ro/Ro ship.

With the exception of the first category, all other types of chains have a bearing on the performance of the corridor, the extent of which depends on the actual overlap of the specific route with the corridor network. In order to exclude the possibility of external distortions, it was decided to restrict the analysis to the so-called ‘corridor chains’ originating and ending within the GreCOR catchment area. The term ‘corridor chain’ is borrowed from the Transport Market Study of the ScanMed RFC (ETC, 2014), which follows exactly the same approach (refer to Section 5.2.2).

This restriction results in 37,446 chains transporting 17.2 million tonnes (refer to Table 15 under the ‘final matrix’ columns). These figures correspond to 1.3% and 3.4% of the initial values respectively. A less dramatic fall results for the chain figure (3.1%) if the flows below 1 tonne per annum are excluded. The percentage share of ‘corridor chains’ in international ones above 1 tonne by chain type is shown in Figure 42. An interesting observation relates to the fact that although Type 1 (1-leg, ‘no crossing’ road) exhibits the highest above average share, the corresponding Type 111 (3-leg, ‘no crossing’ road with feeder services at both ends) displays the lowest below average score. In fact, the same applies to all other road types at a lesser extent. This can be a proof that the design of the GreCOR catchment area (Figure 41) has succeeded in capturing the core services of the corridor, placing less emphasis on the feeder services from/to more remote areas. In any case, the 37,446 chains of the ‘final matrix’ cover all commodity groups and are still sufficient to ensure a well-designed sample, as they represent 100% of the international chains above 1 tonne in yearly volume that originate and end within the GreCOR catchment area.

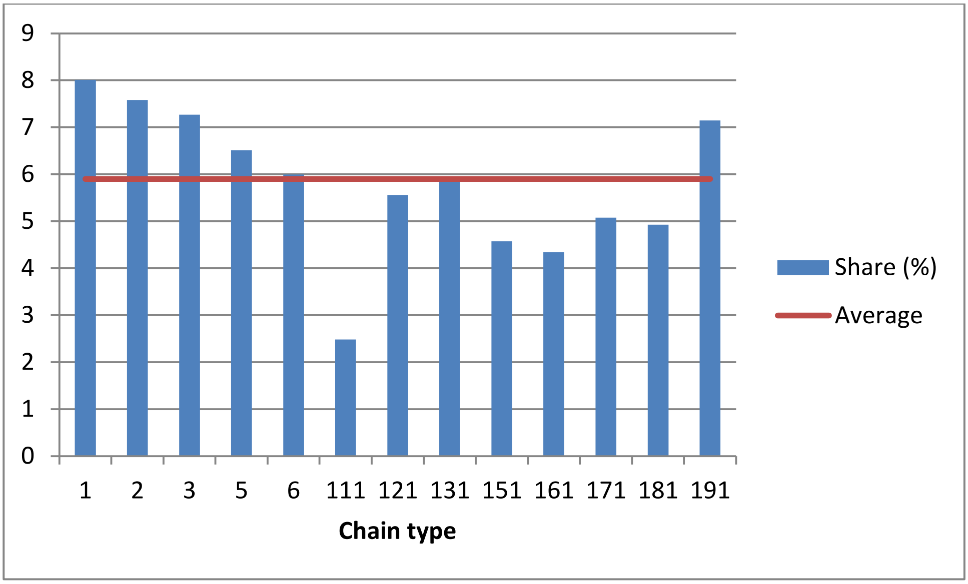


**Figure 42. Corridor chains as percentage of international (>1t) ones by chain type**

(Source: Own compilation)

## 5.3.4 Sampling criteria and method

The method developed for this application takes advantage of basically all information provided by LTM. As shown in Figure 43, the sample has four levels of aggregation. The corridor (Level 1) consists of commodity groups (Level 2), as it is this attribute that basically defines the modes, chain types and vehicles used. Commodity groups are further decomposed into sub-groups on the basis of chain type (Level 3). These sub-groups comprise of individual chains (Level 4).

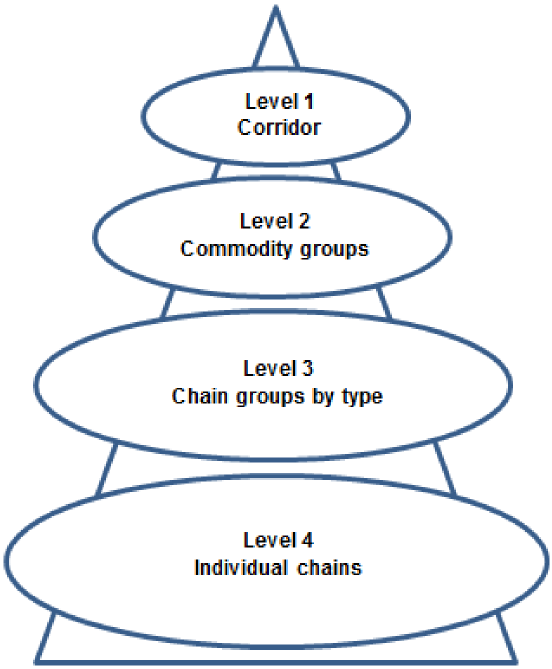


**Figure 43. Sample structure**

(Source: Own compilation)

Taking into consideration the requirements that cargoes impose on all aspects of transport operations, the commodities of Table 15 have been rearranged into 13 commodity groups as follows:

- Commodity 1 (agricultural products, fish, etc.) is kept separate due to its perishable nature. In fact, it is broken down into two commodity groups; Group 1A involving containers (most probably refrigerated) and Group 1B for non-containerised cargoes, which still need to be treated with extra care due to their sensitivity.
- Commodity 6 (wood & products) is divided in two parts. Non-containerised wood and wood products are kept as a separate commodity group as they require special handling equipment and facilities. Containerised wood and products are included in the group RestA, together with all other commodities using dry containers.
- Commodities 2, 3, 7, 14, 15, 21, 22 and 23 are kept separate because

they: (i) require special vehicles, (un)loading facilities and/or handling equipment; (ii) cannot be mixed easily with other cargoes; or (iii) entail special business arrangements.
- All other commodities (4, 5, 8, 9, 10, 11, 12, 13, 16, 17 and 18) are treated collectively because they can be mixed in the same vehicle. They are divided into two commodity groups; Group RestA involving containers and Group RestB concerning non-containerised cargoes.

As a next step, each one of the above commodity groups has to be decomposed into sub-groups by chain type. As a general principle, the chains included in the sample should be selected carefully to represent the range of services acquired by the shippers using the corridor. In doing so, the following criteria should be taken into consideration:

- The importance of a particular chain type relative to the total traffic. In general, higher importance should be reflected in a larger number of chains in the sample.
- The degree of homogeneity in the range of services provided under a particular chain type. Higher homogeneity should lead to fewer sample chains.
- The degree to which the various services covered by a chain type are subject to different influences and pressures in relation to the KPIs that will be used in the analysis. Higher sensitivity differences require more chains in the sample.
- The likelihood that a particular service will continue to be available for a reasonable period of time. Unstable services should be avoided.
- The extent to which a service can be defined and described clearly and unambiguously to ensure constant quality of service over time. Inadequately defined services should be avoided.

**Table 16. Sample design for Commodity group 22 (fertilizers)**

| Chain type | | Model results | | | | Corresponding sample | | |
|---|---|---|---|---|---|---|---|---|
| ID | Description | Annual tonnes | No of chains | Average distance | Tonne*km | No of chains | Adjusted tonnes | Adjusted tonne*km |
| 1 | 1 leg; road 'no crossing' | 2,250 | 9 | 453 | 1,019,240 | | | |
| 2 | 1 leg; road 'land border' | 18,462 | 100 | 502 | 9,275,328 | 1 | 21,259 | 10,889,129 |
| 3 | 1 leg; road 'ferry' | 3,515 | 82 | 564 | 1,980,694 | 1 | 3,601 | 2,047,783 |
| 5 | 1 leg; road 'transit DK' | 547 | 2 | 1,087 | 594,561 | | | |
| 6 | 1 leg; road 'direct ferry' | 86 | 1 | 780 | 67,088 | | | |
| 111 | 3 legs; road / road 'no crossing' / road | 47 | 10 | 423 | 19,870 | | | |
| 121 | 3 legs; road / road 'land border' / road | 7,335 | 422 | 664 | 4,867,086 | 4 | 8,904 | 6,321,915 |
| 131 | 3 legs; road / road 'ferry' / road | 4,539 | 428 | 633 | 2,874,265 | 4 | 5,971 | 3,600,961 |
| 151 | 3 legs; road / road 'transit DK' / road | 1,522 | 12 | 943 | 1,434,959 | | | |
| 161 | 3 legs; road / road 'direct ferry' / road | 1,433 | 13 | 507 | 726,696 | | | |
| 171 | 3 legs; road / rail / road | 4,642 | 16 | 982 | 4,556,469 | 1 | 4,642 | 4,556,469 |
| 181 | 3 legs; road / conventional ship / road | 9,588 | 21 | 684 | 6,555,747 | 1 | 9,588 | 6,555,747 |
| | Total Commodity group 22 | 53,964 | 1,116 | 630 | 33,972,003 | 12 | 53,964 | 33,972,003 |

(Source: Own compilation)

Commodity group 22 (fertilizers) is used here as an example. The 1,116 chains of Table 15 for this commodity are broken down by chain type in Table 16. The aim is to express the distribution of model chains among the various types with as few sample chains as possible. It is obvious that the fit depends on the number of chains to be selected. Having in mind a total sample in the order of 100 chains, we set a tentative target at about 10 chains per commodity group. In the fertilizer case, this would roughly mean selecting one chain per hundred. So, chain types 2 and 3 are represented in the sample with one chain each, while 4 chains are selected for each one of types 121 and 131.

Provided that the 10 first chain types of Table 16 (1 to 161) refer to road transport, the selection made so far would leave rail and maritime transport uncovered. Given that tonnage-wise both these types deserve to be represented in the sample, it was decided to add one additional chain in the sample for each one of these two types. The comparison between the model and sample chain distribution for the fertilizer group, shown in Table 16, is schematically depicted in **Error! Reference source not found.**.

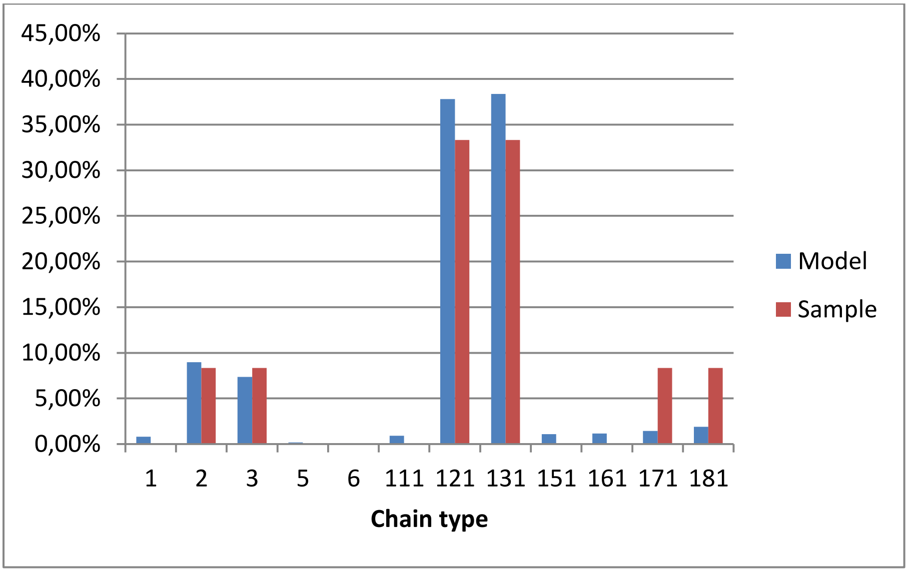


**Figure 44. Model and sample distributions of chains for Commodity group 22 (fertilizers)**

(Source: Own compilation)

Once the sample has been designed, the weights (annual tonnages and tonne*km) need to be adjusted to reflect this design. This is done through allocating the weights of types not represented in the sample to the most closely related chain types in the sample under the assumption that their corresponding KPI evolution over time is similar. As such, the weights of Types 1 ('no crossing') and 5 ('transit DK') have been added to the figures of Type 2 ('land border') as the distinction is basically geographic, while the Type 3 ('ferry') weights have been increased by those of Type 6 ('direct ferry'). Similar adjustments have been made to the 3-leg road transport chains.

The next step is the selection of individual chains. Two types of chains will be presented here as examples of varying complication. The simpler one concerns Chain type 2 and relates to 1-leg road voyages crossing the DK-DE land border. One chain has to be selected out of the 100 connections of Table 16.

The first criterion to be applied relates to the types of vehicles used in this trade. It appears that 86 out of the 100 journeys involve articulated trucks, leaving no room for doubts as for the vehicle type of the selected chain. A number of criteria deriving directly from the LTM results can be applied for the selection among the articulated truck journeys e.g. the origin with the highest number of connections (Utrecht, NL) or the highest annual volume (Fredericia, DK), the destination with the highest number of connections (Kolding-rural, DK) or the highest annual volume (Kolding-rural, DK), the connection with the highest annual volume (Fredericia, DK – Borken, DE) or the connection with an annual volume as close as possible to the average tonnes per chain as derives from Table 16 (Borken, DE – Køge, DK). In this case, the link with the highest tonnage, Fredericia-Borken, was selected (appears in Figure 45 in light blue).

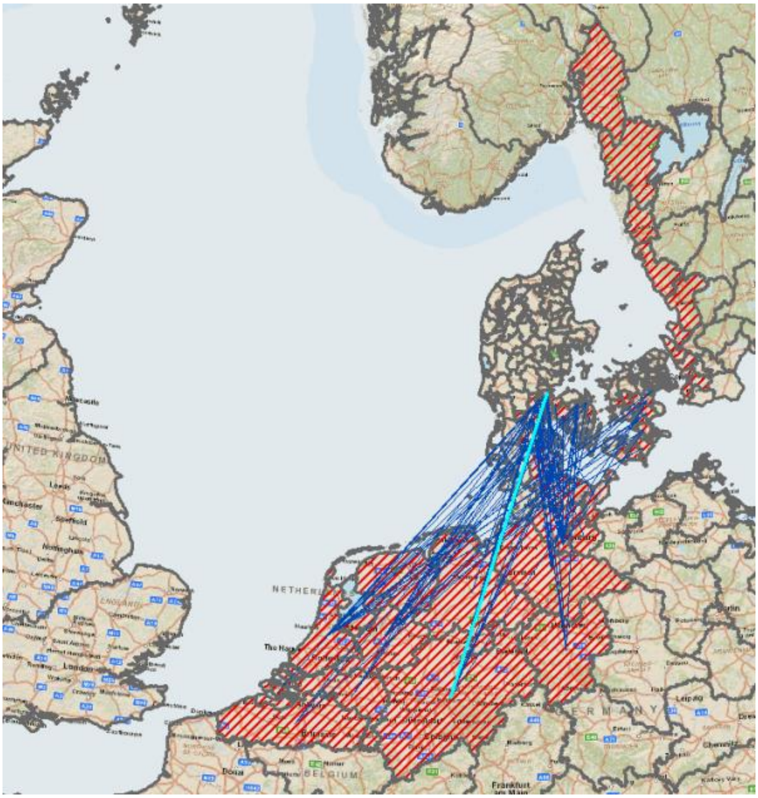

**Figure 45. One-leg 'land border' road chains for Commodity group 22 (fertilizers)**

(Source: Own compilation)

The more complicated example concerns Chain type 131, which combines a ferry-related middle leg with feeder services at both ends. Four chains need to be selected among the 428 OD pairs of Figure 46. The composition of the fleets involved in all 3 legs is shown in Table 17. It is of no surprise that only articulated trucks are employed for the middle leg. In order to achieve the best possible representation, the selected chains should involve one 3.5-12t and three 12-18t trucks for Leg 1. Similarly, Leg 3 should be performed by one light truck, one 3.5-12t and two 12-18t vehicles. The highest volume connections that fulfil these restrictions are the starting point for selecting the sample chains. The final set takes also into consideration the need to avoid selecting chains involving the same ferry link. The selected chains are marked in light blue in Figure 46.

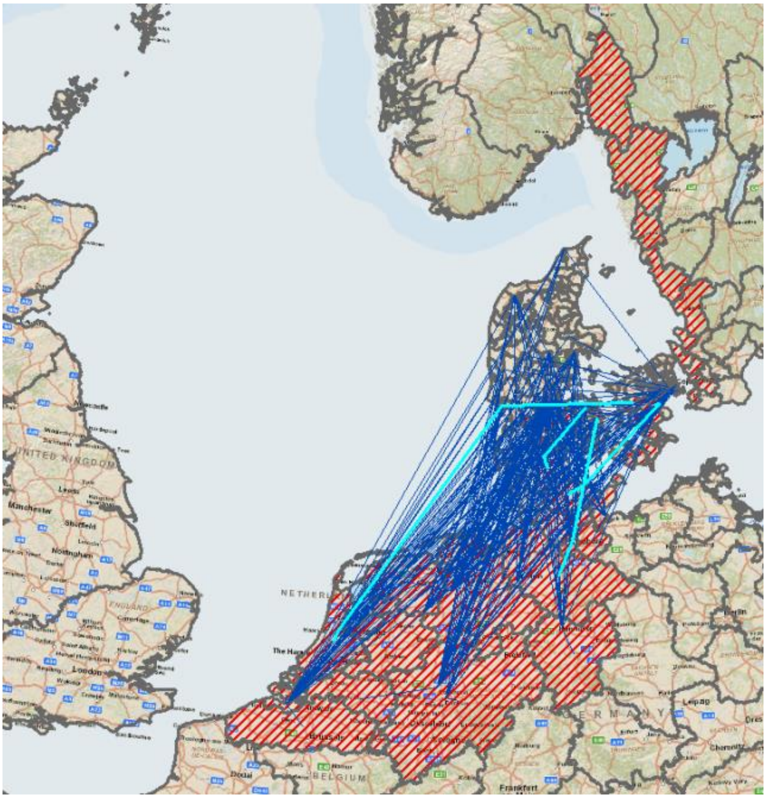


**Figure 46. Three-leg 'ferry' road chains for Commodity group 22**

(Source: Own compilation)

**Table 17. Vehicle types involved in the 3-leg 'ferry' connections for fertilizers**

| | Leg 1 | | Leg 2 | | Leg 3 | |
|---|---|---|---|---|---|---|
| Vehicle type | Annual tonnes | No. of chains | Annual tonnes | No. of chains | Annual tonnes | No. of chains |
| Light goods vehicle | 310 | 26 | 0 | 0 | 436 | 66 |
| Truck 3.5-12 tonnes | 289 | 56 | 0 | 0 | 243 | 44 |
| Truck 12-18 tonnes | 1,374 | 261 | 0 | 0 | 1,249 | 235 |
| Truck 18-26 tonnes | 305 | 8 | 0 | 0 | 373 | 10 |
| Truck with trailer 12-18 tonnes | 765 | 40 | 0 | 0 | 780 | 39 |
| Truck with trailer >18 tonnes | 357 | 6 | 0 | 0 | 411 | 7 |
| Articulated truck | 1,137 | 31 | 4,539 | 428 | 1,045 | 27 |
| Total | 4,539 | 428 | 4,539 | 428 | 4,539 | 428 |

(Source: Own compilation)

In a similar way all 156 individual chains comprising the GreCOR sample were selected. The 12 chains of the sample pertaining to fertilizers are presented in Table 18, while the entire sample appears in Appendix III.

### 5.3.5 KPI values and their aggregation

The remaining steps of the proposed methodology are identical to those of the SuperGreen approach, namely the estimation of the values of the pre-determined KPIs for each and every chain of the sample and their aggregation at corridor-level. The KPI estimation method involves the use of specialised studies and/or stakeholder surveys which, however, was beyond the scope of GreCOR that only aimed at demonstrating the methodology. An attempt to solicit such data is described in Chapter 6. Solely for the purpose of displaying the aggregation mechanism, it was decided to apply here the methodology on the basis of available default values.

The initial aim was the six indicators suggested by SuperGreen, namely the cost and speed of transport, the reliability and frequency of service, and the $CO_2$-eq and SOx emissions. The modal choice function of the Danish LTM model is performed by a logistics sub-model that encompasses default cost and speed estimates for all transport modes. Based on these figures, the values of the relevant KPIs of all sample chains can be calculated. Furthermore, the vehicle type information of LTM, in combination with the default values of the EcoTransIT World web-based tool[31] can lead to the necessary emission estimates. The reliability indicator had to be dropped early in the process due to lack of data. Frequency data was collected for all scheduled services in the corridor. However, it turned out that they comprise only a very small percentage of the flows along the corridor, rendering the corresponding figures statistically meaningless. Thus, the frequency KPI had to be dropped from further examination as well.

Three rounds of KPI aggregation are required to reach the corridor level. The first one concerns the chain types within each commodity group (Level 3 of Figure 43) that are represented in the sample by more than one chain. Examples are the Chain types 121 and 131 of Commodity group 22 (refer to Table 16).

[31] http://www.ecotransit.org/

**Table 18. The GreCOR sample chains for fertilizers**

| Chain type | Annual tonnes | Production zone | Vehicle Leg 1 | First terminal | Vehicle Leg 2 | Second terminal | Vehicle Leg 3 | Consumption zone |
|---|---|---|---|---|---|---|---|---|
| 2 | 1,716 | Fredericia (DK) | | | Articulated | | | Borken (DE) |
| 3 | 168 | Borken (DE) | | | Articulated | | | Køge (DK) |
| 121 | 13 | Ghent (BE) | 12-18t | Terneuzen (NL) | Articulated | Odense (DK) | 12-18t | Nyborg (DK) |
| 121 | 12 | Nyborg (DK) | 3.5-12t | Odense (DK) | Articulated | Amsterdam (NL) | 3.5-12t | Utrecht (NL) |
| 121 | 23 | Hannover (DE) | 12-18t | Hannover-Linden (DE) | Articulated | Kolding (DK) | Light truck | Kolding city (DK) |
| 121 | 29 | Padborg (DK) | 12-18t | Aabenraa Havn (DK) | Articulated | Dörpen (DE) | 12-18t | Ov. Groningen (NL) |
| 131 | 18 | Utrecht (NL) | 12-18t | Amsterdam (NL) | Articulated | Esbjerg (DK) | 12-18t | Sorø (DK) |
| 131 | 10 | Schleswig-Flensburg (DE) | 12-18t | Flensburg (DE) | Articulated | Odense (DK) | Light truck | Odense NØ (DK) |
| 131 | 10 | Nyborg (DK) | 3.5-12t | Nyborg Havn (DK) | Articulated | Hamburg (DE) | 3.5-12t | Rotenburg (Wumme) (DE) |
| 131 | 10 | Rendsburg-Eckernforde (DE) | 12-18t | Kiel (DE) | Articulated | Køge (DK) | 12-18t | Køge (DK) |
| 171 | 1,460 | Akershus (NO) | Articulated | Oslo (NO) | Conv. train | Coevorden (NL) | Articulated | Veluwe (NL) |
| 181 | 2,399 | Akershus (NO) | Articulated | Oslo (NO) | Conv. ship | Amsterdam (NL) | Articulated | Utrecht (NL) |

(Source: Own compilation)

In such cases, the chain-level KPIs need to be combined into composite figures. This is done by applying the simple weighted average formula using as weights the tonne*km (tkm) of each chain for combining the cost, $CO_2$-eq and SOx emission KPIs, and the annual tonnes for combining the speed indicator. The second round of aggregation moves from chain type groups (Level 3) to commodity groups (Level 2). The same methodology is applied for reaching these higher level indicators. The only difference concerns the weights used in the process. Now, the weights are not the tkm and tonnes of the participating chains but the 'adjusted' ones of Table 16, taking also into consideration the chain types not represented in the sample. The direct weighted average method of the first round is also used for the third one converting commodity group indicators (Level 2) to corridor KPIs (Level 1).

The final step of indexing involves a normalisation procedure setting the corridor-level values of each KPI to 100.0 and converting all other values accordingly. An index constructed in this way allows the comparison of two sets of values either over time (temporal indices) or transport modes (modal indices) for a common commodity or group of commodities. The resulting corridor indices by commodity group are summarised in Table 19.

**Table 19. KPI values and indices by commodity group**

| Commodity group | KPI values | | | | KPI indices | | | |
|---|---|---|---|---|---|---|---|---|
| | Cost (DKK/tkm) | Speed (km/h) | $CO_2$-eq (g/tkm) | SOx (g/tkm) | Cost | Speed | $CO_2$-eq | SOx |
| Agricultural products | 0.34 | 12.90 | 75.38 | 0.0753 | 77.4 | 107.3 | 107.9 | 68.2 |
| Coal & lignite | 0.18 | 6.97 | 29.60 | 0.0357 | 41.1 | 58.0 | 42.4 | 32.4 |
| Iron ore & metal ores | 0.49 | 9.22 | 42.31 | 0.0497 | 110.5 | 76.7 | 60.6 | 45.1 |
| Wood & products | 0.34 | 8.73 | 23.19 | 0.0333 | 76.2 | 72.6 | 33.2 | 30.2 |
| Coke & petroleum products | 0.16 | 4.68 | 10.93 | 0.0217 | 35.7 | 38.9 | 15.6 | 19.7 |
| Raw material & wastes | 0.30 | 8.21 | 18.75 | 0.0290 | 66.9 | 68.3 | 26.9 | 26.2 |
| Mail & parcels | 1.52 | 29.29 | 91.66 | 0.0965 | 343.8 | 243.7 | 131.2 | 87.4 |
| Crude oil & natural gas | 0.42 | 6.68 | 27.34 | 0.0375 | 94.4 | 55.5 | 39.2 | 33.9 |
| Fertilizers | 1.10 | 24.47 | 60.45 | 0.0683 | 249.1 | 203.6 | 86.6 | 61.9 |
| Stone & quarry products | 0.48 | 11.83 | 37.77 | 0.0449 | 109.3 | 98.4 | 54.1 | 40.7 |
| All other commodities | 0.57 | 15.93 | 114.40 | 0.1912 | 129.5 | 132.6 | 163.8 | 173.2 |
| Corridor | 0.44 | 12.02 | 69.84 | 0.1104 | 100.0 | 100.0 | 100.0 | 100.0 |

(Source: Own compilation)

The variation in KPI values is impressive. At first sight it was thought that the very high values for cost, speed and $CO_2$-eq emissions for the mail & parcels group can be explained by the small size of the vehicles employed and the necessity for speedy delivery that characterises these cargoes. But this does not seem to be the case for fertilizers that also exhibit very high costs and speeds. A closer look shows that the common feature of these two commodity groups is the low share of maritime transport in the respective trade. It was, thus, decided to regroup the chains by mode to check this hypothesis. The results are shown in Table 20.

**Table 20. KPI values and indices by mode**

| Mode | KPI values | | | | KPI indices | | | |
|---|---|---|---|---|---|---|---|---|
| | Cost (DKK/tkm) | Speed (km/h) | $CO_2$-eq (g/tkm) | SOx (g/tkm) | Cost | Speed | $CO_2$-eq | SOx |
| Road | 1.52 | 26.14 | 79.55 | 0.0888 | 344.6 | 217.5 | 113.9 | 80.4 |
| Rail | 0.35 | 18.56 | 48.54 | 0.0553 | 79.0 | 154.4 | 69.5 | 50.1 |
| Shipping | 0.19 | 6.11 | 46.02 | 0.1025 | 42.6 | 50.8 | 65.9 | 92.8 |
| Ro-Ro shipping | 0.70 | 28.11 | 377.28 | 0.3145 | 158.1 | 233.9 | 540.2 | 284.9 |
| Corridor | 0.44 | 12.02 | 69.84 | 0.1104 | 100.0 | 100.0 | 100.0 | 100.0 |

(Source: Own compilation)

It should be kept in mind that the results of Table 20 refer to door-to-door services that include road feeder services at both ends of the chain. It is confirmed that shipping is by far the least expensive and slowest mode of transport. It is also characterised by the best GHG emission performance. Its SOx emissions score slightly below average but this is only because Ro-Ro shipping, by far the biggest polluter, is excluded from the shipping figures while participating in the formation of the corridor average. It is worth mentioning that the poor environmental performance of Ro-Ro shipping is basically due to the so called ‘double load factor effect’ and the relatively high sailing speeds of these vessels (Panagakos et al., 2014). By double load factor effect one means the adverse effect on the fuel consumption and emissions of a Ro-Ro ship, when expressed on a per tonne*km basis, caused by the fact that the transport work performed is determined by both the load factor of the ship (in terms of lane meters occupied) and the load factor of the trucks onboard (in terms of the carrying capacity of the trucks taken up by the cargo).

It is noted that the SOx emissions of all segments of shipping have been drastically reduced since the beginning of 2015, when the new stricter IMO regulations on the sulphur content of marine fuels in the so-called SOx Emission Control Areas (that include both the North Sea and Baltic Sea of the GreCOR corridor) have taken effect.

Another surprising result regarding Ro-Ro shipping is its higher than road speed. This is because the Ro-Ro shipping chains are basically road services along routes with distances closer to the 'as-crow-flies' routes.

Rail transport seems to exhibit positive behaviour in relation to all KPIs examined, as its performance is below average in terms of cost, $CO_2$-eq and SOx emissions, and above average in terms of speed. From the perspective of the four indicators examined here, the promotion of rail appears to be a win-win solution leading to gains in terms of both economy and environment. It is unfortunate that the reliability and frequency indicators, where rail operations trail, could not be included in the analysis.

Before closing, it needs to be stressed that the indices presented above cannot be used for benchmarking as they are based on the default values of the LTM and EcoTransIT models and mainly reflect the composition of the freight flows comprising the corridor sample. It is worth noticing, however, that the corridor wide cost average of 0.44 DKK/tkm translates to 0.0780 USD/tkm (in 2010 prices), which is comparable to the figure of 0.0712 USD/tkm estimated by ADB (2013) for the six CAREC corridors in 2010. In addition to the geographical incompatibility which affects basic cost parameters like labour and fuel costs, this comparison needs to be qualified by the fact that the GreCOR figure would have been much higher if the waterborne trade was excluded as is the case in Asia. On the other hand, the Asian figure almost doubled during the period 2010-2013, a development not paralleled in Europe. To remain in Asia, Regmi and Hanaoka (2012) estimate an average cost of 0.91 USD/TEU/km for the Incheon-Ulaanbaatar corridor which combines road, rail and sea transport. On the assumption of 12 tonnes of cargo per TEU (Janic, 2007), this is equivalent to 0.0758 USD/tkm, a figure very close to our estimates.

Furthermore, the 0.35 DKK/tkm cost average for rail translates to 0.0467 €/tkm. For the average distance of 1,182 km of our sample journeys involving rail transport, Janic (2007) provides an estimate of 0.0275 €/tkm (in 2000 prices) for rail/road intermodal services in Europe, which is inflated to 0.0337 €/tkm when brought to 2010 denominator. The higher labour costs of Northern Europe can certainly explain a good part of the 39% difference between the two estimates. However, this discrepancy verifies the fact that the proposed method, albeit permitting the monitoring of the performance of a single corridor over time, is not suitable for comparisons between corridors, as it does not consider differences in corridor characteristics that can be decisive in their overall performance (Panagakos, 2012; Panagakos, 2016b; ITF, 2016b).

In terms of speed, the corridor average of 12.02 km/h reflects a significant influence by the tardiness of shipping that sails at an average speed of 6.1 km/h. Road (26.1 km/h) and rail (18.6 km/h) transport in Europe perform better than their Asian counterparts that ran at 22.3 and 12.8 km/h respectively during 2013 (ADB, 2013).

## 5.4 Conclusions

The chapter presented a new corridor assessment methodology and the results of its application under the GreCOR project. The purpose of this section is to summarise the conclusions of this work in terms of both methodology and results, and to present recommendations for further development and refinement of the applied method.

### 5.4.1 Methodological aspects

The method developed here is a variation of the SuperGreen methodology proposed earlier that involves decomposing the corridor into transport chains, selecting a sample of typical chains, benchmarking periodically these chains through a set of KPIs, and then aggregating the chain-level KPIs to corridor-level ones using proper weights for the averaging. SuperGreen suggested a study-based approach for constructing the corridor sample through information contained in the Transport Market Studies of the TEN-T Core Network Corridors and the corresponding Rail Freight Corridors. However, due to the scarcity and incompatibility of the information availed by these sources, a new methodology is proposed relying on a model-based approach for the sample construction.  The method was tested on the GreCOR corridor. The Danish National Traffic Model (LTM) was used not only for sample construction but for the KPI estimation as well.

The basic conclusion is that the methodology described in this paper can effectively assess the performance of a freight transport corridor. However, the proposed method is not suitable for comparisons between corridors, as it does not consider differences in corridor characteristics that can affect their overall performance.

The application benefited from the advantages of the ‘model-based’ approach, namely the provision of a comprehensive and coherent picture of all flows on each section of the corridor. It suffered, however, from the absence of a model offering European coverage, having to rely on the Danish LTM model, which imposed undesirable geographic restrictions (only the Oslo-Randstad part of the corridor was examined) and led to diminishing accuracy of results as the distance from Denmark increases.

Ensuring reliable data remains a hard problem to address. The service reliability and frequency KPIs had to be dropped due to lack of data. Furthermore, the method will not be complete unless the chain-level KPIs are estimated through raw data obtained from specialised studies covering specific routes or directly from the stakeholders (shippers, freight forwarders and transport service providers) who use the relevant chains. In addition, the stakeholder input might prove useful in adjusting for any unrealistic model results that might have entered the corridor sample. This combination of the model-based approach for the sample construction with the study-based approach for the estimation of chain-level indicators exploits the strengths of each method and avoids their weaknesses.

### 5.4.2 Corridor-specific aspects

There are five points that need to be made here. The first one relates to the boundaries of the analysis. Restricting coverage to ‘corridor chains’ that have both ends within the GreCOR catchment area was a decisive step that led to a drastic reduction of chains from 635 to 37 thousand. From the practical point of view, this proved a very useful intervention, as it improved dramatically the manageability of the dataset, without losing potentially interesting transport arrangements. In fact, as mentioned in Section 5.3.3, evidence shows that the design of the GreCOR catchment area (and, thus, the ‘corridor chains’) has succeeded in capturing the core services of the corridor, placing less emphasis on the feeder services from/to more remote areas.

The second point concerns the composition of the sample. Although a number of criteria were evaluated for constructing the sample, the ‘model-based’ approach did not permit the identification and exclusion of atypical chains. At the stage of KPI estimation, however, when the chains are looked into more detail, atypical chains may be spotted. At a second iteration of sample composition, which is missing from the present application, such chains should be omitted.

The third point also relates to sample revision. The size of the sample (156 chains) is considered too big, especially if real data have to be collected from stakeholders. In addition to excluding atypical chains, a second iteration could reduce the sample without much loss in its effectiveness. To do so, a sensitivity analysis is required to check the robustness of corridor-level KPIs in relation to specific chains. Stakeholders may also suggest merging some commodity groups together reducing the number of chains in the sample. The dry bulk Commodity groups 2 (coal & lignite), 3 (iron ore & non-ferrous metal ores) and 23 (stone, sand, gravel & quarry products) are possible candidates.

In terms of modal comparisons, it turns out that a safe way to improve the environmental performance of the corridor is to enhance rail operations, which combine 30% below average GHG and 50% below average SOx emissions with 21% below average cost and almost 55% above average speed. Shipping is also performing well in terms of the environment (34% below average GHG) and very well in terms of cost (57% below average) but the price shippers have to pay comes in speed, which is only half the average value for the corridor. However, not all shipping sectors share these characteristics. Unlike conventional ships, containerships move cargoes at above average speeds but at extremely high GHG and SOx emissions. The performance of Ro-Ro shipping in terms of $CO_2$-eq emissions is even worse but these chains offer the fastest services in the corridor at about 58% above average cost. A little lower speed (still more than 2 times the corridor average) but at a very high cost (3.4 times the average) is offered by road chains which emit 14% above average GHG and 20% below average SOx.

A final point relates to the composition of trade. Shipping accounts for 70% of the annual tonnage and 75% of the tonne*km of the ‘corridor chains.’ Therefore, it plays an extremely important role in forming the corridor indices. It could be of interest to see how the indices look if calculated on land-based modes only.

It follows that improvements can be achieved by:

(i) excluding from the sample possible atypical chains identified during the analysis;

(ii) revising the sample with the aim of merging commodity groups that use the same type of vehicles and have similar characteristics in terms of the KPIs examined;

(iii) revising the sample with the aim of excluding chains that do not affect the corridor indices (when expressed as one decimal point numbers); and
(iv) calculating corridor indices excluding shipping (Ro-Ro ships should not be excluded as they serve road transportation).

# 6. Stakeholder input in corridor benchmarking

The purpose of this chapter is to complete the application of the methodology proposed in Chapter 5 by incorporating stakeholder input. It consists of three sections: Section 6.1 revises the sample of corridor chains already produced in Section 5.3.4 in order to eliminate atypical and insignificant chains. It also recalculates the corridor indices after excluding shipping, thus, freeing corridor results from the significant volume effect that this mode imposes. The data solicitation effort is described in Section 6.2. The chapter closes with a section on missing observations, an issue that address a possible future complication due to the recurring nature of the proposed methodology.

## 6.1 Sample improvements

The following improvements in the composition of the corridor sample were suggested in Section 5.4.2:

(i) Exclusion of possible atypical chains identified during the analysis;
(ii) Merging of commodity groups that use the same type of vehicles and have similar characteristics in terms of the KPIs examined;
(iii) Exclusion of chains that do not affect the corridor indices (when expressed as one decimal digit numbers); and
(iv) Recalculation of corridor indices after the exclusion of shipping.

The search for atypical chains has resulted in the three chains of Table 21. All of them are of type ‘131’ that involves a ferry connection along the main haul. According to 2010 LTM results, the main haul segment of all these chains is between Fredericia Havn on the Danish side and Lübeck on the German side.

**Table 21. Atypical chains in the corridor sample**

| Chain No. | Commodity | Production zone | Consumption zone | Annual tonnes |
|---|---|---|---|---|
| 54 | Coke & petroleum products | Fredericia (DK) | Ostholstein (DE) | 21 |
| 80 | Crude oil & natural gas | Fredericia (DK) | Ostholstein (DE) | 22 |
| 142 | Various - Non-containerised | Ostholstein (DE) | Haderslev (DK) | 63 |

(Source: Own compilation)

However, no direct Ro-Ro service between Fredericia Havn and Lübeck appears in the Baltic Transport Maps database.[32] Combinations of two ferry links should, then, be examined as a possibility. Potential solutions of this type would include the following alternatives:

(i) Spodsbjerg (DK) – Tårs (DK) and Rødby (DK) – Puttgarden (DE);
(ii) Spodsbjerg (DK) – Tårs (DK) and Gedser (DK) – Rostock (DE);
(iii) Fredericia (DK) – Copenhagen (DK) and Malmö (SE) – Lübeck (DE).

All of them, however, are inferior to the land-based connection in terms of both transit cost and time. Even if one assumes that a direct connection was indeed in operation back in 2010, the fact that it has been discontinued renders these chains atypical and, as such, they have to be dropped from the corridor sample.

In relation to the potential merging of commodity groups, the groups 2 (coal & lignite), 3 (iron ore & non-ferrous metal ores) and 23 (stone, sand, gravel & quarry products) comprise a possible candidate due to the fact that they are transported by similar dry bulk vehicles/vessels. Non-containerised agricultural products transported in bulk (Commodity group 1B), like grain and maize, fall into this category, too.

The decision on merging these commodities into the same group or not depends on their behaviour in relation to the KPIs examined. It is reasonable to assume that the type of cargo exerts little influence on the frequency and reliability of the services offered, as well as on the average speed of a dry bulk vehicle/vessel. It certainly affects the speed of cargo handling operations, however, which depends on the type and availability of the relevant facilities and equipment in ports/terminals.

32 http://www.baltictransportmaps.com/rofemap.html#?z=1&x=0&y=0

The case of the remaining three KPIs (cost, GHG and SOx emissions), which are expressed on a per-tonne*km basis, is a more complicated one. The complication stems from the fact that, in the case of volume cargoes, the weight of the cargo carried by a full vehicle depends on the density of the cargo. In turn, this difference in tonne*km produced by 1 vehicle*km affects the allocation of the fixed component[33] of the cost and emissions associated with a transport.

**Table 22. Stowage factors of selected commodities (in cu.m./m.t.)**

| Commodity | Cargo form | | |
|---|---|---|---|
| | Bulk | Bagged | Baled |
| Cement | 0.60 – 0.75 | 0.65 – 0.80 | |
| Chalk | 1.00 – 1.15 | | |
| Clay | 0.80 – 1.15 | | |
| Coal | 1.10 – 1.40 | | |
| Coffee | | 1.70 – 2.00 | |
| Coke | 1.70 – 2.85 | | |
| Corn (maize) | 1.35 – 1.45 | 1.45 – 1.60 | |
| Cotton | | | 1.70 – 3.70 |
| Iron ore | 0.55 | | |
| Limestone | 0.70 – 0.85 | | |
| Logs | 3.10 | | |
| Marble blocks | 0.40 – 0.55 | | |
| Pellets (grain - widely) | 1.25 – 1.85 | 1.70 – 2.55 | |
| Rice - white (polished) | | 1.40 – 1.45 | |
| Sands | 0.30 – 0.70 | | |
| Soybeans | 1.35 – 1.45 | 1.55 – 1.65 | |
| Wheat | 1.25 – 1.40 | 1.35 – 1.45 | |
| Woodchips | 2.80 | | |

(Source: Based on https://www.scribd.com/doc/28433128/Stowage-Factor-Cbft-Mt)

Table 22 shows the stowage factors of some common dry bulk cargoes of the commodity groups mentioned above. In shipping, the stowage factor indicates how many cubic metres of space one metric tonne of a particular type of cargo occupies in a hold of a cargo ship. It includes stowage losses caused by the means of transportation and packaging. Unlike most other vessels today, dry bulk carriers are *weight limited*, meaning that they are

[33] In contrast to the variable component which is proportional to the tonnes of cargo moved over a distance of one km.

designed for the transport of dense cargoes (Lamb, 2003). The same publication notes that the transition from *weight limited* to *volume limited* comes when the cargo stowage factor is about 1.30 $m^3$/t. The fact that all agricultural products, coke and some types of coal have a stowage factor above this figure indicates that the daily charter rate of a ship transforms into different unit cost figures depending on the cargo onboard.

Due to these cargo handling nonconformities and stowage factor complications, the decision has been made to retain the commodity groups as determined in Section 5.3.4.

As for the exclusion of chains that do not affect the corridor indices, all chains were listed in ascending order of annual tonnage and the corridor indices were checked against the exclusion of each chain starting from the top of the list. The chains that when excluded left all corridor KPI indices unaltered (at the level of one decimal digit) are listed in Table 23.

**Table 23. Insignificant chains in the corridor sample**

| Chain No. | Commodity | Production zone | Consumption zone | Annual tonnes |
|---|---|---|---|---|
| 65 | Secondary raw materials & wastes | Herzogtum Lauenburg (DE) | Midtlolland (DK) | 2 |
| 100 | Stone, sand, gravel & quarry products | Zuidoost-Noord-Brabant (NL) | Ishøj (DK) | 1 |
| 104 | Stone, sand, gravel & quarry products | Overig Groningen (NL) | Køge (DK) | 2 |
| 105 | Stone, sand, gravel & quarry products | Veluwe (NL) | Kastrup Lufthavn (DK) | 1 |

(Source: Own compilation)

It follows that the corridor sample to be presented to the stakeholders consists of 149 chains resulting from the 156 initial chains of Appendix III after excluding the 3 atypical chains of Table 21 and the 4 insignificant chains of Table 23. It is worth noting that the weights used for KPI aggregation (columns ‘Adjusted tonnes’ and ‘Adjusted tonne*km’ of Table 16) have been readjusted to reflect the exclusion of these 7 chains.

Before switching focus to the stakeholder input, it is worth investigating the significant volume effect that shipping imposes on the corridor indices. To this end, Table 24 recalculates the indices after excluding shipping. The corridor level indices of all runs are also summarised in Table 26 to ease comparisons. The exclusion of shipping increases the average transit cost along the corridor by 170% (from 0.44 to 1.19 DKK/tonne*km), increases the average speed by 116% (from 12.02 to 25.97 km/h) and increases the GHG emissions by 102% (from 69.84 to 140.86 g/tonne*km). The SOx emissions are also increased but by a moderate rate of 21% (from 0.1104 to 0.1340 g/tonne*km).

**Table 24. Corridor indices after exclusion of shipping**

| Commodity group | KPI values | | | | KPI indices | | | |
|---|---|---|---|---|---|---|---|---|
| | Cost (DKK/tkm) | Speed (km/h) | $CO_2$-eq (g/tkm) | SOx (g/tkm) | Cost | Speed | $CO_2$-eq | SOx |
| Agricultural products | 1.02 | 27.35 | 303.84 | 0.2637 | 85.5 | 105.3 | 215.7 | 196.7 |
| Coal & lignite | 1.29 | 26.23 | 65.04 | 0.0719 | 108.6 | 101.0 | 46.2 | 53.6 |
| Iron ore & metal ores | 1.20 | 20.52 | 60.48 | 0.0718 | 100.3 | 79.0 | 42.9 | 53.6 |
| Wood & products | 1.25 | 23.99 | 65.94 | 0.0724 | 104.9 | 92.4 | 46.8 | 54.0 |
| Coke & petroleum products | 1.36 | 27.97 | 67.00 | 0.0752 | 113.9 | 107.7 | 47.6 | 56.1 |
| Raw material & wastes | 1.66 | 24.02 | 76.94 | 0.0853 | 139.3 | 92.5 | 54.6 | 63.6 |
| Mail & parcels | 1.52 | 29.29 | 91.66 | 0.0965 | 127.1 | 112.8 | 65.1 | 72.0 |
| Crude oil & natural gas | 0.66 | 20.82 | 32.08 | 0.0380 | 55.7 | 80.2 | 22.8 | 28.3 |
| Fertilizers | 1.33 | 28.20 | 69.47 | 0.0792 | 111.4 | 108.6 | 49.3 | 59.1 |
| Stone & quarry products | 1.45 | 21.14 | 64.74 | 0.0755 | 121.6 | 81.4 | 46.0 | 56.3 |
| All other commodities | 1.17 | 25.76 | 140,32 | 0.1336 | 97.9 | 99.2 | 99.6 | 99.6 |
| Corridor | 1.19 | 25.97 | 140.86 | 0.1340 | 100.0 | 100.0 | 100.0 | 100.0 |

(Source: Own compilation)

The effect on the individual commodity groups is even more profound depending on the participation of shipping in the particular flows along the corridor. The increase in unit price ranges from 0% for mail and parcels which are moved exclusively by other modes to 750% for coke and petroleum products, where shipping has a 98% market share.[34] The speed and GHG emission values exhibit substantial increases, too, which for the coke and petroleum product group reach the 500% mark.

The exclusion of shipping also affects the variation of performance among the commodity groups. The variance of cost decreases from 0.17 to 0.07, while the drop is more profound for the variance in speed (from 66.04 to 10.99). On the contrary, the variance of both types of emissions increases by one order of magnitude as the absence of shipping highlights the differences

[34] It is worth noting that this extremely high growth rate is partly due to the very low start price for this commodity group (0.16 DKK/tonne*km), which is even lower than the average shipping price reported in Table 20 (0.19 DKK/tonne*km). Despite sounding like a paradox, this is due to the fact that all shipping chains of this study comprise of 3-leg arrangements, two of which are always road journeys that influence the overall average ‘shipping’ price proportionally to the relative distances.

between Ro-Ro connections, which are still present, and the land-based modes.

**Table 25. Corridor indices after exclusion of shipping and Ro-Ro services**

| Commodity group | KPI values | | | | KPI indices | | | |
|---|---|---|---|---|---|---|---|---|
| | Cost (DKK/tkm) | Speed (km/h) | $CO_2$-eq (g/tkm) | SOx (g/tkm) | Cost | Speed | $CO_2$-eq | SOx |
| Agricultural products | 1.12 | 26.66 | 58.90 | 0.0661 | 84.2 | 105.2 | 78.9 | 79.1 |
| Coal & lignite | 1.29 | 26.23 | 65.04 | 0.0719 | 97.3 | 103.5 | 87.2 | 86.1 |
| Iron ore & metal ores | 1.20 | 20.52 | 60.48 | 0.0718 | 89.8 | 81.0 | 81.1 | 86.0 |
| Wood & products | 1.25 | 23.99 | 65.94 | 0.0724 | 94.0 | 94.6 | 88.4 | 86.8 |
| Coke & petroleum products | 1.36 | 27.97 | 67.00 | 0.0752 | 102.0 | 110.4 | 89.8 | 90.1 |
| Raw material & wastes | 1.66 | 24.02 | 76.94 | 0.0853 | 124.8 | 94.8 | 103.1 | 102.1 |
| Mail & parcels | 1.50 | 29.08 | 87.74 | 0.0928 | 113.0 | 114.7 | 117.6 | 111.1 |
| Crude oil & natural gas | 0.66 | 20.82 | 32.08 | 0.0380 | 49.9 | 82.1 | 43.0 | 45.5 |
| Fertilizers | 1.33 | 28.20 | 69.47 | 0.0792 | 99.8 | 111.2 | 93.1 | 94.9 |
| Stone & quarry products | 1.45 | 21.14 | 64.74 | 0.0755 | 108.9 | 83.4 | 86.8 | 90.4 |
| All other commodities | 1.34 | 25.01 | 76.57 | 0.0861 | 100.6 | 98.7 | 102.6 | 103.1 |
| Corridor | 1.33 | 25.35 | 74.62 | 0.0835 | 100.0 | 100.0 | 100.0 | 100.0 |

(Source: Own compilation)

The effect on KPIs resulting from further excluding the Ro-Ro services[35] from the sample appears in Table 25. As expected, the cost and speed values are only moderately affected (12% and -2% respectively). On the contrary, GHG emissions decrease by 47% close to their 'All modes' value (refer to Table 26), while SOx emissions drop by 38% even below the corresponding figure of the 'All modes' scenario. Among the commodity groups, the only ones affected are those that include Ro-Ro chains: 'Agricultural products', 'Mail & parcels', and 'All other commodities.'

**Table 26. Summary table of corridor indices**

| Mode | KPI values | | | |
|---|---|---|---|---|
| | Cost (DKK/tkm) | Speed (km/h) | $CO_2$-eq (g/tkm) | SOx (g/tkm) |
| All modes[a] | 0.44 | 12.02 | 69.84 | 0.1104 |
| Excluding shipping | 1.19 | 25.97 | 140.86 | 0.1340 |
| Excluding shipping & Ro-Ro | 1.33 | 25.35 | 74.62 | 0.0835 |

[a] The results include the 7 chains that have subsequently dropped from the sample

(Source: Own compilation)

[35] The exclusion does not affect the ferry connections along the corridor that are served by Ro-Pax vessels.

It is interesting to note that the KPI values of the group named ‘All other commodities’ are very close to those of the entire corridor. The maximum differential in Table 24 concerns the cost indicator and lies within a +/- 2.1% interval. The respective differentials in Table 25 are all within a +/- 3.1% range. This remark leads to the conclusion that the 42 chains that comprise the sample for ‘All other commodities’ when shipping is excluded or the 28 chains of the same group when both shipping and Ro-Ro connections are excluded can serve as a proxy for the entire corridor with very small distortions.

## 6.2 Solicitation of corridor data

The next step involves the collection of data on the 149 chains that resulted from the sample improvement actions described above in order to: (i) recalculate the indices of Section 5.3.5 on the basis of actual data provided directly by the stakeholders, and (ii) extend coverage to include indicators on service frequency and reliability.

A draft questionnaire was prepared for this purpose. Due to the volume of the desired information, the questionnaire took the form of a spreadsheet. A testing round involving two peers and a stakeholder resulted in its present form. For indicative purposes, only the part of the questionnaire pertaining to Commodity group 22 (fertilizers) is shown in Table 27.

It consists of four parts. Part A provides the basic information for the chains comprising the sample, grouped by commodity. Each line corresponds to one chain. An appendix to Part A describes the chain types entering the sample (refer to Table 28). For the 1-leg chains, the information given is the origin (Production zone), the destination (Consumption zone) and the vehicle used (Vehicle Leg 2). For the 3-leg chains, information on the transhipment terminals and the feeder vehicles is also provided. Leg 2 is always the main haul of the journey. The annual tonnage of cargoes moved is specified, too. The size of the shipments, however, is not provided and an assumption needs to be made on the basis of the respondent’s experience.

Part B is the main part of the questionnaire that needs to be filled out by the respondent. In addition to the assumed average shipment size, the respondent provides input that is needed for calculating the desired KPIs:

**Table 27. Indicative part of the questionnaire referring to Commodity group 22 (fertilizers)**

## PART A. CHAIN DESCRIPTION

| NO OF CHAIN | CHAIN TYPE | ANNUAL TONNES | PRODUCTION ZONE | VEHICLE LEG 1 | FIRST TERMINAL | VEHICLE LEG 2 | SECOND TERMINAL | VEHICLE LEG 3 | CONSUMPTION ZONE |
|---|---|---|---|---|---|---|---|---|---|
| Commodity group 22: Fertilizers | | | | | | | | | |
| 83 | 2 | 1716 | Fredericia (DK) | | | Articulated truck | | | Borken (DE) |
| 84 | 3 | 168 | Borken (DE) | | | Articulated truck | | | Køge (DK) |
| 85 | 121 | 13 | Ghent (BE) | Truck 12-18t | Terneuzen (NL) | Articulated truck | Odense (DK) | Truck 12-18t | Nyborg (DK) |
| 86 | 121 | 12 | Nyborg (DK) | Truck 3.5-12t | Odense (DK) | Articulated truck | Amsterdam (NL) | Truck 3.5-12t | Utrecht (NL) |
| 87 | 121 | 23 | Hannover (DE) | Truck 12-18t | Hannover-Linden (DE) | Articulated truck | Kolding (DK) | Light truck | Kolding city (DK) |
| 88 | 121 | 29 | Padborg (DK) | Truck 12-18t | Aabenraa Havn (DK) | Articulated truck | Dörpen (DE) | Truck 12-18t | Overig Groningen (NL) |
| 89 | 131 | 18 | Utrecht (NL) | Truck 12-18t | Amsterdam (NL) | Articulated truck | Esbjerg (DK) | Truck 12-18t | Sorø (DK) |
| 90 | 131 | 10 | Schleswig-Flensburg (DE) | Truck 12-18t | Flensburg (DE) | Articulated truck | Odense (DK) | Light truck | Odense NØ (DK) |
| 91 | 131 | 10 | Nyborg (DK) | Truck 3.5-12t | Nyborg Havn (DK) | Articulated truck | Hamburg (DE) | Truck 3.5-12t | Rotenburg (Wumme) (DE) |
| 92 | 131 | 10 | Rendsburg-Eckernforde (DE) | Truck 12-18t | Kiel (DE) | Articulated truck | Køge (DK) | Truck 12-18t | Køge (DK) |
| 93 | 171 | 1460 | Akershus (NO) | Articulated truck | Oslo (NO) | Conventional train | Coevorden (NL) | Articulated truck | Veluwe (NL) |
| 94 | 181 | 2399 | Akershus (NO) | Articulated truck | Oslo (NO) | Conventional ship | Amsterdam (NL) | Articulated truck | Utrecht (NL) |

## PART B. KPI VALUES

| SHIPMENT SIZE (tonnes) | PRICE (DKK/tonne) | TIME (Hours) | RELIABILITY (% of shipments) | FREQUENCY (services / year) | VEHICLE TYPE (EURO I, II, ...) | LOAD FACTOR (% of capacity) | COMMENTS |
|---|---|---|---|---|---|---|---|
| Commodity group 22: Fertilizers | | | | | | | |
| | | | | | | | |
| | | | | | | | |
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## PART C. GEOGRAPHICAL INFORMATION

| ORIGIN | | LEG 1 | FIRST TERMINAL | | LEG 2 | OUT OF WHICH FERRY | | | | SECOND TERMINAL | | LEG 3 | DESTINATION | | DISTANCE SUMMARY (km) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Latitude | Longitude | Distance | Latitude | Longitude | Distance | Connection | Dist. (km) | Time (h) | Freq. /week | Latitude | Longitude | Distance | Latitude | Longitude | Road | Rail | Sea | TOTAL |
| Commodity group 22: Fertilizers | | | | | | | | | | | | | | | | | | |
| 55,5734 | 9,6837 | | | | 591,50 | | | | | | | | 51,4756 | 7,5536 | 591,50 | | 0,00 | 591,50 |
| 51,4756 | 7,5536 | | | | 623,32 | Rødby-Puttgarden | 18,00 | 0,75 | every 1/2 h | | | | 55,4561 | 12,0701 | 605,32 | | 18,00 | 623,32 |
| 51,0378 | 4,2348 | 61,47 | 51,3219 | 3,8348 | 910,95 | | | | | 55,3695 | 10,4948 | 22,23 | 55,2944 | 10,7012 | 994,65 | | 0,00 | 994,65 |
| 55,2944 | 10,7012 | 22,23 | 55,3695 | 10,4948 | 800,29 | | | | | 52,4634 | 4,5865 | 39,13 | 52,2033 | 4,7742 | 861,65 | | 0,00 | 861,65 |
| 52,1115 | 10,0530 | 48,34 | 52,4563 | 9,7998 | 381,65 | | | | | 55,4909 | 9,4808 | 3,86 | 55,4991 | 9,4648 | 433,85 | | 0,00 | 433,85 |
| 54,9769 | 9,4171 | 8,18 | 55,0396 | 9,4245 | 407,71 | | | | | 52,9680 | 7,3416 | 117,08 | 53,0505 | 6,3577 | 532,97 | | 0,00 | 532,97 |
| 52,2033 | 4,7742 | 39,13 | 52,4634 | 4,5865 | 645,12 | Esbjerg-Rotterdam | 531,52 | 21,00 | 1/week | 55,4680 | 8,4343 | 223,18 | 55,4859 | 11,5585 | 375,91 | | 531,52 | 907,43 |
| 54,6287 | 9,5082 | 21,01 | 54,7833 | 9,4333 | 126,22 | Bøjden-Fynshav | 14,57 | 0,83 | 12/day | 55,3695 | 10,4948 | 10,40 | 55,4192 | 10,4291 | 143,06 | | 14,57 | 157,63 |
| 55,2944 | 10,7012 | 11,44 | 55,3138 | 10,8024 | 295,78 | Bøjden-Fynshav | 14,57 | 0,83 | 12/day | 53,5339 | 9,9999 | 79,99 | 52,9988 | 10,0383 | 372,64 | | 14,57 | 387,21 |
| 54,2704 | 9,9786 | 38,38 | 54,3971 | 10,3688 | 220,49 | Rødby-Puttgarden | 18,00 | 0,75 | every 1/2 h | 55,4885 | 12,1619 | 8,50 | 55,4561 | 12,0701 | 249,37 | | 18,00 | 267,37 |
| 59,7336 | 11,2227 | 44,21 | 59,9098 | 10,7089 | 1.506,36 | | | | | 52,6610 | 6,7405 | 96,42 | 52,2575 | 6,0596 | 140,63 | 1.506,36 | | 1.646,99 |
| 59,7336 | 11,2227 | 44,21 | 59,9098 | 10,7089 | 940,01 | | | | | 52,4634 | 4,5865 | 39,13 | 52,2033 | 4,7742 | 83,34 | | 940,01 | 1.023,35 |

## PART D. RESPONDENT AND AFFILIATION INFORMATION

| AFFILIATION INFORMATION | | | RESPONDENT INFORMATION | | | | | |
|---|---|---|---|---|---|---|---|---|
| Name | | | First name | | Last name | | Title | |
| Type of business | Shipper : | | Position in affiliated organisation | | | | | |
| | Transport service provider : | | Address | | | | | |
| | Forwarder/logistics service provider : | | Telephone | | E-mail | | | |
| Active in transport modes | Road : | | OTHER COMMENTS | | | | | |
| | Rail : | | | | | | | |
| | Maritime : | | | | | | | |
| | Combined road/rail : | | | | | | | |
| | Combined road/maritime : | | | | | | | |
| | Combined road/rail/maritime : | | | | | | | |
| Number of employees on 31/12/2015 | | | | | | | | |

(Source: Own compilation)

**Table 28. Chain types entering the corridor sample**

| TYPE* | DEFINITION |
|---|---|
| 1 | 1-leg road chains between Denmark and other Scandinavian countries (irrelevant to a future Fehmarn Belt fixed link) |
| 2 | 1-leg road chains crossing the land border between Denmark and Germany |
| 3 | 1-leg road chains connecting Denmark to locations south of the Fehmarn Belt, which involve the use of a ferry |
| 5 | 1-leg road chains between origins/destinations outside Denmark that cross the country in transit |
| 6 | 1-leg road chains between origins/destinations outside Denmark that use a direct Ro-Ro connection bypassing Denmark |
| 111 | 3-leg road chains, where a main chain of Type 1 is combined with feeder road services for the first and last miles. |
| 121 | 3-leg road chains, where a main chain of Type 2 is combined with feeder road services for the first and last miles. |
| 131 | 3-leg road chains, where a main chain of Type 3 is combined with feeder road services for the first and last miles. |
| 151 | 3-leg road chains, where a main chain of Type 5 is combined with feeder road services for the first and last miles. |
| 161 | 3-leg road chains, where a main chain of Type 6 is combined with feeder road services for the first and last miles. |
| 171 | 3-leg rail chains, where a main rail transport (Type 7) is combined with feeder road services for the first and last miles. |
| 181 | 3-leg maritime chains, where a main sea transport (Type 8) is combined with feeder road services for the first and last miles. Containerised cargoes are carried by containerships. |
| 191 | 3-leg maritime chains, where a main sea transport by a Ro-Ro ship (Type 9) is combined with feeder road services for the first and last miles. |
| * Types 4 and 141 are intentionally omitted as unrelated to the project. | |

(Source: Own compilation)

- Transport price to the shipper (excluding VAT), in DKK/tonne (the figure will later be transformed into DKK/tonne-km);
- Total transport time, in hours (will be used to calculate average speed);

- Reliability of service in terms of delivery within the agreed (contractual) time windows, in percentage of shipments;
- Frequency of service, in services offered per year;
- $CO_2$-eq emissions, in grams of $CO_2$ / tonne-km (emissions will be calculated later on the basis of the environmental class of the vehicle and the average load factor which should also take empty trips into consideration); and
- $SO_2$ emissions, in grams of $SO_2$ / tonne-km (emissions will be calculated later on the basis of the environmental class of the vehicle and the average load factor which should also take empty trips into consideration).

Ideally, actual data for year 2015 are solicited. Knowing however that this is improbable, respondents are requested to provide information on any origin-destination pair that is close to the one suggested as long as it is sufficiently described. Origin, destination and transhipment points need to be defined in a way that enables the calculation of distances. In the absence of actual data, the respondent's estimates are solicited as good approximations, provided that they are clearly defined as 'Estimates' in the 'Comments' column. Respondents are reminded that ideally the price estimates should be market-determined figures, meaning that in case of using own transport means, they need to be valued at the prevailing hire/charter rates.

Part C of the questionnaire provides complementary information of geographical nature. More specifically, it provides the coordinates of the origin, destination and transhipment terminals used by the LTM model, as well as the distances involved. In case of a sea-leg, the ferry connection is also described.

Part D seeks some basic information on the respondent's identity and contact details, as well as the activities and size of their affiliation.

The questionnaire was sent to the following associations of transport/logistics service providers and shippers with the request to be forwarded to their members:

- **DTL - Danish Transports and Logistics** (http://www.dtl.eu/). DTL is a trade organisation consisting of 2,100 road hauliers and 59 locomotives. It represents the interests of its members when negotiating with politicians and authorities and offers expert advice to its members.

- **ITD - Association for the Danish road transport of goods** (http://itd.dk/). In January 2016 ITD's membership accounted for more than 730 Danish road hauliers, 10% of which are engaged exclusively in the international trade, while 65% are active in both national and international markets. ITD aims to strengthen the professionalism, competitiveness and profitability of its members by representing their interests in the political dialogue and by offering specialised services like insurance, safety guidance and bookkeeping.
- **Dansk Banegods – Danish Rail Freight** (http://banegods.dk/) Danish Rail Freight brings together companies, ports, freight operators and other stakeholders in one organisation promoting railway as an important element in the transition of freight transport towards higher energy efficiency and improved competitiveness in the international arena.
- **Danmarks Rederiforening - Danish Shipowners' Association** (www.shipowners.dk/). The Danish Shipowners' Association is a trade and employer organisation for more than 40 shipowners and two offshore companies. Since its establishment in 1884, it has been working as a collective point for the Danish shipping industry and a promoter of its interests both nationally and internationally. Apart from its members, it serves the two other shipowners' associations in Denmark: the Shipowners' Association of 2010 and the Danish Car Ferry Association. It maintains a permanent representation office in Brussels.
- **DASP - Danish Freight Forwarders** (www.dasp.dk). DASP promotes the interests of its members through: (i) direct influence to Danish Ministries and political parties, (ii) media campaigns, and (iii) international representation through the World Association of Freight Forwarders (FIATA).
- **FDT – Association of Danish Transport Centres** (http://fdt.dk/). FDT promotes knowledge, deployment and use of transport centres in Denmark and the rest of Europe. It represents the interests of its members in the political dialogue and decision making in the areas of infrastructure, transport and logistics.
- **DI – Confederation of Danish Industry** (http://di.dk/). DI is a private organisation funded, owned and managed entirely by 10,000 companies within the Danish manufacturing, trade and service

industry. In addition, a number of sectorial employers' associations and branch federations are integrated in part or in full in DI’s framework. It aims to provide the best possible corporate conditions for Danish industry.

As the dialogue with these institutions is still on-going, there are no results to be reported at this time. Concerns have been raised, though, in relation to disclosure of sensitive information and the perceived risk of infringement of the EU Competition Law. In view of these difficulties, an alternative proposal has been formulated that will be presented to the recipient organisations if the on-going round terminates without yielding the expected results. It substitutes relative for absolute values for the parameters that are considered commercially sensitive.

Consider as an example the index $I_p$ of price estimates, which happen to be the most sensitive ones among the desired information. In price index theory, bilateral indices are used to compare two sets of prices corresponding to two different periods. Denote the first period as period *0* and the second period as period *t*. In the Laspeyres approach followed here, the two sets of prices are applied on the same basket of N goods and services which is the one that was purchased in the first period (Pink, 2011). If:

$p_{i0}$ = the price of item *i* in period *0* (*i* = 1…N),

$p_{it}$ = the price of item *i* in period *t* (*i* = 1…N), and

$q_{i0}$ = the quantity of item *i* purchased in period *0* (*i* = 1…N),

then, the ratio $p_{it}/p_{i0}$ between the prices of item *i* in the two periods is called price relative, the expenditure on item *i* in period *0* is given by:

$$e_{i0} = p_{i0} \times q_{i0} \tag{4}$$

and the price index for period *t* is expressed by:

$$I_{pt} = \frac{\sum p_{it} \times q_{i0}}{\sum p_{i0} \times q_{i0}} \times 100 \tag{5}$$

where the summation operator is applied on all items in the basket of period *0* (*i* = 1…N). By multiplying the numerator of Eq. (5) by $p_{i0}/p_{i0}$ and rearranging, the price index can be expressed in terms of price relatives as:

$$I_{pt} = \sum \frac{p_{it}}{p_{i0}} \left( \frac{p_{i0} \times q_{i0}}{\sum p_{i0} \times q_{i0}} \right) \times 100 \tag{6}$$

If:

$$w_{pi} = \frac{p_{i0} \times q_{i0}}{\sum p_{i0} \times q_{i0}} = \frac{e_{i0}}{\sum e_{i0}} \qquad (7)$$

is defined as the expenditure share of item *i* in period *0*, Eq. (6) can be rewritten as:

$$I_{pt} = \sum w_{pi} \left(\frac{p_{it}}{p_{i0}}\right) \times 100 \qquad (8)$$

Eq. (8) shows that the price index $I_{pt}$ can be expressed as a function of price relatives $(p_{it}/p_{i0})$ provided that the weights are adjusted to denote expenditure shares. In the corridor context, this means that stakeholders can indicate only price changes (%) compared to a base year (2010) rather than the absolute prices for the chains in question. The weights that enter the index formula now are the outlay[36] shares of each chain in the entire corridor figure as result from LTM for year 2010. A similar approach can be followed for all other data requested from the stakeholders. Minor complications arise with the vehicle type that enters emission calculations due to its discrete nature when referring to a single vehicle (Euro I, II…). The problem can be circumvented either by considering the average vehicle along a chain as a continuous variable or by assuming that no significant alteration in the average vehicle fleet can take place within a year.

In any case, the conclusion reached in Section 5.4.1 about the effectiveness of the method needs to be qualified with regard to the degree that the necessary periodic data is actually collected from the stakeholders.

## 6.3 Temporarily missing observations

The purpose of this section is to complete the methodological aspects by proposing an approach for handling temporarily missing information, an issue that occurs often in periodic data collection campaigns. Examples of such disruptions in the context of a freight transport corridor include the case of construction works, severe weather conditions, major business restructuring etc.

According to Pink (2011), the available options to deal with such

[36] The outlay of a chain is calculated as the product of the unit price (DKK/tonne*km) and the transport work performed (tonne*km).

occurrences are very few. The most prominent among them are:

(i) repeat the previous period's value of the missing item;
(ii) introduce an artificial value based on the average value movement for all other items in the sample; and
(iii) introduce an artificial value based on the average value movement of another sample.

The second option, which is equivalent to excluding the missing item, is the most commonly applied one in practice. The same interpolation principle is basically used by Arvis et al. (2016) to fill in missing values with regard to the World Bank's international LPI. It also forms the framework for dealing with changes in the composition of the sample which, in the case of the GreCOR corridor, can only happen when a new version of the LTM model is released.

# PART IV. CONSIDERATIONS FOR GREEN MARITIME CORRIDORS

# 7. A taxonomy of $CO_2$ emission reduction measures[37]

## 7.1 Introduction

With the goal of limiting climate change below 2ºC, the latest EU White Paper on transport has set the ambitious target of reducing by year 2050 transport-related greenhouse gas (GHG) emissions by at least 60% with respect to 1990 (EC, 2011a). Despite the fact that: (i) shipping exhibits by far the lowest energy consumption per tonne-km among all transport modes[38] and, (ii) the entire shipping industry accounts for merely 2.5% of global GHG emissions on a $CO_2$-equivalent ($CO_2$-eq) basis (IMO, 2015), the growth of global transport demand could pose a significant challenge to the achievement of this ambitious emission reduction goal.

A wide range of measures have been proposed to improve vessel efficiency, reduce fuel consumption and lower emissions (Eide et al., 2011; ABS, 2012). The classification of such measures is the subject of several publications. The Second GHG Study of the International Maritime Organization (IMO, 2009) is the most influential among them and identifies three fundamental categories of carbon emission reduction options: (i) energy efficiency improvements which are further sub-divided into the areas of ship design and operations; (ii) renewable energy sources; and (iii) fuels with lower lifecycle emissions per unit of work. A fourth category concerns emission removal from exhaust gases but it does not relate to $CO_2$.

[37] With the exception of some minor editorial changes, this chapter is identical to a paper by Panagakos and Psaraftis entitled *A taxonomy of carbon emission reduction measures in waterborne freight transportation* and submitted to the Maritime Policy & Management journal (currently under review).

[38] As shown in Chapter 5, the accuracy of this statement should be qualified as regards Ro-Ro shipping.

Variations of this scheme have been proposed by Balland et al. (2010) and Calleya, Pawling, and Greig (2015).

In addition to the usual technical, operational and alternative fuel measures, Eide et al. (2011) introduce ‘structural changes’ involving two or more actors in the shipping industry that cooperate to increase efficiency and/or reduce emissions. Speed reductions made possible by either fleet increases or port efficiency improvements are mentioned as examples. Furthermore, Eide and his colleagues argue that it is measures like those mentioned above that actually reduce emissions, while market-based measures (like a fuel levy or an emission trading scheme) are only incentives to enforce faster implementation. In this respect, IMO (2009) classifies the environmental policies according to the applied enforcement mechanism into market-based, command-and-control, and voluntary instruments.

From a different perspective, Lun et al. (2014) identify six dimensions in green shipping practices: company policy and procedure, shipping documentation, shipping equipment, shipper cooperation, shipping materials, and shipping design and compliance.

Classification schemes like the ones mentioned above are simple and practical but lack rigid theoretical foundations. On the other hand, schemes that attempt to capture the multiplicity of interrelations among all factors affecting emission volumes are often of limited practical value due to their high level of complexity. IMO (2009) provides such an example. Although it clearly acknowledges that, by definition, the $CO_2$ emissions for most ships depend on the operational efficiency of the fleet and the transport work performed, when it comes to identifying the principal factors affecting the volume of emissions, the study presents a rather complex model including external and internal parameters that influence transport demand, modal split and fleet operations among others. McKinnon’s analytical framework for green logistics falls into this category, too (McKinnon, Browne, and Whiteing, 2012).

The objective of this chapter is to address these weaknesses. More specifically, it aims to develop a simple and practical framework for classifying emission reduction measures in the shipping industry which, however, is sufficiently supported by theory. Such a framework would put available options into a better perspective and serve as guidance in assessing their effectiveness and compatibility. It should be stated at the outset that the chapter does not intend to provide an exhaustive list of potential carbon emission reduction measures in waterborne transport. Instead, it refers to the most important practices and policies in the field in order to demonstrate the applicability of the proposed taxonomy.

The chapter covers all segments of waterborne freight transport: deep-sea shipping, short-sea shipping and inland navigation. Although by nature the subject is of universal applicability, some of the policy-related references used have a distinct, yet nonexclusive, European tint.

Section 7.2 provides a brief review of frameworks that have been proposed for assessing the sustainability of transportation and selects the most appropriate structure for the intended use. Section 7.3 decomposes the shipping-related GHG emissions into a number of suitable factors, thus, formulating the taxonomy mechanism. Section 7.4 is devoted to the classification of the most prevalent measures in the area of waterborne transport. A brief discussion of potential gains achieved through shifts among transport modes appears in Section 7.5, while the last section of the chapter summarises the main findings.

## 7.2 Sustainability frameworks

Although there is no standard definition for sustainable transportation, there seems to be a consensus that it involves three pillars: economic development, environmental protection and social acceptance (Council, 2006; Ramani et al., 2011b, Panagakos and Psaraftis, 2014). No consensus, however, can be identified in relation to the indicators used in monitoring progress in these three dimensions (Gudmundsson et al., 2016; Jeon and Amekudzi, 2005). The purpose of this section is to present the main types of frameworks employed in assessing transport sustainability and select the most appropriate one for the application in hand.

A sustainability framework is being viewed as 'a formalised system of goals, objectives, and performance measures applied for sustainability' (Ramani et al., 2011b). Gudmundsson et al. (2016) organise overarching frameworks of transport sustainability into four categories related to: transportation appraisal, environmental policy review and reporting, sustainability assessment, and performance management.

A simpler typology is suggested by Jeon and Amekudzi (2005), who assessed selected sustainable transportation initiatives around the world in order to investigate what constitutes sustainability in transport planning and how it is measured. Their classification consists of three types: impacts-based, linkages-based, and influence-oriented frameworks.

Impacts-based frameworks focus on the effects of various actions on the sustainability of the system under consideration. A common impacts-based framework is the three-dimensional framework of indicators based on economic, environmental, and social impacts, also known as the 'triple-bottom-line' framework (Pei et al., 2010). It is often applied in conjunction with a multi-criteria decision analysis (MCDA) approach to evaluate system sustainability. Goals addressing the impacts of the transportation system are decomposed into actions, which are further turned into quantifiable performance measures. The framework places emphasis on the balance among the different dimensions of sustainability, while offering flexibility in terms of varying priorities through different weights in MCDA. On the other hand, it cannot reflect causal factors neither relationships among goals. Thus, the danger of double counting cannot be ruled out as sometimes intermediary effects are measured in addition to ultimate ones.

The linkages-based frameworks go one step further and capture relationships between the causal factors, impacts and the corrective actions that have been selected to achieve sustainability. A widely used example of a linkages-based framework is the Pressure-State-Response (PSR) framework: Human activities exert 'pressures' on the environment and affect the 'state' of natural resources and the quality/quantity of life. The society reacts to these changes through environmental/economic policies and behavioural shifts ('response') that, in turn, influence human activities.

The PSR model is highly intuitive and can help decision makers and the public to see environmental and other issues as interconnected. It can also be easily adjusted to reflect varying priorities. Its main weakness stems from the fact that the economic and social dimensions of sustainability are not covered as thoroughly as the environmental one, which is the focus of the model by design.

The influence-oriented frameworks refer to a particular institution and are developed bearing in mind the relative levels of influence that this institution has on various actions affecting progress toward sustainability. Existing examples of such frameworks include three levels of indicators: state-level indicators (measuring the state of the transportation system in terms of sustainability), behavioural indicators (measuring the activities of the stakeholders involved that can be influenced by the institution), and operational indicators (that assess the activities of the institution itself). The ability of these frameworks to explicitly consider behaviour affecting factors (like education and incentives) is an additional advantage.

Another type of framework that focuses on stakeholder concerns is formally introduced by Pei et al. (2010). It is named ‘performance prism framework’ and explores five perspectives: (i) who are the key stakeholders and what do they need, (ii) which strategies must be put in place to satisfy these needs, (iii) which processes are required to implement these strategies, (iv) what capabilities are needed to enhance these processes, and (v) what contributions from stakeholders are required if these capabilities are to be developed. The advantage of devising strategies based on different groups of stakeholders that the performance prism exhibits is compromised by its complexity in cases of multiple objectives.

The fact that the taxonomy envisioned by this chapter is intended for general use, unconnected to specific stakeholders or institutions, confines selection among the impacts- and linkages-based frameworks. Our focus on corrective actions and their relationship to causal factors further renders the latter as the most appropriate framework.

A special type of the PSR scheme is the Criterion-Influences-Actions-Measures (CIAM) framework that models the relationships among sustainability criteria and produces a set of indicators as output (Jeon and Amekudzi, 2005). The framework consists of four stages:

(i) the selection of a suitable criterion,
(ii) the decomposition of the selected criterion into a number of influences,
(iii) the identification of actions triggered by these influences, and
(iv) the identification of measures that policy makers adopt to facilitate the actions to be taken.

Although decomposition has been used widely as a method for analysing $CO_2$ emissions, it has not been applied explicitly in classifying shipping-related emission reduction measures. The present chapter seeks to close this gap.

# 7.3 Decomposition of $CO_2$ emissions

The purpose of this section is to implement the second stage of the CIAM framework, namely to decompose the $CO_2$ emissions that comprise the selected criterion into a number of influences.

The first decomposition of this sort, known as the Kaya identity, was proposed by the Japanese scholar Yoichi Kaya with a paper presented to a 1990 IPCC Working Group meeting in Paris and later published in Kaya and Yokobori (1997). The Kaya identity expresses the global energy-related carbon emissions as a product of the carbon intensity of the energy consumed, the energy intensity of global economy, the per capita global product and the population, in the form:

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{GDP} \times \frac{GDP}{P} \times P \quad (9)$$

where:

$CO_2$ = global energy-related carbon emissions

$E$ = global energy consumption

$GDP$ = global product

$P$ = global population.

Since then, decomposition analysis has become a popular analysis tool and several studies have used it to study energy consumption and emissions in a wide range of applications. In the area of freight transportation, the simplest variation of Kaya identity is the one proposed by Yang et al. (2009):

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{T} \times \frac{T}{P} \times P \quad (10)$$

where:

$CO_2/E$ = carbon intensity of the fuel mix used (in grams of $CO_2$-eq per MJ consumed)

$T$ = transport activity (in tonne-km also expressed as tkm)

$E/T$ = energy intensity (in MJ/tkm)

$T/P$ = transport intensity (in tkm per capita)

$P$ = population.

For the purposes of the present chapter, three changes are introduced to Eq. (10). Firstly, the population factor is dropped from the identity as it lies outside the scope of our analysis. The upward trend of the world population is well documented and, despite the pressure it exerts on the planetary resources, any attempt to contain emissions through this factor extends far beyond the boundaries of the waterborne transport examined here. On the contrary, it intensifies the need to curb emissions through improvements in the remaining drivers. Secondly, the term vehicle-km (vkm) is introduced into the identity in order to express the fact that energy intensity is determined by the energy efficiency and the utilisation rate of the vehicles employed. Thirdly, the total GHG emissions of the waterborne transport sector are calculated as a sum over the vessels employed and the types of fuel used. The extended Kaya identity now becomes:

$$CO2eq = \sum_{vessel} \sum_{fuel} \frac{CO2eq}{MJ} \times \frac{MJ}{vkm} \times \frac{vkm}{tkm} \times tonnes \times km \qquad (11)$$

where:

| | | |
|---|---|---|
| $CO2eq$ | = | total GHG emissions produced by waterborne transport ($gCO_2$-eq) |
| $CO2eq/MJ$ | = | carbon intensity of the fuel mix used ($gCO_2$-eq/MJ) |
| $MJ/vkm$ | = | energy efficiency of the vessels employed (MJ/vkm) |
| $vkm/tkm$ | = | vessel traffic required to handle a given amount of freight movement |
| $tonnes$ | = | freight tonnes lifted by seagoing and inland waterway vessels, and |
| $km$ | = | average length of haul resulting from dividing tkm by tonnes. |

Eq. (11) is very similar to the formulation of Schipper et al. (1997) which, however, does not decompose energy intensity into energy efficiency and utilisation rate, despite the fact that this relationship is clearly mentioned in the text. Their scope is also broader covering all transport-related emissions, while they aim at reviewing trends in freight activity and energy use rather than classifying emission reduction measures. The formulation of Eq. (11) is also in line with the conclusions of McKinnon, Browne, and Whiteing

(2012), although they follow a much more detailed framework in analysing green logistics.

A further refinement of Eq. (11) concerns the term vkm/tkm. If we define capacity utilisation rate ($CUR$) as the metric comparing actual to potential output, it can take the form of Eq. (12) for a ship of payload capacity $C$ (in tonnes):

$$CUR = \frac{actual\ output}{potential\ output} = \frac{tkm}{C \times vkm} \quad (12)$$

Eq. (12) can then be rearranged as:

$$\frac{vkm}{tkm} = \frac{1}{C} \times \frac{1}{CUR} \quad (13)$$

and Eq. (11) becomes:

$$CO2eq = \sum_{vessel} \sum_{fuel} \frac{CO2eq}{MJ} \times \frac{MJ}{vkm} \times \frac{1}{C} \times \frac{1}{CUR} \times tonnes \times km \quad (14)$$

signifying the role that increasing payload capacity ($C$) and capacity utilisation rate ($CUR$) can have in minimising emissions.

# 7.4 $CO_2$ reduction measures

Eq. (14) will be used in this chapter as the framework for the classification of carbon emission reduction measures in waterborne transport. Each one of the six factors of the right-hand side of Eq. (14) will be dealt with separately. Energy efficiency improvements will be further divided into technological and operational measures. The section will also cover two types of measures aimed at a combination of factors: optimisation schemes and market-based measures.

## 7.4.1 Alternative fuels

Carbon intensity ($CO2e/MJ$) is the first factor in the right-hand side of Eq. (14) and reflects the fuel mix used. The role of alternative fuels in mitigating GHG emissions is well documented. As mentioned in Section 2.3.3, in its effort to decarbonise the transport sector, reduce the oil dependency and boost the growth of EU economy, the European Commission has adopted a comprehensive alternative fuels strategy covering all modes of transport (EC, 2013a).

Liquefied natural gas (LNG) offers a cost-efficient alternative to the heavy fuel and marine diesel/gas oils used for all waterborne activities. It is also an attractive option for vessels required to meet the new stricter limits for sulphur content in marine fuels that apply to the Sulphur Emission Control Areas since 1 January 2015. According to the EC's action plan on LNG for shipping (EC, 2013b), all TEN-T (trans-European transport network) core ports will have to provide LNG refuelling facilities by 1 January 2020.

Second-generation liquid biofuels, made from ligno-cellulosic biomass, residues, waste, and other non-food biomass, are also proposed by the EU strategy for all divisions of waterborne transport. Liquefied petroleum gas is proposed for inland navigation and short-sea shipping, while the recent advances in fuel cell technology enable the use of hydrogen in inland ship applications.

Electricity is not considered by the EU strategy as an alternative fuel of significant commercial interest in the shipping field. Although there have been battery-powered submarines for more than 100 years, the world's first electrically-powered car ferry entered service in early 2015 linking Lavik and Oppedal in the Norwegian Sognefjord (Siemens, 2016), demonstrating the feasibility of electric ships in short-distance connections. Another marine application of electrical power is the shore-side electricity used by ships berthed at ports. The so-called 'cold ironing' is gaining popularity in cases where air quality or noise limits are exceeded (Tzannatos, 2010).

Renewable energy sources like wind and solar energy have also been considered but are mostly in the experimental phase. Towing kites comprise the only wind power technology that is currently available to ships on a commercial basis. Although significant fuel savings are associated with such systems, their use is restricted to slower ships (bulk carriers and tankers) and to a relatively narrow range of wind conditions (ABS, 2012).

### 7.4.2 Energy efficiency improvements – Technological measures

Technological measures aiming at improved vessel efficiency, expressed as $MJ/vkm$ in Eq. (14), can be classified into the areas of ship design, construction materials, main/auxiliary machinery, and other energy-saving devices.

In addition to the capacity and speed of a ship, which will be discussed later on, the principal dimensions of a vessel need to be optimised at the design stage. The vessel's hull form (lines development) and her propulsion system also need to be optimised with regard to hydrodynamic performance in order to minimise total resistance and increase propulsion efficiency. The IMO's Energy Efficiency Design Index (EEDI) that sets fuel consumption standards for new ships contracted after 1 January 2013 is a policy instrument that has to be considered at this stage (refer to Section 2.6.1). Compliance with the standards that get progressively stricter requires the adoption of innovative technologies or a reduction in the design service speed which, however, is a non-intended side effect of EEDI.

Optimisation of a ship's lightweight for a given size increases the available deadweight and improves its energy efficiency. For commercial shipping, this is basically done through the use of higher strength steel. The energy efficiency gains, however, have to be adjusted for the need to control the fatigue life of this material.

Numerous energy efficiency enhancement technologies exist in relation to the ship's main and auxiliary engines. The electronic control of fuel injection and exhaust valve timing, the automated cylinder oil lubricators, and the advanced exhaust gas and turbocharger control equipment are a few examples. Additional improvements can be achieved by installing engine performance monitoring and control instruments that allow the proper tuning of the engines. In addition to the conventional slow- and medium-speed diesel engine plans, other hybrid arrangements like the diesel-electric propulsion systems can lead to fuel and emission savings. Furthermore, a variety of exhaust gas heat recovery systems, shaft generators and variable speed motors for pumps and fans that are in common use today improve the energy efficiency of ships.

Other energy-saving devices include high efficiency propellers (e.g. controllable-pitch, ducted, and contra-rotating propellers) and a wide range of other propulsion improving devices like spoilers, wake equalising ducts and tunnels, pre- and post-swirl fins and stators, and asymmetric rudders. Air lubrication and hull surface texturing have also been proposed as resistance reduction methods but both are still in their infancy (ABS, 2012).

### 7.4.3 Energy efficiency improvements – Operational measures

A number of daily operational decisions on running and maintaining a vessel can also have significant energy efficiency implications (in terms of $MJ/vkm$ in Eq. (14)). The most important ones that reflect on both the financial and environmental performance of the ship are briefly presented below.

The exponential relationship between the propulsive power requirement and the speed of a ship is well known (Kontovas and Psaraftis, 2011; Psaraftis and Kontovas, 2016). Slow steaming, the sailing at lower than the design speed on the legs of the voyage that the schedule allows, is the most common speed optimisation practice. It is noted that, in contrast to Eide et al. (2011), many rightly argue that slow steaming is not an energy efficiency improvement measure. It is simply a reaction to the spot rate and bunker cost for a given speed/fuel curve (Devanney, 2011). On the other hand, there are limitations in speed reductions stemming from the charter parties themselves, the delivery dates agreed with the shippers, the increased capital and labour costs of the assets, the increased cargo inventory costs, the sub-optimal efficiencies of machinery operating at lower loads, and the fact that more ships are needed to perform the same transport work. Voyage speed optimisation is the process of identifying the speed at each leg of a voyage that maximises operator profits. Another practice is the so-called 'virtual arrival' scheme, where the speed of a ship along a voyage leg is controlled by the availability window specified by the port of the next call.

Weather routing was initially developed to avoid potentially dangerous heavy weather conditions. However, as practiced today, it is the process of selecting a course that minimises fuel consumption while taking into account actual wind, wave and current conditions expected during the voyage. It is more commonly used on high-speed ships in liner services like cruise liners and containerships.

Trim/draft optimisation is the process of minimising resistance by selecting the proper draft and trim for any given voyage leg. Optimum is achieved through the appropriate positioning of cargo and consumables on board combined with selecting the proper amount and location of ballast water (Maddox, 2012).

A ship's hull and propeller condition greatly affects the frictional part of its total resistance, which is by far the most significant one. Condition management of these wetted surfaces is achieved by applying proper hull antifouling coatings, underwater cleaning by divers or vehicles operated remotely from the surface, propeller polishing, as well as the application of special foul-release coatings for propeller blades (ABS, 2012).

A number of policies targeting energy efficient operations have also been introduced at the global and regional level. Together with EEDI, in July 2011 the IMO adopted the Ship Energy Efficiency Management Plan (SEEMP) in order to establish a mechanism for a company and/or a ship to improve the energy efficiency of ship operations. Although its effectiveness has been questioned (Johnson et al., 2013), the SEEMP takes the form of a mandatory management plan forcing the responsible entities to consider new technologies and practices when optimising operations. The Energy Efficiency Operational Indicator (EEOI), assessing the average actual $CO_2$ emissions per unit of transport work performed, has been proposed by the IMO as a monitoring tool for the SEEMP of an individual ship but not suitable for comparisons between ships (refer to Section 2.6.1 for more details).

In the framework of its strategy addressing GHG emissions from maritime transport, the EU adopted Regulation 2015/757 on monitoring, reporting and verification of $CO_2$ emissions, the so-called 'MRV Regulation.' Section 2.6.3, covering the period up to Dec. 2014, refers to the Commission's proposal that eventually led to this regulation. The immediate objective of the MRV Regulation is to produce accurate information on the $CO_2$ emissions of large ships using EU ports and incentivise energy efficiency improvements by making this information publicly available. A lighter version of EU's MRV Regulation was approved at the 69th meeting of the Marine Environmental Protection Committee of the IMO (MEPC 69) that took place in April 2016. It stipulates the collection of energy efficiency data by IMO in an anonymised form precluding public identification of specific ship data.

### 7.4.4 Vessel capacity

The inverse relationship of Eq. (14) between the payload capacity ($C$) of a ship and the emissions produced highlight the positive effect that the employment of larger capacity vessels can have on emissions through economies of scale, which also affect costs in the same direction. Another reason is the need to maintain available capacity along liner services affected by slow steaming.

All ship types have grown larger over the last decades, the container fleet exhibiting the highest pace. The average capacity of a container ship has doubled during the last decade. Currently, the largest container ship can carry 19 200 TEUs, but ships with a capacity of more than 21 000 TEUs have been ordered and will be operational in 2017 (ITF, 2015).

However, it needs to be mentioned that the relative gains in fuel consumption diminish with capacity increases and can only be fully realised if the larger ships are effectively used (Cullinane and Khanna, 2000). Furthermore, larger ships require adaptations of infrastructure mainly in relation to access channels and berths. They also place greater demands on terminals in terms of equipment, yard facilities and manning levels to effectively handle increased heights and peak cargo volumes.

### 7.4.5 Vessel/fleet utilisation

When it comes to the emissions of Eq. (14), vessel utilisation ($CUR$) acts in the same way as payload capacity. Ceteris paribus, higher utilisation leads to lower emissions. But how utilisation can be improved? It is worth mentioning that in the $CUR$ definition of Eq. (12) the kms entering the term tkm in the nominator are not identical to the kms of the term vkm in the denominator, as the latter number is inflated by the length of the empty trips. More specifically, $CUR$ can be expressed as a function of the load factor ($LF$) and the empty trip factor ($ET$):

$$CUR = LF/(1 + ET) \qquad (15)$$

where:

$LF = mass\ of\ cargo/payload\ capacity$ (%) $and$
$ET = distance\ empty/distance\ loaded$ (%).

As expected, the utilisation rate increases when the load factor grows and/or the empty trip factor declines. It is evident that utilisation improvements belong to the so-called 'win-win solutions' that reduce the environmental impact of logistics while saving money, avoiding the need to trade off economic costs against environmental benefits.

In order to identify potential options for improving vessel/fleet utilisation, it is necessary to investigate the reasons for low utilisation rates. A basic problem in shipping is the unbalanced trade flows, which have a major impact on the $LF$ of the liner services and the $ET$ of the tramp services. Regulations can also affect asset utilisation as is the case with cabotage rules that restrict domestic maritime trade to national fleets and various administrative restrictions that apply in inland navigation to protect local, national and regional interests. From the shippers' point of view, it should be realised that other company activities like sales and customer satisfaction, production planning, procurement policy, and inventory management might have higher priority in decision making than transport efficiency.

Ship owners/operators can improve asset utilisation by enhancing the flexibility of their vessels at the design stage, optimising the type/size of vessels employed in a particular trade and by establishing hub-and-spoke networks that achieve cargo consolidation in both directions. On the other hand, shippers can achieve financial and environmental gains by selecting the appropriate packaging solutions, by employing more space-efficient handling equipment and, where applicable, by optimising the cargo mix (heavy and light cargoes) for exploiting both the weight and volume capacity of a container/vehicle.

An approach towards improved utilisation rates that should not be overlooked concerns collaborative business strategies. In addition to mergers, shipping companies in the liner business enter into alliances that involve vessel sharing agreements including slot exchange and slot chartering arrangements (Heaver, 2015). In fact, Cullinane and Khanna (2000) argue that improved rationalisation of the sector through alliances, mergers and acquisitions should not be seen independently from investments in ever-larger containerships. Such deals are also useful in counterbalancing the increased market power that shippers have achieved during the last decades through the extensive consolidation that has taken place in manufacturing (Poulsen et al., 2016). Groothedde et al. (2005) present the design and implementation of a collaborative hub network in The Netherlands for the distribution of fast moving consumer goods (FMCG) using a combination of trucking and inland barges.

### 7.4.6 Transport demand management

The $tonnes$ element of Eq. (14) is the subject of this heading. McKinnon (2014) identifies four developments that may 'dematerialise' international trade in the short term: miniaturisation, digitisation, 3D-printing and postponement. Miniaturisation describes the trend of product shrinkage in size while their functionality expands. It is very common in the computing, electrical equipment and telecommunications sectors, although good examples can also been found in the FMCG area like detergents. Digitisation defines the change in distribution form - from physical to digital - that media products like books, magazines, software and entertainment increasingly take. The technology of additive manufacturing reduces complex supply chains to the simple delivery of the necessary powders to a 3D-printer located at or near the final consumer, thus shrinking freight volume. Postponement describes the act of adding value as late as possible in a production process. The final assembly, customisation and packaging of products only after they have reached their end market can substantially reduce freight volumes and emissions. Adding water to a soft drink essence or a detergent mix, and wine bottling near the point of consumption are well known examples of this practice.

### 7.4.7 Supply chain structure

The average length of haul ($km$ of Eq. (14)) is the topic here. The last decades have seen an impressive growth of freight transport activity, which is mainly attributed to greater average distances rather than to higher volumes of cargo (McKinnon, 2010). The basic drivers behind this development have been the wider sourcing of supplies and the centralisation of economic activity. Certainly none of these processes can continue indefinitely. In fact, many argue that the recent trend of technologically driven disintermediation is causing a global shift away from the economic value of manufacturing to the value of human capital (Goldberg, 2014).

It should be emphasised, however, that even if the weakening of the globalisation forces result in the relocation of some production operations closer to the markets, it is not certain that the total life-cycle emissions of traded products will be reduced. This is due to the fact that production-related emissions typically account for a much higher percentage of total life-cycle emissions than transport operations. Therefore, the life-cycle assessment approach suggests locating production operations where their carbon intensity is low even if this means that goods have to be transported over longer distances to market.

### 7.4.8 Optimisation of transport operations

In addition to measures targeting a single factor of the right-hand side of Eq. (14), a variety of measures exist that target a combination of these factors.

The operational research (OR) applications that aim at minimising the distance sailed (in $vkm$), which is the product of the last four factors of Eq. (14), is the subject of the present heading.

The OR problem family with most maritime applications is the vehicle routing problem (VRP), a combinatorial optimisation and integer programming problem which selects the optimal set of routes that a fleet of vessels needs to sail in order to serve a given set of shippers. It generalises the well-known travelling salesman problem. Although most formulations of the VRP problem minimise costs rather than distances, they are still useful as cost reduction comes partly from reducing the unnecessary distance sailed due to sub-optimal routes, which in itself can lead to a reduction in fuel consumption and emissions. Christiansen et al. (2013) provide a review of numerous ship routing and scheduling applications. They cover decisions at strategic, tactical and operational levels, while they discuss separately the different shipping segments: industrial, tramp, and liner shipping.

### 7.4.9 Market-based measures

Market-based measures (MBMs) are the second family of measures aimed at an assembly of the $CO_2$ emission drivers of Eq. (14). They comprise the instrument for internalising the external cost of transport operations, a long-standing target of EU transport policy, for achieving efficiency gains through conveying the right price signal to all economic actors. The principle applies to all modes with particular emphasis on road and rail transport. As for shipping, the adoption of an MBM is the ultimate objective of the MRV Regulation of the EU. The introduction of an MBM has also been discussed at IMO for years. Including MBMs in a comprehensive package of GHG-emission controlling measures was agreed in July 2009 (MEPC 59). However, the IMO work on the subject was suspended in May 2013 (MEPC 65) in the wake of a clash between developed and developing Member States. This reflected a channelling of the discussion towards the subject of MRV, discussed in Section 7.4.3 (Psaraftis, 2016b).

In principle, the application unit of an MBM can be the distance travelled, the fuel consumed or the emissions produced. A distance-based toll system is in place for heavy duty vehicles in Switzerland and Germany. Although it has been suggested in the past for inland waterways (Kreis et al., 2014), it has never been applied in the waterborne transport mode. An MBM on fuel can take the form of either a tax on fossil fuel or a tax rebate/subsidy on renewable energy sources. At the emissions level, a well discussed MBM is the inclusion of shipping in the Emission Trading System, the European 'cap and trade' scheme that covers more than 11,000 power stations and industrial plants in 31 countries, as well as airlines. Differentiated port dues rewarding ships exhibiting advanced environmental performance are becoming increasingly popular. Although they basically concern local air pollutants, a bonus for reporting energy efficiency information is sometimes offered.

However, the effectiveness of an MBM depends on the price sensitivity of the transport user. As such, internalisation often has to be accompanied by other measures intended to create greater elasticity of demand, i.e. the provision of credible alternatives, enhanced competition with regard to a particular mode of transport, sufficient incentive to innovate and switch to clean practices, etc.

## 7.5 Modal considerations

The discussion of Section 7.4 was confined to possible measures targeting $CO_2$ emission reductions within shipping. This excludes gains associated with shifting freight from a mode of high carbon intensity like air and road to a low-carbon mode like rail and shipping. Given the significant differences in carbon intensities, as they have been documented in IMO (2009), such gains can be substantial. Eq. (14) can capture the effects of modal shifts if the formulation is expanded by adding a summation operator over all transport modes.

As large differences in freight rates and transit times between sea and air basically eliminate competition between these modes, environmental gains are possible only from shifts between land-based modes and short-sea shipping. The EU and national governments in Europe have tried for more than 30 years to shift cargoes away from the congested European roads, albeit with little success so far. It appears that the drawbacks associated with rail and waterborne transport, such as lower flexibility and accessibility, slower transit times, lower reliability and service quality and, maybe, inadequate marketing, outpace their advantages in the form of lower freight rates and superior climate change related performance.

In view of the rather disappointing results of previous efforts providing subsidies for the purchase of vehicles and equipment and revenue-support for rail and waterborne services, the EU-funded TEN-T and ‘Motorways of the Sea’ programmes now follow a corridor approach, providing priority financing to multimodal investments along pre-specified transport corridors. Among other benefits, by concentrating freight traffic over long distances, the ‘green corridors’ of Chapters 3 and 4 improve the competitiveness of rail and waterborne services and create the economies of scale needed for establishing a network of refuelling/recharging stations for alternative fuels and for optimising in terms of energy use and emissions.

## 7.6 Concluding remarks

The chapter has briefly reviewed the main types of frameworks employed in assessing transport sustainability and has selected the Criterion-Influences-Actions-Measures structure as the most suitable one for the classification of $CO_2$ emission reduction measures. The waterborne transport related GHG emissions have been decomposed into a number of drivers through an extended Kaya identity.  The carbon intensity of the fuels used, the energy efficiency of the vessels employed, the vessel capacity and utilisation rate, as well as the transport activity expressed by cargo volumes and average haul lengths have been identified as the most important factors affecting emissions.

A wide range of $CO_2$ reducing practices and policies, albeit by no means exhaustive, have been examined and classified on the basis of these factors. The main contribution of this classification framework is that it provides a wider perspective on possible measures and their effectiveness. Many studies in the literature have concluded that pursuing single policies or initiatives is not sufficient for reaching the ambitious goals set by the international society with regard to climate change, as they tend to have a rather modest effect on $CO_2$ reduction (Yang et al., 2009; Eide et al., 2011). Instead, the objective of sustainable mobility requires the employment of packages of complementary instruments.

The classification framework can also help in assessing the compatibility and side effects of the various carbon reduction measures proposed. As is the case with any political initiative, sufficient care should be given to the ‘push-down/pop-up principle’. Undesirable results due to the substitution and income effects of political interventions are not uncommon in the transport field.

An additional use of the classification framework relates to the sometimes heated discussion on economy versus environment. All measures addressing the five last factors in the right-hand side of Eq. (14) result in lower fuel consumption and, thus, savings in terms of both costs and emissions. In the search for win-win solutions, therefore, we should not overlook the environmental benefits derived indirectly by many profit maximising measures.

A final comment relates to the scope of this chapter, which is restricted to waterborne transport. It should be kept in mind that shipping is only one of the transport modes involved in freight logistics. Sustainable ships need to be served by sustainable ports, and together they have to interact with sustainable trains and trucks through sustainable intermodal terminals. Even the sustainability of the entire supply chain might prove misleading in cases of great differentiations in the sustainability of the production processes. A life-cycle assessment methodology is suggested for such occurrences.

# 8. The possible designation of the Mediterranean Sea as a SECA: A case study[39]

## 8.1 Introduction

The stricter standards on the sulphur content of marine fuels as introduced by MARPOL Annex VI in 2008, particularly the 0.1% limit applicable to the SECAs as of 1 January 2015, caused serious concerns mainly within the shipping industry in Europe, as they are expected to have a negative impact on the competitiveness of shipping operations, potentially leading to a shift to other less environmentally friendly modes of transport. A number of studies were undertaken to examine the impact of these stricter requirements. Four of them were performed by countries within SECAs: Finland (Kalli et al., 2009), Sweden (Ljungström et al., 2009), the UK (Stavrakaki et al., 2009) and Germany (Hader et al., 2010). Four more studies were commissioned by stakeholder organisations: one by the European Community Shipowner Association (ECSA) (Notteboom et al., 2010) and three by the European Commission (Bosch et al., 2009; Kehoe et al., 2010; Delhaye et al., 2010). Two additional studies were commissioned to assess and compare the results of the previous studies: one by a group of Northern shipowner associations, endorsed by ECSA and the International Chamber of Shipping (ICS) (Grebot et al., 2010), and one by the European Maritime Safety Agency (EMSA, 2010).

For as long as the new IMO requirements had not been transposed into European law, shipping and other industries in the SECAs developed aspirations of either relaxed sulphur content limits or prolonged enforcement dates. Several interest groups even attempted to reopen negotiations at the IMO level. Yet others hoped that this could be a chance

[39] With the exception of some minor editorial changes basically concerning cross-references, this chapter is identical to the homonymous Transportation Research Part D article by Panagakos, Stamatopoulou and Psaraftis (Panagakos et al., 2014).

at least to make the rules equal within the EU territory, as the increased cost of shipping in the SECAs was not borne by the southern EU operators. These intense lobbying efforts came to an end in November 2012 with the adoption of Directive 2012/33/EU. None of the aspirations of the industry materialised. The only compromise was that the Directive brings the 0.5% limit into force on 1 January 2020 for all EU sea territory, even if on global scale this limit gets postponed to 2025 (Malmqvist and Aldén, 2013).

During the inter-institutional debates that preceded the adoption of this Directive, the Commission was asked by the legislation to consider extending the stricter SECA limits to all EU territorial waters. This renewed the discussion on possible designation of the Mediterranean Sea as a SECA (Bosch et al., 2009; Delhaye et al., 2010; Kehoe and Woxenius, 2010). The Committee on Transport and Tourism of the European Parliament commissioned an assessment of a possible extension of SECAs to the entire European coastline (Schinas and Bani, 2012), which confirms the wider societal benefits of any reduction in the environmental burden and concludes that the extension of a SECA around the EU would level the playing field for all stakeholders, enhance the technical compatibility of the short-sea fleet servicing European ports, provide a stimulus to technical research in the area of abatement and alternative fuels and enable efficient enforcement of the regulations under the existing Port State Control regime.

Against this background, the present chapter examines the impact of designating the Mediterranean Sea as a SECA on the transport of consolidated cargoes between Thessaloniki, Greece and industrial hubs of northern Germany. A road-only option is assessed against a combined-transport route involving a ferry service for crossing the Ionian/Adriatic Seas and a truck-on-train service for crossing the Alps. A binomial logit model, considering transport cost and time as determinants of modal choices, is used for predicting the modal split. The corresponding $CO_2$-eq, SOx, NOx and $PM_{10}$ emissions are calculated through the EcoTransIT World web based tool.

The chapter makes the following contributions. Firstly, it adds to the literature on the subject, which happens to be much thinner for this part of Europe in comparison to the Baltic and North Seas. Secondly, none of the previous studies uses a logit model that takes into consideration transport time in addition to costs. Only two of these studies have applied the simplest possible form of such models: one explicitly (Hader et al., 2010), the other implicitly (Kehoe et al., 2010; Kehoe and Woxenius, 2010). In fact, while the former is based on revealed preferences, the latter is calibrated on the assumption (found through interviews with shippers) that transporting goods by short-sea shipping (SSS) must be approximately 15% cheaper than the land alternative to be considered equitable. That is to say that when the SSS option is 15% cheaper than the land alternative, approximately 50% of the cargo will travel by SSS and 50% by land. On the contrary, the present application involves a binomial logit model that takes into consideration both transport cost and time and is calibrated through revealed preferences. A third point that makes this chapter distinct relates to its scope. Aiming at addressing the SME subsector of the logistics industry that happens to be quite substantial in Greece, the chapter applies a micro-level perspective, which is handful in securing comparable door-to-door transport chains on one hand, while it allows the delineation of an emission allocation scheme for a multi-load multi-drop operation on the other.

The model and its calibration are presented in Section 8.2. Section 8.3 is devoted to the model results and their sensitivity to changes in variables exhibiting a high degree of uncertainty. The environmental implications of a Mediterranean SECA are discussed in Section 8.4, while Section 8.5 presents the conclusions of the chapter.

## 8.2 The model and its calibration

In general, modal split models determine the number of trips on different modes given the travel demand between an origin-destination (OD) pair. They try to mathematically describe the mode choice mechanism, based on the assumption that the probability of choosing a particular mode is the probability that the perceived utility from that mode is greater than the perceived utility from each of the other available modes.

There are various forms of modal split models but by far the most common one is the logit model, which has been found to fit the mode choice behaviour quite well. The binomial form of the logit model, where there are only two alternative modes of transport to choose from, is being used for this application.

The formulation of Psaraftis and Kontovas (2010) has been selected. If $x_i$ is the fraction of the cargo that will choose mode $i$ ($i$ = 1, 2), assuming there is available capacity to do so ($0 \leq x_i \leq 1$), the binomial logit model defines $x_i$ as:

$$x_i = \exp(-\lambda C_i) / [\exp(-\lambda C_1) + \exp(-\lambda C_2)] \quad (16)$$

where $C_i$ is the generalised cost or disutility associated with mode *i* and λ is a positive constant to be estimated at model calibration. $C_i$ can be expressed as a function (usually linear) of a number of variables. Depending on the particular application, the following variables have been proposed in the literature as determinants of $C_i$:

- total monetary costs (freight rates and other direct or indirect costs);
- total transport time (in-vehicle, idling, border-crossing, etc.);
- reliability and regularity (in terms of on-time delivery);
- flexibility (ability to adapt to changes in annual demand/volume, size of consignment and time table);
- resilience (ability to cope with serious disruptions);
- safety and security; and
- environmental performance (e.g. emissions of GHG and air pollutants).

The present application is confined in the first two of the variables listed above. Then:

$$C_i = p_i + \mathrm{k}t_i \quad (17)$$

where $p_i$ stands for the total transport cost associated with mode *i* (€/tonne), $t_i$ is the corresponding total transport time (days) and k is a positive constant (€/tonne/day).

For the purposes of this chapter, the model is applied to estimate shares of cargo moved not just by alternative transport modes but along alternative routes between a given OD pair. Each available option, then, concerns a particular supply chain involving one or more transport modes. It is important to keep in mind that the model results are being used to assess the emissions associated with each alternative route examined. It is, therefore, necessary all alternative routes to concern door-to-door services between the same OD pair.

The scenario examined here concerns consolidated cargoes transported by truck between Thessaloniki, Greece and industrial hubs of northern Germany. Clothing products, agricultural products and marble are the usual exports to Germany originating in the Thessaloniki region. Road is the exclusive transport mode used for clothing products due to their high value and product nature (timely positioning in the marketplace is critical). The industry norm is that exports to Germany are scheduled for the last day of each calendar week (Friday). Products that are for some reason delayed are in most cases flown to destination at the expense of the party responsible for the delay.

There are two routes from Thessaloniki to northern Germany that trucks follow. The first one ('road-only') is Thessaloniki – Skopje – Belgrade – Budapest – Bratislava – Prague – Dresden – Berlin. Route 1 appears in Figure 47. It is the most common one for destinations in northern Germany, as it avoids the restrictions of Austria and minimises the high road tolls of Germany.


**Figure 47. The 'road-only' route (Route 1)**

(Source: Own compilation)

The second route, Thessaloniki – Igoumenitsa – Ancona – Bologna – Verona – Munich – Nurnberg – Berlin ('combined-transport') involves crossing the Ionian/Adriatic Seas by ferry boats. Route 2, depicted in Figure 48, is faster than the first one but, as far as exports are concerned, it is selected only in cases of short delivery times as ferry services result in higher total costs, while the security problems created by illegal immigrants trying to reach Italy onboard westbound trucks from Igoumenitsa are not negligible.

It is noted that Igoumenitsa is also connected via ferry services to the Italian ports of Bari and Brindisi. However, these connections are rarely used by trucks heading towards northern Germany. The combined-transport route examined here involves also a truck-on-train service between Brenner and Wörgl.

The information needed for model calibration was obtained through interviews with a small-size Greek truck operating company that specialises in services between Thessaloniki and destinations in Italy and Germany. It uses 40-tonne EURO III, IV and V trucks that are mainly owned by third parties and usually operated by their owners themselves. Data gathered cover year 2010, which was selected as the basis for the analysis due to the fact that the present financial and economic crisis in the country makes the more recent information rather atypical.


**Figure 48. The 'combined-transport' route (Route 2)**

(Source: Own compilation)

In 2010, the company arranged 250 round trips from Thessaloniki to Germany. Only 73 of them (29.2%) concern full loads. The remaining are loads consisting of less-than-full cargoes consolidated in Thessaloniki. The transport chain examined here belongs to the latter type (177 trips in 2010). It is noted that before the present crisis, full cargoes were much more frequent, comprising about 70% of the total.

The vehicle examined is a EURO III 40 t truck with a maximum payload of 24 t and 85 cu.m. Provided that consolidated freight consists of a mix of light and heavy cargoes, it is estimated that the average full payload is about 18 t. Due to cargo consolidation, the trucks leave Thessaloniki almost full. Load factors are above 95%.

In the typical case analysed here, the truck carries three cargoes on its outbound leg: The first batch is clothing products that have to be delivered directly to cargo owner's facilities in Berlin. A typical consignment is 350 cartons 60cm X 40cm X 30 cm, which in total amounts to 25.2 cu.m. and weighs about 3.5 tonnes. A typical value of such cargo can be in the area of € 145,000. The transport cost for this type of cargo from Thessaloniki to Berlin is 37 €/cu.m. or € 932.40 in 2010 prices. An additional amount of about € 50.00 is charged for agency fees. The insurance cost is 0.15% of the value of goods or € 217.50. So, the total cost for this first batch is about € 1,200.[40]

The second batch consists of 10 t of olives destined to the warehouse of a freight forwarder in Hannover. They are packaged in metal canisters 24cm X 24 cm X 35 cm weighing 20 kg each. Each pallet is 120cm X 80cm in dimensions and carries 45 canisters (in 3 layers of 15 canisters each) or 900 kg in total. The consignment consists of 11 pallets. Total transport cost is estimated at about € 1,100.

The third batch of cargo is 3.6 t of clothing products to be delivered to the facilities of the cargo owner in Bremen. A figure of € 1,250 is estimated as above for the transport cost of this batch. So, the total transport cost for the outbound leg is € 3,550.

[40] Although the case study examined here focuses on this first batch of cargo, data on all three cargoes are provided in order to be able to calculate the distances and load factors needed for allocating emissions along this multi-load multi-drop vehicle trip.

It is noted that when consignment is above 18 cu.m. in volume or 3 t in weight, the cost estimate provided above includes the cost of cargo collection from the site of the exporter. In this case the same truck that will do the long haul goes to the exporter's site and picks up the cargo. When cargo volume is below 18 cu.m. or 3 t, it is the exporter's obligation to bring the cargo to the facilities of the service provider, located 8 km away from the centre of Thessaloniki, where the consolidation process takes place. In these cases exporters use their own light trucks or can arrange for a pick up by a third party for about € 60. The average distance that a truck needs to travel in the Thessaloniki area to pick up cargoes before it starts its main journey is about 80 km.

### 8.2.1 The road-only route

A typical itinerary of the truck along the road-only route, which accounted for 121 of the 177 trips in year 2010 (68.36%) is described in detail in Table 29. Although cargo is picked up on a Friday afternoon, the truck doesn't leave prior to Sunday 5:00 in order to avoid the weekend traffic restrictions. It reaches Berlin on Wednesday at 8:00 in the morning. The general pattern consists of driving for 4.5 hours, pausing for 1 hour, driving for another 4.5 hours and resting for 11 hours.

On the Thessaloniki – Berlin segment, the truck crosses three borders involving non-EU states, those of Greece – FYROM, FYROM – Serbia, and Serbia – Hungary. The average time spent for clearing these borders is 1.5, 3.0, and 3.5 hours respectively. Depending on the season of the year, the day of the week and the time of the day, border clearance times can be as long as twice the average figures indicated. The truck also stops to rest three times; one outside Belgrade, one close to the Slovakian – Czech border, and one outside Berlin.

The first batch of cargo is unloaded in Berlin. Note that the type of consignee influences delivery time. If the consignee is the cargo owner himself, as is the case here, the delivery takes place at the consignee's facilities that most of the times are open only during working hours. If the consignee is the warehouse of a freight forwarding company, delivery can be made at any time of the day at advance notice. In our case, the truck has to wait outside Berlin for 7.5 hours on top of the 11 hours stipulated by the regulations, so as to reach the cargo owner's facilities at 8:00 in the morning.

**Table 29. Typical itinerary along the road-only route**

| No. | Activity | Origin | Destination | Dist. (km) | Tons | Tkm | Start Day | Start Time | Finish Day | Finish Time | Duration (hours) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Driving from depot to Site 1 in Thessaloniki | Thessaloniki | Thessaloniki | 32 | 0 | 0 | Fr. | 11:30 | Fr. | 12:30 | 1 | 0.5 hours delay due to congestion |
| 2 | Pick up Consignment 1 of 3.5 t to Berlin | - | - | 0 | 3.5 | 0 | Fr. | 12:30 | Fr. | 14:00 | 1.5 | |
| 3 | Driving from Site 1 to Site 2 in Thessaloniki | Thessaloniki | Thessaloniki | 15 | 3.5 | 53 | Fr. | 14:00 | Fr. | 14:30 | 0.5 | |
| 4 | Pick up Consignment 2 of 10 t to Hannover | - | - | 0 | 10 | 0 | Fr. | 14:30 | Fr. | 15:30 | 1 | |
| 5 | Driving from Site 2 to Site 3 in Thessaloniki | Thessaloniki | Thessaloniki | 18 | 13.5 | 243 | Fr. | 15:30 | Fr. | 16:30 | 1 | 0.5 hours delay due to congestion |
| 6 | Pick up Consignment 3 of 3.6 t to Bremen | - | - | 0 | 3.6 | 0 | Fr. | 16:30 | Fr. | 18:30 | 2 | |
| 7 | Driving from Site 3 to depot in Thessaloniki | Thessaloniki | Thessaloniki | 15 | 17.1 | 257 | Fr. | 18:30 | Fr. | 19:00 | 0.5 | |
| 8 | Off duty | - | - | 0 | 17.1 | 0 | Fr. | 19:00 | Su. | 5:00 | 34 | |
| 9 | Driving from Thessaloniki to Skopje | Thessaloniki | Skopje | 236 | 17.1 | 4036 | Su. | 5:00 | Su. | 8:30 | 4.5 | 1.5 hours to clear the GR-FRM borders<br>1 hour time difference |
| 10 | Driving from Skopje to Belgrade | Skopje | Belgrade | 393 | 17.1 | 6720 | Su. | 8:30 | Mo. | 4:00 | 19.5 | 3 hours to clear the FRM-SRB borders<br>11 hours idle |
| 11 | Driving from Belgrade to Budapest | Belgrade | Budapest | 373 | 17.1 | 6378 | Mo. | 4:00 | Mo. | 12:00 | 8 | 3.5 hours to clear the SRB-HU borders |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | Driving form Budapest to Bratislava | Budapest | Bratislava | 200 | 17.1 | 3420 | Mo. | 12:00 | Mo. | 15:30 | 3.5 | 1 hour idle |
| 13 | Driving from Bratislava to Prague | Bratislava | Prague | 338 | 17.1 | 5780 | Mo. | 15:30 | Tu. | 8:00 | 16.5 | 12 hours idle |
| 14 | Driving from Prague to Dresden | Prague | Dresden | 158 | 17.1 | 2702 | Tu. | 8:00 | Tu. | 10:00 | 2 | |
| 15 | Driving form Dresden to Berlin | Dresden | Berlin | 196 | 17.1 | 3352 | Tu. | 10:00 | We. | 8:00 | 22 | 18.5 hours idle<br>1 hour delay due to congestion |
| 16 | Unloading in Berlin | - | - | 0 | 3.5 | 0 | We. | 8:00 | We. | 9:30 | 1.5 | |
| 17 | Driving from Berlin to Hannover | Berlin | Hannover | 291 | 13.6 | 3958 | We. | 9:30 | We. | 13:30 | 4 | |
| 18 | Unloading in Hannover | - | - | 0 | 10 | 0 | We. | 13:30 | We. | 14:30 | 1 | |
| 19 | Driving from Hannover to Bremen | Hannover | Bremen | 132 | 3.6 | 475 | We. | 14:30 | We. | 16:30 | 2 | |
| 20 | Unloading in Bremen | - | - | 0 | 3.6 | 0 | We. | 16:30 | We. | 18:00 | 1.5 | |
| 21 | Off duty | - | - | 0 | 0 | 0 | We. | 18:00 | Th. | 18:00 | 24 | |
| | **Total road-only route** | | | **2,397** | **km** | **37,372** | **tkm** | | | | **151.5** | **hours** |

(Source: Own compilation)

Following unloading in Berlin, the truck drives to Hannover to unload the second cargo batch, and then to Bremen for the final consignment. The unloading operation is finalised on Wednesday at 18:00 hours. Delivery by the end of working day Wednesday is the contractual obligation of the service provider. This is achieved in 99% of the cases. In fact, the company's statistics show delivery 5 hours ahead of schedule on the average. Note that the 7.5 hours of idling in Berlin serves as a buffer for unexpected delays.

After all cargoes have been delivered, the truck goes off duty for 24 hours according to the regulations. The road-only statistics are summarised below:

- Total distance: 2,397 km
- Total time: 151.5 hours, of which: driving: 34.5 hours[a]
  loading/unloading: 8.5 hours
  border crossing: 8.0 hours
  onboard other means: 0.0 hours
  idling: 100.5 hours
- Total tkm: 37,372 tkm, of which: 7,649 tkm are attributed to the first consignment of clothing products (3.5 tons) from Thessaloniki to Berlin (= 37,372 tkm * 3.5 t / 17.1 t)
- Nominal distance:[b] 2,186 km (= 7,649 tkm / 3.5 t), of which:
  - first mile: 16 km (= 80 km in Thessaloniki * 3.5 t / 17.1 t)
  - main journey 1,894 km (Thessaloniki – Berlin)
  - last mile: 276 km (= 2,186 – 1,894 – 16)
- Average nominal speed: 15.8 km/h (= 2,397 km / 151.5 hours)
- Average speed driving: 69.5 km/h (= 2,397 km / 34.5 hours)
- Actual cost (for the consignment of interest): 342.86 €/t (= 1,200 € / 3.5 t)
- Actual time (for the consignment of interest): 4.92 days (= 118 hours / 24)
- Unit value (for the consignment of interest): 41,430 €/t (~ 145,000 € / 3.5 t)

[a] It includes about 3 hours of congestion related delays (2 of these 3 hours are recorded, the remaining is not recorded as it comprises of less than 30 min. intervals).
[b] For the consignment of interest.

## 8.2.2 The combined-transport route

A typical itinerary of the truck along the combined-transport route, which in 2010 accounted for 56 of the 177 trips (31.64%), is described in Table 30. There is a 10% surcharge for this service, meaning that the cost for moving clothing products from Thessaloniki to Berlin is now 40.70 €/cu.m. (= 37 €/cu.m * 1.10). The additional charges for agency fees and insurance remain unchanged, bringing the total cost for the first batch to € 1,293.14 (= 40.70*25.2 + 50 + 217.50).

According to this schedule, the collection of cargoes has to be over by 15:00 on Friday afternoon, so that the truck can reach Igoumenitsa the same evening at least 2 hours prior to the departure of the ferry boat. The ship arrives in Ancona at 16:00 of the following day. The truck reaches Brenner (through Bologna and Verona) at 01:30 on Sunday morning and stays in the ROLA terminal there until 00:30 Monday morning, when it gets on the train for the Brenner-Wörgl link. It is noted that this itinerary cannot be followed from June 1 to September 20, when the usual Sunday ban on heavy goods vehicles in Italy is extended to cover the entire weekend from Friday 18:00 to Sunday 24:00.[41]

After driving off the train, the truck reaches its first destination in Berlin at about 14:00 on Monday afternoon, 42 hours earlier than with the road-only option. Note that the time gain for the other two deliveries is lower, as the driver has to rest for 11 hours right after the first stop in Berlin. Once again, the truck goes off duty for 24 hours after all deliveries are made in order to ensure comparability between the two itineraries.

[41]For traffic restrictions in Italy refer to: http://troxoikaitir.gr/periorismoi-kikloforias/italia-it (in Greek)

**Table 30. Typical itinerary along the combined-transport route**

| | | | | Dist. | | | Start | | Finish | | Duration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Activity | Origin | Destination | (km) | Tons | Tkm | Day | Time | Day | Time | (hours) | Comments |
| 1 | Driving from depot to Site 1 in Thessaloniki | Thessaloniki | Thessaloniki | 32 | 0 | 0 | Fr. | 08:00 | Fr. | 09:00 | 1 | 0.5 hours delay due to congestion |
| 2 | Pick up Consignment 1 of 3.5 t to Berlin | - | - | 0 | 3.5 | 0 | Fr. | 09:00 | Fr. | 10:30 | 1.5 | |
| 3 | Driving from Site 1 to Site 2 in Thessaloniki | Thessaloniki | Thessaloniki | 15 | 3.5 | 53 | Fr. | 10:30 | Fr. | 11:00 | 0.5 | |
| 4 | Pick up Consignment 2 of 10 t to Hannover | - | - | 0 | 10 | 0 | Fr. | 11:00 | Fr. | 12:00 | 1 | |
| 5 | Driving from Site 2 to Site 3 in Thessaloniki | Thessaloniki | Thessaloniki | 18 | 13.5 | 243 | Fr. | 12:00 | Fr. | 13:00 | 1 | 0.5 hours delay due to congestion |
| 6 | Pick up Consignment 3 of 3.6 t to Bremen | - | - | 0 | 3.6 | 0 | Fr. | 13:00 | Fr. | 15:00 | 2 | |
| 7 | Driving from Site 3 to depot in Thessaloniki | Thessaloniki | Thessaloniki | 15 | 17.1 | 257 | Fr. | 15:00 | Fr. | 15:30 | 0.5 | Change drivers |
| 8 | Driving from Thessaloniki to Igoumenitsa | Thessaloniki | Igoumenitsa | 350 | 17.1 | 5985 | Fr. | 15:30 | Fr. | 21:30 | 6 | 1 hour idle |
| 9 | Waiting to board ferry | - | - | 0 | 17.1 | 0 | Fr. | 21:30 | Fr. | 23:30 | 2 | |
| 10 | Crossing the Adriatic Sea | Igoumenitsa | Ancona | 735 | 17.1 | 12569 | Fr. | 23:30 | Sa. | 16:00 | 17.5 | 1 hour time difference |
| 11 | Driving form Ancona to Bologna | Ancona | Bologna | 227 | 17.1 | 3882 | Sa. | 16:00 | Sa. | 19:00 | 3 | |
| 12 | Driving from Bologna to Verona | Bologna | Verona | 151 | 17.1 | 2582 | Sa. | 19:00 | Sa. | 22:00 | 3 | 1 hour idle |
| 13 | Driving from Verona to Brenner | Verona | Brenner | 239 | 17.1 | 4087 | Sa. | 22:00 | Su. | 01:30 | 3.5 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | Waiting in ROLA terminal | - | - | 0 | 17.1 | 0 | Su. | 01:30 | Mo. | 00:30 | 23 | |
| 15 | Crossing Austria by train | Brenner | Wörgl | 97 | 17.1 | 1659 | Mo. | 00:30 | Mo. | 03:30 | 3 | |
| 16 | Driving from Wörgl to Munich | Wörgl | Munich | 109 | 17.1 | 1864 | Mo. | 03:30 | Mo. | 05:00 | 1.5 | |
| 17 | Driving from Munich to Nurnberg | Munich | Nurnberg | 167 | 17.1 | 2856 | Mo. | 05:00 | Mo. | 07:00 | 2 | |
| 18 | Driving from Nurnberg to Berlin | Nurnberg | Berlin | 438 | 17.1 | 7490 | Mo. | 07:00 | Mo. | 14:00 | 7 | 1 hour idle |
| 19 | Unloading in Berlin | - | - | 0 | 3.5 | 0 | Mo. | 14:00 | Mo. | 15:30 | 1.5 | |
| 20 | Driving from Berlin to Hannover | Berlin | Hannover | 291 | 13.6 | 3958 | Mo. | 15:30 | Tu. | 06:30 | 15 | 11 hours idle |
| 21 | Unloading in Hannover | - | - | 0 | 10 | 0 | Tu. | 06:30 | Tu. | 07:30 | 1 | |
| 22 | Driving from Hannover to Bremen | Hannover | Bremen | 132 | 3.6 | 475 | Tu. | 07:30 | Tu. | 09:30 | 2 | |
| 23 | Unloading in Bremen | - | - | 0 | 3.6 | 0 | Tu. | 09:30 | Tu. | 11:00 | 1.5 | |
| 24 | Off duty | - | - | 0 | 0 | 0 | Tu. | 11:00 | We. | 11:00 | 24 | |
| | **Total combined – transport route** | | | **3,016** | **km** | **47,957** | **tkm** | | | | **124** | **hours** |

(Source: Own compilation)

The statistics of the combined-transport route are as follows:

- Total distance: 3,016 km
- Total time: 124 hours, of which: driving: 32.0 hours[a]
  loading/unloading: 8.5 hours
  border crossing: 8.0 hours[b]
  onboard other means: 20.5 hours
  idling: 63.0 hours
- Total tkm: 47,957 tkm, of which: 9,816 tkm are attributed to the first consignment of clothing products (3.5 tons) from Thessaloniki to Berlin (= 47,957 tkm * 3.5 t / 17.1 t)
- Nominal distance:[c] 2,805 km (= 9,816 tkm / 3.5 t), of which:
  - first mile: 16 km (= 80 km in Thessaloniki * 3.5 t / 17.1 t)
  - main journey 2,513 km (Thessaloniki – Berlin)
  - last mile: 276 km (= 2,805 – 2,513 – 16)
- Average nominal speed: 24.3 km/h (= 3,016 km / 124 hours)
- Average speed driving: 68.3 km/h (= 2,184 km / 32 hours)[d]
- Actual cost (for the consignment of interest): 369.47 €/t (=1,293.14 € / 3.5 t)
- Actual time (for the consignment of interest): 3.31 days (= 79.5 hours / 24)

[a] It includes about 1 hour of congestion related delays.
[b] Border crossings between EU Member States are excluded.
[c] For the consignment of interest.
[d] Distance excludes segments where the truck was onboard other means.

### 8.2.3 Value of time

The coefficient k in the generalised cost function (Eq. 17) is known in literature as 'value of time.' It is usually expressed as:

$$k = CV * r / 365 \qquad (18)$$

where:
*CV* = the unit cargo value (€/tonne), and
*r* = the opportunity cost of capital (%).

In most applications *r* is taken as the annual yield of a risk-free investment. The interest rate of long-term government bonds is a usual indicator for *r*.

While for years the yields of 10-year Greek government bonds fluctuated below 5% in the pre-crisis era, starting from 2009 they exhibit a meteoric rise reaching 29.24% in February 2012 just before the second 'haircut' of the Greek debt.[42] A more meaningful indicator is, thus, needed. The interest rate on outstanding amounts of Euro-denominated deposits with agreed maturity of up to 2 years by non-financial corporations with domestic financial institutions, as reported by the Bank of Greece for year 2010 (2.97%) has been selected for this purpose.

It should be mentioned, however, that the value of time for fashion items like clothing products can be much higher. Nordås et al. (2006) argue that labour-intensive products such as clothing are increasingly time-sensitive forcing suppliers to shorten lead time in order to stay competitive. Furthermore, in recent decades, the so-called 'fast fashion' strategy, a concept developed in Europe to serve customers who desire trendy and relatively inexpensive clothing, is followed by many fashion retailers. Critical in fast fashion is the lead time, which has been reduced in just a few weeks (Sull and Turconi, 2008). Discounts in the area of 10% for a 2-week delay in delivery are not unusual for manufacturing contracts in this sector, while for delays of 3 weeks and more the retailer has the right to cancel the contract altogether. Although such rates are inconceivable for deliveries within contractual margins, are nevertheless indicative of a value of time much higher than that implied by an opportunity cost of 2.97%. The sensitivity of model results to different *r* values is examined in Section 8.3.

### 8.2.4 Estimation of λ

Eq. (16) can be transformed into:

$x_1 / x_2 = \exp[-\lambda (C_1 - C_2)]$, leading to:

$$\lambda = - \ln (x_1 / x_2) / (C_1 - C_2) \quad (19)$$

If k = 41,430 * 0.0297 / 365 = 3.37 €/tonne/day, Eq. (17) results in:

$C_1$ = 342.86 + 3.37 * 4.92 = 359.45 €/tonne, and

$C_2$ = 369.47 + 3.37 * 3.31 = 380.63 €/tonne.

[42] Bank of Greece (2012). Bulletin of the Conjunctural Indicators, Number 147, November-December 2012.

Taking into consideration that $x_1$ = 0.6836 and $x_2$ = 0.3164, Eq. (19) produces a λ value of 0.036368.

It is worth mentioning that the value of time estimated above is equivalent to 0.1404 €/tonne/hour, almost identical to the 0.1350 €/tonne/hour figure that Delhaye et al. (2010) borrow from the TRANS-TOOLS model for manufactured articles.

## 8.3 Modal split and sensitivity analysis

The model as calibrated above is used to estimate the potential impact of designating the Mediterranean Sea as a SECA. As with other SECAs, the maritime industry has three alternative ways to react to such a development: (i) install an exhaust gas scrubber system and continue burning Heavy Fuel Oil (HFO), (ii) switch fuel from HFO to Marine Gas Oil (MGO) with sulphur content below 0.1% or (iii) use Liquefied Natural Gas (LNG) as marine fuel.

Although LNG is the cleanest fossil fuel and reduces SOx, PM and NOx emissions drastically and even $CO_2$ emissions significantly, the scarcity of LNG refuelling stations in Europe[43] and the necessary conversion of the propulsion system involving twice as big fuel tanks renders only the first two options feasible in the short run. Furthermore, it appears that the shipping industry still considers scrubbers as a rather immature technology (Ljungström et al., 2009; Notteboom et al., 2010; Kehoe et al., 2010; Malmqvist and Aldén, 2013). This leaves switching from HFO to MGO as the only real option in the immediate future and the only scenario examined in our case study.

Increased transport cost is a certain outcome of this fuel switch. However, the quantitative assessment of the cost rise is associated with a number of uncertainties. A ‘basic scenario’ is, thus, developed reflecting a set of

[43] As mentioned in Section 2.3.3, on 24 January 2013 the Commission announced its Clean Power for Transport Package that includes an action plan for the development of LNG in shipping. According to this plan, LNG refueling stations should be installed in all 139 maritime and inland ports on the trans-European core network by 2020 and 2025 respectively.

assumptions, while the role of parameters exhibiting a high degree of ambiguity is examined through sensitivity analysis later on.

In terms of the time frame, all previous studies focus on 1 January 2015, when the 0.1% limit will be enforced in the existing SECAs. There is no indication for the time the Mediterranean Sea will (if ever) become a SECA. The only certainty we have is that, according to Directive 2005/33/EC, the limits apply 12 months after the date of entry into force of the SECA designation. Provided that designating a new SECA involves rather cumbersome procedures, the scenario of applying the SECA limits in the Mediterranean Sea by 1 January 2015 is not very probable. However, solely for the sake of comparability, it is hereby assumed that the new limits will become effective in this part of the world together with the other SECAs.

### 8.3.1 Fuel prices

The scientific community seems to agree on the following facts:

- There is a strong correlation between the prices of marine fuels and the price of crude oil.
- During the last 25 years the price of crude oil follows an upward trend due to increased demand (especially from Asia) and depletion of conventional oil fields.
- Forecasting fuel prices is not easy.

A number of studies project fuel prices to 2015 and beyond (Stavrakaki et al., 2009; Hader et al., 2010; Kehoe et al., 2010; Delhaye et al., 2010), whereas others have simply applied historic prices (Kalli et al., 2009). It appears that forecasting directly the price differential between the HFO (1% sulphur) and MGO (0.1% sulphur), which is actually what we need, is probably safer than independent price projections for the two fuel qualities, as the former approach takes advantage of the existing correlation between prices. Ljungström et al. (2009), Notteboom et al. (2010) and Malmqvist and Aldén (2013) follow this approach.

Based on Oct-Nov 2008 figures, Ljungström et al. (2009) report a differential of 297 USD/tonne between MGO and HFO in the port of Rotterdam. According to Malmqvist and Aldén (2013), this figure was dropped to 240 USD/tonne on 16 July 2012 but elevated to 330 USD/tonne three months later, on 16 October 2012. By the end of February 2013, the www.bunkerworld.com site was reporting a differential of 305 USD/tonne, while the price difference between these two fuel qualities in the port of Piraeus was 317 USD/tonne.

On the basis of this information and the expectation that the demand for MGO will be increased by 2020, when all EU countries would need to meet the stricter sulphur limits, Malmqvist and Aldén (2013) predict a 500 USD/tonne differential for that year. Thinking along the same lines, we accept the present differential of 330 USD/tonne as the default value for our basic scenario. The effects of higher price differences will be assessed in the sensitivity analysis part of the chapter. It is noted that the exchange rate of the end of February 2013 (1.34 $/€) is used for converting USD prices into Euro-denominated ones.

It needs to be added that a second order effect of designating the Mediterranean Sea as a SECA might be a price increase of the diesel oil used by road transport, triggered by a potential inability of the oil refining industry to cope with the increased demand for distillates that another SECA might cause. However such effects are outside the scope of the present work and are not pursued further.

### 8.3.2 Fuel consumption

The Ro-Pax vessel SUPERFAST XI is selected as the representative vessel employed on the Patras – Igoumenitsa – Ancona route. According to the company's website, she was built in Germany in 2002. The 199.9 m long ship carries on its 10 decks up to 1 639 passengers and 653 vehicles. Her four 12 000 KW Wärtsilä engines allow her to sail at a maximum speed of 29.3 knots.

The Face$^3$ts (2008) report provides an estimate of the fuel being consumed by SUPERFAST XI on the one-way sailing Patras – Igoumenitsa – Ancona. She is burning 167 tonnes of fuel oil and 350 litres of lubricants. A quantity amounting to 30% of the fuel oil is consumed while in port and, back in 2008, was of the 1.5% sulphur quality. The sulphur content of the remaining quantity (70%) was 2.7%. The fuel qualities used today are HFO (1% sulphur) at sea and MGO (0.1% sulphur) in port. Therefore, the additional fuel cost associated with the Mediterranean SECA concern only the 70% of the fuel oil consumed, since the remainder is of the 0.1% quality anyway.

It needs to be clarified that the figures mentioned above include the segment Patras – Igoumenitsa that does not actually belong to the journey examined here. However, the company in its pricing policy treats both origins as a single one (the freight rates are identical regardless of the port of embarkation). The additional fuel costs that will eventually be allocated to our truck, then, basically concern a fictitious average truck originating somewhere between Patras and Igoumenitsa. This is not unreasonable, however, should one consider that a truck getting on board in Igoumenitsa has reserved space that remains unexploited during the Patras - Igoumenitsa segment (not allowed by Greek legislation).

### 8.3.3 Allocation of additional costs

The additional costs related to the switching of fuel from HFO to MGO need to be allocated to the vessel's payload. For Ro-Pax vessels carrying a mixture of trucks/trailers, passengers, cars, caravans etc., this is easier said than done. Different proportions and significance of passengers lead to substantially different cost structures.

After acknowledging that "*it is hardly feasible to make a valid allocation of the costs – and particularly the fuel costs – to individual cargo units, ... [nor is it] possible to make any accurate assignment on the basis of fares*", Hader et al. (2010) provide for a number of representative Ro-Ro vessels indicative estimates of the share of total voyage costs that is being borne by the cargo. Moreover, they consider passenger volumes to be more elastic than cargo with respect to price increases, allocating to the latter an over proportional share of the additional costs and the associated price rises. The estimates of Hader et al. (2010) appear in Table 31.

Interestingly enough, the vessel SUPERFAST VII,[44] which is similar in dimensions, capacity and modus operandi with our SUPERFAST XI, has been selected by Hader et al. (2010) as the representative ship for the route Rostock-Helsinki. The share of costs estimated to be borne by the cargo for this ship is 35%. Taking the elasticity into consideration, the proportion of additional costs estimated to be borne by the cargo becomes 45%. This is the default value used in our basic scenario.

[44] As of Sept. 2011, the vessel was renamed to STENA SUPERFAST VII. It is now operated by Stena Line on the Belfast Cairnryan route.

**Table 31. Estimated proportion of total costs assigned to cargo**

| Corridor | Routes | Ship | est. no. of trailers/FEUs per roundtrip | costs attributable to/borne by trailers/trucks/ FEUs today | share of additional costs to be borne by the cargo |
|---|---|---|---|---|---|
| German Baltic Sea ports - Western Sweden | Kiel-Gothenburg | STENA HOLLANDICA | 340 | 40% | 60% |
| German Baltic Sea ports - Norway | Kiel-Oslo | COLOR FANTASY | 120 | 17% | 25% |
| German Baltic Sea ports - Southern Sweden | Travem.-Trelleborg | ROBIN HOOD | 160 | 80% | 100% |
| | Travem.-Malmö | FINNEAGLE | 200 | 95% | 100% |
| | Rostock-Trelleborg | ROBIN HOOD | 100 | 80% | 100% |
| German Baltic Sea ports - Finland | Lübeck-Finnland* | FINNSTAR | 320 | 95% | 100% |
| | Lübeck-Hanko | TIMCA | 280 | 100% | 100% |
| | Rostock-Helsinki | SUPERFAST VII | 120 | 35% | 45% |
| German Baltic Sea ports - Russia | Kiel-St.Petersburg | TRANSLUBECA | 190 | 100% | 100% |
| | Lübeck-Hamina-St.P. | PAULINE RUSS | 140 | 100% | 100% |
| | Lübeck-Sass.-St.P. | TRANSLUBECA | 190 | 100% | 100% |
| German Baltic Sea ports - Baltics | Kiel-Klaipeda | LISCO GLORIA | 180 | 80% | 95% |
| | Rostock-Ventspils | URD | 140 | 80% | 100% |
| Belgium - Western Sweden | Gent-Gothenburg | TOR MAGNOLIA | 250 | 100% | 100% |
| | Zeebrügge-Gothenburg | SCHIEBORG | 120 | 100% | 100% |

* Rauma/Turku/Hels./Kotka

(Source: Hader et al., 2010)

Another entry in Table 31 that deserves our attention is the LISCO GLORIA ship serving the Kiel-Klaipeda route. Although this vessel did[45] not resemble SUPERFAST XI, she used to serve a route identical to the Igoumenitsa – Ancona one in terms of length (~400 nautical miles). To the extent that distance is an important factor in shaping voyage costs, the 95% figure of Table 31 for the proportion of additional costs to be borne by LISCO GLORIA's cargo is taken as the maximum value for the sensitivity analysis performed later on.

The only piece of information still needed is the average number of trucks/trailers on the SUPERFAST XI on her voyages across the Ionian and Adriatic Seas. Face[3]ts (2008) reports that in year 2007, the four SUPERFAST ships employed on the Greece-Italy routes executed 1 372 one-way voyages transporting 576,000 passengers and 150,000 trucks/trailers. The average figure per voyage was, thus, 420 passengers and 109 trucks.

[45] An explosive fire engulfed the ship while en route to Klaipeda on 9 October 2010. She was later declared to be a constructive total loss and was scrapped in 2011.

## 8.3.4 Modal shift

The model of Section 8.2 can be depicted schematically by the graph of Figure 49. The X-axis in this graph is the difference (percent) in the transport cost along the combined-transport route (Route 2) resulting from the fuel switch necessitated by the Mediterranean SECA under study. The Y-axis is the corresponding share of the road-only route (Route 1). Note that for X=0 (no difference in transport costs), Y=0.6836 (the initial share of Route 1).

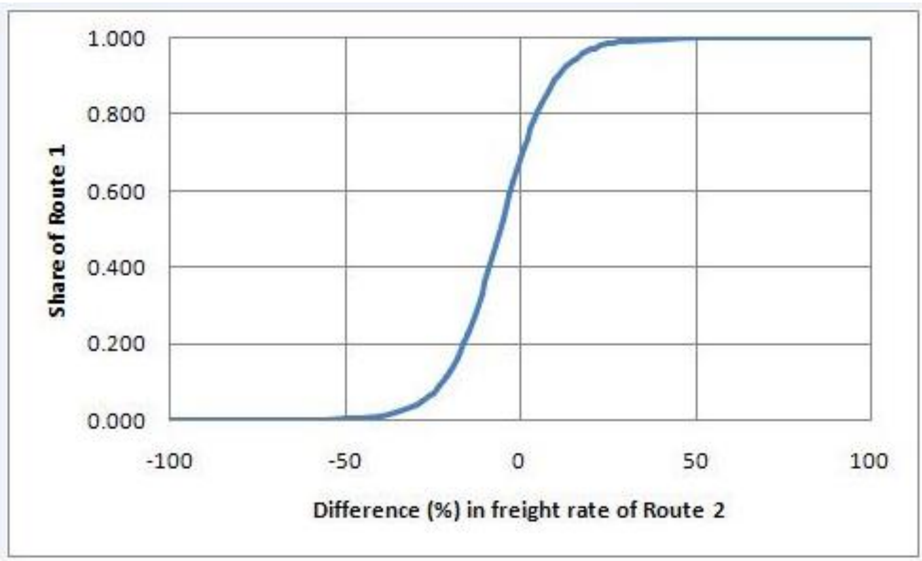


**Figure 49. The effect of changes in the transport cost along Route 2 on the share of Route 1**

(Source: Own compilation)

The new modal split resulting from the requirement to switch fuels is assessed as follows:

- Total fuel consumption: 167 t/voyage
- Of which, exceeding S limits: 116.9 t/voyage (= 167 t * 70%)
- Additional fuel cost per voyage: 38,577 $/voyage (= 116.9 t * 330 $/t)
- Or in Euro/voyage: 28,788.81 €/v. (= 38,577 $/v.÷1.34 $/€)
- Borne by the cargo: 12,954.96 €/v. (= 28,788.81 €/v.*45%)

- Additional cost per truck: 118.85 €/tr. (=12,954.96 €/v.÷109 tr./v)
- Additional cost per cargo tonne: 6.95 €/t (= 118.85 €/tr ÷ 17.1 t/truck)

It is assumed that in the long run, actors operating in a competitive market will be forced to pass on this additional cost to their customers (the truck operators in our case). In turn, truck operators will pass it on to shippers, who will see the transport cost along the combined-transport route increasing to 376.42 €/tonne (= 369.47 + 6.95).

This cost rise produces a new share for Route 1 equal to 0.7356, meaning that 5.2% of the traffic will shift itineraries from Route 2 (combined-transport) to Route 1 (road-only).

### 8.3.5 Sensitivity analysis

The robustness of model results with respect to the opportunity cost of capital, the price difference between HFO and MGO and, the share of the additional fuel cost that is being borne by the cargo of a Ro-Pax vessel is examined here.

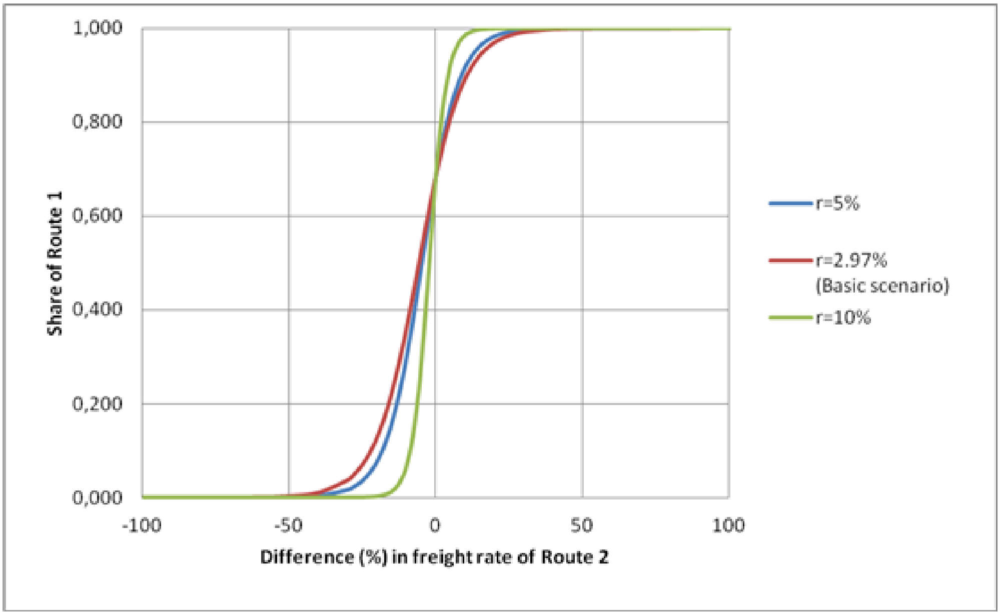


**Figure 50. The effect of the opportunity cost of capital on model results**

(Source: Own compilation)

The opportunity cost of capital, r, proves to be a very significant factor in forming modal shares. Figure 50 shows the S-curves of the modal split model for three different values of r: 2.97% (default value of the basic scenario), 5% and 10%. The additional cost of 6.95 €/tonne calculated above leads to a modal shift of 5.2% for r = 2.97%; 6.2% for r = 5%; and 12.1% for r = 10%. In line with the discussion of Section 8.2.3, opportunity costs in the area of 10% are closer to the realities of the fashion industry. In such case, shifts in the region of 12% should be expected.

Figure 51 exhibits the effect of price difference between HFO and MGO on model results. In the basic scenario a differential of 330 USD/tonne has been selected leading to a modal shift of 5.2% towards the road-only option. This shift escalates to 7.6% should the price difference between the two fuel qualities become 500 USD/tonne, as assumed by Malmqvist and Aldén (2013).

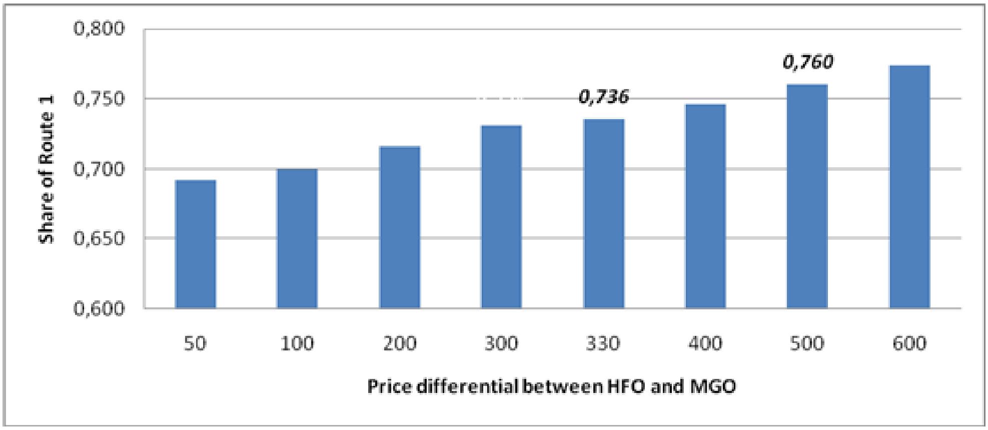


**Figure 51. The effect of fuel price differential on model results**

(Source: Own compilation)

The effect on modal shift of the share of additional costs that the cargo of a Ro-Pax vessel has to bear is presented in Figure 52. This parameter depends on the significance of passenger traffic on the route and the price elasticities of both passengers and cargoes with respect to price increases, which in turn depend on the existence and price/quality relation of alternative transport solutions. For the Greece-Italy ferry trades under study, all operators give priority to passengers and private cars over trucks/trailers. In fact, during the summer months, when the tourist traffic between the two countries is quite dense, trucks often encounter difficulties booking space on the ships. The 45% estimate of the basic scenario corresponds to a modal shift of 5.2% in favour of the road-only route, which is doubled to 10.3% when 95% of the additional fuel cost is allocated to the cargo.

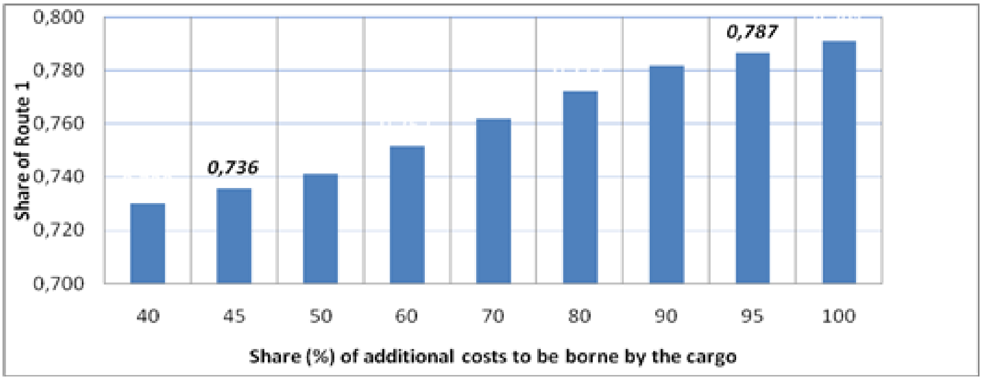


**Figure 52. The effect of the cost bearing capacity of cargo on model results**

(Source: Own compilation)

It is noted that an average value of 70% for this parameter, combined with an r value of 10% leads to a shift in the area of 17.1%, which is comparable to the results of Hader et al. (2010) for Germany.

## 8.4 Environmental implications

The environmental consequences of the modal shift estimated above are discussed in this section. The web-based EcoTransIT World[46] tool has been used for the necessary calculations. Table 32 presents the emissions as they stand today prior to the designation of the Mediterranean Sea as a SECA. The emissions reported concern the $CO_2$-eq, $PM_{10}$, NOx and $SO_2$ and correspond to the transport of 3.5 tonnes of clothing products from Thessaloniki to Berlin.

[46] http://www.ecotransit.org/index.en.html

**Table 32. Emissions without a new SECA (for 3.5 tonnes of cargo)**

| Link | Dist. (km) | Load factor (%) | $CO_2$-eq (tonnes) | $PM_{10}$ (kg) | NOx (kg) | $SO_2$ (kg) |
|---|---|---|---|---|---|---|
| **ROUTE 1** | | | | | | |
| First mile in Thessaloniki | 16 | 38.54 | 0.0051 | 0.0011 | 0.0040 | 0.0059 |
| Thessaloniki - Skopje | 236 | 95.00 | 0.0389 | 0.0078 | 0.2968 | 0.0452 |
| Skopje - Belgrade | 393 | 95.00 | 0.0624 | 0.0127 | 0.4778 | 0.0731 |
| Belgrade - Budapest | 373 | 95.00 | 0.0588 | 0.0122 | 0.4561 | 0.0699 |
| Budapest - Bratislava | 200 | 95.00 | 0.0315 | 0.0064 | 0.2463 | 0.0374 |
| Bratislava - Prague | 338 | 95.00 | 0.0533 | 0.0102 | 0.4097 | 0.0625 |
| Prague - Dresden | 158 | 95.00 | 0.0253 | 0.0053 | 0.2001 | 0.0295 |
| Dresden - Berlin | 196 | 95.00 | 0.0309 | 0.0063 | 0.2373 | 0.0371 |
| Last mile in Germany | 276 | 58.22 | 0.0625 | 0.0134 | 0.4648 | 0.0741 |
| **TOTAL ROUTE 1** | **2186** | | **0.3687** | **0.0753** | **2.7930** | **0.4348** |
| **ROUTE 2** | | | | | | |
| First mile in Thessaloniki | 16 | 38.54 | 0.0051 | 0.0011 | 0.0040 | 0.0059 |
| Thessaloniki - Igoumenitsa | 350 | 95.00 | 0.0562 | 0.0110 | 0.4312 | 0.0662 |
| Igoumenitsa - Ancona | 735 | 95.00 | 0.2780 | 0.1441 | 4.7051 | 1.0193 |
| Ancona - Bologna | 227 | 95.00 | 0.0357 | 0.0073 | 0.2732 | 0.0420 |
| Bologna - Verona | 151 | 95.00 | 0.0236 | 0.0048 | 0.1821 | 0.0278 |
| Verona - Brenner | 239 | 95.00 | 0.0381 | 0.0076 | 0.2884 | 0.0443 |
| Brenner - Wörgl | 97 | 95.00 | 0.0031 | 0.0006 | 0.0029 | 0.0029 |
| Wörgl - Munich | 109 | 95.00 | 0.0172 | 0.0035 | 0.1312 | 0.0202 |
| Munich - Nurnberg | 167 | 95.00 | 0.0270 | 0.0053 | 0.2000 | 0.0310 |
| Nurnberg - Berlin | 438 | 95.00 | 0.0697 | 0.0139 | 0.5375 | 0.0816 |
| Last mile in Germany | 276 | 58.22 | 0.0625 | 0.0134 | 0.4648 | 0.0741 |
| **TOTAL ROUTE 2** | **2805** | | **0.6161** | **0.2127** | **7.2207** | **1.4153** |
| **AVERAGE (without SECA)** | | | **0.4470** | **0.1188** | **4.1939** | **0.7450** |

(Source: Own compilation)

Due to the cargo collection and distribution operations performed by the same vehicle used for the long haul, average distances and load factors have been calculated for the first and last miles. However, this part of the operation is identical in the two alternative routes and does not produce any differences.

It is noted that, according to IFEU (2011), the EcoTransIT default values for the sulphur content of marine fuels outside SECAs are taken equal to 2.37% for main engines burning HFO; 1.5% for main engines burning MDO/MGO; 1.5% for the auxiliary engines at sea; and 0.5% for the auxiliary engines in port. This is not the case for the vessels operating on the Greece-Italy routes. To overcome this difficulty, the emissions along the Igoumenitsa-Ancona segment were calculated on the basis of the Kiel-Klaipeda link, which happens to be in a SECA and of an almost identical distance.

When compared with the figures that Delhaye et al. (2010) extracts from Notteboom et al. (2010) concerning the large Ro-Pax vessel ToR Petunia (employed on the Gent-Gothenburg route), the emissions of SUPERFAST XI (expressed in kg/tonne-km) appear much higher. The only exception relates to $PM_{10}$ emissions that basically coincide. The service speed is certainly an explanatory parameter, since Notteboom et al. (2010) use 18.5 knots as the basis for their calculation, while SUPERFAST XI sails at almost 23 knots. The load factor of the vessels is another parameter of immense significance when it comes to relative (per tonne-km) figures. Nevertheless, it was decided to retain the EcoTransIT estimates as they are much closer to the actual fuel consumption figures (167 tonnes per voyage) provided by the Face$^3$ts (2008) report.

The emissions produced by the two alternative routes are compared in Figure 53.[47] The road-only option (Route 1) exhibits considerable environmental advantages over the combined-transport alternative. This is due to the fact that:

- Route 2 is longer than Route 1 by more than 28%;
- the sea leg is characterised by impressively poor performance in terms of all GHG and air pollutants examined; and

[47] Mind the different units used. $CO_2$-eq is denominated in tonnes, while the other emissions in kg.

- the train leg, which appears to be the most environmentally friendly mode, comprises a very small part of Route 2 and cannot make a difference.

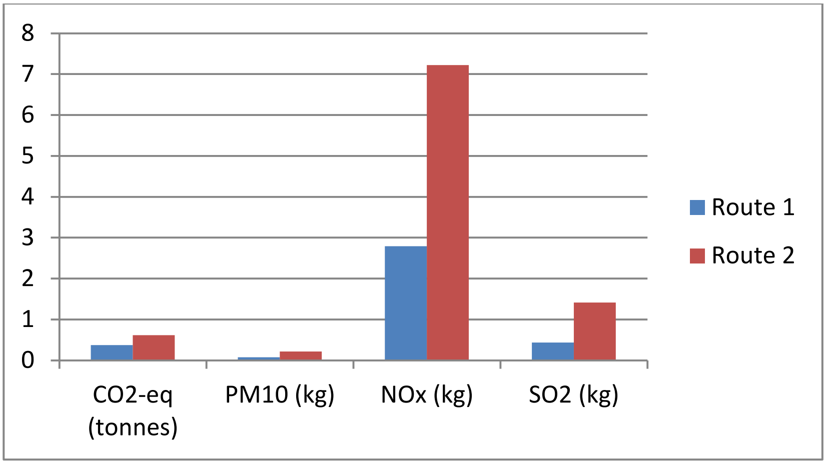


**Figure 53. Comparison of the two alternative routes without a new SECA**

(Source: Own compilation)

The last row of Table 32 calculates the average emissions produced by the 3.5-tonne consignment after accounting for the existing shares of the two alternative options.

The emissions pertaining to the basic scenario after the designation of the Mediterranean Sea as a SECA appear in Table 33. The only differentiation concerns the $SO_2$ and $PM_{10}$ figures of Route 2. The new $SO_2$ amount is based on the old one after taking into consideration that 70% of the total fuel consumption will need to be switched from the 1% to the 0.1% sulphur quality and that the latter produces 10 times less $SO_2$ emissions that the former. Similarly, the correction concerning PM emissions is based on the $PM_{10}$ emission factors for S-content 1% (0.72 g/kWh) and S-content 0.1% (0.30 g/kWh) provided by IFEU (2011).

Despite the significant improvements in terms of $SO_2$ and $PM_{10}$ emissions that the stricter regulations will trigger along the Igoumenitsa-Ancona segment (refer to Figure 54), Route 1 continues being friendlier to the environment.

**Table 33. Emissions with a new SECA (for 3.5 tonnes of cargo)**

| Link | Dist. (km) | Load factor (%) | $CO_2$-eq (tonnes) | $PM_{10}$ (kg) | NOx (kg) | $SO_2$ (kg) |
|---|---|---|---|---|---|---|
| **ROUTE 1** | | | | | | |
| First mile in Thessaloniki | 16 | 38.54 | 0.0051 | 0.0011 | 0.0040 | 0.0059 |
| Thessaloniki - Skopje | 236 | 95.00 | 0.0389 | 0.0078 | 0.2968 | 0.0452 |
| Skopje - Belgrade | 393 | 95.00 | 0.0624 | 0.0127 | 0.4778 | 0.0731 |
| Belgrade - Budapest | 373 | 95.00 | 0.0588 | 0.0122 | 0.4561 | 0.0699 |
| Budapest - Bratislava | 200 | 95.00 | 0.0315 | 0.0064 | 0.2463 | 0.0374 |
| Bratislava - Prague | 338 | 95.00 | 0.0533 | 0.0102 | 0.4097 | 0.0625 |
| Prague - Dresden | 158 | 95.00 | 0.0253 | 0.0053 | 0.2001 | 0.0295 |
| Dresden - Berlin | 196 | 95.00 | 0.0309 | 0.0063 | 0.2373 | 0.0371 |
| Last mile in Germany | 276 | 58.22 | 0.0625 | 0.0134 | 0.4648 | 0.0741 |
| **TOTAL ROUTE 1** | **2186** | | **0.3687** | **0.0753** | **2.7930** | **0.4348** |
| **ROUTE 2** | | | | | | |
| First mile in Thessaloniki | 16 | 38.54 | 0.0051 | 0.0011 | 0.0040 | 0.0059 |
| Thessaloniki - Igoumenitsa | 350 | 95.00 | 0.0562 | 0.0110 | 0.4312 | 0.0662 |
| Igoumenitsa - Ancona | 735 | 95.00 | 0.2780 | 0.0728 | 4.7051 | 0.1396 |
| Ancona - Bologna | 227 | 95.00 | 0.0357 | 0.0073 | 0.2732 | 0.0420 |
| Bologna - Verona | 151 | 95.00 | 0.0236 | 0.0048 | 0.1821 | 0.0278 |
| Verona - Brenner | 239 | 95.00 | 0.0381 | 0.0076 | 0.2884 | 0.0443 |
| Brenner - Wörgl | 97 | 95.00 | 0.0031 | 0.0006 | 0.0029 | 0.0029 |
| Wörgl - Munich | 109 | 95.00 | 0.0172 | 0.0035 | 0.1312 | 0.0202 |
| Munich - Nurnberg | 167 | 95.00 | 0.0270 | 0.0053 | 0.2000 | 0.0310 |
| Nurnberg - Berlin | 438 | 95.00 | 0.0697 | 0.0139 | 0.5375 | 0.0816 |
| Last mile in Germany | 276 | 58.22 | 0.0625 | 0.0134 | 0.4648 | 0.0741 |
| **TOTAL ROUTE 2** | **2805** | | **0.6161** | **0.1414** | **7.2207** | **0.5357** |
| **AVERAGE (SECA)** | | | **0.4341** | **0.0928** | **3.9637** | **0.4615** |

(Source: Own compilation)

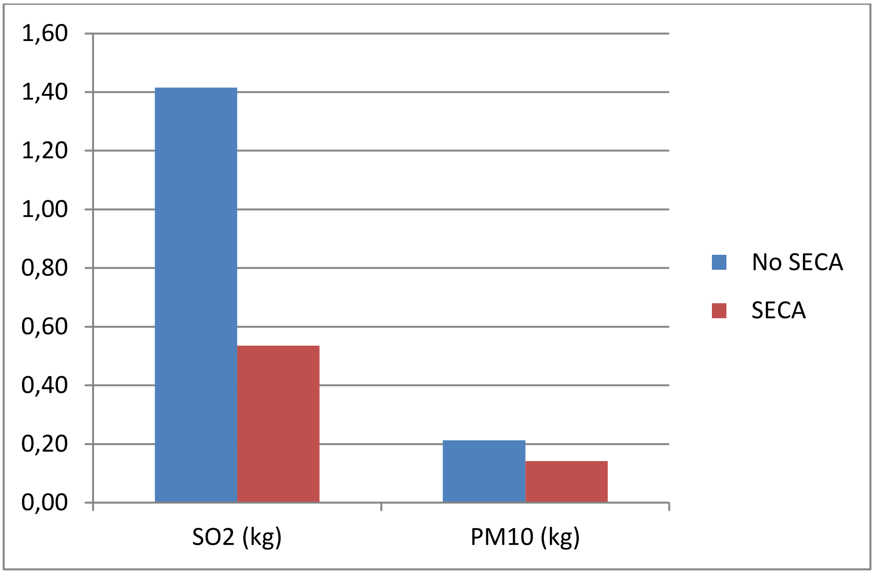


**Figure 54. Improvements in $SO_2$ and $PM_{10}$ emissions along Route 2 due to fuel switch**

(Source: Own compilation)

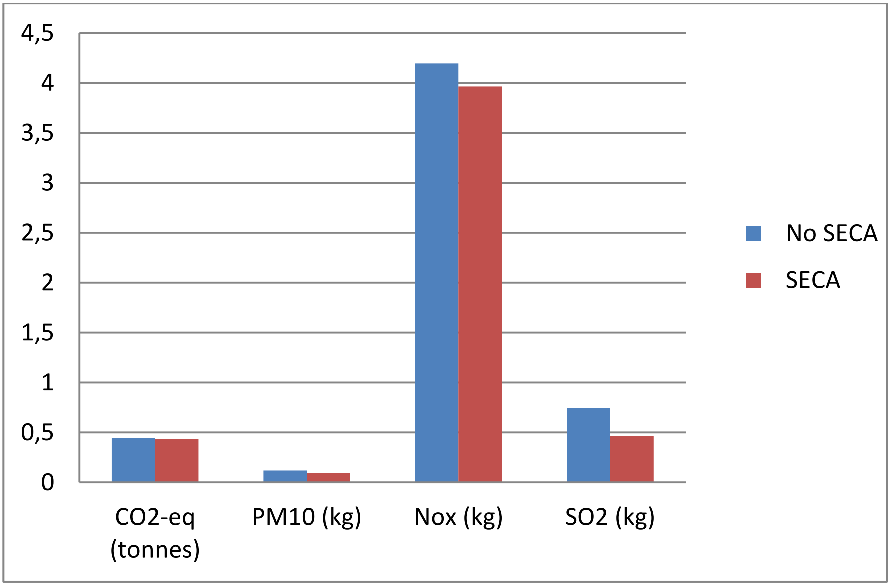


**Figure 55. Average emissions for a 3.5-tonne consignment**

(Source: Own compilation)

Figure 55 compares the average emissions for the 3.5-tonne consignment when the Igoumenitsa-Ancona connection lies outside and inside a SECA. The designation of the Mediterranean Sea as a SECA brings about significant improvements on all fronts. Given that in most relevant studies the potential backshift from sea- to land-based routes is associated with a deterioration of the environmental performance, this is a rather unexpected result. It is explained by the fact that the switching to a cleaner and more expensive fuel:

- leads to a modal shift in favour of the road only option, which in this case exhibits better environmental characteristics; and
- the $SO_2$ and $PM_{10}$ emissions of the remaining Route 2 traffic is substantially improved compared to the status quo.

Knowing that shipping is the friendliest transport mode to the environment, isn't this result a paradox? The answer is no. Shipping is not just a single service offered in the same way around the world. There are many types of vessels employed on many different operations meeting a broad range of transport needs for people and freight. In our case, SUPERFAST XI has to sail at an average speed of 22.9 knots in order to reach Ancona in 17.5 hours. The negative repercussions of speed on the environment are well known. The question is whether the business concept that a Ro-Pax ship serves can make sense at lower speeds. In any event, the stricter sulphur limits of the regulation examined in this chapter provide the right incentives.

## 8.5 Conclusions

The chapter applies a modal split model on a case study that investigates the impact of a possible designation of the Mediterranean Sea as a SECA. The model is of a binomial logit type, taking into consideration transport cost and time as explanatory variables of the choices made.

Among the three compliance options available to the shipping industry, switching fuels from HFO (S-content 1%) to MGO (S-content 0.1%) is the preferred one in the short run, as the scrubber technology is fairly new on ships and LNG is more likely to be used as a marine fuel in newbuildings.

The specific case study examined concerns the transport of clothing products from Thessaloniki, Greece to northern Germany. The small size of the consignment, which is the norm under the present economic conditions, necessitates cargo consolidation/distribution at both ends of the voyage. The two alternative routes examined involve a road-only solution along the path Thessaloniki–Skopje–Belgrade–Budapest–Bratislava–Prague–Dresden–Berlin and a combined-transport solution following the path Thessaloniki–Igoumenitsa–Ancona–Bologna–Verona–Munich–Nurnberg–Berlin. In addition to crossing the Ionian/Adriatic Seas with a Ro-Pax vessel, the latter solution involves also a truck-on-train operation along the segment Brenner–Wörgl.

Information was gathered through interviews with a small-size Greek truck operating company that specialises in services between Thessaloniki and destinations in Italy and Germany. It concerns actual trips made in year 2010. As such, the application follows the revealed preference approach.

Under certain assumptions comprising the 'basic scenario,' the designation of the Mediterranean as a SECA will cause an increase of transport costs by 6.95 €/tonne (equivalent to 1.9%).[48] According to our model, this rise will result in a modal shift of 5.2% in favour of the road-only route.

The shift grows to 12.1% for an opportunity cost of 10%, which is much closer to the realities of the clothing industry than the 2.97% value assumed in the basic scenario. Should this figure be combined with a 70% cost bearing ratio by the cargo of a Ro-Pax ship (in contrast to the 45% ratio of the basic scenario), the modal shift reaches the level of 17.1%, which is comparable to previous results for the existing SECAs.

As for the environmental implications of this shift, it turns out that the stricter regulations bring about significant improvements in relation to all emissions examined ($CO_2$-eq, $PM_{10}$, NOx and $SO_2$). This is attributed to the longer (by 28%) distance of the combined-transport solution in comparison to the road-only route and the poor performance of the Ro-Pax vessels basically due to the need to maintain a relatively high speed (22.9 kn). The railway involved in the combined-transport case appears to be the most environmentally friendly mode but comprises a very small part of this route in order to make a difference.

[48] The increase would have been higher if the ships were given the opportunity to use fuel with the maximum permissible sulphur content, which is not the case in the particular trade.

It is of course necessary to note that designating the Mediterranean Sea as a SECA is a political decision that should adopt a broader scope and cannot be based simply on a case study like the present one, as its results may not necessarily generalise to other scenarios. However, we think the results of this chapter are worthy of note and believe that the methodology used in the chapter could form the basis for such broader analyses.

# PART V. CONCLUSIONS

# 9. Findings and further research

## 9.1 Research results and contribution

This section is structured around the three objectives of the thesis as presented in Section 1.2. It is for this reason that the titles of the headings below are identical to those of Section 1.2. After briefly presenting the activities undertaken, each heading summarises findings in accordance with the research questions posed and discusses the contribution of the thesis in this respect.

### 9.1.1 Objective 1: Green corridors and their assessment

| | |
|---|---|
| ***General objective*** | |
| OB1 | Quantitative analysis of the performance of a green freight transport corridor in terms of pre-specified key performance indicators (KPIs) |
| ***Specific objectives*** | |
| SO1.1 | Define a green freight transport corridor |
| SO1.2 | Develop and refine a methodology for corridor performance benchmarking, placing emphasis on the:<br>- construction of the sample of representative transport chains,<br>- estimation of chain-level KPI values on the basis of available data<br>- developing the methods for aggregating chain-level indicators to corridor- level KPIs |
| SO1.3 | Collect and process relevant data from various databases and other sources |
| SO1.4 | Apply the above methodology to a specific corridor |

Following an introductory chapter on the policy framework of the 'green' freight logistics in Europe, which has set the scene for the subsequent discussion, objective OB1 is dealt with in Parts II and III of this thesis comprising of four chapters in total (Chapters 3 to 6). Chapter 3 presented the available definitions of green corridors, identified the characteristics that distinguish a green corridor from any other efficient corridor, provided examples of green corridor projects in Europe, and briefly presented the early attempts of formulating a corridor performance monitoring methodology. Chapter 4 discussed the existing corridor governance schemes, presented the recent developments of the EU transport infrastructure policy and scrutinised the TEN-T Guidelines to investigate the relation between the TEN-T core network corridors and the green corridor concept. Chapter 5 proposed a new methodology for benchmarking corridor performance, which differs from the previous one to the extent that the selection of the typical chains that form the basis for benchmarking is relying on model rather than on study results. The methodology was tested on the GreCOR corridor, and the Danish National Traffic Model (LTM) was used as the principal source of information for both sample construction and KPI estimation. Chapter 6 implemented the possible improvements suggested by the previous chapter and completed the methodology by proposing an approach for handling temporarily missing information that often occurs in periodic data collection activities. It also described the activities undertaken towards obtaining the necessary input from the stakeholders which, however, have not yet yielded sufficient results worth reporting as they are still on-going.

The research questions of OB1 are listed below together with a summary of the corresponding findings:

***Q1.1: Which are the specific characteristics that distinguish a green corridor from any other efficient transport corridor?***

To answer this question, a single list of all characteristics appearing in the two (EU and Swedish) existing definitions of green corridors was created. The green characteristics resulted from this list after excluding the features pertaining to all efficient corridors. They are presented below:

a) Reliance on co-modality, i.e. the efficient use of different modes on their own and in combination, which in turn requires:
   - adequate transhipment facilities at strategic locations; and
   - integrated logistics concepts.

b) Reliance on advanced technology allowing use of alternative clean fuels (in addition to energy efficiency that can be viewed as a characteristic of an efficient corridor anyway).

c) Development and demonstration capabilities of environmentally-friendly and innovative transport solutions, including advanced telematics applications.

d) Collaborative business models.

***Q1.2: Are the TEN-T core network corridors green according to the criteria of Q1.1?***

To answer this question, Section 4.4 analysed the TEN-T Guidelines from the perspective of the green characteristics of Q1.1. The conclusion reached is that all these green qualities are more or less shared by the TEN-T core network corridors. In conjunction with the enabling governance structure foreseen by Regulation EU 1315/2013 (refer to Section 4.2.3), one can conclude that the new TEN-T Guidelines have established a network of green corridors in Europe. It is noted that this statement relates only to the freight dimension of the TEN-T core network, which also involves passenger transport and aviation.

***Q1.3: Is it possible to assess the performance of a green corridor?***

The general answer is yes provided that reliable data can be obtained in sufficient quantity. A methodology has evolved through the SuperGreen project, the GreCOR project and the present thesis. It basically consists of:

(i) decomposing the corridor into transport chains;
(ii) selecting a sample of typical transport chains;
(iii) estimating KPI values for all chains in the sample; and
(iv) aggregating these values into corridor level KPIs by using appropriate weights.

Yet, the difficulties in securing stakeholder input remain. The experience acquired in this respect suggests that a clear statement of objectives from the corridor management is necessary for defining the scope of the analysis, the indicators to be used, the data needs and frequency of collection, the data sources and the audience for the outputs. It is only when the private sector stakeholders see a meaningful role for themselves in determining national or regional priorities and strategic objectives in the logistics industry that they accept to be involved. This view is also shared by ITF (2016b) in the context of a logistics observatory.

***Q1.4: Which assessment approach (study- or model-based) is recommended?***

It depends on the intended use. In the context of monitoring corridor performance, these two approaches have been proposed as alternative paths for selecting the sample of typical chains to be used for the subsequent benchmarking. In the study-based approach, the selection is based on the analysis of existing transport plans and feasibility studies of infrastructure projects undertaken mostly at national and sometimes at regional level. In the model-based approach, the sample is constructed on the basis of traffic flows that result from a transport model.

Although the study-based approach was successful in assessing the infrastructure along the ScanMed TEN-T core network corridor (EC, 2014d), it proved inadequate in assessing the logistics operations, suffering from fragmented and incomplete coverage of the corridor (Herrero, 2015). On the other hand, the model-based approach provides a comprehensive and coherent picture of all flows along the corridor but the accuracy of the estimates only reflects the quality of the model used.

It is for this reason that the methodology proposed by this thesis consists of a combination of both these approaches. Model results are used for constructing the sample, which is subsequently refined and assessed on the basis of stakeholder input that is provided either directly or through recurrent studies.

***Q1.5: What policy recommendations can be drawn from the application of this methodology on a green corridor?***

In addition to the general applicability of the methodology and the related qualification in terms of data availability discussed in Q1.3, the GreCOR case confirmed the need for a transport model offering uniform coverage of all European space. The application at hand was negatively affected by the absence of such a model. The fact that the sample construction had to rely on the Danish LTM model imposed undesirable geographic restrictions (only the Oslo-Randstad part of the corridor was examined) and led to diminishing accuracy of results as the distance from Denmark increases.

In relation to the indices produced and on the assumption that their numerical values will not be much different when recalculated on the basis of stakeholder input, the following conclusions have been drawn:

- A safe way to improve the environmental performance of the corridor is to enhance rail operations, which combine 30% below average GHG and 50% below average SOx emissions with 21% below average cost and almost 55% above average speed.
- Shipping is also performing well in terms of the environment (34% below average GHG) and very well in terms of cost (57% below average) but the price shippers have to pay comes in speed, which is only half the average value for the corridor.
- However, not all shipping sectors share these characteristics. Unlike conventional ships, containerships move cargoes at above average speeds but at extremely high GHG and SOx emissions.
- The performance of Ro-Ro shipping in terms of $CO_2$-eq emissions is even worse but these chains offer the fastest services in the corridor at about 58% above average cost.
- A little lower speed (still more than 2 times the corridor average) but at a very high cost (3.4 times the average) is offered by road chains which emit 14% above average GHG and 20% below average SOx.
- Shipping imposes a significant volume effect on the corridor indices. Its exclusion increases the average transit cost along the corridor by 170% (from 0.44 to 1.19 DKK/tonne*km), increases the average speed by 116% (from 12.02 to 25.97 km/h) and increases the GHG emissions by 102% (from 69.84 to 140.86 g/tonne*km). The SOx emissions are also increased but by a moderate rate of 21% (from 0.1104 to 0.1340 g/tonne*km).

***Q1.6: Is it possible to develop a more quantitative definition of a green corridor on the basis of the results achieved in the case study?***

A positive answer to this question presupposes the following conditions:

1. There is a universal (or pan-European, depending on the scope) set of KPIs applicable on all corridors.
2. The corridor-level KPIs have been successfully computed on the basis of direct stakeholder input and the results have been verified by an accredited third party in accordance with a pre-defined standardisation process.
3. The corridor-level KPIs can be combined into a single corridor rating.
4. The benchmarking method takes into consideration the specific

characteristics of each corridor enabling comparisons across corridors.

The status quo in relation to these conditions is briefly given below:

1. The KPI set used in this thesis is the one suggested by SuperGreen as a result of a cumbersome stakeholder consultation process which, however, does not ensure universal acceptance. In theory, the KPIs should be selected so as to reflect the objectives set by the corridor management, a view also supported by ITF (2016b). In this respect, there is no guarantee that all corridors will select the same KPIs. In addition, there is no institution with a mandate to propose a minimum mutually acceptable set of KPIs even in the case that such an option existed.
2. On top of the difficulties in collecting the necessary stakeholder input reported in Chapter 6, any notion on standardisation seems very distant if not totally unrealistic. Besides the content of this thesis, which admittedly remains sketchy in this respect, only elements of guidelines can be found in the literature: For a corridor context refer to work by the World Bank (Arnold, 2006; Raballand et al. 2008), the Asian Development Bank (Regmi and Hanaoka, 2012; ADB, 2013) and the EU East-West Transport Corridor project (Fastén and Clemedtson, 2012). For a logistics observatory context refer to work by the Inter-American Development Bank (Guerrero and Abad, 2013) and OECD (ITF, 2016a; ITF, 2016b).
3. Although a weighted averaging procedure[49] is being used to combine the six components of the World Bank LPI into a single indicator (LPI), the SuperGreen stakeholders decided against aggregating the six SuperGreen KPIs. The following concerns have been expressed:
    - The weights needed for such calculation very much depend on the user (different users will propose different weights),
    - It is a political issue best left for policy makers to decide,[50]
    - Weights, if assigned, might lead to wrong interpretations,

[49] The weights are chosen by principal component analysis so as to maximise the percentage of variation in the original six components that is accounted for by the summary indicator (Arvis et al., 2016).

[50] Michel Savy has put it nicely: "*Indeed, logistics development is now, and will remain, a political issue*" (Savy, 2016).

- Weights change over time (e.g. social issues might become more significant in the future), and
- Weights would not reflect country specific characteristics of transport operations.

4. In its present form, the method is unable to handle differences in the specific characteristics of each corridor. Such capability would involve the introduction of a corrective factor for each specific characteristic under examination (e.g. mountainous terrain) that could only result from the statistical analysis of long series of data pertaining to different corridor segments. No such data exist or is expected in the foreseeable future. So, the method presented in this thesis is not suitable for comparisons across corridors and can be used only for monitoring the performance of a single corridor over time. ITF (2016b) supports this view, as well.

The fact that none of the above preconditions is met precludes the notion of a quantitative definition of green corridors.

The combination of the model-based approach for the sample construction and the study-based approach for the estimation of chain-level indicators is the main contribution of the thesis towards OB1. A necessary condition, of course, is securing the stakeholder input which, as the GreCOR application shows, has proven easier said than done. The output of the study is expected to provide guidance and support to all green corridor projects that are currently in their implementation phase, particularly in relation to methodological issues.

### 9.1.2 Objective 2: Green maritime corridors – $CO_2$

| *General objective* | |
|---|---|
| OB2 | Simple theoretical framework for classifying carbon emission reduction measures in the shipping industry |
| ***Specific objectives*** | |
| SO2.1 | Review existing sustainability frameworks and select the most appropriate one for the intended use |
| SO2.2 | Decompose carbon emissions into a number of factors |
| SO2.3 | Classify carbon emission reduction measures in waterborne transport according to the factors identified in SO2.2 |

This objective is addressed in Chapter 7 of the thesis. In accordance with the specific objectives shown above, the chapter reviewed the main types of frameworks found in assessing transport sustainability and suggested the 'Criterion-Influences-Actions-Measures' structure as the most suitable one for the intended use. In implementing this framework, an extended Kaya identity was used to decompose shipping-related carbon emissions into a number of factors which, either alone or in combination, provided the necessary partitions for the classification of a wide range of carbon emission reduction practices and policies. The taxonomy helps visualising policy recommendations that tend to skip our attention.

The research questions of OB2 are listed below together with a summary of the corresponding findings:

***Q2.1: Which is the most suitable sustainability framework for classifying carbon emission reduction measures in the shipping industry?***

Several frameworks used in investigating transport sustainability can be found in the literature. According to a simple typology, they can be classified into three types: impacts-based, linkages-based, and influence-oriented frameworks. Impacts-based frameworks focus solely on the effects of various actions on the sustainability of a system. The linkages-based ones go one step further and capture relationships between the causal factors, impacts and the corrective actions that have been selected to achieve sustainability. The influence-oriented frameworks refer to a particular institution and are developed bearing in mind the relative levels of influence that this institution has on various actions affecting sustainability. The fact that the envisioned taxonomy is unconnected to a specific institution and places emphasis on the corrective actions and their relationship to causal factors confines selection among the linkages-based frameworks.

A special type of a linkages-based framework is the Criterion-Influences-Actions-Measures scheme that consists of four stages:

(i) selection of a suitable criterion,
(ii) decomposition of the selected criterion into a number of influences,
(iii) identification of actions triggered by these influences, and
(iv) identification of measures that policy makers adopt to facilitate the actions to be taken.
(v)

The ability of the Criterion-Influences-Actions-Measures framework to model the relationships among sustainability criteria and produce a set of indicators as output is the reason for selecting this scheme for the envisioned taxonomy.

***Q2.2: Which are the most important factors influencing carbon emissions in waterborne transport?***

Inspired by the well-known Kaya identity, the total GHG emissions produced by waterborne transport ($CO2eq$) can be expressed by Eq. (14) which, for the sake of convenience, is repeated below:

$$CO2eq = \sum_{vessel} \sum_{fuel} \frac{CO2eq}{MJ} \times \frac{MJ}{vkm} \times \frac{1}{C} \times \frac{1}{CUR} \times tonnes \times km \quad (14)$$

The following terms that appear in the right-hand side of Eq. (14):

$CO2eq/MJ$ = carbon intensity of the fuel mix used,

$MJ/vkm$ = energy efficiency of the vessels employed,

$C$ = payload capacity of a ship,

$CUR$ = capacity utilisation rate of a vessel comparing her actual to potential output,

$tonnes$ = freight tonnes lifted by seagoing and inland waterway vessels, and

$km$ = average length of haul

comprise the principal factors affecting carbon emissions according to this decomposition formula. It is noted that the formula can be further expanded to include factors like transport intensity linking transport activity (tonne-km) to GDP or population but it was decided that such causal factors lie outside the scope of the present analysis.

***Q2.3: Which are the most important practices and policies in the field that address the factors identified in Q2.2?***

The thesis does not intend to provide an exhaustive list of the carbon emission reduction measures that have been proposed in the area of waterborne transport. However, the most important practices and policies that can be found in the extensive literature on the subject are listed below by name only:

| | |
|---|---|
| Carbon intensity: | LNG and second-generation biofuels for all waterborne activities; LPG for inland navigation and short-sea shipping; hydrogen for inland navigation; electricity for short-distance ferry connections; shore-side electricity; towing kites. |
| Energy efficiency: (technological) | Optimisation of a ship's principal dimensions, hull form and propulsion system at the design stage; compliance with EEDI; use of high strength steel; various energy efficiency enhancement technologies in relation to the ship's main and auxiliary engines (e.g. electronic control of fuel injection and exhaust valve timing, automated cylinder oil lubricators, advanced exhaust gas and turbocharger control equipment); installation of engine performance monitoring and control instruments; diesel-electric propulsion systems; exhaust gas heat recovery systems; shaft generators; variable speed motors for pumps and fans; high efficiency propellers (e.g. controllable-pitch, ducted, and contra-rotating propellers); propulsion improving devices like spoilers, wake equalising ducts and tunnels, pre- and post-swirl fins and stators, and asymmetric rudders; air lubrication; hull surface texturing. |
| Energy efficiency: (operational) | Voyage speed optimisation including slow steaming and virtual arrival scheme; weather routing; trim/draft optimisation; hull and propeller condition management through proper antifouling coatings, underwater cleaning and propeller polishing; the mandatory Ship Energy Efficiency Management Plan; the MRV Regulation. |
| Ship capacity: | Capacity maximisation. |
| Utilisation rate: | Elimination of administrative restrictions that apply in some domestic maritime trades and inland navigation; optimisation of the type/size of vessels employed on the basis of specific trade characteristics; network optimisation (hub-and-spoke schemes); collaborative business strategies through alliances, mergers and acquisitions; optimisation of cargo mix, packaging and |

| | |
|---|---|
| | handling equipment. |
| Transport demand: | Miniaturisation, digitisation; 3D-printing; postponement. |
| Supply chains: | Weakening of the globalisation forces. |
| OR applications: | Numerous ship routing and scheduling applications at strategic, tactical and operational levels. |
| Market-based: | Fossil fuel tax; tax rebate/subsidy on renewable energy sources; inclusion of shipping in the EU Emission Trading System; differentiated port dues. |
| Modal shifts: | Green corridors; financing through the EU TEN-T and the ‘Motorways of the Sea’ programmes. |

***Q2.4: What policy recommendations can be drawn from this taxonomy?***

The taxonomy provides a holistic view of the factors influencing the volume of carbon emissions from ships. This helps realising that the ambitious goals set by the international society with regard to climate change can be reached at the lowest possible total cost only if pursued through multi-dimensional initiatives or policies. Sustainable mobility is a complex objective requiring the employment of packages of complementary instruments, a conclusion also supported by many other studies in the literature.

A second recommendation stems from the fact that all measures addressing the five last factors in the right-hand side of Eq. (14) result in lower fuel consumption and, thus, savings in terms of both costs and emissions. Many profit maximising measures, then, lead indirectly to environmental benefits, something that should not be overlooked in the search for win-win solutions.

The main contribution of the thesis in relation to OB2 is a simple and practical classification framework that is sufficiently supported by theory. It provides a wider perspective on possible measures and their effectiveness and, as such, can comprise good didactic material.[51] Given that the occurrence of undesirable complications due to the substitution and income effects of political interventions are not uncommon in the transport field, the

[51] The topic has been well-received by the M.Sc. students taking the DTU course ‘Green Transport logistics.’

framework can also help in assessing the compatibility and side effects of the various carbon reduction measures. It can be easily expanded to cover other types of shipping emissions and/or other transport modes.

### 9.1.3 Objective 3: Green maritime corridors – SOx

| **General objective** | |
|---|---|
| OB3 | A case study examining the impacts on modal split and emissions of designating the Mediterranean Sea as a SECA |
| **Specific objectives** | |
| SO3.1 | Collect detailed cost and time data for the two alternative door-to-door options examined in the case study |
| SO3.2 | Develop and calibrate a binomial logit model for the calculation of modal split |
| SO3.3 | Use the model developed in SO3.2 to calculate the modal shift resulting from the designation of the Mediterranean Sea as a SECA |
| SO3.4 | Estimate $CO_2$-eq, SOx, NOx and $PM_{10}$ emissions on the basis of the results of SO3.3 |
| SO3.5 | Run sensitivity analyses on the basic parameters entering the calculations |

OB3 is dealt with in Chapter 8 of the thesis. In accordance with the specific objectives shown above, a case study was developed involving two alternative routes that exports from Thessaloniki, Greece follow when moved to urban centres in northern Germany. A road-only option was assessed against a combined-transport route involving a ferry (Greece–Italy) and a truck-on-train (Italy–Austria) service. Route choice was modelled through a binomial logit formulation that takes transit cost and time into consideration. The model was calibrated on data derived through a series of interviews from actual trips undertaken by a small transport service provider, typical for Greece. Once developed, the model was used to predict the modal shift resulting from a possible designation of the Mediterranean Sea as a SECA. The emissions associated with the resulting modal choices were calculated through the EcoTransIT World web based tool. Sensitivity analyses were run to cope with uncertainties in the values of basic parameters entering the calculations.

The research questions of OB3 are listed below together with a summary of the corresponding findings:

***Q3.1: Which are the available options of the maritime industry to comply with the stricter standards on the sulphur content of marine fuel in SECAs?***

In 2013 when this study was conducted there were three alternative compliance options:

(i) install an exhaust gas scrubber system and continue burning Heavy Fuel Oil (HFO),
(ii) switch fuel from HFO to Marine Gas Oil (MGO) with sulphur content below 0.1% or
(iii) use Liquefied Natural Gas (LNG) as marine fuel.

Because of the need for an extensive conversion of the propulsion system involving much larger fuel tanks, many consider the LNG solution as an option only for newbuildings. This fact combined with the scarcity of LNG refuelling stations in Europe has led to the rejection of this option for the purpose of this case study. Scrubbing was also rejected as a rather immature (at the time) technology. Switching from HFO to MGO was, therefore, the only real option in the immediate future and the only scenario examined in the case study.

It is worth mentioning that the option of Ultra-Low Sulphur Fuel Oils (ULSFO) is available today, which comply with the 0.1% limit at a lower than MGO price. In addition, they offer a higher viscosity and better lubricity than MGO, as well as similar temperature requirements to HFO, reducing the risks associated with the fuel switch over procedure (Zis et al., 2015).

***Q3.2: What is the impact of a costlier marine fuel on the modal split along the routes examined in the case study?***

Under the basic scenario involving the following assumptions:

- the opportunity cost of capital is 2.97%;
- the price differential between MGO and HFO is 330 USD/tonne;
- the exchange rate is 1.34 $/€;
- the typical ship employed on the Adriatic route burns 167 tonnes of fuel per voyage;

- 30% of this fuel is consumed while at port and already complies with the 0.1% limit;
- the ship carries 109 trucks per voyage on average;
- the trucks will bear 45% of the additional fuel cost; and
- a 40 t truck carries 17.1 tonnes of cargo;

an estimated 5.2% of the traffic will shift its route choice in favour of the road-only alternative.

***Q3.3: What are the implications of the expected modal shift on the average emissions along the corridor?***

Prior to the designation of the Mediterranean Sea as a SECA, a consignment of 3.5 tonnes of clothing products from Thessaloniki to Berlin produces on average 0.4470 tonnes of $CO_2$-eq, 0.1188 kg of $PM_{10}$, 4.1939 kg of NOx, and 0.7450 kg of $SO_2$. These average values reflect the fact that the road-only route enjoys a market share of 68.36%.

The designation of the Mediterranean Sea as a SECA increases the market share of the road-only option to 73.56% and improves substantially the $SO_2$ and $PM_{10}$ emissions of the traffic remaining on the combined-transport route. The same consignment now produces on average 0.4341 tonnes of $CO_2$-eq, 0.0928 kg of $PM_{10}$, 3.9637 kg of NOx, and 0.4615 kg of $SO_2$.

Given that the backshift from sea- to land-based routes is usually associated with a deterioration of the environmental performance, the improvement in $CO_2$-eq emissions that the SECA designation brings is rather surprising. The explanation lies to the fact that:

- the combined-transport route is longer than the road-only route by more than 28%;
- the sea leg is characterised by impressively poor performance in terms of all GHG and air pollutants examined; and
- the train leg, which appears to be the most environmentally friendly mode, comprises a very small part of the combined-transport route and cannot make a difference.

***Q3.4: Which are the most important parameters entering the modal split calculations and how sensitive the results are in relation to these parameters?***

Among the assumptions listed in Q3.2, the ones concerning the opportunity cost of capital, the price differential between MGO and HFO, and the share of the additional cost borne by the cargo of a Ro-Pax vessel exhibit the highest uncertainty and deserve a sensitivity analysis. The modal shift of 5.2% of the basic scenario:

- escalates to 6.2% when the opportunity cost (r) is raised to 5%, and to 12.1% for r=10%;
- increases to 7.6% when the price difference between the two fuel qualities becomes 500 USD/tonne; and
- doubles to 10.3% when 95% of the additional cost is allocated to the cargo carrying vehicles onboard.

Combinations of changes in these parameters produce stronger shifts. A 17.1% shift results for an r value of 10% when 70% of the additional cost is allocated to the trucks.

***Q3.5: What policy recommendations can be drawn from this case study?***

The first recommendation relates to the poor performance of the Ro-Pax vessels, which was confirmed here after having been identified in Section 5.3.5. The 'double load factor effect'[52] and the relatively high sailing speeds of these vessels are the causes of this problem.

In relation to the former, the Ro-Pax shipping lines can only address the load factor of their vessels, as they have no control on the load factor of the trucks onboard. Among the measures of Section 7.4.5 on improving the vessel/fleet utilisation, the collaborative business strategies comprise the only applicable option in this case. The continuous restructuring of the shipping lines serving these routes through a spree of alliances, mergers and acquisitions is not surprising.

In relation to speed, though, there might be more room to manoeuvre. Given the well-known negative repercussions of speed on the environment, even small reductions in speed can have serious improvements in fuel consumption and emissions. Acknowledging the limitations in speed reduction that the business concept of a Ro-Pax ship imposes, slower

[52] This is defined as the adverse effect on the fuel consumption and emissions of a Ro-Ro ship, when expressed on a per tonne-km basis, caused by the fact that the transport work performed is determined by both the load factor of the ship (in terms of lane meters occupied) and the load factor of the trucks onboard (in terms of the carrying capacity of the trucks taken up by the cargo).

sailings can only be viable in the short run if accompanied by improvements in port operations. Optimising the gate and yard arrangements of the port, as well as the ship/port interface in terms of loading/unloading operations can save the time needed to allow slower steaming. In the longer term, improvements can come from changes in the business concept itself and depend on whether the general public will accept to trade off transit time for a better environment. Fundamental changes of this sort can affect all facets of the Ro-Pax business sector including the overall design of the network.

A second recommendation relates to the designation of the Mediterranean Sea as a SECA. The present study concludes that, in such an event, a backshift to land-based routes in the range of 5-17% should be expected which, however, is associated with positive environmental repercussions. The designation of a SECA, of course, is a political decision that cannot be based simply on a case study like the present one, which may be too limited in scope hampering the transferability of its results to other scenarios.

In relation to OB3, the thesis contributes by adding to the literature on the subject, which happens to be much thinner for this part of Europe in comparison to the Baltic and North Seas. Although the designation of the Mediterranean Sea as a SECA cannot be decided simply on a case study like this, its results are worthy noting and its methodology could form the basis for broader analyses. Secondly, none of the previous studies on this topic uses a logit model that takes into consideration transport time in addition to costs. A third point that makes this case study distinct relates to its scope. The study applies a micro-level perspective that: (i) addresses the SME subsector of the logistics industry that happens to be quite substantial in Greece (World Bank, 2013), (ii) secures comparable door-to-door transport chains, and (iii) allows the delineation of an emission allocation scheme for a multi-load multi-drop operation.

## 9.2 Suggestions for future work

There is still substantial work to be done with respect to the application of the proposed methodology in assessing the GreCOR corridor. The following activities need to be taken before the assessment is considered complete:

- Finalise discussions with the business associations. Change the questionnaire if necessary to replace absolute with relative values for the commercially sensitive parameters.

- Circulate the questionnaire to selected members of the associations.
- Undertake follow up actions to support the response rate.
- Collate responses and refine the corridor sample on the basis of the input received.
- Estimate the KPI values at the chain and corridor levels.
- Disseminate results to:
  - the participating stakeholders;
  - the management of the ScanMed TEN-T core network corridor;
  - the Danish administration;
  - the scientific community; and
  - the general public.

In connection to informing the Danish administration on the results achieved on the GreCOR corridor, there is a need to initiate a broader dialogue on monitoring not only the ScanMed corridor crossing Denmark but the entire logistics industry in the country. The complete absence of cost and quality data in the official Danish transport statistics is noteworthy; as is the persistently poor performance of Denmark in terms of LPI compared to its neighbours and other GreCOR countries (Denmark scores lower than all GreCOR countries with the exception of Norway).

There are solutions to these problems. The annual '*Freight Facts and Figures*' report that the Bureau of Transportation Statistics of the US Department of Transportation produces in cooperation with the Federal Highway Administration is a good example. The report provides a comprehensive set of data on the physical characteristics of the national freight transport system and the freight moved, with selected indicators on congestion, environmental impacts and safety among others (ITF, 2016a).

National observatories comprise another solution that either has been already followed (France, Canada, South Africa) or is being contemplated (Chile, Mexico) by several countries. ITF (2016a) makes reference to at least four such observatories in France covering a spectrum of transport and logistics issues relating to policy (The Observatory of Transport Policy and Strategy in Europe), mode-specific information (The National Road Freight Transport Economics Observatory), region-specific data (Alsace transport and logistics observatory), and export data (The French-Italian transport observatory).

A different approach is followed by the Netherlands where Dinalog, the Dutch Institute for Advanced Logistics (http://www.dinalog.nl/en/about_us/), was established in 2009 as a non-profit institute with a focus on training and collaborative projects between businesses, government, universities and other knowledge institutions for innovation in logistics (ITF, 2016a).

The close contacts that DTU maintains with the Danish transport administration can be instrumental for initiating this dialogue.

Furthermore, the PhD work on green corridors (Chapters 3-6) already helps improve the effectiveness of the governing structures of the TEN-T core network corridors in the Baltic region in the framework of the Interreg project '*TENTacle – Capitalising on TEN-T core network corridors for prosperity, growth and cohesion*' project (2016-2019), which will be running for the period 2016-19.

In addition, DTU is a partner of the Interreg project '*Scandria®2Act - Sustainable and multimodal transport actions in the Scandinavian-Adriatic corridor*' which, during the period 2016-19, will apply the methodology presented in Chapter 8 to assess the implications of the recent stricter sulphur limits on the environmental performance of transport operations along the Scandinavian-Mediterranean TEN-T core network corridor that include a Ro-Ro connection. The methodology will be further developed to take into consideration the implications of the modal shifts on the financial performance and viability of the existing Ro-Ro services.

The warm reception that the work on the taxonomy of $CO_2$ emission reduction measures in shipping (Chapter 7) has experienced from DTU students provides an incentive to expand coverage to other transport modes and different pollutants, mainly for didactic purposes.

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# APPENDIX I. THE SUPERGREEN PROJECT

## Project identity

- Project full title: Supporting EU's Freight Transport Logistics Action Plan on Green Corridors Issues
- Type of project: Coordination and Support Action
- Financed through: 7th Framework Programme
- Duration: 15 Jan. 2010 – 14 Jan. 2013
- Consortium: 22 partners from 13 countries
- Leader: National Technical University of Athens
- Total budget: 3,453,747 EUR
- EC contribution: 2,634,698 EUR
- Web site : http://www.supergreenproject.eu/

## Project partners

| Partner Number * | Partner name | Partner short name | Country |
|---|---|---|---|
| 1 (Coordinator) | National Technical University of Athens | NTUA | Greece |
| 2 | Norsk Marinteknisk Forskningsinstitutt AS, MARINTEK | MAR | Norway |
| 3 | Sito Ltd (Finnish Consulting Engineers Ltd) | SITO | Finland |
| 4 | D'Appolonia S.p.A. | DAPP | Italy |
| 5 | Autoridad Portuaria de Gijon Gijón Port Authority- | PAG | Spain |
| 6 | DNV Det norske Veritas | DNV | Norway |
| 7 | via donau Österreichische Wasserstraßen-Gesellschaft mbH | VIA | Austria |
| 8 | NewRail - Newcastle University | UNEW | UK |
| 9 | CONSULTRANS | CONS | Spain |
| 10 | PSA Sines | PSAS | Portugal |
| 11 | Finnish Transport Agency | FMA | Finland |
| 12 | Straightway Finland Ry | SWAY | Finland |
| 13 | SNCF Fret Italia | SFI | Italy |
| 14 | Procter & Gamble Eurocor | PG | Belgium |
| 15 | VR Group | VRG | Finland |
| 16 | Lloyd's Register-Fairplay Research | LRFR | Sweden |
| 17 | Hellenic Shortsea Shipowners Association | HSSA | Greece |
| 18 | Dortmund University of Technology | DUT | Germany |
| 19 | TES Consult Ltd | TES | Ukraine |
| 20 | Turkish State Railways | TCDD | Turkey |
| 21 | DB Schenker AG | SCH | Germany |
| 22 | Norwegian Public Road Administration | NPRA | Norway |

## Project objectives

- Give overall support and recommendations on green corridors to EU's Freight Transport Logistics Action Plan

- Encourage co-modality for sustainable solutions

- Provide a schematic for overall benchmarking of green corridors based on selected KPIs covering all aspects of transport operations and infrastructure (emissions, internal and external costs)

- Conduct a programme of networking activities between stakeholders (public and private) and ongoing EU and other research and development projects to facilitate information exchange, research results dissemination, communication of best practices and technologies at a European, national, and regional scale, thus adding value to ongoing programmes

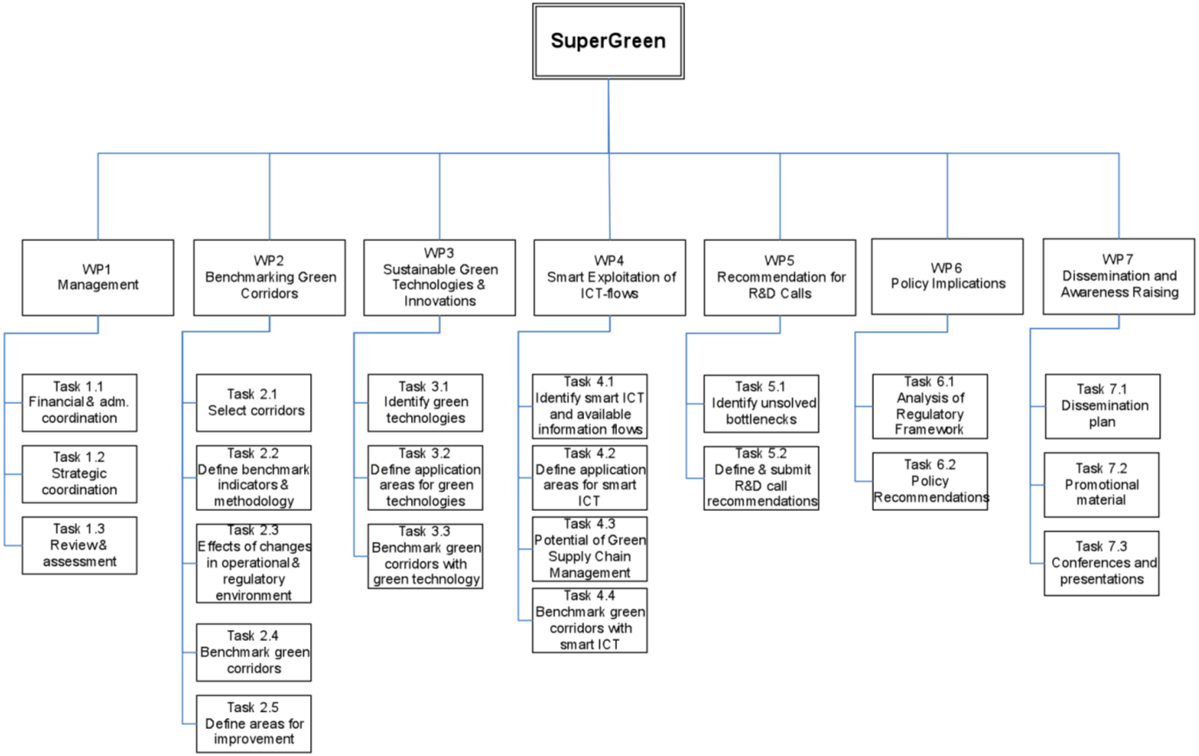
- Deliver policy recommendations at a European level for the further development of green corridors

- Provide recommendations concerning new calls for R&D proposals to support development of green corridors

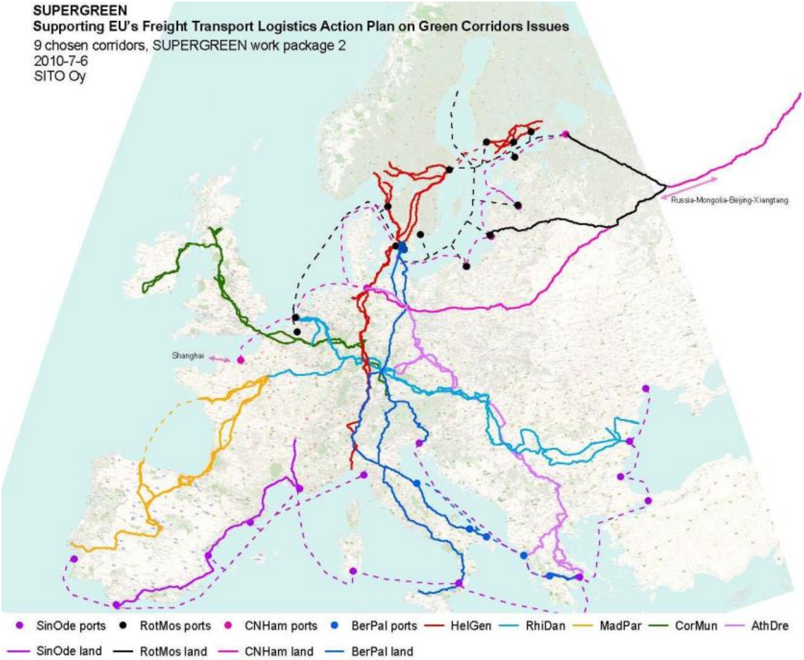
## Modes covered

- Road
- Rail
- Short sea shipping
- Deep sea shipping
- Inland waterway transport
- Intermodal transport

# Project structure



# SuperGreen corridors




| Nicknames | Acronym | Corridor Description |
|---|---|---|
| **Brenner** | **BerPal** | Malmö-Trelleborg-Rostock/Sassnitz-Berlin-Munich-Salzburg-Verona-Bologna-Naples-Messina-Palermo<br>Branch A: Salzburg-Villach-Trieste (Tauern axis)<br>Branch B: Bologna-Ancona/Bari/Brindisi-Igoumenitsa/Patras-Athens |
| **Finis Terrae** | **MadPar** | Madrid-Gijon-Saint Nazaire-Paris<br>Branch A: Madrid-Lisboa |
| **Cloverleaf** | **CorMun** | Cork-Dublin-Belfast-Stranraer<br>Branch A: Munchen-Friedewald-Nuneaton Branch B: West Coast Main line |
| **Edelweiss** | **HelGen** | Helsinki-Turku-Stockholm-Oslo-Göteborg-Malmö-Copenhagen (Nordic triangle including the Oresund fixed link)- Fehmarnbelt - Milan - Genoa |
| **Nureyev** | **RotMos** | Motorway of Baltic sea<br>Branch: St. Petersburg-Moscow-Minsk-Klapeida |
| **Strauss** | **RhiDan** | Rhine/Meuse-Main-Danube inland waterway axis<br>Branch A: Betuwe line<br>Branch B: Frankfurt-Paris |
| **Two Seas** | **AthDre** | Igoumenitsa/Patras-Athens-Sofia-Budapest-Vienna-Prague-Nurnberg/Dresden-Hamburg |
| **Mare Nostrum** | **SinOde** | Odessa-Constanta-Bourgas-Istanbul-Piraeus-Gioia Tauro-Cagliari-La Spezia-Marseille-(Barcelona/Valencia)-Sines<br>Branch A: Algeciras-Valencia-Barcelona-Marseille-Lyon |
| **Silk Way** | **CNHam** | Shanghai-Le Havre/Rotterdam-Hamburg/Gothenburg-Gdansk-Baltic ports-Russia<br>Branch:Xiangtang-Beijing-Mongolia-Russia-Belarus-Poland-Hamburg |

# APPENDIX II. TRAVISIONS 2016 CONTEST

# TRAVISIONS 2016

## EU CHAMPIONS OF TRANSPORT RESEARCH 2016

*Second Place*

**CROSS-MODALITY**

*Georgios Panagakos*

*Technical University of Denmark*

has contributed to outstanding research results in the EU funded Project "Performance assessment of green corridors" and is awarded in the TRAVISIONS 2016 contest on innovative transport ideas for senior researchers

George Smyrnakis
Project Leader TRAVISIONS 2016

Clara de la Torre
Transport Director
Directorate-General for Research & Innovation
European Commission

Horizon 2020
European Union Funding
for Research & Innovation

# APPENDIX III. THE GRECOR SAMPLE (Chapter 5)

| NO OF CHAIN | CHAIN TYPE | ANNUAL TONNES | PRODUCTION ZONE | VEHICLE LEG 1 | FIRST TERMINAL | VEHICLE LEG 2 | SECOND TERMINAL | VEHICLE LEG 3 | CONSUMPTION ZONE |
|---|---|---|---|---|---|---|---|---|---|
| Commodity group 1A: Agro products - Containerised | | | | | | | | | |
| 1 | 191 | 351 | Ghent (BE) | Articulated truck | Ghent (BE) | Ro-Ro ship | Tønsberg (NO) | Articulated truck | Akershus (NO) |
| 2 | 191 | 86 | Hamburg (DE) | Truck 18-26t | Lübeck (DE) | Ro-Ro ship | Helsingborg (SE) | Truck 18-26t | Valby (DK) |
| 3 | 191 | 263 | Zuidoost-Noord-Brabant (NL) | Articulated truck | Antwerp (BE) | Ro-Ro ship | Göteborg (SE) | Articulated truck | Uddevalla (SE) |
| 4 | 191 | 248 | Utrecht (NL) | Articulated truck | Amsterdam (NL) | Ro-Ro ship | Esbjerg (DK) | Articulated truck | Fredericia (DK) |
| 5 | 191 | 183 | Hamburg (DE) | Articulated truck | Hamburg (DE) | Ro-Ro ship | Göteborg (SE) | Articulated truck | Uddevalla (SE) |
| Commodity group 1B: Agro products - Non-containerised | | | | | | | | | |
| 6 | 2 | 239 | Assens (DK) | | | Articulated truck | | | Rotenburg (Wumme) (DE) |
| 7 | 3 | 57 | Faxe (DK) | | | Articulated truck | | | Borken (DE) |
| 8 | 121 | 36 | Greve (DK) | Truck 18-26t | Tønder (DK) | Articulated truck | Bremen (DE) | Truck 18-26t | Cloppenburg (DE) |
| 9 | 121 | 211 | Overig Groningen (NL) | Articulated truck | Dörpen (DE) | Articulated truck | Silkeborg (DK) | Articulated truck | Fredericia (DK) |
| 10 | 121 | 7 | Veluwe (NL) | Truck 12-18t | Coevorden (NL) | Articulated truck | Esbjerg (DK) | Truck 12-18t | Næstved NV (DK) |
| 11 | 131 | 25 | Kastrup Lufthavn (DK) | Light truck | Køge (DK) | Articulated truck | Hannover-Linden (DE) | Truck/trailer 12-18t | Hannover (DE) |
| 12 | 131 | 29 | Køge (DK) | Truck 18-26t | Køge (DK) | Articulated truck | Hamburg (DE) | Truck 18-26t | Segeberg (DE) |
| 13 | 131 | 39 | Ringsted (DK) | Truck 18-26t | Esbjerg (DK) | Articulated truck | Terneuzen (NL) | Truck 18-26t | Overig Zeeland (NL) |
| 14 | 171 | 820 | Svalöv (SE) | Articulated truck | Helsingborg (SE) | Conventional train | Antwerp (BE) | Articulated truck | Ghent (BE) |
| 15 | 181 | 4668 | Herzogtum Lauenburg (DE) | Articulated truck | Hamburg (DE) | Conventional ship | Oslo (NO) | Articulated truck | Akershus (NO) |
| Commodity group 2: Coal & lignite | | | | | | | | | |
| 16 | 2 | 6243 | Padborg (DK) | | | Articulated truck | | | Rotenburg (Wumme) (DE) |
| 17 | 5 | 180 | Uddevalla (SE) | | | Articulated truck | | | Utrecht (NL) |
| 18 | 6 | 70 | Uddevalla (SE) | | | Articulated truck | | | Zuidoost-Noord-Brabant (NL) |
| 19 | 171 | 23 | Zuidoost-Noord-Brabant (NL) | Articulated truck | Genk (BE) | Conventional train | Oslo (NO) | Articulated truck | Akershus (NO) |
| 20 | 181 | 3627 | Utrecht (NL) | Articulated truck | Amsterdam (NL) | Conventional ship | Kolding Havn (DK) | Articulated truck | Kolding city (DK) |
| Commodity group 3: Iron ore & non-ferrous metal ores | | | | | | | | | |
| 21 | 2 | 242 | Hamburg (DE) | | | Articulated truck | | | Assens (DK) |
| 22 | 2 | 55 | Rendsburg-Eckernforde (DE) | | | Articulated truck | | | Padborg (DK) |
| 23 | 3 | 29 | Hamburg (DE) | | | Articulated truck | | | Middelfart (DK) |
| 24 | 3 | 18 | Rotenburg (Wumme) (DE) | | | Articulated truck | | | Falster (DK) |
| 25 | 121 | 15 | Ghent (BE) | Articulated truck | Terneuzen (NL) | Articulated truck | Copenhagen (DK) | Articulated truck | Vesterbro (DK) |
| 26 | 121 | 10 | Slagelse (DK) | Truck 12-18t | Fredericia (DK) | Articulated truck | Marl (DE) | Truck 12-18t | Zuidoost-Noord-Brabant (NL) |
| 27 | 121 | 15 | Glostrup (DK) | Light truck | Herning (DK) | Articulated truck | Coevorden (NL) | Truck 18-26t | Veluwe (NL) |
| 28 | 121 | 23 | Brøndby (DK) | Light truck | Køge (DK) | Articulated truck | Dörpen (DE) | Truck 18-26t | Overig Groningen (NL) |
| 29 | 131 | 4 | Hamburg (DE) | Truck 18-26t | Hamburg (DE) | Articulated truck | Rødby Havn (DK) | Truck 18-26t | Midtlolland (DK) |
| 30 | 131 | 11 | Rotenburg (Wumme) (DE) | Truck/trailer > 18t | Hamburg (DE) | Articulated truck | Copenhagen (DK) | Light truck | Vesterbro (DK) |
| 31 | 131 | 6 | Midtlolland (DK) | Truck 12-18t | Rødby Havn (DK) | Articulated truck | Terneuzen (NL) | Truck 12-18t | Ghent (BE) |
| 32 | 131 | 24 | Køge (DK) | Truck/trailer > 18t | Køge (DK) | Articulated truck | Terneuzen (NL) | Truck/trailer > 18t | Overig Zeeland (NL) |
| 33 | 171 | 871 | Borken (DE) | Articulated truck | Duisburg (DE) | Conventional train | Padborg (DK) | Articulated truck | Padborg (DK) |
| 34 | 181 | 2627 | Køge (DK) | Articulated truck | Køge Havn (DK) | Conventional ship | Bremen (DE) | Articulated truck | Borken (DE) |

| NO OF CHAIN | CHAIN TYPE | ANNUAL TONNES | PRODUCTION ZONE | VEHICLE LEG 1 | FIRST TERMINAL | VEHICLE LEG 2 | SECOND TERMINAL | VEHICLE LEG 3 | CONSUMPTION ZONE |
|---|---|---|---|---|---|---|---|---|---|
| Commodity group 6: Wood products - Non-containerised | | | | | | | | | |
| 35 | 2 | 1985 | Hamburg (DE) | | | Articulated truck | | | Kolding rural (DK) |
| 36 | 2 | 589 | Rotenburg (Wumme) (DE) | | | Articulated truck | | | Assens (DK) |
| 37 | 2 | 220 | Veluwe (NL) | | | Articulated truck | | | Haderslev (DK) |
| 38 | 3 | 222 | Køge (DK) | | | Articulated truck | | | Ostholstein (DE) |
| 39 | 3 | 152 | Lolland Øst (DK) | | | Articulated truck | | | Rendsburg-Eckernforde (DE) |
| 40 | 121 | 229 | Zuidoost-Noord-Brabant (NL) | Articulated truck | Marl (DE) | Articulated truck | Silkeborg (DK) | Articulated truck | Middelfart (DK) |
| 41 | 121 | 24 | Nyborg (DK) | Truck/trailer > 18t | Odense (DK) | Articulated truck | Hannover-Linden (DE) | Truck/trailer > 18t | Hannover (DE) |
| 42 | 131 | 46 | Midtlolland (DK) | Articulated truck | Rødby Havn (DK) | Articulated truck | Marl (DE) | Articulated truck | Zuidoost-Noord-Brabant (NL) |
| 43 | 131 | 30 | Ghent (BE) | Articulated truck | Terneuzen (NL) | Articulated truck | Esbjerg (DK) | Light truck | Slagelse (DK) |
| 44 | 171 | 2498 | Malmö (SE) | Articulated truck | Malmö (SE) | Conventional train | Duisburg (DE) | Articulated truck | Borken (DE) |
| 45 | 181 | 208000 | Halmstad (SE) | Articulated truck | Halmstad (SE) | Conventional ship | Bremen (DE) | Articulated truck | Borken (DE) |
| 46 | 181 | 78381 | Akershus (NO) | Articulated truck | Oslo (NO) | Conventional ship | Antwerp (BE) | Articulated truck | Ghent (BE) |
| 47 | 181 | 15500 | Uddevalla (SE) | Articulated truck | Uddevalla (SE) | Conventional ship | Antwerp (BE) | Articulated truck | Zuidoost-Noord-Brabant (NL) |
| Commodity group 7: Coke & petroleum products | | | | | | | | | |
| 48 | 1 | 567 | Akershus (NO) | | | Articulated truck | | | Køge (DK) |
| 49 | 2 | 465 | Hamburg (DE) | | | Articulated truck | | | Padborg (DK) |
| 50 | 3 | 112 | Hannover (DE) | | | Articulated truck | | | Brøndby (DK) |
| 51 | 5 | 158 | Akershus (NO) | | | Articulated truck | | | Overig Zeeland (NL) |
| 52 | 111 | 630 | Kolding city (DK) | Articulated truck | Kolding (DK) | Articulated truck | Drammen (NO) | Articulated truck | Akershus (NO) |
| 53 | 121 | 23 | Zuidoost-Noord-Brabant (NL) | Articulated truck | Marl (DE) | Articulated truck | Brørup (DK) | Light truck | Brøndby (DK) |
| 54 | 131 | 21 | Fredericia (DK) | Truck/trailer 12-18t | Fredericia Havn (DK) | Articulated truck | Lübeck (DE) | Truck/trailer 12-18t | Ostholstein (DE) |
| 55 | 151 | 25 | Akershus (NO) | Truck/trailer 12-18t | Munkedal (SE) | Articulated truck | Bremen (DE) | Truck/trailer 12-18t | Cloppenburg (DE) |
| 56 | 161 | 205 | Akershus (NO) | Articulated truck | Drammen (NO) | Articulated truck | Terneuzen (NL) | Articulated truck | Ghent (BE) |
| 57 | 171 | 273 | Hannover (DE) | Articulated truck | Hannover-Linden (DE) | Conventional train | Sävenäs (SE) | Articulated truck | Göteborg (SE) |
| 58 | 181 | 32639 | Fredericia (DK) | Articulated truck | Fredericia Havn (DK) | Conventional ship | Oslo (NO) | Articulated truck | Akershus (NO) |
| 59 | 181 | 50590 | Hamburg (DE) | Articulated truck | Hamburg (DE) | Conventional ship | Fredericia Havn (DK) | Articulated truck | Fredericia (DK) |
| Commodity group 14: Secondary raw materials & wastes | | | | | | | | | |
| 60 | 1 | 211 | Valby (DK) | | | Articulated truck | | | Halmstad (SE) |
| 61 | 2 | 107 | Hamburg (DE) | | | Articulated truck | | | Odense S (DK) |
| 62 | 3 | 71 | Rotenburg (Wumme) (DE) | | | Articulated truck | | | Køge (DK) |
| 63 | 121 | 13 | Ishøj (DK) | Light truck | Padborg (DK) | Articulated truck | Hamburg (DE) | Truck 18-26t | Rotenburg (Wumme) (DE) |
| 64 | 121 | 17 | Roskilde (DK) | Truck/trailer > 18t | Vejle (DK) | Articulated truck | Hamburg (DE) | Truck/trailer > 18t | Hamburg (DE) |
| 65 | 131 | 2 | Herzogtum Lauenburg (DE) | Truck 12-18t | Lübeck (DE) | Articulated truck | Rødby Havn (DK) | Truck 12-18t | Midtlolland (DK) |
| 66 | 131 | 4 | Ostholstein (DE) | Truck/trailer 12-18t | Lübeck (DE) | Articulated truck | Copenhagen (DK) | Truck/trailer 12-18t | Faxe (DK) |
| 67 | 171 | 98 | Borken (DE) | Articulated truck | Duisburg (DE) | Conventional train | Sävenäs (SE) | Articulated truck | Göteborg (SE) |
| 68 | 181 | 1924 | Akershus (NO) | Articulated truck | Oslo (NO) | Conventional ship | Kiel (DE) | Articulated truck | Rendsburg-Eckernforde (DE) |

| NO OF CHAIN | CHAIN TYPE | ANNUAL TONNES | PRODUCTION ZONE | VEHICLE LEG 1 | FIRST TERMINAL | VEHICLE LEG 2 | SECOND TERMINAL | VEHICLE LEG 3 | CONSUMPTION ZONE |
|---|---|---|---|---|---|---|---|---|---|
| **Commodity group 15: Mail & parcels** | | | | | | | | | |
| 69 | 2 | 1582 | Utrecht (NL) | | | Articulated truck | | | Padborg (DK) |
| 70 | 121 | 162 | Veluwe (NL) | Truck 12-18t | Coevorden (NL) | Articulated truck | Silkeborg (DK) | Truck 12-18t | Middelfart (DK) |
| 71 | 121 | 97 | Køge (DK) | Truck 12-18t | Køge (DK) | Articulated truck | Marl (DE) | Truck 12-18t | Zuidoost-Noord-Brabant (NL) |
| 72 | 121 | 101 | Kolding rural (DK) | Truck 12-18t | Kolding (DK) | Articulated truck | Brunsbüttel (DE) | Truck 12-18t | Segeberg (DE) |
| 73 | 131 | 67 | Køge (DK) | Truck 12-18t | Køge (DK) | Articulated truck | Lübeck (DE) | Truck 12-18t | Herzogtum Lauenburg (DE) |
| 74 | 131 | 199 | Ringsted (DK) | Truck/trailer 12-18t | Esbjerg (DK) | Articulated truck | Terneuzen (NL) | Truck/trailer 12-18t | Ghent (BE) |
| 75 | 131 | 71 | Brøndby (DK) | Light truck | Køge (DK) | Articulated truck | Kiel (DE) | Truck 12-18t | Rendsburg-Eckernforde (DE) |
| 76 | 191 | 49 | Hamburg (DE) | Truck 12-18t | Lübeck (DE) | Ro-Ro ship | Helsingborg (SE) | Truck 12-18t | Glostrup (DK) |
| 77 | 191 | 53 | Zuidoost-Noord-Brabant (NL) | Truck 12-18t | Antwerp (BE) | Ro-Ro ship | Göteborg (SE) | Truck 12-18t | Køge (DK) |
| **Commodity group 21: Crude oil & natural gas** | | | | | | | | | |
| 78 | 2 | 76 | Fredericia (DK) | | | Truck 18-26 t | | | Rendsburg-Eckernforde (DE) |
| 79 | 121 | 23 | Rotenburg (Wumme) (DE) | Truck 12-18t | Hamburg (DE) | Articulated truck | Kolding (DK) | Light truck | Kolding city (DK) |
| 80 | 131 | 22 | Fredericia (DK) | Truck/trailer 12-18t | Fredericia Havn (DK) | Articulated truck | Lübeck (DE) | Truck/trailer 12-18t | Ostholstein (DE) |
| 81 | 171 | 74 | Rotenburg (Wumme) (DE) | Articulated truck | Hamburg (DE) | Conventional train | Oslo (NO) | Articulated truck | Akershus (NO) |
| 82 | 181 | 63484 | Fredericia (DK) | Articulated truck | Fredericia Havn (DK) | Conventional ship | Bremen (DE) | Articulated truck | Borken (DE) |
| **Commodity group 22: Fertilizers** | | | | | | | | | |
| 83 | 2 | 1716 | Fredericia (DK) | | | Articulated truck | | | Borken (DE) |
| 84 | 3 | 168 | Borken (DE) | | | Articulated truck | | | Køge (DK) |
| 85 | 121 | 13 | Ghent (BE) | Truck 12-18t | Terneuzen (NL) | Articulated truck | Odense (DK) | Truck 12-18t | Nyborg (DK) |
| 86 | 121 | 12 | Nyborg (DK) | Truck 3.5-12t | Odense (DK) | Articulated truck | Amsterdam (NL) | Truck 3.5-12t | Utrecht (NL) |
| 87 | 121 | 23 | Hannover (DE) | Truck 12-18t | Hannover-Linden (DE) | Articulated truck | Kolding (DK) | Light truck | Kolding city (DK) |
| 88 | 121 | 29 | Padborg (DK) | Truck 12-18t | Aabenraa Havn (DK) | Articulated truck | Dörpen (DE) | Truck 12-18t | Overig Groningen (NL) |
| 89 | 131 | 18 | Utrecht (NL) | Truck 12-18t | Amsterdam (NL) | Articulated truck | Esbjerg (DK) | Truck 12-18t | Sorø (DK) |
| 90 | 131 | 10 | Schleswig-Flensburg (DE) | Truck 12-18t | Flensburg (DE) | Articulated truck | Odense (DK) | Light truck | Odense NØ (DK) |
| 91 | 131 | 10 | Nyborg (DK) | Truck 3.5-12t | Nyborg Havn (DK) | Articulated truck | Hamburg (DE) | Truck 3.5-12t | Rotenburg (Wumme) (DE) |
| 92 | 131 | 10 | Rendsburg-Eckernforde (DE) | Truck 12-18t | Kiel (DE) | Articulated truck | Køge (DK) | Truck 12-18t | Køge (DK) |
| 93 | 171 | 1460 | Akershus (NO) | Articulated truck | Oslo (NO) | Conventional train | Coevorden (NL) | Articulated truck | Veluwe (NL) |
| 94 | 181 | 2399 | Akershus (NO) | Articulated truck | Oslo (NO) | Conventional ship | Amsterdam (NL) | Articulated truck | Utrecht (NL) |

| NO OF CHAIN | CHAIN TYPE | ANNUAL TONNES | PRODUCTION ZONE | VEHICLE LEG 1 | FIRST TERMINAL | VEHICLE LEG 2 | SECOND TERMINAL | VEHICLE LEG 3 | CONSUMPTION ZONE |
|---|---|---|---|---|---|---|---|---|---|
| **Commodity group 23: Stone, sand, gravel & quarry products** | | | | | | | | | |
| 95 | 1 | 250 | Malmö (SE) | | | Articulated truck | | | Vesterbro (DK) |
| 96 | 2 | 176 | Hamburg (DE) | | | Articulated truck | | | Assens (DK) |
| 97 | 2 | 192 | Rendsburg-Eckernforde (DE) | | | Articulated truck | | | Padborg (DK) |
| 98 | 3 | 46 | Hamburg (DE) | | | Articulated truck | | | Slagelse (DK) |
| 99 | 3 | 10 | Segeberg (DE) | | | Articulated truck | | | Odense S (DK) |
| 100 | 121 | 1 | Zuidoost-Noord-Brabant (NL) | Truck 3.5-12t | Marl (DE) | Articulated truck | Padborg (DK) | Light truck | Ishøj (DK) |
| 101 | 121 | 30 | Overig Groningen (NL) | Articulated truck | Dörpen (DE) | Articulated truck | Århus (DK) | Articulated truck | Haderslev (DK) |
| 102 | 121 | 5 | Veluwe (NL) | Truck 18-26t | Coevorden (NL) | Articulated truck | Odense (DK) | Truck 18-26t | Nyborg (DK) |
| 103 | 131 | 3 | Ostholstein (DE) | Truck/trailer 12-18t | Lübeck (DE) | Articulated truck | Køge (DK) | Light truck | Kastrup Lufthavn (DK) |
| 104 | 131 | 2 | Overig Groningen (NL) | Truck 12-18t | Dörpen (DE) | Articulated truck | Køge (DK) | Truck 12-18t | Køge (DK) |
| 105 | 131 | 1 | Veluwe (NL) | Truck 3.5-12t | Coevorden (NL) | Articulated truck | Køge (DK) | Light truck | Kastrup Lufthavn (DK) |
| 106 | 171 | 195 | Borken (DE) | Articulated truck | Duisburg (DE) | Conventional train | Halmstad (SE) | Articulated truck | Halmstad (SE) |
| 107 | 181 | 2000 | Göteborg (SE) | Articulated truck | Göteborg (SE) | Conventional ship | Antwerp (BE) | Articulated truck | Zuidoost-Noord-Brabant (NL) |
| **Commodity group RESTA: Various - Containerised** | | | | | | | | | |
| 108 | 171 | 990 | Hannover (DE) | Truck/trailer > 18t | Hannover-Linden (DE) | Combi train | Hallsberg (SE) | Truck/trailer > 18t | Akershus (NO) |
| 109 | 181 | 31820 | Borken (DE) | Articulated truck | Antwerp (BE) | Containership | Fredericia Havn (DK) | Articulated truck | Fredericia (DK) |
| 110 | 181 | 6232 | Utrecht (NL) | Articulated truck | Rotterdam (NL) | Containership | Oslo (NO) | Articulated truck | Akershus (NO) |
| 111 | 181 | 16020 | Ghent (BE) | Articulated truck | Antwerp (BE) | Containership | Göteborg (SE) | Articulated truck | Göteborg (SE) |
| 112 | 181 | 171 | Hamburg (DE) | Truck/trailer > 18t | Hamburg (DE) | Containership | Malmö (SE) | Truck/trailer > 18t | Malmö (SE) |
| 113 | 181 | 15571 | Glostrup (DK) | Articulated truck | Københavns Havn (DK) | Containership | Rotterdam (NL) | Articulated truck | Borken (DE) |
| 114 | 191 | 4919 | Hannover (DE) | Articulated truck | Lübeck (DE) | Ro-Ro ship | Helsingborg (SE) | Articulated truck | Brøndby (DK) |
| 115 | 191 | 4132 | Borken (DE) | Articulated truck | Bremen (DE) | Ro-Ro ship | Oslo (NO) | Articulated truck | Akershus (NO) |
| 116 | 191 | 4484 | Ghent (BE) | Articulated truck | Antwerp (BE) | Ro-Ro ship | Göteborg (SE) | Articulated truck | Göteborg (SE) |
| 117 | 191 | 81 | Rendsburg-Eckernforde (DE) | Articulated truck | Lübeck (DE) | Ro-Ro ship | Göteborg (SE) | Articulated truck | Göteborg (SE) |
| 118 | 191 | 1137 | Ghent (BE) | Articulated truck | Ghent (BE) | Ro-Ro ship | Tønsberg (NO) | Articulated truck | Akershus (NO) |
| 119 | 191 | 117 | Utrecht (NL) | Articulated truck | Amsterdam (NL) | Ro-Ro ship | Esbjerg (DK) | Articulated truck | Kolding city (DK) |
| 120 | 191 | 1638 | Hannover (DE) | Articulated truck | Hamburg (DE) | Ro-Ro ship | Göteborg (SE) | Articulated truck | Göteborg (SE) |
| 121 | 191 | 2197 | Overig Zeeland (NL) | Articulated truck | Zeebrugge (BE) | Ro-Ro ship | Göteborg (SE) | Articulated truck | Göteborg (SE) |

| NO OF CHAIN | CHAIN TYPE | ANNUAL TONNES | PRODUCTION ZONE | VEHICLE LEG 1 | FIRST TERMINAL | VEHICLE LEG 2 | SECOND TERMINAL | VEHICLE LEG 3 | CONSUMPTION ZONE |
|---|---|---|---|---|---|---|---|---|---|
| Commodity group RESTB: Various - Non-containerised | | | | | | | | | |
| 122 | 1 | 7250 | Hvidovre (DK) | | | Articulated truck | | | Malmö (SE) |
| 123 | 2 | 20051 | Hamburg (DE) | | | Articulated truck | | | Haderslev (DK) |
| 124 | 2 | 11079 | Hannover (DE) | | | Articulated truck | | | Fredericia (DK) |
| 125 | 3 | 3546 | Falster (DK) | | | Articulated truck | | | Hamburg (DE) |
| 126 | 3 | 753 | Faxe (DK) | | | Articulated truck | | | Rendsburg-Eckernforde (DE) |
| 127 | 6 | 3996 | Uddevalla (SE) | | | Articulated truck | | | Veluwe (NL) |
| 128 | 111 | 250 | Göteborg (SE) | Articulated truck | Kungsbacka (SE) | Articulated truck | Copenhagen (DK) | Articulated truck | Valby (DK) |
| 129 | 121 | 1759 | Ghent (BE) | Articulated truck | Terneuzen (NL) | Articulated truck | Silkeborg (DK) | Articulated truck | Fredericia (DK) |
| 130 | 121 | 445 | Overig Groningen (NL) | Articulated truck | Dörpen (DE) | Articulated truck | Kolding (DK) | Articulated truck | Kolding rural (DK) |
| 131 | 121 | 128 | Veluwe (NL) | Truck 12-18t | Coevorden (NL) | Articulated truck | Silkeborg (DK) | Truck 12-18t | Middelfart (DK) |
| 132 | 121 | 173 | Utrecht (NL) | Truck 12-18t | Amsterdam (NL) | Articulated truck | Odense (DK) | Truck 12-18t | Nyborg (DK) |
| 133 | 121 | 182 | Valby (DK) | Truck/trailer > 18t | Christiansfeld (DK) | Articulated truck | Duisburg (DE) | Truck/trailer > 18t | Borken (DE) |
| 134 | 121 | 122 | Ishøj (DK) | Light truck | Padborg (DK) | Articulated truck | Duisburg (DE) | Truck 18-26t | Borken (DE) |
| 135 | 121 | 155 | Høje Taastrup (DK) | Articulated truck | Høje Taastrup (DK) | Articulated truck | Terneuzen (NL) | Articulated truck | Ghent (BE) |
| 136 | 121 | 212 | Assens (DK) | Truck/trailer 12-18t | Århus (DK) | Articulated truck | Hamburg (DE) | Truck/trailer 12-18t | Rotenburg (Wumme) (DE) |
| 137 | 121 | 662 | Fredericia (DK) | Articulated truck | Silkeborg (DK) | Articulated truck | Marl (DE) | Articulated truck | Zuidoost-Noord-Brabant (NL) |
| 138 | 131 | 831 | Køge (DK) | Truck/trailer > 18t | Køge (DK) | Articulated truck | Hamburg (DE) | Truck/trailer > 18t | Hamburg (DE) |
| 139 | 131 | 365 | Ringsted (DK) | Articulated truck | Esbjerg (DK) | Articulated truck | Terneuzen (NL) | Articulated truck | Ghent (BE) |
| 140 | 131 | 91 | Brøndby (DK) | Light truck | Køge (DK) | Articulated truck | Hamburg (DE) | Truck 18-26t | Hamburg (DE) |
| 141 | 131 | 111 | Midtlolland (DK) | Truck 12-18t | Rødby Havn (DK) | Articulated truck | Kiel (DE) | Truck 12-18t | Rendsburg-Eckernforde (DE) |
| 142 | 131 | 63 | Ostholstein (DE) | Truck 3.5-12t | Lübeck (DE) | Articulated truck | Fredericia (DK) | Truck 3.5-12t | Haderslev (DK) |
| 143 | 131 | 121 | Ringsted (DK) | Truck 12-18t | Esbjerg (DK) | Articulated truck | Amsterdam (NL) | Truck 12-18t | Utrecht (NL) |
| 144 | 131 | 179 | Vesterbro (DK) | Light truck | Copenhagen (DK) | Articulated truck | Duisburg (DE) | Truck/trailer 12-18t | Borken (DE) |
| 145 | 131 | 46 | Kastrup Lufthavn (DK) | Light truck | Køge (DK) | Articulated truck | Hannover-Linden (DE) | Truck 18-26t | Hannover (DE) |
| 146 | 131 | 54 | Køge (DK) | Truck 3.5-12t | Køge (DK) | Articulated truck | Dörpen (DE) | Truck 3.5-12t | Overig Groningen (NL) |
| 147 | 151 | 8261 | Göteborg (SE) | Articulated truck | Kungsbacka (SE) | Articulated truck | Coevorden (NL) | Articulated truck | Veluwe (NL) |
| 148 | 171 | 8255 | Borken (DE) | Articulated truck | Duisburg (DE) | Short train | Sävenäs (SE) | Articulated truck | Göteborg (SE) |
| 149 | 171 | 2429 | Malmö (SE) | Articulated truck | Malmö (SE) | Conventional train | Rotterdam (NL) | Articulated truck | Utrecht (NL) |
| 150 | 181 | 873999 | Hamburg (DE) | Articulated truck | Hamburg (DE) | Conventional ship | Helsingborg (SE) | Articulated truck | Helsingborg (SE) |
| 151 | 191 | 48099 | Ghent (BE) | Articulated truck | Antwerp (BE) | Ro-Ro ship | Göteborg (SE) | Articulated truck | Uddevalla (SE) |
| 152 | 191 | 16222 | Cloppenburg (DE) | Articulated truck | Bremen (DE) | Ro-Ro ship | Oslo (NO) | Articulated truck | Akershus (NO) |
| 153 | 191 | 10146 | Borken (DE) | Articulated truck | Lübeck (DE) | Ro-Ro ship | Helsingborg (SE) | Articulated truck | Glostrup (DK) |
| 154 | 191 | 7426 | Ghent (BE) | Articulated truck | Ghent (BE) | Ro-Ro ship | Tønsberg (NO) | Articulated truck | Akershus (NO) |
| 155 | 191 | 2760 | Hamburg (DE) | Articulated truck | Hamburg (DE) | Ro-Ro ship | Göteborg (SE) | Articulated truck | Göteborg (SE) |
| 156 | 191 | 2568 | Utrecht (NL) | Articulated truck | Amsterdam (NL) | Ro-Ro ship | Esbjerg (DK) | Articulated truck | Kolding city (DK) |

The subject of this thesis is 'green corridors,' a European concept denoting a concentration of freight traffic between major hubs and by relatively long distances. The thesis has three objectives, all related to green corridors. The first one aims to develop a methodology for the quantitative monitoring of the performance of a green corridor in terms of pre-specified key performance indicators. It suggests a combined approach involving the use of a transport model for the construction of a sample of typical transport chains that forms the basis for the periodic performance assessment, followed by stakeholder refinement and verification. The second objective uses the decomposition approach to develop a simple and practical framework for classifying the carbon emission reduction measures that have been proposed for the shipping industry. The third one examines the impacts on modal split and emissions of designating the Mediterranean Sea as a Sulphur Emission Control Area, where stricter limits on the sulphur content of marine fuels apply.

COVER PHOTO: COLOURBOX

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