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The Coordinator of the project consortium via a return email has approved the final version of this SuperGreen Deliverable.

DISCLAIMER

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Executive Summary

The purpose of the SuperGreen project[1] is to support the European Commission (EC) in defining and benchmarking green corridors throughout Europe against their current performance (baseline) and their greening potential with respect to technical, environmental, economic, and social aspects.

SuperGreen is the acronym for the project "Supporting EU's Freight Transport Logistics Action Plan on Green Corridors Issues", supported by the EC under THEME [7]: Transport (including Aeronautics) of the 7th Framework Programme. The support is given under Grant Agreement No. TREN/FP7TR/233573/"SUPERGREEN". The project consortium is comprised of 22 partners from 13 EU countries, including transport operators, shippers, research and development institutions, academia, consultants, and authorities for social and spatial planning. The project was kicked-off in January 2010 and ends in January 2013.

The 3rd work package (WP3) of the project aims at identifying, selecting and benchmarking Green Technologies to be applied to the Green Corridors, in order to improve the baseline performance and solve bottlenecks. The WP3 tasks are:

- Task 3.1: *Identify Green Technologies* [Recagno et al., 2012]. This task is dedicated to the collection of information on technologies that are suitable for improving the sustainability footprint of the corridors, the so-called *green technologies*. All transport modes apart from air (maritime, inland waterways, road, rail) and various technology categories are covered[2].
- Task 3.2: *Define Application Areas for Green Technologies* [Recagno et al., 2012]. In this task, the application areas of the green technologies over the corridors are investigated.
- Task 3.3: *Benchmark Green Corridors with Green Technologies*. This activity is dedicated to the comparative evaluation of the effects that green technologies could have on the current corridor performance. The effects are analysed with respect to a set of Key Performance Indicators (KPIs) related to transport cost, CO_2 and NOx emissions, average transport speed, frequency and reliability of service. The task is decomposed into two phases: (a). the baseline preparation, i.e. the analysis of current corridor performance by conventional technologies, and (b). the benchmark creation, i.e. the evaluation of green technology impacts with respect to the baseline. The first phase was completed in 2011 and the results were presented in [Georgopoulou et al., 2011].

This report presents the results of the second phase of Task 3.3 for the benchmark creation. This work is based on:

- The SuperGreen corridors of Task 2.1[Salanne et al, 2010] (WP2);
- The corridor Key Performance Indicators of Task 2.2 [Paalsson, 2010] (WP2);

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[1] http://www.supergreenproject.eu/

[2] The technology categories are: engine and propulsion systems, fuels and sources of energy, navigation technologies, cargo handling systems, heating and cooling technologies, vehicles (road and rail vehicles, and waterborne vessels), best practices, and innovative units with their treatment.

- The baseline corridor benchmark of Task 2.4 [Ilves, 2010] (WP2);
- The green technology database of Task 3.1 [Recagno et al., 2012] (WP3);
- The baseline description of Task 3.3 [Georgopoulou et al., 2011] (WP3);
- Research work on environmental friendly technologies, including private research bodies and EC-funded projects;
- Published success case stories on green technologies and publications from manufacturers;
- Survey on the green technology performance within the SuperGreen consortium.

A stepwise methodology is followed. In the first step, the KPIs are analysed into factors, in order to create a mapping between the green technologies and the KPIs. The factors were selected according to data availability on the performance of the green technologies. In the second step, the performance of the green technologies is analysed independently of the application area with respect to the factors of the KPIs. In the third step, the greening impacts are assessed with respect to the current corridor performance for selected baseline case studies. The case studies were selected according to the following criteria:

- Coverage of all corridors analysed in Task 2.4;
- Assessment of at least one technology per technology category;
- Comparison of different technologies on the same corridor;
- Assessment of technologies on different possible applications (transport mode or corridor);
- Availability of information.

The study results in a set of green technologies, techniques and procedures that could be applied to the corridors, both over the different transport legs and at transhipment points, accompanied by estimates on their greening potential. An outlook of multi-modal technologies is created, showing the green technology potential benefits and drawbacks. The deficiencies of the approach are discussed and suggestions for future research on the greening of corridors with advanced technologies are given.

1. Introduction

1.1 Purpose of work

In the framework of the Freight Transport Logistics Action Plan for European freight transport operations[3] [EC, 2007], the European Commission introduced the *green corridor* concept for long distance transport networks. According to [EC, 2007], "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 and on advanced technology in order to accommodate rising traffic volumes, while promoting environmental sustainability and energy efficiency… Green corridors could be used to experiment with environmentally-friendly, innovative transport units, and with advanced Intelligent Transport Systems (ITS) applications". Green corridors aim at reducing the environmental and climate impact and increase safety and efficiency [Tetraplan, 2011].

The SuperGreen project[4] aims to support the European Commission (EC) in defining and benchmarking green corridors throughout Europe with regards to the current conditions and their greening potential. This effort forms the initial steps and methodologies towards the assessment of European transport corridors, [Psaraftis and Panagakos, 2012], [Fozza and Recagno, 2012], [Clausen et al, 2012]. The project consortium is comprised of 22 partners from 13 EU countries, including shippers, transport operators, academia, research and development institutions, consultancy bodies, and social and spatial planning authorities. The project was kicked-off in January 2010 and has a duration of three years. The project work packages (WP) are:

- WP1 Management;
- WP2 Benchmarking Green Corridors;
- WP3 Sustainable Green Technologies & Innovations;
- WP4 Smart Exploitation of ICT-flows;
- WP5 Recommendation for R&D Calls;
- WP6 Policy Implications;
- WP7 Dissemination and Awareness Rising.

WP3 aims at identifying, selecting and benchmarking Green Technologies, to be applied into specific Green Corridors while solving bottlenecks to their effective operation. The WP3 tasks are:

- Task 3.1: *Identify Green Technologies* [Recagno et al., 2012]. This task is dedicated to the identification of Green Technologies, i.e. technologies that were considered suitable (during the analysis of technologies in WP3) for improving the corridors' performance with regards to energy efficiency, emissions reduction, service quality and reliability. All transport modes apart from air (maritime, inland waterways,

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[3] http://ec.europa.eu/transport/logistics/freight_logistics_action_plan/action_plan_en.htm

[4] http://www.supergreenproject.eu/

road, rail) and various technology categories are covered. The task started in January 2010 and has a duration of three years.

- Task 3.2: *Define Application Areas for Green Technologies*. In this task, a Technology vs. Application matrix is created, which gives the primary indications about the possible application of each green technology to the corridors. The task started in January 2010 and has a duration of three years.
- Task 3.3: *Benchmark Green Corridors with Green Technologies*. This is the final activity within WP3, dedicated to the comparative evaluation of the effects that green technologies could have on the current corridor performance (baseline). The effects are analysed with respect to a set of Key Performance Indicators (KPIs) related to transport cost, CO_2 and SOx emissions, average transport speed, frequency and reliability of service. The task started in January 2011 and has a duration of two years. The task is decomposed into two phases: (a). the baseline preparation, i.e. the description of the current corridor conditions (year 1: 1/2011-1/2012), and (b). the benchmark creation, i.e. the evaluation of the green technology impacts with respect to the baseline (year 2: 1/2012-1/2013). The first phase ended in 2011 and the results can be found in [Georgopoulou et al., 2011].

The purpose of this report is to present the results of the second phase of Task 3.3 on the benchmarking of the SuperGreen corridors with green technologies. The objective is to describe the applicability of multi-modal green technologies over the corridors and estimates their greening potential. The participants to this task are: Det Norske Veritas, Marintek and D'Appolonia. Support was provided from the following partners: National Technical University of Athens, NewRail University of Newcastle, Finnish Maritime Administration, DB Schenker, SNCF Fret Italia and VR Group.

The structure of the document is as follows: Section 1 closes with the description of the Task 3.3 connections to other SuperGreen WPs and Tasks (paragraph 1.2). In Section 2, the benchmarking methodology is presented. Sections 3 and 4 are dedicated to the benchmarking phases, namely the high-level and the detailed benchmark. Section 5 analyses a selection of important green technologies for multi-modal applications. Finally, section 6 presents the conclusions of this study.

1.2 Connection with other work packages

As shown in Figure 1, Task 3.3 is connected with the following WPs:

- Work package 2: Benchmarking green corridors
    - Task 2.1: Selection of corridors;
    - Task 2.2: Definition of benchmark indicators and methodology;
    - Task 2.4: Benchmarking of green corridors;
- Work package 3: Sustainable green technologies and innovations
    - Task 3.1: Identify green technologies;
    - Task 3.2: Define application areas for green technologies.

In Task 2.1, a set of 9 European corridors was formed (Figure 2). The corridors included established and under development transport segments and nodes across the EU countries [Salanne et al, 2010]. All modes of transport apart from air were considered.

In Task 2.2, the corridor KPIs were defined [Paalsson, 2010]:

- Relative cost [€/tn.km],
- Average speed [km/hr],
- Reliability [%],
- Frequency [no/year],
- CO_2 [gr/tn.km], and
- SOx [gr/tn.km].

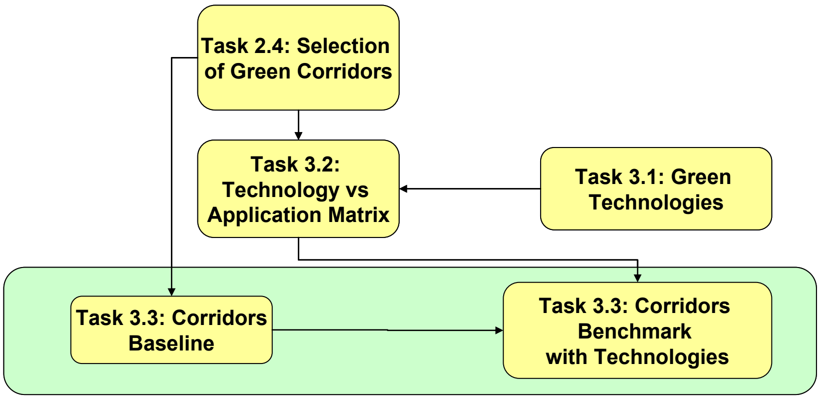

Figure 1 Connection of Task 3.3 with other SuperGreen tasks.

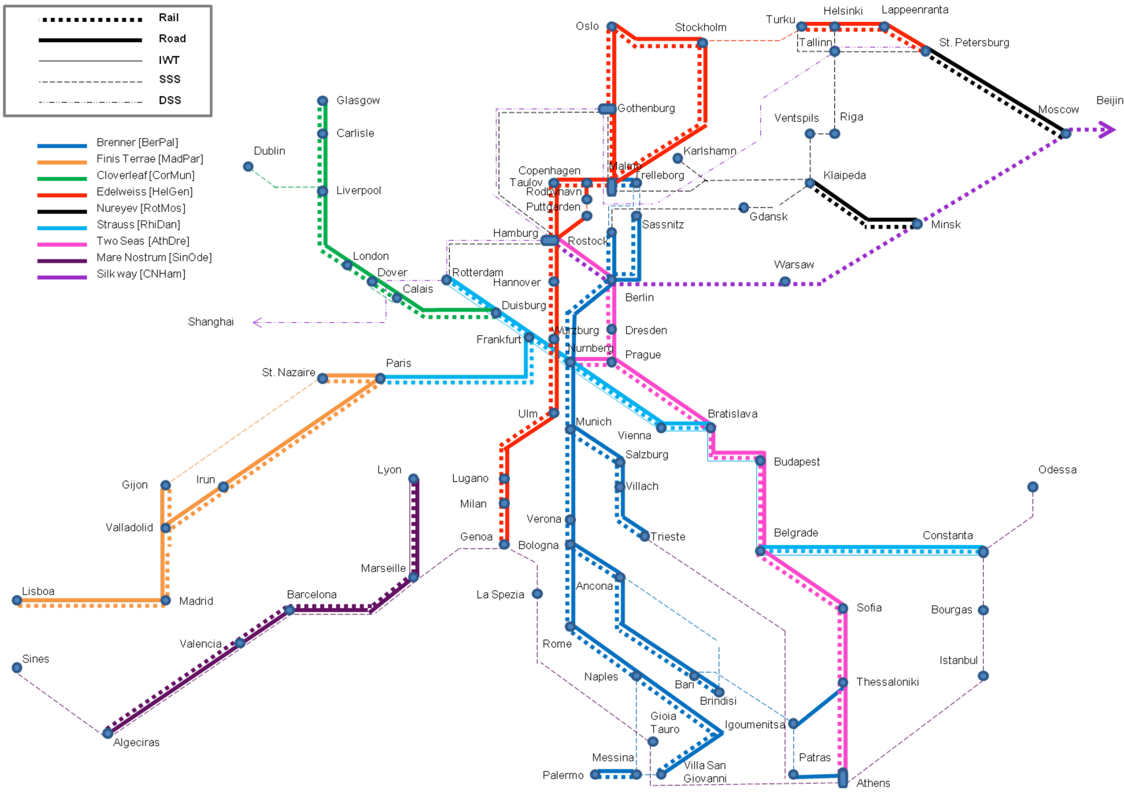

Figure 2 The SuperGreen corridor network.

From a policy perspective, it is important to mention that there is a certain consistency of the SuperGreen corridors (established in 2010) with the Trans-European Transport

Network (TEN-T) core network to be completed by 2030. The figure below presents the TEN-T core network including the core network corridors[5].

Figure 3 TEN-T core network including the core network corridors.

In Task 2.4, the current performance for the 6 of the 9 SuperGreen corridors was evaluated with respect to the KPIs. No corridor benchmarking study was identified in the literature [Psaraftis and Panagakos, 2012]. The SuperGreen methodology was based on previous work for the benchmarking of transport chains, such as the one developed in the EC-funded BE LOGIC project [Kramer et al., 2009]. In this work, the corridors were decomposed into transport chains, based on a survey on various transport operators across Europe. The transport chain performance was evaluated using the KPIs and the results were aggregated at the corridor level, expressing the corridor performance in ranges of values according to the minimum and maximum transport chain results. The baseline benchmark is shown in Table 1[Ilves, 2010].

Table 1 SuperGreen corridor baseline performance. Source: [Ilves, 2010].

Corridor name	**Mode of transport**	**CO2** *(g/tkm)*	**SOx** *(g/tkm)*	**Cost** *(€/tkm)*	**Average speed** *(km/h)*	**Reliability** *%*	**Frequency** *x times/year*
Brenner	*Intermodal*	**10.62-42.11**	**0.020-0.140**	**0.03-0.09**	**9-41**	**95-99**	**26-624**
	Road	**46.51-71.86**	**0.050-0.080**	**0.05-0.06**	**19-40**	**25-99**	**52-2600**
	Rail	**9.49-17.61**	**0.040-0.090**	**0.05-0.80**	**44-98**	**60-95**	**208-572**
	SSS	**16.99**	**0.050-0.120**	**0.04-0.05**	**23**	**100**	**52-520**
Cloverleaf	*Road*	**68.81**	**0.091**	**0.06**	**40-60**	**80-90**	**4680**
	Rail	**13.14-18.46**	**0.014-0.021**	**0.05-0.09**	**45-65**	**90-98**	**156-364**
Nureyev	*Intermodal*	**13.43-33.36**	**0.030-0.150**	**0.10-0.18**	**13-42**	**80-90**	**156-360**
	SSS	**5.65-15.60**	**0.070-0.140**	**0.05-0.06**	**15-28**	**90-99**	**52-360**
Strauss	*IWT*	**9.86-22.80**	**0.013-0.031**	**0.02-0.44**	-	-	-
Mare Nostrum	*SSS*	**6.44-27.26**	**0.092-0.400**	**0.003-0.200**	**17**	**90-95**	**52-416**
	DSS	**15.22**	**0.22**	-	-	-	-
Silk Way	*Rail*	**41.00**	-	**0.05**	**26**	-	-
	DSS	**12.50**	-	**0.004**	**20-23**	-	-

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[5] http://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/site/maps_upload/tent_core_network1920_1200.pdf

In Task 3.1, a collection of information on approximately 200 green technologies was achieved [Fozza and Recagno, 2012]. The technology categories were: engine and propulsion systems, fuels and sources of energy, navigation technologies, cargo handling systems, heating and cooling technologies, vehicles (road and rail vehicles, and waterborne vessels), best practices, and innovative units with their treatment. The technologies were, then, analysed according to their importance for the corridor greening.

In Task 3.2, a matrix indicating the application areas of green technologies along the SuperGreen corridors was created. The final results for this matrix will be stored in a web-based tool. Table 2 presents a part of the matrix.

Task 3.3 is connected to the afore-presented tasks:

- The baseline description is based on Tasks 2.1 and 2.4.
- The baseline performance is derived from Task 2.4.
- The KPIs are derived from Tasks 2.2 and 2.4.
- The benchmark is applied on the technologies marked as *very important* (rate A) and *important* (rate B) in the final round of the Task 3.1 analysis (63 technologies). According to the first Task 3.3 phase, the green technologies that already appear in the baseline are excluded from the benchmark. These are: EN02, EN03, EN07 and NA02[6]. Despite the fact that Global Navigation Satellite Systems (NA07) were described as a baseline technology, they are included in this study to solve bottlenecks at specific regions (Cloverleaf road segments at the Birmingham area). As a result, the following 59 technologies are considered[7]: EN11, EN16, EN18, EN21, EN24, EN06, EN39, EN48, EN51, EN61, FU02, FU03, FU08, FU18, FU05, FU06, FU13, FU25, FU26, HT01, HT03, HT07, HT08, HT09, HT10, HT06, HT11, HT20, HT28, HT36, HC02, HC03, HC04, VE02, VE03, VE09, VE10, VE01, VE22, VE25, VE29, VE33, NA15, NA01, NA05, NA12, NA13, NA14, NA16, NA17, NA18, BP04, BP07, BP02, BP03, BP08, BP13, LU13 and LU14. The full technology names can be found in Table 4 of Section 3. Figure 4 presents a categorisation of these technologies by means of the transport mode and the technology category.

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[6] EN02: Directly driven propeller, EN03: Mechanically connected propeller, EN07: Diesel-mechanic propulsion with high speed engine and NA02: Automatic Identification System (AIS).

[7] Herein, only the acronyms are given.

Table 2 Task 3.2: Technology versus Application matrix - Part of the matrix for the Strauss corridor. The annotation X corresponds to technology applicability at the specific transport mode and segment.

				Inland water ways		Rail		Road	
Cate gory	ID	Technology Name	Transport Mode	Rotterdam - Duisburg	Vienna-Bratislava	Belgrade-Constanta	Vienna-Bratislava	Nurnberg-Vienna	Rotterdam-Duisburg
Cargo Handling	HT32	River-Sea Push Barge System	Inland Waterways	X	X				
	HT33	Combined Traffic Carrier Ship/Barge (CTCB)	Maritime						
	HT34	Intermodal loading unit	Multimodal	X	X	X	X	X	X
	HT36	FlexiWaggon	Railway			X	X		
Cargo Preparation	CP01	Cardboard pallets	Multimodal					X	X
	CP02	Modularized Boxes	Multimodal	X	X	X	X	X	X
Innovative units and treatment	LU05	2,5 wide container	Multimodal	X	X	X	X	X	X
Vehicles	VE20	River-Sea Push Barge System	Inland Waterways	X	X				
	VE22	Road-rail cargo interchange	Railway			X	X		
	VE31	Innovative bogie	Railway			X	X		

The combination of green technologies with corridor segments and nodes is based on the results of Task 3.2, as well as the solution of bottlenecks and the improvement of current performance.

Figure 4 Green technology categorisation: transport mode (left) and category (right).

2. Methodology

The benchmarking of green corridors with green technologies is performed in three steps.

2.1 Step 1: KPI factorisation

In the first step, the SuperGreen KPIs are analysed into factors which influence the values of the KPIs. As an example, the KPI related to cost covers aspects like the fuel costs, the efficiency of logistics activities, the influence of regulation on the transport operations (e.g. taxes), etc. The KPI factors are selected in such a way that they relate to efficiency benefits of the technologies, such as fuel savings, reduction of emissions, increase in service speed, delays mitigation, etc. Therefore, the factors form an interface between the specifications of the green technologies and the KPIs. Table 3 presents the adopted KPI factorization; a denser factorization would be feasible depending on data availability.

A first factorisation has been made in the context of Task 3.1, including the collection of data for the technology effects on the KPI factors. The initial effort to collection information was defined in the framework of a WP3 workshop, which was held in Genoa at the premises of D'Appolonia (12-13 October 2011). There, it was decided that an initial round of data gathering would initiate in the framework of Tasks 3.1 and 3.2, to collect literature sources and informative material for the effect of the technologies on the KPIs. This effort resulted in a list of documents, reports, articles and web-sites for each green technology, which were reviewed and compiled by the Task 3.3 partners. Based on the gathered information and a series of internal Task 3.3 meetings, a list of KPI factors and a data set for the technology impact were identified. The collected material was used to develop an initial version of the high-level benchmark and a set of demonstration cases for the detailed benchmark. These were presented to the WP3 and WP4 partners, in the framework of a Joint WP3 and WP4 meeting, which was hosted by NTUA (26 June 2012). The meeting provided with valuable feedback that led to the finalisation of the methodology and the KPI factorisation (Table 3). Based on the identified KPI factors, the high-level benchmark data collection was finalised by the Task 3.3 partners, by performing data reviews and communicating with technology experts within the SuperGreen consortium. The collected material was uploaded in the web-based SuperGreen Knowledge Base and used to provide with "default values" for the technology influence on the KPIs.

In September 2012, the SuperGreen partners were asked by the Task 3.2 leader to provide feedback regarding this material, in the framework of a web-based questionnaire. The partners' replies (some received by e-mails) were considered to update the benchmark.

The list of factors is not exhaustive and even more ones could be used. However, the selection of factors depends on the availability of information and the resolution of the analysis. Herein, the selected factors were the ones that could be determined for most of the case studies. Also, there are cases that the technology effect on certain factors is not easy to determine, or there is lot of uncertainty relevant to it. In these cases, the KPI factor effects are not analysed. Hence a more detailed factorisation could be used for detailed corridor/technology assessment analyses.

Uncertainty relevant to the calculation of the baseline KPIs may also affect the results of the benchmark case. Therefore, in future benchmarking studies, well-defined baseline conditions and KPIs need to be carefully considered. In this study, the high-level benchmark technology effects have been determined irrespective of the baseline SuperGreen corridor performance KPIs. However, the detailed benchmark analysis depends on the baseline calculations of Task 2.4.

Finally, it is noted that the SuperGreen KPIs (Tasks 2.2 and 2.4) differ from the KPI factors. The SuperGreen KPIs have been used in Task 2.4 to evaluate the performance of the corridors. The KPI factors are used herein to link the corridor performance (KPIs of the corridors) with the green technology specifications.

Table 3 Mapping between the SuperGreen KPIs, the KPI factors and the green technologies specifications. It has to be noted that the SuperGreen KPIs (left column) have been used in Task 2.4 to evaluate the performance of the corridors. The column in the middle presents the list of KPI factors, which are used to link the green technology performance with the performance of the corridors.

SuperGreen KPIs (Tasks 2.2 & 2.4)	**KPI factors**	**Green technology specifications**
Relative cost	Fuel cost; General costs;	Savings in fuel consumption; Savings in taxes or consumption of resources (e.g. use of chemicals)
CO_2 emissions	CO_2 emissions caused during the operation of the vehicles. (The effort is to collect information on both Tank-to-Wheel (TTW) and Well-to-Wheel (WTW) emissions.)	Reduction of CO_2 emissions
SOx emissions	SOx emissions caused by the vehicles used. (The effort is to collect information on both Tank-to-Wheel (TTW) and Well-to-Wheel (WTW) emissions.)	Reduction of SOx emissions
Average speed	Delays reduction potential.	Decrease in loading/unloading times; Mitigation of problems that cause delays (e.g. weather)
Frequency of service	Potential increase in frequency.	Decrease in loading/unloading times;

	(possibility to increase frequency, as a result of delays reduction)	Mitigation of problems that cause delays (e.g. weather)
Reliability & solution of bottlenecks	Reliability improvement.	Mitigation of problems that cause delays (e.g. because of bad weather)

2.2 Step 2: Non-corridor specific benchmarking

In the second step, a high-level benchmark is generated, where the green technology impacts on the KPI factors are estimated and compared against a conventional technology or practice, irrespective of their application area/corridor.

The benchmark is presented in the form of a matrix, which includes the technology effects, the capital cost[8] and the baseline description. Depending on the availability of information, the technology evaluation is either qualitative or quantitative. More elaborated presentation of the high-level benchmark is given in section 3.

2.3 Step 3: Corridor specific benchmarking

The third step is dedicated to the estimation of the green technology effects on the current corridor performance, the so-called detailed benchmark. The analysis is applied on a number of cases derived from Task 2.4 [Ilves, 2010]. Each case is a combination of a green technology and a set of corridor segments and nodes. The scope is to mitigate bottlenecks and improve the baseline performance. The cases are selected according to the following criteria:

- the results of Task 3.2 (application areas of green technologies);
- the solution of targeted bottlenecks;
- the availability of information;
- technology maturity[9], apart from some exemptions.

The baseline analysis provides information on transport features like the loading factor, the duration of the trip, the loading and unloading times, etc. This information helps the evaluation of the KPI factors as percentages of the KPIs, e.g. the percentage of fuel cost to the overall cost. Following trivial algebraic calculations, the green technologies influence on the KPIs is estimated. The detailed benchmarking is presented in section 4.

3 High-level benchmarking

3.1 Description and literature resources

The high-level benchmark extends to all modes of transport and multi-modal applications. The analysis incorporates estimations produced through a process of internal SuperGreen interviews, assessments, and industry and academic works. For example, in [Eide et al.,

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[8] Not for all cases, due to lack of data.

[9] In the study of [Acciaro et al., 2012], a survey on freight transport operators shows that hardware solutions and immature technologies are generally more difficult to adopt.

2011], a study on the potential cost-effective reduction of CO_2 emissions by 2030 with the introduction of new technologies in the shipping industry was presented. The study was based on a future global fleet projection up to 2030 and the production of marginal abatement cost curves (MACC), which relate the price of a ton of CO_2 averted to the amount of emissions reduction that take place at this price. In [NESCCAF, 2009], a study on technologies that improve the efficiency and environmental performance of road transport was presented. This study analysed existing and emerging technologies that could be used for the improvement of energy efficiency and the reduction of CO_2 emissions from heavy-duty long-haul trucks in the United States from 2012 to 2017. Information on innovative energy efficiency solutions for railways was collected by means of communication with the EC-funded project RailEnergy[3]. Information on energy efficiency measures for inland waterways was gathered via the EC action program NAIADES[4].

3.2 Analysis of the results

The high-level benchmark for the 58 green technologies, which were screened out as important in Task 3.1, is shown in the Table 4 to Table 11. The Tables summarise the expected impact on the KPI factors for Cost, Emissions (CO_2 and SOx), Frequency of service, Reliability and Average Speed. The different colours indicate positive (green), negative (red) and neutral (orange) impact of the technologies on the KPI factors. In the case of no information, the cell is coloured yellow. The information was gathered from literature review on the green technologies, as well as from internal SuperGreen consortium expertise.

Figure 5 summarises the influence of the technologies on the KPI factors. The horizontal axis shows the KPI factors and the vertical axis presents the percentage of green technologies that have positive, negative or neutral influence on the factors. An average positive influence of 35% on all KPI factors is estimated for all 59 technologies. The negative impact on the cost KPI factor is due to high capital cost (CAPEX) and/or operational costs (OPEX) (such as resources, maintenance, carrying capacity reduction, etc) from the introduction of new or immature technologies. The relative negative impact in the fuel costs and CO_2 emissions factors appears due to technologies like scrubbers, selective catalytic reduction, and biofuels. In general, the capital cost influence was considered in a qualitative manner and depending on the availability of information. A better approach would consider the quantitative influence of capital cost on the revenues from the use of the technology. The average percentage of unknown impact is around 24% and, therefore, the benchmark picture could change if more data on the technology performance could become available. The average positive quantitative benchmarking is 39%. As shown in Figure 6, it is much easier to find quantitative information on cost and fuel savings and emissions reduction than for service quality.

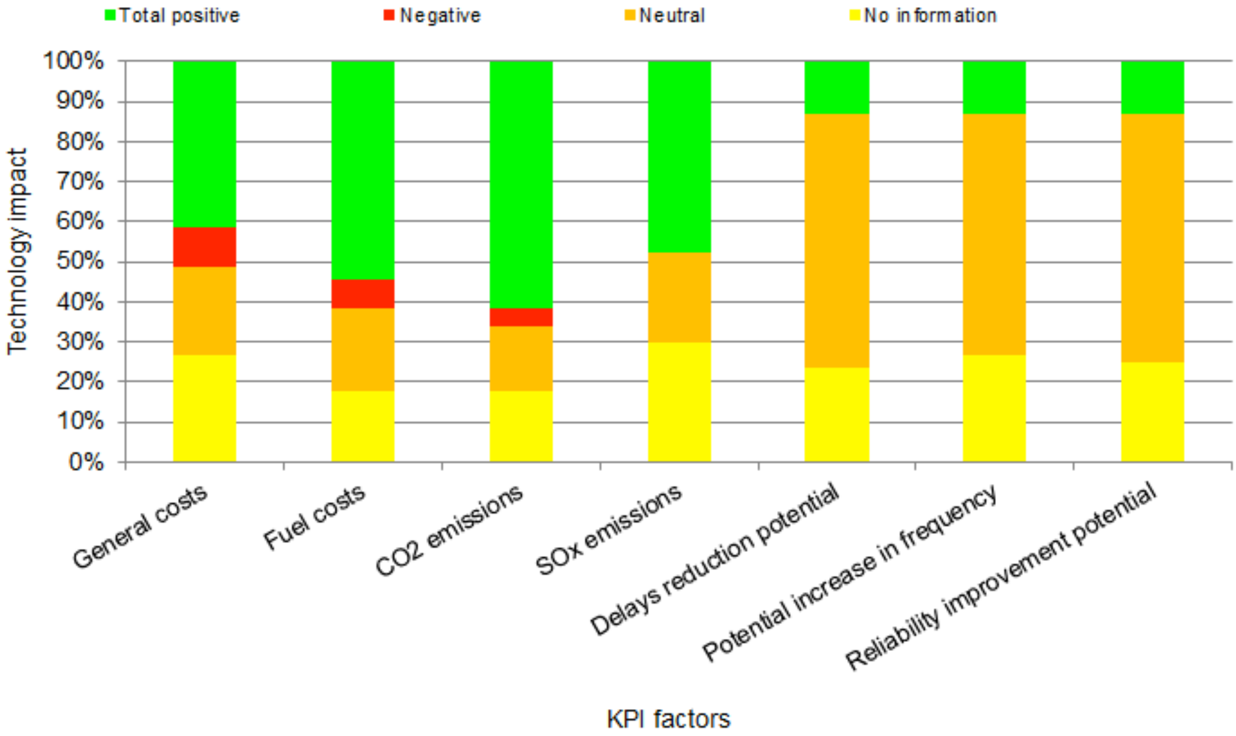

Figure 5 Estimated impacts of the green technologies on the KPI factors. The horizontal axis shows the KPI factors. The vertical axis shows the percentage of technologies (number of technologies per total technology number) with positive (green), negative (red), neutral/not relevant (orange) impact on the factors, and no information (yellow).

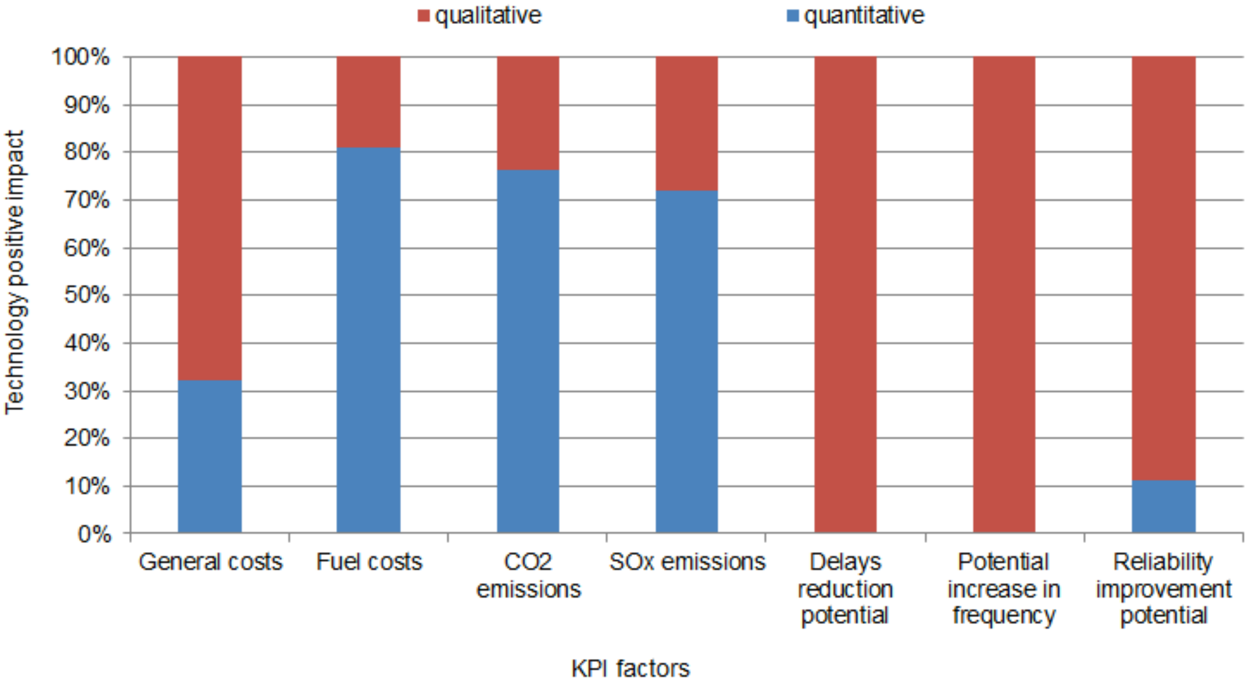

Figure 6 Green technology positive impact per KPI factor. The vertical axis shows the high-level benchmark information that corresponds to positive technology effects, analysed with respect to quantitative (blue) or qualitative (red) format. This means that we calculate the number of green technologies that give a positive effect per factor with qualitative or quantitative format per total number of green technologies with positive effect (per factor), respectively.

Table 4 Engine & propulsion systems. High-level benchmarking results- KPI factors.

🟩	Positive impact
🟥	Negative impact
🟧	Not relevant
🟨	No information

					KPI factors						
					Relative Cost		Emissions		Service & bottlenecks		
ID	Technology Name	Transport Mode	Description	Baseline technology	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
EN11	Dual fuel engine	Maritime	Medium speed engine using LNG (Liquefied Natural Gas) as primary fuel and HFO (Heavy Fuel Oil) or MDO (Marine Diesel Oil) as pilot fuel. 20 year life time, running 5500 h/a. Environmental savings assumes LNG operation mode.	Conventional diesel engine	🟩 OpeX currently positive but depends on price difference between gas and oil	🟩	🟩 10-20%	🟩 90-99%	🟧	🟧	🟧
EN16	Full/parallel hybrid	Road	Electrical support of engine power by saving and re-use of break-energy; combination of 6 cylinder engine plus electrical engine.	Conventional diesel engine	🟨	🟩 0-35%	🟩 0-35%	🟩 0-35%	🟧	🟧	🟧
EN18	Fuel cell technology	Road	> 3,5 ton transporter running on renewable fuel cell technology.	No fuel cell	🟩 The efficiency of the fuel cell system will reduce drastically the energy bill (in the case of a mass production of fuel cells).	🟨	🟩 50%	🟩 100%	🟨	🟨	🟨
EN21	Exhaust Abatment System	Maritime – SOx scrubbers	Has the potential to reduce OPEX as it allows the vessel to sail on fuel with higher sulphur content than what is allowed, for example in SECAs. At the same time, the use of different fuels in different regions will be subject to stricter regulations in the near future.	No exhaust abatement system.	🟩 SOX scrubber: Has the potential to reduce OPEX as it allows the vessel to sail on fuel with higher sulphur content than what is allowed, for example in SECAs.	🟥 2 - 3%	🟥 2 - 3%	🟩 75-95%	🟧	🟧	🟧
		Maritime / Inland waterways – SCR	Selective-catalytic reduction (SCR) systems are based on urea injection on the flue gas and a catalytic reactor.		🟥 Increased CAPEX.	🟥 -2 to 🟩 5 %	🟥 -2 to 🟩 5 %	🟧	🟧	🟧	🟧
EN24	Improved Gas Engine	Road	Integrated approach using electronic valve motion management, enhanced cylinder head cooling, near-to-valve port fuel injection system, advanced integrated control.	Conventional diesel engine	🟨	🟨	🟨	🟨	🟨	🟨	🟨
EN06	Azimuthing thrusters	Maritime	Electric/hydraulic engine connected to azimuth thruster.	Mechanically connected propeller by reduction gear to	🟩 Potential lower Opex	🟩 0-20%	🟩 0-20%	🟩 0-20%	🟧	🟧	🟧

				the propeller shaft, thruster assisted	🟩	🟩	🟩	🟩	🟨	🟨	🟨
EN39	Gas engines	Maritime	Engines running on natural gas (different solutions available, pure gas engines, gas-diesel engines, dual fuel engines).	Traditional diesel engines	Opex currerntly positive but depends on price difference between gas and oil	🟧	15-25%	90-95%	🟨	🟨	🟨
EN48	CCNR III Engine	Inland Waterways	Still under negotiation.	CCNR II Engine	🟩	🟩	🟩	🟨	🟨	🟨	🟨
EN51	CCNR IV Engine	Inland Waterways	Still under negotiation.	CCNR III Engine	🟩	🟩	🟩	🟨	🟨	🟨	🟨
EN61	Counter rotating propeller	Maritime	Thrust system consisting of a pair of propellers behind each other which rotates in opposite directions, so that the aft propeller recovers some of the rotational energy in the slipstream from the forward propeller.	Single rotating propeller	Reduced Opex (depends on vessel type and operational profile)	5-15%	5-15%	5-15%	🟨	🟨	🟨

Table 5 Fuels & sources of energy. High-level benchmarking results- KPI factors.

🟩	Positive impact
🟥	Negative impact
🟧	Not relevant
🟨	No information

					KPI factors						
					Relative Cost		Emissions		Service & bottlenecks		
ID	Technology Name	Transport Mode	Description	Baseline technology	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
FU02	Ethanol and bio-diesel	Maritime	Alternative fuel.	Diesel 10 ppm	🟥	1-2% for biodiesel	Bioethanol: 70-85%, biodiesel 15-75%	Bioethanol: ~100%, biodiesel: 20-100%	🟧	🟧	🟧
		Road		Diesel 10 ppm	🟥	1-2% for biodiesel / road	Bioethanol: 70%, biodiesel 45%	Bioethanol: ~100%, biodiesel: 20-100%	🟧	🟧	🟧
FU03	CGN (compressed natural gas)	Multimodal	Cleaner fuel for yard handling equipment (Prime movers).	ULSD	Depending on the tax rates, emission taxes per country/region, future fuel prices	🟩	Road: 2-6%	90-95%	🟧	🟧	🟧
FU08	LNG	Multimodal	Liquefied natural gas.	ULSD	Depending on the tax rates, emission taxes per country/region, future fuel prices	up to 20%	Road: 2-6%, Maritime: 20-25%	90-100%	🟧	🟧	🟧
FU18	Biogas	Multimodal	Biogas is mainly produced from bio-waste, agricultural residues and residues from sewage treatment plants.	ULSD	🟧	40% cheaper from diesel	For WTW: 80-90% less than liquid fossil fuels	🟩	🟧	🟧	🟧
FU05	Alternative maritime power (AMP)	Maritime	Alternative Maritime Power is a shore-side power source that transforms the shore-side power voltage to match the vessel power system.	Ship based power generation in harbour	🟧	Tank-to-wheel: 100% when in harbour/port. Well-to-wheel: depends on the electricity source ashore..			🟧	🟧	🟧
FU06	Wind energy	Multimodal	Wind turbines which to terminals.		🟧	100%	100%	100%	🟧	🟧	🟧
		Inland Waterways		ULSD	🟧	100%	100%	100%	🟧	🟧	🟧
FU13	Electricity	Road	Electricity is today produced from fossil fuels, nuclear energy and renewable energy sources	Diesel	🟧	🟧	100% on site emissions reduction. However, WTT emissions depend on the energy mix of the country. If the source is renewables, then the footprint is positive.		🟧	🟧	🟧

		Railway					100% on site emissions reduction. However, WTT emissions depend on the energy mix of the country. If the source is renewables, then the footprint is positive.				
FU25	Sky sails system	Maritime	It uses large towing kites for the propulsion of the ship. The tractive forces are transmitted to the ship via a highly tear proof, synthetic rope.	No sky-sails	5-20% on Opex	5-20%	5-20%	5-20%			
FU26	Waste heat recovery system	Maritime	It passes exhaust gases from the ship's main engine through a heat exchanger to generate steam for a turbine driven generator the electrical power generated assists ship propulsion or supplies shipboard services.	Vessels without steam driven turbine generator (ocean going vessels with installed power exceeding 20 MW)		4-8%, large container vessels up to 10%	4-8%, large container vessels up to 10%	4-8%, large container vessels up to 10%			

Table 6 Cargo handling systems. High-level benchmarking results- KPI factors.

🟩	Positive impact
🟥	Negative impact
🟧	Not relevant
🟨	No information

					KPI factors						
					Relative Cost		Emissions		Service & bottlenecks		
ID	Technology Name	Transport Mode	Description	Baseline technology	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
HT01	Diesel to electric power convertor (RTGs)	Multimodal	RTGs fitted with electrical components in place of traditional hydraulic parts. Conversion will eliminate black emissions and lower noise levels of engines.		🟩 Reduced maintenance costs by 70%	🟩 95%	🟩	🟩	🟧	🟧	🟧
HT03	Hybrid hydraulic drive Terminal tractors	Maritime	Storing braking energy into hydraulic system for acceleration and system.	No braking energy recovery systems	🟧	🟩 20%	🟩 20%	🟩 20%	🟧	🟨	🟨
HT07	Low emission engines	Multimodal	Euro III/ IV compliant engines burn diesel more efficiently, reducing emission of CO_2 and providing up to 5% reduction on fuel consumption.	Euro II	🟩	🟩 5%	🟩	🟩	🟨	🟨	🟨
HT08	ZF transmission systems	Multimodal	Installation in the new PM (prime movers) of new transmission system operating based on Automatic-Manual transmission concept. Reduction of fuel consumption by 10% when compared with older existing transmission systems.		🟨	🟩 Road: 6% 10%	🟨	🟨	🟨	🟨	🟨
HT09	Green schemes to improve RTGs emissions and noise	Multimodal	Addition of a super-capacitor on RTGs. When RTGs engine is running, it charges the super capacity at the same time, and when super capacitor is fully charged, it will supply electricity to the cranes when it is hoisting a container.		🟨	🟩 Super-capacitors: 8-25%	🟩	🟩	🟨	🟨	🟧
HT10	Horizontal container (un)loading	Multimodal	Metrocargo is an innovative solution for containers cargo handling in overhead electrified railways. It is a container horizontal movement system from an automated platform to train wagons. This technology is ready to experimentation. Metrocargo will be tested on new Maersk's Platform in Vado Ligure (SV), Italy.	Traditional containers cargo handling	🟩	🟩	🟩	🟩	🟩	🟩	🟩 92,6% reliability
HT06	MP-RTGs	Multimodal	Mains-powered RTGs transfer the power generation from the engine of the yard crane to a far more efficient power station. Power	Traditional gantry cranes	🟩 Reduces equipment	🟩 30-40% more efficient	🟩	🟩	🟩	🟩	🟩

			station can be up to 40% more efficient than equipment engine.		🟩	🟩	🟩	🟩	🟩	🟩	🟩
HT11	Cargo Cassette and Translifter	Maritime	Wheel less cargo cassette is a loading platform which is used together with a translifter in a cassette system. Translifter is a steerable lifting trailer which together with cassettes replaces roll trailers in Ro-Ro and StoRo handling.	Traditional container cargo handling	(based on the assumption that techn. will lead to increased cargo through put)	🟧	🟧	🟧	Potential for faster ship turn around due to increased efficiency during loading and unloading operations	Possible to increase frequency, but highly dependent on operational conditions	potential positive effect
HT20	BEX	Inland Waterways	Barge Express is an integrated concept for transport for automated handling of large scale barge container at terminals.		🟩	🟩	🟩	🟩	🟩	🟩	🟩
HT28	Automatic RoRo cargo unit handling	Multimodal	The concept is based on self (un)loading of units using a roll-on/roll-off system with a special train of platform cars, called a train loader. The performance of a train loader is often limited by the operation of the stockpile and reclaim system and the capacity of the train loader surge bin. While both are separate systems, they operate in concert to achieve a given performance. Poorly designed reclaim systems, or insufficient train loader surge capacity can significantly downgrade train-loading performance.		🟨	🟨	🟨	🟨	🟨	🟨	🟨
HT36	FlexiWaggon	Railway	Flexiwaggon can combine lorries, buses, cars, containers on one and the same waggon. Individual loading and unloading of waggons. Loading and unloading is done horizontally which means no consideration is necessary for overhead contact lines. The emissions will be reduced by 75%, including carbon dioxide emissions. Strong decrease of the CO_2 emissions is estimated, because the transport is by rail and not by truck (the truck is on the train). The technology is still at conceptual level and no data are available.		🟨	🟨	75%	🟨	🟨	🟨	🟨

Table 7 Heating & cooling technologies. High-level benchmarking results- KPI factors.

🟩	Positive impact
🟥	Negative impact
🟧	Not relevant
🟨	No information

					KPI factors						
					Relative Cost		Emissions		Service & bottlenecks		
ID	Technology Name	Transport Mode	Description	Baseline technology	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
HC02	Intelligent temperature unit	Multimodal	Current refrigerated boxcars will be built with energy efficient cooling systems, GPS (Global Positioning System) tracking, fresh air exchange and the ability to remote monitoring the systems, sometimes from thousands of km away on a network. RFID (Radio Frequency Identification) for tracking services are the main support in management systems of perishable goods.	Traditional boxcars	🟧	🟧	🟧	🟧	🟧	🟧	🟩
		Road			🟧	🟧	🟧	🟧	🟧	🟧	🟩
		Inland Waterways		Traditional boxcars	🟧	🟧	🟧	🟧	🟧	🟧	🟩
		Maritime		Traditional boxcars	🟧	🟧	🟧	🟧	🟧	🟧	🟩
		Railway			🟧	🟧	🟧	🟧	🟧	🟧	🟩
HC03	Temperature control units	Road	CryoTech: Liquid CO_2 modules for temperature for multi temperature control (cooling/heating).		🟧	🟧	🟧	🟧	🟧	🟧	🟧
HC04	RFID tag antenna with temperature alarm sensor	Multimodal	RFID tag antenna with ultra-low cost temperature alarm sensors which is capable of detecting temperature violations above a critical temperature threshold.		🟩	🟧	🟧	🟧	🟧	🟧	🟧

Table 8 Vehicles. High-level benchmarking results: High-level benchmarking results- KPI factors.

🟩	Positive impact
🟥	Negative impact
🟧	Not relevant
🟨	No information

					KPI factors						
					Relative Cost		Emissions		Service & bottlenecks		
ID	Technology Name	Transport Mode	Description	Baseline technology	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
VE02	Electric Locomotive	Railway	NS 999 is an entirely electric locomotive that uses a lead-acid energy storage system without the use of a diesel engine and with zero exhaust emissions. The project's goal was to demonstrate the feasibility of a plug-in battery powered locomotive that would eliminate direct rail yard emissions and save up to 50,000 gallons of diesel fuel per year (Daimler public document, pag 5 and 12).		🟩 ~ 50	🟩 ~ 40-50	🟩 100	🟩 100	🟧	🟧	🟧
VE03	Hybrid Truck	Road	The M2e Hybrid Freightliner; Support engine plus auxiliary drive to operate an elevating platform of the truck; combination of 6 cylinder engine plus electrical engine	If the truck is during operation, then the baseline technology is a conventional diesel truck. If it is idle, the baseline technology to compare with is the fuel (diesel).	🟨	🟩 25-30%	🟩 25-30%	🟨	🟨	🟨	🟨
VE09	Electric vehicles	Road	Battery-electric vehicles	For truck in operation, the baseline technology is a conventional diesel truck. For idle status, the baseline technology to compare with is the fuel (diesel).	🟥 The battery physical physical dimensions are high.	🟩 100%	🟩 100%	🟨	🟨	🟨	🟨
VE10	Euro VI vehicles	Road	Euro VI is compulsory for new trucks from 2013, replacing Euro V. The EU target is the reduction of PM and NOx. Probably slight increase of CO_2 due to an increase of fuel consumption (2-3%).	Euro IV	🟧	🟥 increase of 2-3%	🟥 increase of 2-3%	🟧	🟧	🟧	🟧
VE01	Hybrid Locomotive	Railway	Technology to capture and store braking energy for later use, increasing power while reducing fuel use and emissions..	Conventional freight ocomotives without brake energy recovery and	🟩 ~ 15-20	🟩 15	🟩 50	🟨	🟧	🟧	🟧

				storage.							
VE22	Road-rail cargo interchange	Railway	The Flexiwagon rail project will allow containers to be moved by road and by train by loading trucks onto railcars.								
VE25	Brake energy recovery system	Railway	Reversible DC Substation for recovering of dynamic braking energy and restitution to national grid.								
VE29	Aerodynamic drag improvements	Road	Aerodynamic mirrors, cab side extenders, integrated cab roof fairings, aerodynamic front bumper, full fuel tank fairings, trailer side skirt fairings, trailer gap fairing, rear mounted trailer fairing.	Conventional diesel trucks	depending on operational patterns	10-26%	10-26%	10-26%			
VE33	Low rolling resistance tires	Road	Tires which are designed to minimize the energy wasted as heat as the tire rolls down the road	Conventional tires	depending on operational patterns	1.5-4.5%	1.5-4.5%	1.5-4.5%			
VE35	Electrification of Trucks on Highways	Road		Diesel trucks		up to 90% depending on traffic (per electrified lane)	Depending on the country's power mix: up to 90% in case of electricity originated from renewable energy sources	90%	rather slight increase	rather no bottleneck reduction	rather no improvements

Table 9 Navigation technologies. High-level benchmarking results: High-level benchmarking results- KPI factors.

🟩	Positive impact
🟥	Negative impact
🟧	Not relevant
🟨	No information

					KPI factors						
					Relative Cost		Emissions		Service & bottlenecks		
ID	Technology Name	Transport Mode	Description	Baseline technology	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
NA15	WiMax	Maritime	Worldwide Interoperability for Microwave Access. Long range, high bandwidth wireless Internet	No internet use	🟩 Potential cost saving through increased efficiency of document handling between ship-shore	🟧	🟧	🟧	🟩 Reduced probability of delays due to more efficient ship reporting/ document handling	🟩 Potential for increased vessel turn around time	🟩 Potential for reduced vessel waiting time outside port
		Road			🟨 depending on operational patterns	🟨	🟨	🟨	🟨	🟨	🟨
		Railway			🟨	🟨	🟨	🟨	🟨	🟨	🟨
NA01	Train Control System	Railway	Train control and tracking system based on a special GPRS method.		🟨	🟨	🟨	🟨	🟨	🟨	🟨
NA05	ECDIS	Maritime	An Electronic Chart Display and Information System (ECDIS) is a computer-based navigation information system that can be used as an alternative to paper nautical charts. Integrates position information from GPS and other navigational sensors (radar, AIS). It may also give Sailing Directions and fathometer.	Paper nautical charts	🟧	🟧	🟧	🟧	🟧	🟧	🟩 Major impact of ECDIS is removal of human error by only navigating on charts, also giving each vessel real time information of operational situation along route. I.e. safety at sea and in port!
NA12 (NA13 &	GEO satellites	Maritime	Geosynchronous Satellite whose orbital track on the Earth repeats regularly over points on the Earth over time. If such a	No use of GEO satellites	🟥 Increased Opex	🟧	🟧	🟧	🟩 Enables early warnings in	🟩	🟩

NA14 also included)			satellite's orbit lies over the equator and the orbit is circular, it is called a geostationary satellite. In terms of benchmarking, GEO, LEO and Inmarsat can be combined. Although representing different types of communication technology systems, all share the same objective of extending communication outside VHF/ WiMax coverage.		🟥	🟧	🟧	🟧	terms of route changes, ship-shore reporting at sea. Difficult to quantify	🟩	🟩
NA16	Route optimisation system (scheduling)	Inland Waterways	The advising Tempomaat (ATM) is a computer program advising the skipper on the most economical combination of route and speed, enabling the vessel to arrive on time with a most efficient use of fuel leading to a reduction of fuel consumption and emissions.	No route optimisation system	🟩	10%	10%	10%	🟩	🟩	🟩
		Maritime	Speed optimisation, weather routing, trim optimisation.		🟩	5-10%	🟩	🟩	🟩	🟩	🟩
NA17	River Information Services (RIS)	Inland Waterways	River Information Services (RIS) are customized information services for inland waterway transport and make it possible to coordinate logistical processes with actual transport situations on a constant basis. RIS play a key role in making cargo transport and passenger services on waterways more efficient leading to a reduction of fuel consumption by approximately 5 %, while at the same time increasing traffic safety .		🟩	5%	🟩	🟩	🟩	🟩	🟩
NA18	Predictive cruise control (PCC)	Road	The PCC assistance system uses map and satellite-based route previews and saves substantial amounts of fuel. Unlike a conventional cruise control system that tries to maintain a preset speed, regardless of how the terrain changes, the PCC system looks for its route a mile in advance and adjusts engine output to the uphill and downhill gradients ahead. Based on this information, the on-board computer calculates the optimum speed to use the momentum of the truck to maximize fuel economy.		depending on operational patterns	🟨	🟨	🟨	🟨	🟨	🟨

Table 10 Best practices, innovative units with their treatment and cargo preparation technologies. High-level benchmarking results- KPI factors.

🟩	Positive impact
🟥	Negative impact
🟧	Not relevant
🟨	No information

					KPI factors						
					Relative Cost		Emissions		Service & bottlenecks		
ID	Technology Name	Transport Mode	Description	Baseline technology	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
BP04	Traffic Flow Management	Railway	A system for online optimization of rail traffic flow to have minimum delays and minimum energy consumption, developed by Emkamatik on behalf of SBB. A reduction of the total consumption by about 5% seems to be realistic in the medium future in Switzerland. Focus on high network capacity at lowest energy consumption • Reduced network dimensions (for development) • Real train data • Demonstration software based on MATLAB • Core is a very fast train run simulation for speed and energy consumption versus location / time	No system for software-based traffic management	5%	20%	5%	🟨	🟧	🟧	🟧
BP07	Carbon-free rail freight transport	Railway	Use renewable sources to cover the electricity demand. DB Schenker Rail UK has outlined plans to introduce carbon-free rail freight services for trains hauled by electric locomotives, further improving the environmental credibility of rail freight. The energy generated by the turbines would be enough to power a 'green fleet' of DB Schenker Rail UK's Class 92 electric locomotives. The electricity would be sold to Network Rail for use in the overhead power cables.	Diesel locomotives and electric locomotives power by fossil fuel power production.	16%	20%	🟨	🟨	🟧	🟧	🟧
BP02	TDS	Railway	Train Control System based on a GPS application method. The basic idea of the train control system (TCS) is to leave the operational principle as it is, but the entire operation gets computer aided support by adding a radio data system for communication between trains and central train controller	No computer aided support with radio data system for communication between trains and central train controller .	20%	🟨	🟨	🟨	🟧	🟧	🟧
BP03	GEKKO	Railway	A system to provide guidance to energy efficiency driving and timetable optimization, developed for Danish State Railways. DSB (Danish State Railways) and SNCF (France) have trialled the device. GEKKO is a device that tells drivers if they are running in the correct schedule pathway. A GEKKO server contains all the necessary information about timetables, route and train characteristics. The driver carries a portable PDA device into which he enters the train number. The PDA then requests the timetable and route information from the server	No software guidance for scheduled route, timetables and train characteristics	10%	0%	15%	🟨	🟧	🟧	🟧

BP08	Integrated shortsea transport	Maritime	Integrated short sea transport and logistics concepts for the accommodation of large container feedering (e.g. the Coaster Express, CoEx concept) include designs of smart docking and automated transhipment port systems. According to [Lui et al., 2002], the automation of operation may provide an estimated increase in cargo throughput and service speed increase service of approximately 43%.	Short sea shipping/ feedering services	🟨	🟨	🟨	🟨	Faster service at port site.	🟩	🟩
BP13	EREX (ERESS)	Railway	The Erex system, has been designed by the European Railway Energy Saving Solution (ERESS), to help railways to save money and reduce CO_2 emissions by providing exact energy consumption data. It provides an efficient, reliable, and flexible energy settlement process, enabling railway undertakings to understand their use of energy and thereby save energy and costs. Erex has been configured with a virtual platform with almost unlimited capacity.	no application of the Best Practice	🟩	🟩	up to 15%	🟨	🟧	🟧	🟧
LU13	Braking energy recovery	Railway	Recovery of dynamic braking energy and restitution to national grid / Reversible DB Substation. In a conventional train engine, energy is dissipated as heat and lost to the atmosphere. But using the dynamic braking system developed by GE, that energy can capture and store This could mean 10% less CO2 emissions and 10% less diesel fuel than a standard locomotive in North America	Conventional train without brake energy recovery	🟨	7%-10% saving of traction energy	10%	🟨	🟧	🟧	🟧
LU14	Onboard energy storage systems	Railway	Supercapacitors, batteries, flywheels, hybrid storage: A flywheel is a mechanical device with a significant moment of inertia used as a storage device for rotational energy. Flywheel energy storage, or the rotational energy of a flywheel, and rechargeable electric traction batteries are also used as storage systems .Batteries are electrochemical energy storage systems. A supercapacitor is a tool offering very high electrical capacitance in a small package. A hybrid train is a locomotive, railcar or train that uses an onboard rechargeable energy storage system (RESS), placed between the power source (often a diesel engine prime mover) and the traction transmission system connected to the wheels. Up to 30% energy saving are measured in a prototype Bombardier's light rail vehicle. Up to 30% C02 emission reduction are measured in a prototype Bombardier's light rail vehicle.		🟨	up to 30% of saving of traction energy	%25-30	🟨	🟧	🟧	🟧
CP01	Cardboard pallets	Multimodal	Cardboard Pallets are ecological cargo preparation pallets, which are made of (completely) recycled materials. Because of their low weight, they have a very low contribution to the bill paid for moving of the cargo (which can give considerable airfreight savings).	Wood pallets.	🟩	🟩	🟧	🟧	🟧	🟧	🟧

Table 11 High-level benchmarking: General findings for CAPEX, bottlenecks mitigation and comments per technology.

Category	ID	Technology Name	CAPEX	Solution of problems	Comments
Engines & propulsion systems	EN11	Dual fuel engine	🟥 CAPEX approximately 10-20% more than baseline technology.	🟧	🟧
	EN16	Full/parallel hybrid	🟥 Small increase in CAPEX.	🟧	🟧
	EN18	Fuel cell technology	🟨	🟨	🟨
	EN21	Exhaust Abatement System	🟥 Increased CAPEX.	🟧	🟧
	EN24	Improved Gas Engine	🟨	🟨	🟨
	EN06	Azimuthing thrusters	🟥 Higher CAPEX.	🟧	🟧
	EN39	Gas engines	🟥 CAPEX approximately 10-20% more than baseline technology.	🟧	🟧
	EN48	CCNR III Engine	🟨	🟧	🟧
	EN51	CCNR IV Engine	🟨	🟧	🟧
	EN61	Counter rotating propeller	🟥 Higher CAPEX (depends on vessel type).	🟧	🟧
Fuels and energy sources	FU02	Ethanol and bio-diesel	🟧	🟧	🟥 Tendency for oxidation and long-term storage issues, deposition on fuel filters, risk of microbial growth
	FU03	CGN (compressed natural gas)	🟨	🟧	🟧
	FU08	LNG	🟨	🟧	🟧
	FU18	Biogas	🟨	🟧	🟧
	FU05	Alternative maritime power (AMP)	🟨	🟩 Reduces noise and local emissions at from vessels when in port.	🟧
	FU06	Wind energy	🟨	🟧	🟧
	FU13	Electricity	🟨	🟩 Noise reduction.	🟧
	FU25	Wind propulsion - sails	🟥 Higher CAPEX.	🟧	🟧
	FU26	Waste heat recovery system	🟨	🟧	🟧
Cargo handling systems	HT01	Diesel to electric power convertor (RTGs)	🟨	🟩 Safer operation , noise reduction	🟧
	HT03	Hybrid hydraulic drive Terminal tractors	🟨	🟨	🟨
	HT07	Low emission engines	🟨	🟧	🟧
	HT08	ZF transmission systems	🟨	🟧	🟧
	HT09	Green schemes to improve RTGs emissions and noise	🟨	🟩	🟧
	HT10	Horizontal container (un)loading	🟨	🟩	🟧
	HT06	MP-RTGs	🟨	🟩	🟧
	HT11	Cargo Cassette and Translifter	🟨	🟩 May contribute to alleviate vessel waiting time outside port.	🟧
	HT20	BEX	🟨	🟩	🟩 Port congestion.

Category	ID	Technology Name	CAPEX	Solution of problems	Comments
	HT28	Automatic RoRo cargo unit handling	🟨	🟨	🟨
	HT36	FlexiWaggon	🟨	🟨	🟨
Heating and cooling technologies	HC02	Intelligent temperature unit	🟨	🟩	🟧
	HC03	Temperature control units			
	HC04	RFID tag antenna with temperature alarm sensor	🟨	🟩	🟧
Vehicles	VE02	Electric Locomotive	🟨	🟧	🟧
	VE03	Hybrid Truck	🟨	🟨	🟨
	VE09	Electric vehicles	the battery cost is very high (CAPEX).	🟨	🟨
	VE10	Euro VI vehicles	🟨	🟧	🟧
	VE01	Hybrid Locomotive	🟨	🟧	🟧
	VE22	Road-rail cargo interchange	🟨	🟨	🟨
	VE25	Brake energy recovery system	🟨	🟨	🟨
	VE29	Aerodynamic drag improvements	🟨	🟧	🟧
	VE33	Low rolling resistance tires	🟨	🟧	🟧
	VE35	Electrification of Trucks on Highways	Key problem is the initial investment which can only be made by a concerted (EU) action	Not necessarily (during change period maybe some flexibility reduction).	🟧
Navigation technologies	NA15	WiMax	🟨	Potential for reduced vessel waiting time outside port.	🟧
			🟨	🟨	🟨
			🟨	🟨	🟨
	NA01	Train Control System	🟨	🟨	🟨
	NA05	ECDIS	🟨	ECDIS: support by navigating on charts and giving real time information of the operational situation along route of each vessel. I.e. safety at sea and in port.	
	NA12 (NA13 & NA14)	GEO satellites	Increased CAPEX	🟩	Extend communication outside VHF/ WiMax coverage.
	NA16	Route optimisation system (scheduling)	🟨	🟩	🟩
			🟨	🟩	🟩
	NA17	River Information Services (RIS)	🟨	🟩	🟩
	NA18	Predictive cruise control (PCC)	🟨	🟨	🟨
Best practices / Technology integration	BP04	Traffic Flow Management	🟨	🟧	🟨
	BP07	Carbon-free rail freight transport	🟨	🟧	🟨
	BP02	TDS	🟨	🟧	🟨
	BP03	GEKKO	🟨	🟧	🟨
	BP08	Integrated shortsea transport	🟨	🟩	Faster service at port site.
	BP13	EREX (ERESS)	🟨	🟧	🟧
Innovative units and treatment	LU13	Braking energy recovery	🟨	🟧	🟨
	LU14	Onboard energy storage systems	🟨	🟧	🟨
Cargo preparation technologies	CP01	Cardboard pallets	🟨	🟧	Made of recycled material. Also, safe to handle because they do not have nails and splinters

4 Detailed benchmarking: Case studies per corridor

4.1 Brenner

4.1.1 Baseline description

The Brenner Corridor (Figure 2) includes road and railway transport networks starting from Sweden, crossing through Germany and ending either to South Italy or Greece via short sea shipping in the Ionian and Adriatic seas. Detailed description of the corridor baseline is given in [Georgopoulou et al., 2011]. Table 12 summarises the baseline KPIs. The following operational and infrastructural bottlenecks are identified:

- The use of ICT is low. Trucks are equipped with GPS, which is, however, used only for security systems (against robberies). The verification of truck position is done simply via phone calls on driver's mobile.
- The main bottleneck is located in Austria, due to the strict limitations to truck circulation imposed by Austrian law which causes an increase of transport time.
- Further delays might be caused by weather conditions in Germany, where snow and ice during winter time force drivers to reduce average speed from 80 km/h to 20-30 km/h.
- Administration: bottleneck due to traffic restrictions in Austria.

Table 12 Brenner corridor KPIs (Source: Task 2.4, [Ilves et al., 2010]).

	Intermodal	**Road**	**Rail**	**SSS**
CO_2 (g/tkm)	10.62-42.11	46.51-71.86	9.49-17.61	16.99
SOx (g/tkm)	0.020-0.140	0.050-0.080	0.040-0.090	0.050-0.120
Cost (€/tkm)	0.028-0.092	0.05-0.06	0.05-0.80	0.04-0.05
Average speed (km/hr)	9-41	19-40	44-98	23
Reliability (%)	95-99	25-99	60-95	100
Frequency (times/year)	26-624	52-2600	208-572	52-520

A trade between Verona and Berlin by heavy-duty EURO V type refrigerated trucks was selected in order to create the benchmarking case studies for the Brenner corridor, targeting on the improvement of the energy use and the reduction of emissions. The trade deals with the transportation of perishable food products requiring controlled temperature (i.e. mainly fruit, vegetables, fish, and cheese), from Brescia (Italy) to Berlin (Germany), via Verona and Munich. The trucks have a typical maximum loading capacity of 18 to 24 tonnes, and a loading factor of approximately 90% for the round-trip. A direct shipment lasts 24 to 26 hours, on average. Yet, in case of intermediate stops, the transit time can increase up to 48 hours. Further delays might be caused due to harsh weather conditions in Germany, dropping the average speed by as much as 75%[10].The frequency for the chosen transport chain is usually 50 deliveries per year with a typical cost of 1.700 €/trip. Approximately 20-27% of the transport cost is dedicated to fuel cost. Service reliability is classified as medium since a percentage of 50-60% of shipments is delivered on time (within specified time window).

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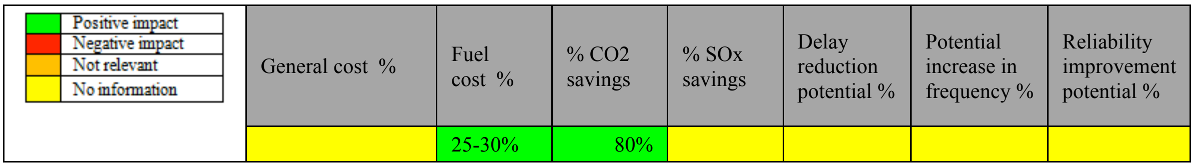
[10] A typical speed is of 80km/h.

The green technologies considered for the benchmark are:

- VE03: Hybrid trucks;
- VE29: Aerodynamic drag improvements of the truck structure;
- VE33: Low rolling resistance tires;
- CP01: Cardboard Pallets.

4.1.2 VE03: Hybrid Trucks

A hybrid truck combines the conventional diesel engine with an electrical motor for auxiliary power generation, resulting in fuel economy and reduction of CO_2 emissions, (Figure 7). The hybrid system includes a lithium-ion battery, which is recharged through regenerative braking. Other indicative features are: (a). the added power boost for hills or rapid acceleration using the electric motor and (b). the engine turning-off when the service brake is applied.



🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟨	🟩 25-30%	🟩 80%	🟨	🟨	🟨	🟨

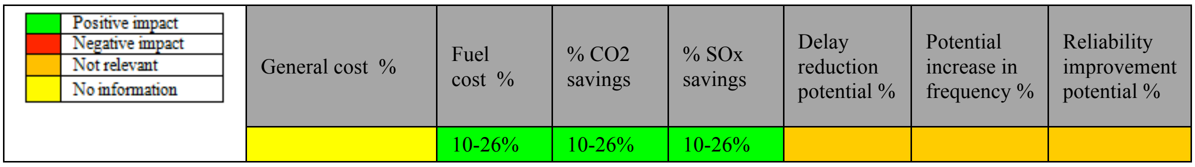
Figure 7 VE03: Performance data considered in the Brenner test case.

4.1.3 VE29: Aerodynamic drag improvements of the truck structure

Aerodynamic drag improvements of the truck structure can bear a saving potential of 10-26% for emissions (CO_2, NOx and SO_2) and energy consumption (Figure 8). Drag improvements are applicable to the mirrors, the cab side extenders, the integrated cab roof fairings and the aerodynamic front bumper.

The California Global Warming Solutions Act of 2006 established a program to reduce GHG emissions through regulatory and market mechanisms; the target is to achieve an approximately 30% reduction of GHG emissions by 2020. For this purpose, a Climate Change Scoping Plan was adopted in December 2008, in order to indicate how emission reductions could be achieved from significant GHG sources via regulations, market mechanisms, and other actions. The scoping plan includes two regulations on the GHG emissions from heavy-duty vehicles. The first action measure was adopted in December 2008 and required new and in-use trucks with 53 foot or longer trailers operating in California to achieve aerodynamic drag and rolling resistance improvements via certified new equipment and retrofits. New tractors and trailers must meet the requirements by 2011, in-use tractors by 2012, and in-use trailers by 2014.

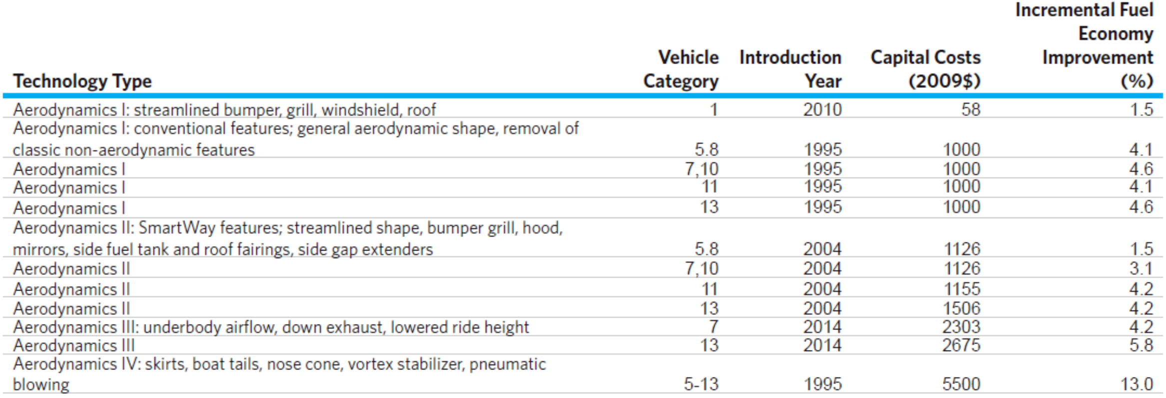
In [NESCCAF, 2009], an assessment of technologies to reduce GHG emissions and fuel consumption from new heavy-duty trucks in the timeframe from 2012 to 2017 is provided. According to the report, currently available technologies for heavy-duty trucks like aerodynamic drag improvements and improved tires are evaluated as good as more advanced technologies, such as bottoming cycle and variable valve actuation. Table 13 is derived from [EIA, 2012] and presents indicative capital costs for applying aerodynamic improvements on different types of freight trucks. The heavy duty trucks are represented by categories 7 and 8.



🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟨	10-26%	10-26%	10-26%	🟧	🟧	🟧

Figure 8 VE29: Performance data considered in the Brenner test case.

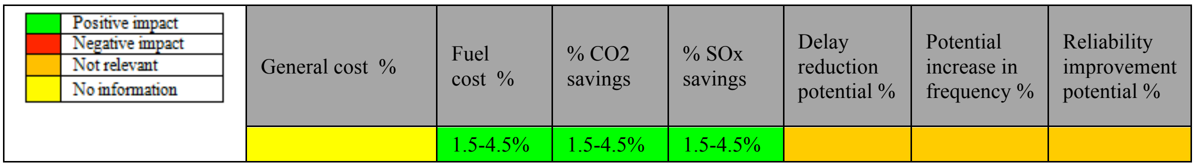
Table 13 VE29 technology details and capital cost indications. Source: [EIA, 2012].



Technology Type	Vehicle Category	Introduction Year	Capital Costs (2009$)	Incremental Fuel Economy Improvement (%)
Aerodynamics I: streamlined bumper, grill, windshield, roof	1	2010	58	1.5
Aerodynamics I: conventional features; general aerodynamic shape, removal of classic non-aerodynamic features	5.8	1995	1000	4.1
Aerodynamics I	7,10	1995	1000	4.6
Aerodynamics I	11	1995	1000	4.1
Aerodynamics I	13	1995	1000	4.6
Aerodynamics II: SmartWay features; streamlined shape, bumper grill, hood, mirrors, side fuel tank and roof fairings, side gap extenders	5.8	2004	1126	1.5
Aerodynamics II	7,10	2004	1126	3.1
Aerodynamics II	11	2004	1155	4.2
Aerodynamics II	13	2004	1506	4.2
Aerodynamics III: underbody airflow, down exhaust, lowered ride height	7	2014	2303	4.2
Aerodynamics III	13	2014	2675	5.8
Aerodynamics IV: skirts, boat tails, nose cone, vortex stabilizer, pneumatic blowing	5-13	1995	5500	13.0

4.1.4 VE33: Low rolling resistance tires

Low rolling resistance tires are designed to minimize the energy wasted as heat as the tire rolls down the road. A 1.4-4.5% reduction of CO_2 emissions is referenced in the relevant literature, (Figure 9). An important feature of lower rolling resistance tires is that the traction and braking performance often suffer due to lower resistance. For the one hand, a balance must be achieved that both energy saving benefits and safety are achieved, [NESCCAF, 2009]. In this respect, good road infrastructure conditions should support the effectiveness of such measures.



🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟨	1.5-4.5%	1.5-4.5%	1.5-4.5%	🟧	🟧	🟧

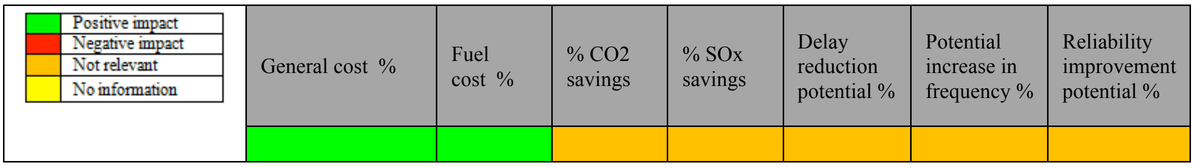
Figure 9 VE33: Performance data considered in the Brenner test case.

4.1.5 CP01: Cardboard Pallets

In the Task 3.1 analysis, none of the identified cargo preparation technologies was rated as important. Even though the benchmark of this study is created on the basis of the important technologies, the inclusion of one cargo preparation technology in the benchmark was decided. The CardBoard Pallets were selected for this purpose, being of multi-modal use in the corridors. Given lack of quantitative information on the technology performance with respect to the KPIs, a qualitative assessment is performed.

Cardboard Pallets are ecological cargo preparation pallets, which are made of (completely) recycled materials. Because of their low weight, they have a very low contribution to the bill paid for moving of the cargo (which can give considerable airfreight savings). On the other hand, they have good strength and can be used for various loads. In fact, Cardboard Pallets support static loads up to 11500 lbs (5200kg) without loosing structural integrity. Potentially, they can transport 2,200 pounds (1000kg), while they weigh 1/4th of a wood pallet. Moreover, they are safe to handle because they do not have nails and splinters. Their life expectancy is rated as high as forty five uses and they are rated as a totally green product.

The application of Cardboard Pallets instead of common wood pallets could reduce the transport cost because this technology is very suitable for one way deliveries. In addition, the Cardboard Pallet price is in fact comparable with wood pallets but they have further cost benefits, such as no costs or penalties for disposal. They can also minimize carbon footprint impact (one-way freight application) and have low costs for reverse logistics.



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🟧 Not relevant
🟨 No information

General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
🟩	🟩	🟧	🟧	🟧	🟧	🟧

Figure 10 CP01: Performance improvement potential.

4.1.6 Benchmarking results

The green technologies impact on the baseline performance is summarised in Table 14. An improvement of 6-7% of the cost KPI is estimated from the application of hybrid trucks. Compared to all three green technologies, this is the maximum estimated operating cost reduction. However, the capital cost should be incorporated to the calculations. Hybrid trucks are more expensive than the conventional ones and, thus, the inclusion of the capital cost in the economic assessment would change the operating cost benefits during the life time of the investment. Regarding CO_2 emissions, a maximum 25% reduction is estimated for hybrid trucks.

Even though an indication of the greening benefits is gained, the total greening potential of the technologies should be assessed on a truck fleet level basis. For this purpose, the inclusion of the capital expenses and the evaluation of the return of investment are essential. This would require a more detailed description of the baseline, which was not available within SuperGreen.

Table 14 Green technologies impact on the Brenner baseline performance. The KPIs are: Cost, CO_2 emissions, SOx emissions, Average speed, Reliability and Frequency. In the case that the impact on a KPI could not be assessed due to data unavailability, the KPI is omitted from the Table for brevity.

Technology name		**Mode**	**KPI**	**Baseline**	**Benchmark**		**Impact on baseline performance**	
					Min	**Max**	**Min**	**Max**
Hybrid trucks	VE03	Road	Cost [euro/tn.km]	0.07	0.066	0.065	6%	7%
			CO_2 emissions [gr/tn.km]	71.86	53.9	53.9	25%	25%
Aerodynamic drag improvements	VE29	Road	Cost [euro/tn.km]	0.07	0.068	0.067	3%	4%
			CO_2 emissions [gr/tn.km]	71.86	64.67	53.18	10%	26%
			SOx emissions [gr/tn.km]	0.08	0.07	0.06	13%	25%
Low rolling resistance tires	VE33	Road	Cost [euro/tn.km]	0.07	0.07	0.069	0%	1%
			CO_2 emissions [gr/tn.km]	71.86	70.78	68.63	2%	4%

4.2 Mare Nostrum

4.2.1 Baseline description

The Mare Nostrum corridor (Figure 2) includes Mediterranean and Black sea trade routes. Shipping is the main transport mode through the corridor. Rail and road connections link the ports to the inland transport networks. The baseline performance of the corridor is summarised in Table 15.

Table 15 Mare Nostrum corridor KPIs (Source: Task 2.4, [Ilves et al., 2010]).

SuperGreen KPIs	**Baseline for SSS**
CO_2 (g/tkm)	14.51
SOx (g/tkm)	0.209
Cost (€/tkm)	0.012*
Average speed (km/hr)	16.71
Reliability (%)	93.75
Frequency (times/week)	2

The Task 2.4 interviewees identified the following infrastructural and operational bottlenecks:

- Delays caused by weather problems;
- Congestion, especially at the road networks around the ports;
- Non-uniformity of ports facilities;
- Geographical restrictions: as addressed by the interviewees, at the Dardanelles Straits traffic congestion appears.

Concerning ICT facilities, the interviewees referred to the use of satellite based applications for cargo tracking during trip, mentioning that the current applications with which the cargo can be tracked only at origin and destination look sufficient.

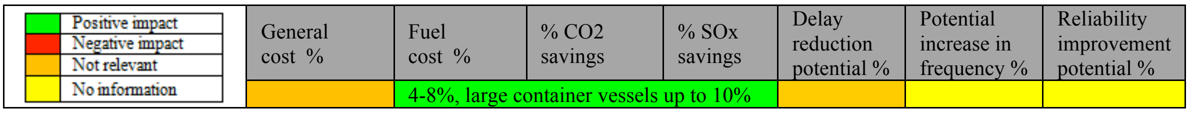
In this analysis, the benchmark cases target on the greening of container transportation amongst the nodes of Barcelona, Valencia, Gioia Tauro, Piraeus and Istanbul. In this region, regular liner services operated once a week by feeder ships around 2000 TEUs serve by priority the local trading between the Mediterranean countries carrying all kinds of goods. An average distance sailed is 1425 km, while the delivery time is 55 hours with a travelling speed of 14 knots. A typical loading factor of 70% is considered.

The effects of the following three green technologies are investigated:

- Heat recovery systems;
- Exhaust gas cleaning systems;
- Integrated short sea transport and logistics concepts for the accommodation of large container feedering.

4.2.2 FU26: Waste heat recovery systems

Waste heat recovery systems are used to recover part of the main engine exhaust gas thermal energy, in order to produce steam and, thereby, electrical power in a steam turbine generator. Heat recovery systems could be applied to all Mare Nostrum corridor segments related to trades operated by large vessels, in order to improve the energy efficiency of baseline diesel engines propulsion. For the Mare Nostrum container ships, a fuel saving gain of 2-7% was assumed [DNV Publication 2012, *Shipping 2020*] (Figure 11). The gains from waste heat recovery (WHR) mainly depend on the system size and complexity. Using phenomenological process modelling of the system, the energy efficiency and environmental performance can be predicted and optimised [Dimopoulos et al., 2011]. The benefits from waste heat recovery are higher for large ships due to the economies of scale. A main drawback is the space requirement for the installation of the heat recovery system, which results in cargo capacity reduction. Therefore, for small ships such systems may be a highly costly option.

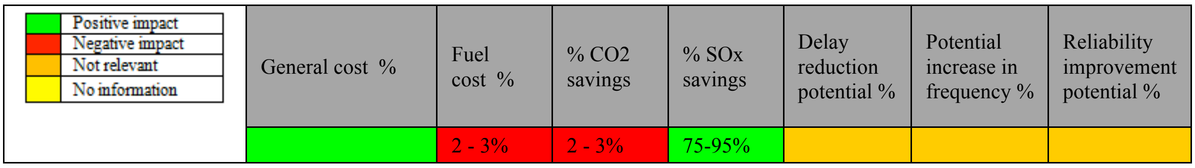


🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟧	🟩 4-8%, large container vessels up to 10%			🟧	🟨	🟨

Figure 11 FU26: Performance data considered in the Mare Nostrum test case.

4.2.3 EN21: Exhaust abatement system

Under the IMO[11] air pollution regulations [MARPOL Annex VI], exhaust gas cleaning systems, like scrubbers, are one option to mitigate sulfur emissions, with alternative fuels like LNG or low-sulfur marine diesel oil being the other technically known option. Scrubbers can remove sulphur from the engine exhaust gas up to 99% by using chemicals, seawater, or dry scrubbing technology. However, the scrubber operation increases the power consumption, thereby increasing the CO_2 emissions, [DNV Publication 2010, *Baltic Report*], [Georgopoulou et al., 2011]. In addition, the scrubber installation requires alterations on-board the vessel, like the installation of additional tanks, pipes, pumps, water treatment system (in case of wet scrubber systems), and sludge tank (the sulfur-rich sludge is treated as special waste). Extra operational costs may be required, if chemicals solvents are in use.



🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩	🟥 2 - 3%	🟥 2 - 3%	🟩 75-95%	🟧	🟧	🟧

Figure 12 EN21 (SOx abatement): Performance data considered in the Mare Nostrum test case. The baseline technology is marine heavy fuel oil.

4.2.4 BP08: Integrated short sea transport

Integrated short sea transport and logistics concepts for the accommodation of large container feedering include designs of smart docking and automated transhipment port systems. Coaster Express (CoEx) is a concept for automated container terminal concept for short sea applications directed to bundling the transport flows, scaling-up the short sea facilities and standardization and automation of the transition processes. However, it is only on a conceptual stage and it is difficult to determine its impact on the greening of corridors. According to [Lui et al., 2002], the automation of operation may provide an

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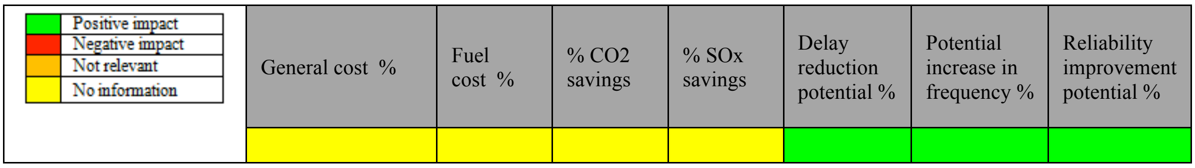
[11] International Maritime Organisation

estimated increase in cargo throughput and service speed increase service of approximately 43%.



🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟨	🟨	🟨	🟨	🟩	🟩	🟩

Figure 13 BP08: Performance data estimated for the Mare Nostrum test case.

4.2.5 Benchmarking results

Table 16 summarises the estimated performance changes of the corridor. It should be noted that the cost KPI changes are on operational basis without capital cost inclusion and refer to specific case studies of the SuperGreen survey [Ilves, 2010]. Further research is required for a full-scale cost benefit analysis from the application of these technologies on a corridor level. Such an analysis should use fleet-based models [Eide et al., 2011] and include the capital cost in the evaluation of the return of the investments.

For the analysed cases, the introduction of energy efficiency measures can bring up to 5% reduction of total transport chain CO_2 emissions. Integrated short sea transport could bring an improvement of up to 8% on the average speed. The use of SOx after treatment systems could reduce SOx emissions while sailing up to 96%.

Table 16 Green technologies impact on the Mare Nostrum baseline performance. The asterisk refers to the use of EN21only during the trip and not at port site. The KPIs are: Cost, CO_2 emissions, SOx emissions, Average speed, Reliability and Frequency. In the case that the impact on a KPI could not be assessed due to data unavailability, the KPI is omitted from the Table for brevity.

Technology name		**Mode**	**KPI**	**Baseline**	**Benchmark**		**Impact on baseline**	
					Min	**Max**	**Min**	**Max**
Waste heat recovery systems	FU26	Maritime	**Cost [euro / tn.km]**	0.0025-0.0035	0.00332-0.00348	0.00237-0.00248	1%	5%
			CO_2 emissions [gr / tn.km]	6.44-27.26	25.803-26.844	6.096-6.342	2%	5%
			SOx emissions [gr/ tn.km]	0.092 - 0.4	0.394-0.379	0.087-0.091	1%	5%
Exhaust abatement systems	EN21	Maritime	**Cost [euro / tn.km]**	0.0025-0.0035	0.00352-0.00363	0.00252-0.00259	-4%	-1%
			SOx emissions [gr/ tn.km]	0.092 - 0.4	0.02-0.04	0.004-0.009	90%	96%
					0.11-0.171*	0.025-0.039*	57%*	73%*
Integrated short sea transport	BP08	Maritime	**Average speed [km/hr]**	19.79	20.83	21.40	5%	8%
* Evaluation for the whole chain, i.e. including operation with the scrubber at idle mode.								

4.3 Nureyev

4.3.1 Baseline description

The Nureyev corridor (Figure 2) is mostly comprised by short sea shipping legs linking European and Russian ports through the Baltic Sea. Rail and road connections from Moscow to St. Petersburg and Klaipeda to Minsk are also parts of the corridor. A special feature of the corridor is the inclusion of the Baltic Area Emissions Control Area (ECA). Due to new sulphur restrictions the use of cleaner fuels or exhaust abatement systems will support greener shipping in the area. Table 17 shows the baseline Nureyev corridor performance.

Table 17 Nureyev corridor KPIs (Source: Task 2.4, [Ilves et al., 2010]).

SuperGreen KPIs	Intermodal	SSS
CO_2 (g/tkm)	13.43-33.36	5.65-15.60
SOx (g/tkm)	0.030-0.150	0.070-0.140
Cost (€/tkm)	0.10-0.18	0.05-0.06
Average speed (km/h)	13-42	15-28
Reliability (%)	80-90	90-99
Frequency (times/year)	156-360	52-360

There are already some green technologies used in the Nureyev corridor. All the trains in Finland and Russia are electrified and belong to the category of 1500 tonnes. Diesel-electric propulsions used in ships may reduce fuel consumption and decrease the amount of emissions. Especially in the Baltic Sea, where the loading profile of the ship is varying, the use of the engines can be optimised with diesel-electric propulsion. Technology also improves on-time running of the ships. A shore-side power source is still rarely used but ports of Helsinki and Gothenburg are already now providing electricity to some of the ships visiting the port. Many ports (e.g Gothenburg and Finnish ports) and shipping companies along the Nureyev corridor have also started the preparations for the use of LNG, which is a step towards greener maritime transport. The identified bottlenecks in the corridor are summarised as follows:

- Border crossings between Finland and Russia and road congestion resulting therefrom. ICT systems would support the solution of this bottleneck.
- During the winter, ice appears in the Baltic Sea. There are efficient and high performance ice breakers in use; however, sometimes if the situation is critical, delays may occur which are caused by the ice conditions. This bottleneck applies only for few months during the winter time and for rest of the year this bottleneck does not exist. A way to improve the situation could be to improve co-operation between the countries and get the maximum use of the available machinery.

Herein, the focus is shed on the increase of energy efficiency and decrease of emissions with the use of green technologies. The transport segment under investigation is located in the Nureyev corridor, more specifically being short sea shipping (SSS), in the Baltic Sea. Although the corridor connects Russia to Europe by also using rail and road transport only the sea leg is covered, and the segment under investigation is the port to port distance linking Rotterdam and Helsinki. The total sailing distance between the two ports are 2019 kilometres[12]. The vessel operating the segment is a common container vessel currently

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[12] Calculated by the distance calculator of portworld.com

operating in the European short sea traffic, and the necessary details for carrying out the analysis were identified in SuperGreen deliverable D2.4v2. For performing the benchmark calculation the following technologies are applied:

- Contra rotating propeller;
- Wind propulsion system – sails ;
- LNG;
- Cargo cassette translifter; and
- Mechanical azimuth thrusters.

4.3.2 EN61: Contra rotating propeller

Although the technology is more expensive than a single propeller system, it holds the possibility to provide fuel savings in the range of 5-15%. Although the idea and technology cannot be regarded as new, it holds the potential of significantly reducing the energy consumption. Since the cost of contra rotating propellers mostly refers to the point of installation/ acquisition, it is assumed that it has no significant impact on the transport cost. This means if installed in a vessel it will increase the capital cost in comparison to a vessel without this technology. However, in terms of energy savings the technology has a potential to provide savings in the range of 5-15% for CO_2, SOx and NOx. The average speed will not be affected, but the technology allows for installation of less engine power, meaning that less energy is needed to maintain the same vessel speed. This means that average speed, frequency of sailing, and reliability can be maintained by consuming less energy.

🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩 Reduced Opex	🟩 5-15%	🟩 5-15%	🟩 5-15%	🟧	🟧	🟧

Figure 14 EN61: Performance data considered in the Nureyev test case.

4.3.3 EN06: Mechanical azimuth thrusters

This is a technology that can result in energy savings depending on the user. It is a baseline technology.

Currently, and compared to a traditional propulsion system (e.g. mechanically connected propeller), procuring such technology will result in an increased capital expenditure, while at the same time opening up for potential fuel savings in the range of up to 20% (i.e. increased capital cost and reduced operating cost). Although the savings in energy consumption are fully dependent on the user of the technology, this naturally also has the corresponding effect on the emission of CO_2 and SOx. As with LNG above, the KPIs average speed, frequency of service and reliability are not likely to be affected by the introduction of mechanical azimuth thrusters.

🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩	🟩 0-20%	🟩 0-20%	🟩 0-20%	🟧	🟧	🟧

Figure 15 EN06: Performance data considered in the Nureyev test case.

4.3.4 FU25: Wind propulsion – sails

Depending on wind conditions this technology can provide considerable energy savings. Wind propulsion has been used for ages. In our days, novel materials and self-adjusting sail systems are introduced to this technology to improve its performance[13].

Apart from the acquisition and installation costs, a marginal maintenance cost for this technology must be included. According to technology manufacturers it is possible to reach energy savings in the range of 5-20% (ideally), all depending on conditions and optimized used of installed equipment. On average, the energy savings from sky sails are up to 6-7%.

The average speed will not be affected, but the utilisation of wind energy allows the captain to reduce the engine thrust while still maintaining the same speed. This gives corresponding savings in CO_2 and SOx. As with the average speed KPI, it is assumed that both frequency of service and the reliability of service will not be affected by the technology. This since it is very unlikely that any user of this technology will rank fuel saving, above the ability to deliver according to customer expectations (e.g. delivering on-time).

🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	5-20% on Opex	5-20%	5-20%	5-20%	🟧	🟧	🟧

Figure 16 FU25: Performance data considered in the Nureyev test case.

4.3.5 FU26: LNG

First and foremost the use of LNG as fuel instead of the more conventional marine gas oil (MGO) (for the Nureyev ECA regions) will provide considerable savings in the emission of CO_2, NOx, and SOx. This technology also receives much attention from both engine manufacturers and the research sector, and more and more vessels are being contracted with this technology. As for the remaining indicators in the table, these are not expected to be significantly affected despite the LNG technology is more expensive in the acquisition phase. It should however be noted that the necessary investments in re-fuelling infrastructure has not been accounted for, and is also beyond the scope of this analysis.

In terms of the KPIs average speed, frequency of service, and reliability, these are not expected to be particularly affected by the implementation of the LNG technology.

Regarding the benefits from the use of LNG there is high uncertainty about the fuel prices in the future. Based on fuel price projections, it is estimated that, for a typical ship and a lifecycle perspective, LNG is expected to be a better option that heavy fuel oil (HFO) with scrubber, whereas MGO is expected to be the most expensive one[14]. Current low LNG prices in Europe and the USA suggest that a price – based on energy content – comparable to heavy fuel oil (HFO) seems possible, even when taking into account the small-scale distribution of LNG.

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[13] http://www.sustainableshipping.com/news/i98766/Wind_power_will_replace_fuel,
http://www.sustainableshipping.com/news/i100536/Skysails_partnership_aimed_at_streamlining_marine_kite_technology

[14] http://blogs.dnv.com/lng

🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩 Reduced Opex by 4-8%	🟩 4-8%, large container vessels up to 10%	🟩 4-8%, large container vessels up to 10%	🟩 4-8%, large container vessels up to 10%	🟧	🟨	🟨

Figure 17 FU26: Performance data considered in the Nureyev test case.

4.3.6 HT11: Cargo cassette translifter

This technology has been chosen due to the importance of designing smart solutions for efficient (un)loading operations allowing for fast turn-around times for vessels in ports, while also enabling advances in intermodal cargo handling (e.g. cargo shift between transport modes).

🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩	🟧	🟧	🟧	🟩	🟩	🟩

Figure 18 HT11: Performance data considered in the Nureyev test case.

Cargo handling technology is a critical component for securing efficient and effective transfer of cargo between transport modes (e.g. reducing vessel port turnaround time), and thus an important prerequisite for establishing intermodal transport solutions. Since this technology has main focus on increasing terminal efficiency, the emission of CO_2 and SOx are not expected to be significantly reduced. This is based on the assumption that the majority of energy is consumed by the transport mode during transit.

However, since the technology allows for increased speed of (un)loading operations, the potential for much faster turnaround time is present. This may also affect the level of reliability, as fast loading increases the operator's ability to deliver according to schedule. Also, the increase in turnaround time may be utilised for achieving two main goals:

- Lowering the operational speed at sea, and thereby reducing the energy consumption and emissions to air, while still upholding the same level of service frequency.
- Increased reliability by more efficient operations in port due to less waiting time for available quay space.

4.3.7 Benchmarking results

The estimated changes of the corridor performance are summarised in Table 18. It should be noted that the main impact of the first two technologies occurs during transit, and that several other parameters may affect the length and duration of different port calls.

Table 18 Green technologies impact on the Nureyev baseline performance. The KPIs are: Cost, CO_2 emissions, SOx emissions, Average speed, Reliability and Frequency. In the case that the impact on a KPI could not be assessed due to data unavailability, the KPI is omitted from the Table for brevity.

Technology name		**Mode**	**KPI**	**Baseline**	**Benchmark**		**Impact on baseline performance**	
					Min	**Max**	**Min**	**Max**
Contra rotating propeller	EN61	Maritime	**CO_2 emissions [gr / tn.km]**	5.65-15.6	4.80-5.36	13.26-14.82	5%	15%
			SOx emissions [gr/ tn.km]	0.07-0.14	0.067-0.059	0.133-0.119	4%	16%
Wind propulsion - sails	FU25	Maritime	**CO_2 emissions [gr/tn.km]**	5.65-15.6	5.65-4.80	15.6-13.26	0%	15%
			SOx emissions [gr/tn.km]	0.07-0.14	0.060-0.070	0.140-0.120	0%	14%
Mechanical azimuth thrusters	EN06	Maritime	**CO_2 emissions [gr / tn.km]**	5.65 – 15.6	15.6 – 12.48	5.65 – 4.52	0%	20%
			SOx emissions [gr/ tn.km]	0.07 – 0.14	0.14 – 0.11	0.07 – 0.06	0%	21%
LNG	FU08	Maritime	**CO_2 emissions [gr / tn.km]**	5.65-15.6	14.04 – 12.48	5.09 – 4.52	10%	20%
			SOx emissions [gr/ tn.km]	0.07-0.14	0.003 – 0.000	0.001 – 0.000	98%	100%
Cargo casette translifter	HT11	Maritime	**Average speed [km/hr]**	24	15-24		0%	38%
			Frequency of service [times / year]	360	360-380		0%	6%
			Reliability [%]	90	90-95		0%	6%

4.4 Strauss

4.4.1 Baseline description

Strauss is the corridor that involves the Danube and Rhine inland waterways (Figure 2). The table below shows the Strauss baseline performance [Ilves et al., 2010].

Table 19 Strauss corridor KPIs (Source: Task 2.4, [Ilves et al., 2010]).

SuperGreen KPIs	**IWT**
CO_2 (g/tkm)	9.86-22.80
SOx (g/tkm)	0.013-0.031
Cost (€/tkm)	0.02-0.44

According to EUROSTATS[15], freight container transportation via inland water ways develops better that total transport in start 2011. From the baseline description of the Strauss corridor we selected the Rotterdam–Duisburg segment, which links also to other corridors like Brenner and Nureyev. The trade considered is on the transportation of

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[15] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Inland_waterways_freight_transport_-_quarterly_and_annual_data

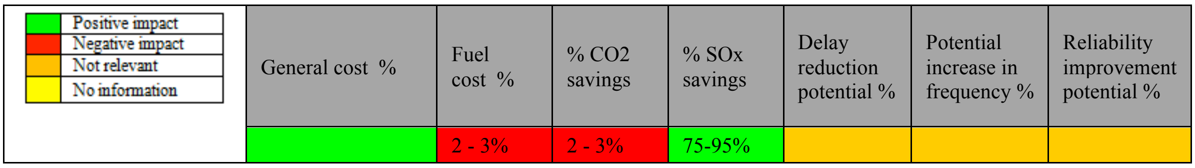
containerized cargo via JOWI class vessels of a 398 TEU capacity. The distance covered is 213 km. The average consignment is 91% and the frequency is 4 trips per week. A typical load of 10.5tn per TEU is considered. The in-bound trip lasts 16 hours and we consider the same duration for the out bound leg.

The KPI factors were estimated based on a literature review on inland water way container routes for this segment. The main engine nominal power output is considered to be 3200 kW, with a typical fuel consumption of 212g/kWh[16]. A 75% engine load during trip is also assumed. The relative cost per tonne transported and km travelled was estimated to 0.438 euro/tn.km, based on information derived from [PLANCO, 2007]. In [PIANC, 2005], a fuel cost factor of 11% for the inland water ways is estimated. Using the Ecotransit tool[17], the tank-to-wheel CO_2 emissions are estimated to 30gr/tn.km, while the SOx emissions are 0.186gr/tn.km. EU Directive 2009/30/EC requires that the fuel burnt for inland water way transport is ultra-low sulfur diesel (ULSD) of not more than 10 milligrams of sulphur per kg of fuel. For the baseline, LS fuel price of 730 to 750 euro/mt was considered; ULSD prices are even higher[18].

4.4.2 EN21: Exhaust abatement technologies

The application of a Selective Catalytic Reduction (SCR) system on the exhaust gas path of the inland water way vessel is considered. SCR is a technique to remove NOx emissions by means of injecting a urea agent (32.5% in water) into the exhaust gas stream. The urea substance reduces both NO and NO_2 to nitrogen and water. According to the high-level benchmark, the SCR technology would require additional operating costs for urea and maintenance. In addition, it could bring a 2-5% fuel increase. On the other hand, according to [Schweighofer, 2005], NOx after-treatment gives the opportunity to increase combustion efficiency, resulting in up to 7.5% less fuel consumed and less CO_2 emitted. Considering that both approaches could be realised, a range of -2% to +7.5% for the fuel cost factor is assumed.

Figure 19 summarises the effects of the technology. The positive impact of the SCR technology in the fuel consumption is based on the assumption that a more efficient combustion process would be evitable. The negative influence refers to the system consumptions. A positive influence is estimated for the average speed and the potential increase of trips frequency; however, this is difficult to quantify. Urea cost and SCR maintenance cost are not included in the calculation, but represented by red colour in Figure 19. The capital cost of the system depends on the ship type and size.



🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩	🟥 2 - 3%	🟥 2 - 3%	🟩 75-95%	🟧	🟧	🟧

Figure 19 EN21: Exhaust abatement system for NOx reduction in inland water ways.

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[16] http://www.ecotransit.org/download/ecotransit_background_report.pdf

[17] http://www.ecotransit.org/calculation.en.html

[18] http://www.bunkerworld.com/prices/port/nl/rtm/

4.4.3 NA16: Route optimisation system

The Advising Tempomaat (ATM) is an electronic control system for optimising the energy efficiency of a vessel's operation [Fozza and Recagno, 2012]. The core of the ATM is formed by a computer program advising the skipper on the most economical combination of route and speed, enabling the vessel to arrive on time with efficient use of fuel leading to a reduction of fuel consumption and emissions by approximately 10%.

Positive fuel and emissions impact is estimated. The technology may also have positive effects on delays reduction and increase of service reliability. The technology can be applied to other types of inland water way vessels, for example ro-ro carriers, bringing similar benefits.

🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩	🟩 5-10%	🟩	🟩	🟩	🟩	🟩

Figure 20 NA16 : Route optimisation system for inland water ways.

4.4.4 FU08: LNG

In order to reduce NOx and PM emissions from medium and large inland ships, there are currently two options: installing after treatment equipment or switching to LNG[19]. Compared to low-sulphur diesel, which is now the baseline fuel for inland water ways, NOx emissions decrease by 80-90%, CO_2 by 20-25%, and particle emissions are close to zero. LNG has almost zero sulfur content, leading to almost 100% tank-to-propeller sulfur emission reduction compared to ultra-low sulfur bunkers (EN590). According to [Schweighofer, 2005], a 19% GHG emission reduction can be achieved from the use of natural gas for inland water way transport, instead of diesel oil. DNV studied on the technology uptake in shipping up to 2020 shows that LNG is expected to have a steady uptake depending on fuel prices [DNV Publication 2012, *Shipping 2020*], [DNVPublication, *Technology Outlook 2020*].

Figure 21 summarises the benefits of the technology for inland waterways. The use of LNG is not expected to affect the frequency of the trips or the quality of service. On the other hand, the use of LNG as inland water way fuel would require LNG bunkering facilities at important nodes of the corridor and, thus, increased infrastructure investments along the inland waterway networks.

🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩	🟩 up to 20%	🟩 Road: 2-6%, Maritime: 20-25%	🟩 90-100%	🟧	🟧	🟧

Figure 21 FU08: Performance data considered in the Strauss test case.

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[19] http://www.inlandnavigation.eu/nl/why-use-waterways/green-logistics/lng-as-alternative-fuel_119.aspx

4.4.5 Benchmarking results

The estimated changes of the corridor performance are summarised in Table 20. It should be noted that LNG is applicable to both inland and maritime shipping, making this technology rather interesting on a corridor basis.

Table 20 Green technologies impact on the Strauss baseline performance. The KPIs are: Cost, CO_2 emissions, SOx emissions, Average speed, Reliability and Frequency. In the case that the impact on a KPI could not be assessed due to data unavailability, the KPI is omitted from the Table for brevity.

Technology name		**Mode**	**KPI**	**Baseline**	**Benchmark**		**Impact on baseline performance**	
					Min	**Max**	**Min**	**Max**
Exhaust abatement systems	EN21	IWW	**Cost KPI [euro/tn.km]**	0.438	0.434	0.44	0%	1%
			CO_2 emissions [gr/tn.km]	29	26.825	30.45	-5%	8%
Route optimisation systems	NA16	IWW	**Cost KPI [euro/ tn.km]**	0.438	0.433	0.438	1%	1%
			CO_2 emissions [gr/tn.km]	29	26.1	29	10%	10%
			SOx emissions [gr/tn.km]	0.186	0.167	0.186	10%	10%
LNG	FU08	IWW	**CO_2 emissions [gr / tn.km]**	29	23.490-26.10		10%	19%
			SOx emissions [gr/tn.km]	0.186	0-0.009		95%	100%

4.5 Cloverleaf

4.5.1 Baseline description

The Cloverleaf corridor passes across the UK mainland, namely from Glasgow – Carlisle – Liverpool – London – Dover with branch link to Dublin (Ireland) at Liverpool through Channel Tunnel to France via Calais and directly to Duisburg (Germany). The corridor segment in Europe mainland passes across Belgium and the Netherlands. The baseline performance is shown in Table 21.

Table 21 Cloverleaf baseline KPIs (Source: Task 2.4, [Ilves et al., 2010]).

SuperGreen KPIs	**Road**	**Rail**
CO_2 (gr/tkm)	68.81	13.14-18.46
SOx (g/tkm)	0.091	0.014-0.021
Cost (€/tkm)	0.06	0.05-0.09
Average speed (km/h)	40-60	45-65
Reliability (%)	80-90	90-98
Frequency (x time/year)	4680	156-364

The identified corridor bottlenecks are:

- Road traffic congestion at the Liverpool and the Midlands segment (Birmingham Area) and the area within the Greater London ring road (M25).
- For the rail networks, the main bottlenecks are within segments where there is only one track.

The Cloverleaf road benchmark cases refer to the route between London and Duisburg. The route is served by Euro IV trucks of 24-40tn capacity. An annual volume of 112350 tonnes is carried with a frequency of 4680 times per year, giving an estimate for the consignment of 24tn per trip. The trip distance is 556km with a time delivery of 10 hrs. Road congestion is reported especially around the entry point of urban areas, causing delays to the overall trip schedule.

The rail benchmark cases deal with the freight transport between Midlands and Duisburg with an electrified long train of a 1500 tonnes capacity. The load factor is 85% and the block train consignment varies per trip. The majority of round trips arrive empty from the UK. The distance travelled is 745 km with a time delivery of 20 hours and a frequency of 156 times per year. No ICT use is reported except from the conventional signal system. The change of locomotives' drivers between country borders (between Germany, France and then UK) results in one extra hour delay per change.

4.5.2 VE29: Aerodynamic drag improvements

The introduction of aerodynamic drag improvements on the truck structure is, also, considered in the Brenner corridor for Euro V and Euro III trucks, with an estimated saving potential of 10-26% for emissions (CO_2, NOx and SO_2), and energy consumption was estimated. Assuming an average loading factor of 85% per trip (no data on loading factor are given in the baseline description) and typical vehicle characteristics on engine power and fuel consumption, a 20-30% fuel cost factor is estimated. Based on this assumption, aerodynamic drag improvements could bring cost and emissions savings of 2.1-7.3% on the Cloverleaf baseline performance.

4.5.3 VE03: Hybrid trucks

The application of hybrid trucks is, also, considered for the Brenner corridor. According to the first benchmarking level, the potential benefits from the use of hybrid trucks compared to conventional diesel vehicles include 60-80% fuel savings and relevant reduction of emissions. If conventional diesel fuel is used, then 60-80% CO_2 and SOx emissions' reduction are estimated. However, this figure is general and can change according to the driving profile, the hybrid system in use, and other factors. Assuming an average loading factor of 85% per trip (no data on loading factor are given in the baseline description) and typical vehicle characteristics on engine power and fuel consumption, a 22-29% fuel cost factor is estimated. Based on this assumption and the first level estimations, the use of hybrid vehicles could possibly bring cost and emissions savings of 13.1-23.2% on the Cloverleaf baseline performance.

4.5.4 BP13: EREX

The Cloverleaf rail routes cross three European countries, namely UK, France and Germany. The traditional solution for energy metering and billing for railway operators is to charge based on an estimate of the energy consumption per country.

EREX[20,21] is a railway system that has been designed by the European Railway Energy Saving Solution (ERESS), to help railways to save money and reduce CO_2 emissions by

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[20] http://www.eress.eu/erex-users/

[21] http://www.railwaypro.com/wp/?p=6259

providing accurate billing based on actual consumption. EREX is an energy settlement system that enables the infrastructure managers to calculate the accurate energy consumption of their clients and the railway undertakings to understand their use of energy, apply smarter driving and, thus, save energy and costs. The EREX system is comprised of:

- advanced energy meters mounted on board trains;
- an energy measurement system, which collects and validates the measured data;
- a system that performs the settlement, cost distribution, data exchange and billing.

EREX can be seen both as ICT technology or an integration of technologies for the reason that it includes energy meters and measuring devices and systems, as well as information systems to perform the settlement.

According to the literature, the application of this technology provides the ability to design energy saving programs of up to 15% - 30% energy and cost savings. As a documented example [EREX Annual report, 2011], the Norwegian National Railway (NSB) started an energy saving project in 2005 based on measured energy data. Between 2004 and 2011 the energy efficiency was improved by 20.5%. This project has thereby allowed NSB to achieve substantial cost savings. The EREX system is, also, designed for cross-European railway traffic, irrespective of the country or the operators, giving the opportunity to calculate the exact energy bill at every country where the train travels.

All users in the system, such as operators, train companies or infrastructure owners can log into the system at any time and extract invoices and basis data in accordance with their access rights. Raw data from energy measurements provide detailed knowledge of the energy consumption and can establish a basis for energy-saving measures. The data (energy values, gross tonnes/km, distances, tonnes/kilo, etc.) can be extracted either automatically or manually on special-format files (Excel) or web services.

A cost benefit of 15% on the energy bill compared to the baseline (Figure 22) is estimated for the SuperGreen benchmark. Qualitatively, a positive influence on CO_2 and SOx emissions due to energy savings is estimated. However, no quantitative estimate is given in this study. In addition, a positive effect on reliability of service is estimated, because of the support to precise train dispatching and collision avoidance.

Train operation costs include costs related to manning, (personnel that operates the trains, managing staff and customer service/management staff), rolling stock costs (including maintenance and capital costs), track access charges, power supply and other costs. The Cloverleaf baseline assessment did not provide with information on the energy cost as a fraction of the total cost. However, according to the EC co-funded project TOSCA [TOSCA, 2011], the average energy cost of European electric rail operations is in the order of 10 % of total operating cost.

🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩	🟩	🟩 up to 15%	🟨	🟧	🟧	🟧

Figure 22. BP13: Performance data considered in the Cloverleaf case.

4.5.5 NA07

According to the baseline Cloverleaf description, road corridors bottlenecks are related to traffic congestion within the segment between Liverpool and the Midlands (Birmingham Area), and the area within Greater London ring road (M25). These segments would benefit from the introduction of a GPS tracking system, improving, thus, the reliability and service quality in the corridor.

4.5.6 Benchmarking results

The estimated changes of the Cloverleaf corridor performance are summarised in Table 22. The first two technologies are also considered in the Brenner corridor. By comparing the results for the use of aerodynamic drag improvements in to Brenner and Cloverleaf, better cost KPI performance is estimated for the latter. This is due the difference between the fuel cost factors for the Cloverleaf and the Brenner case studies; therefore, the effects on cost are highly dependent on the case study and the assumptions made.

Table 22 Green technologies impact on the Cloverleaf baseline performance. The KPIs are: Cost, CO_2 emissions, SOx emissions, Average speed, Reliability and Frequency. In the case that the impact on a KPI could not be assessed due to data unavailability, the KPI is omitted from the Table for brevity.

Technology name		Mode	**KPI**	**Baseline**	**Benchmark**		**Impact on baseline performance**	
					Min	**Max**	**Min**	**Max**
Aerodynamic drag improvements	VE29	Road	**Cost KPI [euro/ tn.km]**	0.057	0.05576	0.052702	2%	8%
			CO_2 emissions [gr/tn.km]	68.81	61.929	50.9194	10%	26%
			SOx emissions [gr/tn.km]	0.09	0.081	0.0666	10%	26%
Hybrid trucks	VE03	Road	**Cost KPI [euro/ tn.km]**	0.057	0.049561	0.043775	13%	23%
			CO_2 emissions [gr/tn.km]	18.45	27.524	13.762	-49%	25%
			SOx emissions [gr/tn.km]	0.013	0.0117	0.00962	10%	26%
EREX	BP13	Rail	**Cost KPI [euro/ tn.km]**	0.095	0.09358		1%	2%

4.6 SilkWay

4.6.1 Baseline description

The Silk Way corridor (Figure 2) consists of two main transport services linking the Far East with Europe. Today, there are mainly two alternatives for shipping goods between the two regions, one being the deep sea service linking Shanghai to the Le-Havre-Hamburg region, while the other is the rail-link between Beijing and Duisburg/EU.

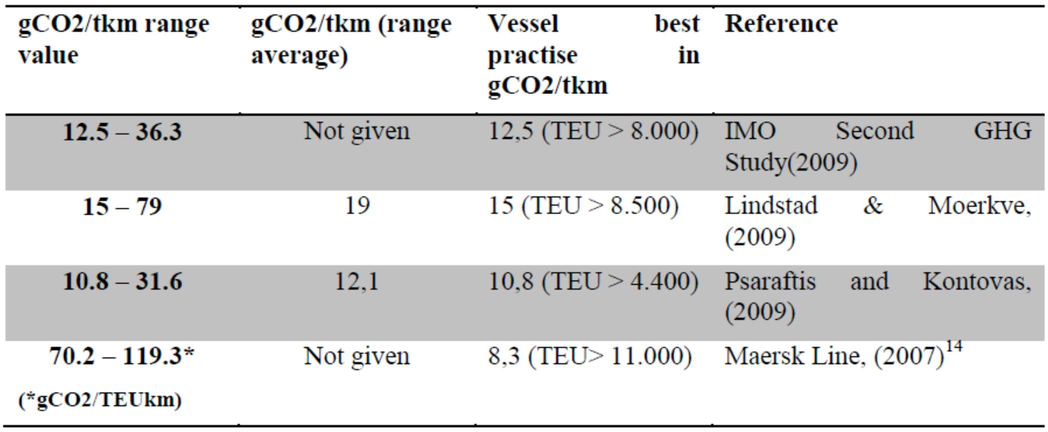
Table 23 shows the results of task 2.4 concerning KPIs indicators of the Silk Way corridor. The results are retrieved from SuperGreen deliverable D2.4v2 [Ilves et al., 2010].

Table 23 Silk Way baseline KPIs (Source: Task 2.4, [Ilves et al., 2010]).

SuperGreen KPIs	**Rail**	**Road**	**DSS**
CO_2 (g/tkm)	41[22]	-	12.5-36.3[23]
NOx (g/tkm)	-	-	-
Cost (€/tkm)	0.050	-	0.004
Average speed (km/h)[24]	26	-	37-44.5
Reliability (%)	-	-	90
Frequency (no per year)	-	-	-
Sailing time (hours/trip)	-	-	840-984

Table 24 presents an overview of studies on the CO_2 emissions for deep sea container transportation [Ilves et al., 2010]. There are considerable differences in the average values of CO_2 emissions (in gr/tnkm). The underlying reason for these differences can be traced back to variations in the baseline for the respective studies (i.e. applied data/statistics and assumptions). Thus, elements such as (a) estimated utilisation of cargo capacity, and (b) level of detail of container fleet segmentation applied will have an impact on the provided results. Looking at segmentation of the world container fleet it is obvious that the more detailed the segmentation is, the more differentiated the reflection of the environmental performance will be. The latter is particularly relevant for explaining the variations in grCO_2/tkm range values between the studies.

Table 24 Overview of gCO_2/tkm emission for deep sea container transport (Source: Task 2.4, [Ilves et al., 2010])



gCO2/tkm range value	**gCO2/tkm (range average)**	**Vessel best practise in gCO2/tkm**	**Reference**
12.5 – 36.3	Not given	12,5 (TEU > 8.000)	IMO Second GHG Study(2009)
15 – 79	19	15 (TEU > 8.500)	Lindstad & Moerkve, (2009)
10.8 – 31.6	12,1	10,8 (TEU > 4.400)	Psaraftis and Kontovas, (2009)
70.2 – 119.3* **(*gCO2/TEUkm)**	Not given	8,3 (TEU> 11.000)	Maersk Line, (2007)[14]

Concerning the maritime routes, there is a deep sea service linking Shanghai to the Le-Havre- Hamburg region. The analysis of the two first technologies, namely waste heat recovery and intelligent temperature unit, focuses on a single journey only. This implies that for a deep sea carrier only the performance of one ship travelling from Shanghai to Hamburg will be analysed. The main goods transported in the corridor are consumer goods, and mode of transport is a large container vessel (e.g. TEU>8.000). The table below

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[22] Block Train

[23] TEU > 8000

[24] Calculation is based on the distance/transit time

refer to different studies focusing on disclosure of environmental performance of the deep sea trade between the Far East and Europe. Depending on the assumptions of taken by the different studies, the results of emitted gCO2/tkm vary. Further, the result applied for this benchmarking exercise is the details provided by the IMO Second GHG Study (2009).

The vessel operating the segment is a standard feeder container vessel used currently operating in the European short sea traffic, and the necessary details for carrying out the analysis were identified in SuperGreen deliverable D2.4v2 [Ilves et al., 2010].

For the third and final technology, Hybrid hydraulic drive terminal tractors, only the terminal operation is accounted for. Since SuperGreen has not derived any KPIs specifically for terminals, the impact of this technology will be based on available literature.

Concerning the rail routes, the Silk Way rail network is electrified. Differences in the voltage and the rail gauges are met at country borders along the corridor. Poland, Germany and China use standard gauge 1435 mm. Russia has its own gauge 1520 mm. Due to these differences, a block train is formed in Zabaykalsk at the Russian/Chinese border. For electric traction, emissions depend on the energy mix supplied to network. The rail service linking Far East to Europe via Russia is based on a regularly scheduled transport with a fixed route and departure days. According to the EcoTransIT online calculation tool the total distance from Shanghai to Duisburg is approximately 11000 km. For cargo transport, the rail link between Shanghai/ Beijing and Duisburg takes approximately 18 days from terminal to terminal. The average load factor is 60%.

4.6.2 LU13 & LU14: Braking energy recovery & on-board energy storage systems

Regenerative braking is a mature and relatively standard technology in new trains. A conventional electric train braking system uses dynamic braking, in which the train kinetic energy is dissipated as waste, like heat. With the use of regenerative braking, the current in the electric motors is reversed, slowing down the train, while the motors generate electricity and return it to the power distribution system. This electricity can be used to power other trains, or to offset power demands of other loads, like lighting[25]. Friction brakes are still needed as backup in the case that the regenerative brakes fail. However, the power recovered via regenerative braking can only be used simultaneously. In order to recover this energy at a different phase in time, an energy storage system is required.

Super-capacitors, batteries, and/or flywheels can serve as energy storage systems. A flywheel is a mechanical device with a significant moment of inertia used as a storage device for rotational energy. Flywheel energy storage or the rotational energy of a flywheel, and rechargeable electric traction batteries are also used as storage systems. Batteries are electrochemical energy storage systems. A super-capacitor is a tool offering very high electrical capacitance in a small package.

On-board energy storage systems deliver an enormous potential for energy saving in traction applications. The most suitable vehicle application might be a Diesel Multiple unit where energy storage (LU14) and reuse of brake energy (LU13) can recover the normally wasted brake energy and lead to energy savings up to 30 to 40%, [communication with

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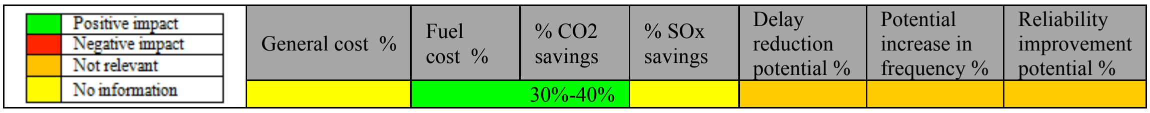
[25] http://climatetechwiki.org/technology/regenerative_braking_in_trains#Status of the technology and its future market potential

RailEnergy[26] project]. This saving can be measured directly in terms of reduced fossil fuel consumption per 100km. In addition there will be emission savings in the same order or even higher, since the small diesel engine can be operated in an optimal fashion. The optimal size and operation mode of such a storage system depends on the considered application and operating conditions.

Reversible DC substation is able to recover into the upstream network the regenerative braking energy; this is done by association of controlled rectifier/inverter with specific control to be able to recover the braking energy between the nominal voltage (Un) and maximal voltage (UMax2) according to the EN standard ref EN 50163. The advantages against the baseline technologies are:

- Maximum efficiency over parallel inverter, storage systems (Flywheel and Supra Capacitors).
- Diode rectifier to be able to cancel braking resistors on board of traction units.

The effects from the application of LU13 and LU14 on the rail routes connecting Shanghai to Brest/Malaszewicze and Slubice Kunowice are assessed. For the LU13 & LU14 combination, the estimation for energy savings is 30 to 40%. Thus, the block train CO_2 emissions would drop from 41gr/tkm (baseline) to the range of 24.6-28.7 gr/tkm. The energy savings would, also, affect the transport costs, as the electricity bill would benefit from the consumption reduction. However, this is difficult to quantify, since no relevant information is available in the baseline description.



🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟨	🟩 30%-40%	🟩	🟨	🟧	🟧	🟧

Figure 23. LU13 & LU14: Performance data considered in the SilkWay case.

4.6.3 FU26: Waste heat recovery

The technology passes exhaust gases from the ship's main engine through a system of heat exchangers, in order to generate steam for a turbine driven generator and, in turn, produces electrical power that assists ship propulsion or supplies shipboard services. Such a system has the potential to provide an overall reduction of emissions up to 10%. This will have a significant impact on fuel consumption, especially for deep sea trades. It is also a technology that has proven concepts and is being implemented by the industry.

Since the majority of costs for waste heat recovery systems mostly refer to the point of acquisition /installation, it is assumed that the transport cost is not significantly affected. This means if installed in a vessel it will increase the capital cost in comparison to a vessel without this technology. However, in terms of energy savings the technology has a potential to provide overall savings in energy consumption in the range of 4-10%. This is a considerable amount for vessels consuming approximately 150-225 tonnes of fuel per 24 hours, mostly being dependent on average sailing speed (24-21 knots).

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[26] http://www.railenergy.org/

No other KPIs will be affected as the main purpose of the technology is to reduce the overall energy consumption, and thus the environmental impact of the vessel during operation.

However, the most important aspect with this technology is that is allows for overall reduction in energy consumption without necessarily reducing the vessel speed.

4.6.4 HC02: Intelligent temperature unit

The main objective of this technology is to monitor the cargo inside the containers, which is particularly relevant for cargo with specific transport requirements (e.g. temperature, moisture, etc.). This aids the transport service provider to better monitor the status of the cargo transported, and in case of undesirable changes in "transport climate" provide an immediate signal (for insurance/claims reasons). This improves the reliability of service, which in turn affects the integrity for the service provider. As mentioned above the intelligent temperature unit only impact the KPI "Reliability", although unfortunately it is difficult to quantify its real impact. Nevertheless it is important to support the development of such technologies of two main reasons:

- The customers will better understand when, where and why possible changes in transport temperature occur.
- For the service providers the technology provides important information for introducing specific measures for improving the service quality, which in turn affects the reliability of the service. This is mainly due to the intelligent temperature unit ability to identify which disruptions occur during transit, in addition to why and how they occur.

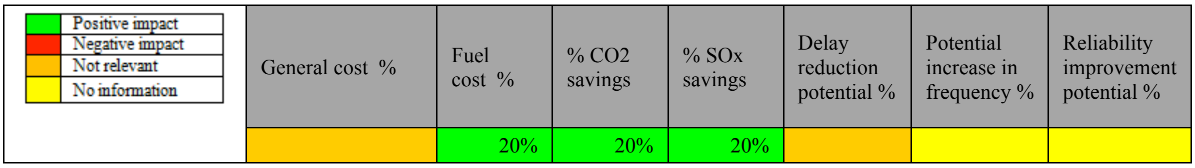
🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟧	🟧	🟧	🟧	🟧	🟧	🟩

Figure 24. HC02: Performance considered in the SilkWay case.

4.6.5 HT03: Hybrid hydraulic drive terminal tractors

Although not directly having an impact on the Silk Way KPIs, it is important to include this technology to describe its greening impact at local level (i.e. the terminal), since the vessel spends a considerable amount of time quay-side. As such, the development of terminal tractors propelled by hybrid technology is important for reducing the local emissions from port operations, but in energy consumption and noise. As mentioned, the Hybrid hydraulic drive terminal tractors have no direct impact on the KPIs developed by the SuperGreen project, mainly since the impact of this technology is limited to terminal operations. Thus, information regarding the environmental impact of applying this technology will be derived from existing literature.

However, to be more concrete about the technology, its main objective is to enable the terminal tractors to generate, recover, store and reuse braking power with very little air pollution. This is realised by a unique hydraulic hybrid power train, and in combination with the use of the cleanest diesel technology, it is estimated that the vehicles fuel consumption can be improved with as much as 20%[27]. Argued benefits from applying such technology are among others: greater uptime, as no re-charging is necessary, no additional investment in refuelling equipment, and no requirement for battery pack replacement or the disposal of pollutants. Further, considering the implementation of this technology across different fleets operating the different ports, the environmental savings are most likely significant [Kalmar, 2010]. Also, the expected savings in energy consumption will naturally also materialise itself in equivalent reductions in CO_2 and SOx.



🟩 Positive impact
🟥 Negative impact
🟧 Not relevant
🟨 No information

General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
🟧	🟩 20%	🟩 20%	🟩 20%	🟧	🟨	🟨

Figure 25 HT03: Performance considered in the SilkWay case.

4.6.6 Benchmarking results

The estimated changes of the baseline SilkWay corridor performance are summarised in Table 25.

Table 25 Green technologies impact on the Silk Way baseline performance. The KPIs are: Cost, CO_2 emissions, SOx emissions, Average speed, Reliability and Frequency. In the case that the impact on a KPI could not be assessed due to data unavailability, the KPI is omitted from the Table for brevity.

Technology name		Mode	**KPI**	**Baseline**	**Benchmark**		**Impact on baseline performance**	
					Min	**Max**	**Min**	**Max**
LU13 & LU14: Braking energy recovery & on-board energy storage systems	LU13 & LU14	Rail	**CO_2 emissions [gr/tn.km]**	41	24.6	28.7	30%	40%
Waste heat recovery	FU26	Maritime	**CO_2 emissions [gr/tn.km**	12.5-36.3	11.25 – 12	32.67 –34.85	4%	10%
Intelligent temperature unit	HC02	Maritime	**Reliability [%]**	90%	+90%		Positive	
Hybrid hydraulic drive terminal tractors	HT03							

5 Multi-corridor green technologies

5.1 FU08 & FU3: Liquefied (LNG) & compressed (CNG) natural gas

Natural gas (NG) is a cleaner alternative to diesel fuel oil, offering environmental and economic benefits from the reduced emissions, price and taxation. As a fuel, it is compressed (CNG) or liquefied (LNG) and it is characterised by high methane concentration and close to zero sulfur and PM content, compared to diesel fuel oil. Figure

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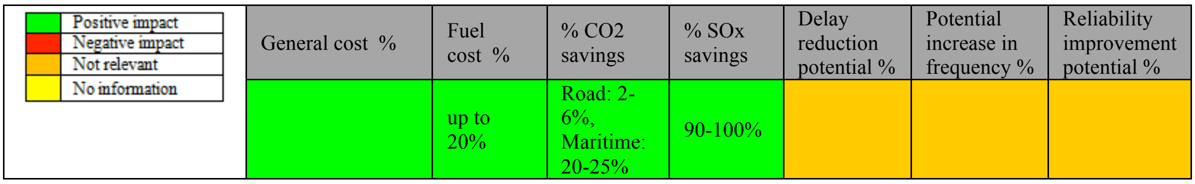
[27] Learnings from field testing at the PSA Singapore Terminals

26 presents the high level benchmarking performance that has been estimated for LNG and CNG.

In the following paragraphs, the use of LNG or CNG as multi-modal purpose fuels is discussed.



🟩 Positive impact 🟥 Negative impact 🟧 Not relevant 🟨 No information	General cost %	Fuel cost %	% CO2 savings	% SOx savings	Delay reduction potential %	Potential increase in frequency %	Reliability improvement potential %
	🟩	🟩 up to 20%	🟩 Road: 2-6%, Maritime: 20-25%	🟩 90-100%	🟧	🟧	🟧

Figure 26 LNG and CNG performance according to the high level benchmark.

5.1.1 Road corridors

The history of natural gas vehicles (NGVs) dates back to 1920, but they were overwhelmed by the low cost diesel fuelled ones [Fryczka, 2004]. The interest in NGVs started again after the two oil shocks in 1974 and 1979 and increased during the last two decades, because of the environmental alerts on the impact of diesel fumes. Currently, there is an increasing number of NGVs in Europe and fuel stations with compressed natural gas (CNG), many of which are integrated into petrol stations.

The most important advantages of using natural gas instead of diesel for heavy duty trucks are the health and environmental benefits. NGVs have reduced carbon emissions compared to diesel ones. In [Krupnick 2010], an effect of 2-6% tank to wheel (TTW) GHG reduction from CNG used in heavy duty vehicles compared to diesel fuel was reported. According to [IEA 2012], a 7% GHG reduction could be achieved under real-world driving conditions, if CNG is used instead of diesel. A report prepared for the California Energy Commission in 2007 [TIAX LLC, 2007] on the full fuel cycle assessment of heavy duty vehicles indicated a CNG energy impact of -2% to +8% and a GHG reduction of 11-23%.

From a safety aspect, NGVs are as safe as petrol vehicles, if the safety measures are taken. Natural gas leakages lead to dissipation of the gas in the atmosphere, whereas diesel (or petrol) leaks on the ground increase the potential of fire hazard.

According to [IEA 2010], fuel taxes tend to be a large portion of end-user fuel prices in OECD countries. For motor fuels, the minimum levels of taxation in January 2010 were 330 euro per 1000 litres of diesel oil and 2.6 euro per GJ of natural gas. According to NGV statistics for 2011, the average CNG price per litre diesel equivalent is 0.80 euro compared to the diesel price of 1.42 euro/lt. However, the cost comparison should be made on an energy equivalent basis (since natural gas contains less energy per unit volume). In addition, a spark ignition engine is typically used for CNG vehicles, which is less efficient than a diesel engine. However, if the diesel efficiency is maintained and a dual-fuel conversion of a heavy duty vehicle is used, then the fuel consumption will be similar to diesel. In this regard, a general estimation for road transport cost impact is not straightforward and an analysis on case dependent transport features would be required.

The capital cost to buy a heavy duty NGV is generally higher than a conventional diesel one, but the prices vary widely. This is mainly due to the scale of production of the NGVs.

However, if the environmental regulations make the "green" diesel options[28] more expensive, then the natural gas fuelled trucks could become a more viable solution in the future.

Apart from the vehicle cost, a very important aspect is the natural gas refuelling infrastructure. The EC project GasHighWay, launched in 2009 under the Intelligent Energy Programme, aimed at promoting the uptake of gaseous vehicle fuels and creating a first international access guide to methane in transport [GasHighWay, 2012]. The GasHighWay project concluded that it would be essential to ensure a coherent public policy framework that would support the switch to natural gas [GasHighWay, 2012]. A European rollout plan and a harmonised strategy for CNG investments were recommended and a set of measures have been suggested, like reduced taxation, special permits for NGVs, increase of awareness, priority lanes and others. The countries analysed in the GasHighWay project were: Sweden, Finland, Estonia, Latvia, Lithuania, Czech Republic, Poland, Austria, Germany and Italy. The SuperGreen corridors that run across these countries are: Brenner, Strauss, Two Seas, SilkWay, Nureyev and Edelweiss.

Even though the use of natural gas for transportation in Europe is rising[29], the current main drawback is the lack of bunkering infrastructure. The current status of natural gas refuelling networks varies among EU countries and regions. In this regard, the development of wide transport corridors with sufficient number of LNG refuelling stations at intermediate nodes would prove beneficial for the increase of natural gas use in multimodal European transportation. Future development of NG refuelling infrastructure should be considered on a corridor level, in order to allow the adoption of this fuel for long distance international trips.

5.1.2 Maritime corridors

LNG for shipping is a proven and safe technology, and an alternative to after-treatment systems to reduce SOx, NOx and PM emissions. LNG is currently used by 30 vessels, as of July 2012, and the new-building order book has approximately the same number of ships. The interest on LNG will increase in the future due to the environmental regulations on sulfur (MARPOL 73/78 Annex VI) and carbon emissions (Energy Efficiency Design Index and Ship Energy Efficiency Management Plan, IMO 2011), and the estimated lower fuel consumption. The estimated CO_2 emissions reduction is 20-25% compared to diesel oil. There are two challenges regarding this reduction: first, the unburned methane (the so-called methane slip) and, second, possible release of methane through the total NG transport chain. Using LNG as a marine fuel, NOx emissions are reduced by 90%, and SOx and PM emissions are eliminated.

The main engine specific fuel consumption is lower for the LNG case (including the pilot fuel) compared to marine diesel oil (3.5% at maximum continuous rating, MCR). Large vessels can benefit more from LNG compared to small ones, due to the economy of scale in the installation. Another important benefit of natural gas is that the noise level reduces during trip.

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[28] vehicles that include various technologies to meet the environmental regulations, like NOx and PM reduction technologies.

[29] http://www.ngvaeurope.eu/ngv-market-growth-in-europe-1995-2010

From a technical point of view, the installation of the cryogenic LNG fuel tanks may require a reduction in cargo capacity. This depends on the type of vessel and system complexity.

The price of LNG varies from country to country. According to EIA and IEA projections, the LNG price is likely to rise to $400-1200 per tonne in 2035, starting from a range of $300-800 per tonne in 2010. DNV has conducted a study on the uptake of gas/dual-fuelled marine engines towards 2020, investigating different pricing scenarios [DNV Publication 2012, *Shipping 2020*]. The scenarios correspond to different LNG prices ranging from 30% of HFO to 110%. Depending on the scenario, a number of 500 to 1500 ships could have achieved a GHG emission reduction of 30 to 35% by 2020, implementing gas fuelled engines, smaller engine/de-rating and hull shape optimisation. Based on the fuel price projections of EIA and IHS up to 2030, it is estimated that, for a typical ship and a lifecycle perspective, LNG is expected to be a better option than HFO with scrubber, whereas MGO is expected to be the most expensive alternative[30]. However, these estimations could change, as there is high uncertainty about the future fuel prices and the LNG prices could continue to develop in a different way at different regions of the globe, depending on the local market trends, politics and the future global economy growth.

Regardless of price uncertainties, LNG is the cleanest of fossil fuels and it is a viable solution to reduce carbon, NOx, SOx and PM emissions. The development of LNG terminals at strategic points across Europe would facilitate the adoption of LNG as a marine fuel in the future.

5.1.3 Inland water way corridors

Similarly to the marine applications, LNG can lead to almost 100% tank-to-propeller sulfur emission reduction compared to ultra-low sulfur bunkers (EN590). According to [Schweighofer, 2005], a 19% GHG emission reduction can be achieved from the use of natural gas for inland water way transport, instead of diesel oil.

According to the EC-funded PLATINA[31] project on the acceleration of the implementation of the NAIADES action programme, "*switching to LNG will only happen if there is enough supply and infrastructure, and enough supply and infrastructure will only be built if a substantial part of the fleet switches to LNG.*" In this direction, the EC-funded *LNG for Danube* project[32] will investigate the benefits and the bottlenecks from using LNG as inland water navigation fuel and as cargo in Danube.

5.1.4 Hubs & transhipment points

Apart from transport fuel, natural gas can be used also for hub operations. CNG can be used as a fuel in lift trucks and fork lifts in transhipment points and logistics hubs[33]. Apart from the energy savings, the reduction of emissions would bring benefits to the occupational environment.

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[30] http://blogs.dnv.com/lng/

[31] http://www.naiades.info/platina/

[32] http://www.naiades.info/platina/page.php?id=103&path=102&article=1912

[33] http://www.iangv.org/natural-gas-vehicles/vehicle-types/

5.2 NA16: Route optimisation

In Task 3.1 [Recagno et al, 2011], the route optimisation systems were identified as technologies for maritime and inland waterway transportation. For both modes, such systems assist the vessel operator in selecting the best route that reduces fuel consumption for inland or maritime trades. If fuel savings are achieved, emissions are also reduced. For maritime transport, route optimisation systems feature weather routing, speed and trim optimisation, allowing for safer and energy efficient operations. In the following paragraphs, the technology is analysed per mode of transport, providing with information on relevant success case stories.

5.2.1 Maritime

Fuel savings and emissions reduction can be achieved by optimising the way that a vessel is operated. Route optimisation measures are: (a). the optimal speed selection, (b). the weather routing and (c). trim optimisation.

Speed optimisation aims to define the optimal vessel speed that leads to fuel savings depending on the freight rates and bunker fuel price – charter agreement. As a result, the optimal speed depends on the relation between total costs and fuel costs. In general, the fuel savings vary from case to case. A survey of speed models in maritime transportation, as well as a taxonomy of these models according to a set of parameters is presented in [Psaraftis and Kontovas, 2012].

Weather routing technologies are computer software programs that support the vessel operator to select the optimal vessel route for which the fuel consumption is minimised given the weather conditions, such as wind, waves, currents, etc. Fuel savings depend on the route and the weather conditions. Training of the navigation officers is required, in order to ensure the best use of the system. The cost of installing a weather routing system varies between $500 and $10000, according to a study by Marintek[34]. A success case story from Applied Weather Technology, Inc. claims fuel savings of up to 8% from individual voyages using a weather routing tool[35].

Trim optimisation aims to determine the most favourable wave pattern for each individual vessel, which leads to lower energy consumption. Success case stories from container transportation using the DNV trim optimisation service show off up to 3.5% savings for selected voyages [DNV Publication 2012, *Fuel Saving Guidelines*].

5.2.2 Inland water ways

Optimal route planning in inland waterways aims at energy savings, by advising the skipper to optimally select the route and speed of the vessel, in order to arrive on time with a most efficient use of fuel. The technology benefits were analysed in [Schweighofer et al, 2006], in the framework of the EC-funded project CREATING (Concepts to Reduce Environmental impact and Attain optimal Transport performance by Inland NaviGation). According to this study, up to 10% reduction of NOx, PM and CO_2 emissions can be achieved.

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[34] http://www.sustainableshipping.com/technology/weather_routing

[35] http://www.sustainableshipping.com/news/i77602/Weather_routing_software_could_save_180_million_in_fuel_costs

5.3 FU26: Waste heat recovery

Waste heat recovery systems exploit the thermal energy of the diesel engine exhaust gases, in order to produce steam and, via a steam turbine, additional power on-board. Depending on the engine size, heat recovery systems can bring benefits of 4% to 10% increase of the main engine power output. Their installation requires certain space, which could lead to reduced cargo capacity. For this purpose and because of the economy of scale, waste heat recovery systems are more attractive for large vessels.

5.3.1 Deep sea shipping

Combined cycle systems with waste heat recovery are promising solutions for increasing the energy efficiency of marine power production plants for deep-sea shipping. The drawbacks are higher capital costs, space and weight requirements, as well as operational constraints and system complexity. However, based on the optimal design of such systems positive net present value can be achieved.

In [Dimopoulos et al, 2011], the optimal design of a waste heat recovery system for a 4500TEU ocean-going containership was performed using process system modelling and simulation of the complex marine plant, including the main engine, the turbocharger , the waste heat recovery system and the steam turbine. The net present value (NPV) of the investment was maximised and the optimal waste heat recovery design was determined with regards to time-varying operation and thermodynamic constraints. The routes considered involve trading between Asia/Pacific and Europe, including trips along the SilkWay corridor. The optimisation yielded fuel savings and cost effectiveness for the overall life time of the vessel. The use of waste heat recovery was proved to be cost-effective for a wide range of market conditions and fuel prices. The payback period of the investment was 8 years and the overall system efficiency was of 51.31%, with relevant CO_2 emission reduction. The study showed that combined cycle systems are attractive for the present and near-future deep sea shipping industry.

The LNG-powered ECO-Ship is an open hatch bulk carrier concept, developed by Oshima Shipbuilding and DNV in 2011, which is estimated to emit half the CO_2 emissions of a traditional bulk carrier of similar type and size [DNV Publication 2011, *Eco-ship*]. Regarding fuel cost, currently, LNG is cheaper than oil; however, there is uncertainty on the future prices. Regarding emissions, by using LNG as a marine fuel, the ECO-Ship is expected to emit about 20% less CO_2, 90% less NOx and zero particulates and sulfur compared to oil-fuelled vessels. The ECO-Ship concept also includes a waste-heat recovery system that leads to about 5% additional fuel savings at normal speeds.

Waste heat recovery (WHR) systems will be included in the Mærsk Triple E class[36] vessels, which are upcoming large, fuel-efficient container ships, designed as successors to the Mærsk E-class vessels. The vessels are expected to reduce CO_2 per container by 50% compared to typical ships' emissions on the Asia-Europe route[37]. The ships are planned to be 400 metres long and 59 metres wide; i.e. only 3 metres longer and 4 metres wider than E-class ships, though able to carry 2,500 more containers that the E-class. They will be

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[36] Triple E class is for three design principles: "Economy of scale, energy efficient and environmentally improved".

http://www.maerskline.com/link/?page=news&path=/news/news20110221

[37] http://www.enn.com/business/article/42386

able to pass through the Suez Canal when sailing between Europe and Asia. The targeted optimal speed for these vessels is 19 knots, compared to 23–26 knots of similar ships. According to the literature[38], the propulsion and hull systems will be designed for slow steaming at 20 knots, which would reduce fuel consumption by 20% at 22.5 kts, 37% at 20 kts and 50% at 17.5 kts. The WHR is expected to cost about $10 million[39].

5.3.2 Short sea shipping

Due to the capital cost and the space requirements, it is difficult to implement cost efficient heat recovery systems in small ships. The overall cost and energy efficiency depends on the size of the vessel, the engine and the design of the heat recovery system.

Heat recovery systems for short-scale applications exist in the market[40], addressing the inland water ways, short sea shipping and railways industries.

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[38] http://articles.maritimepropulsion.com/article/Maersk-Orders-10-Triple-E-Class-18000TEU-Container-Ships-1264.aspx

[39] http://www.motorship.com/news101/maersk-orders-10-green-mega-boxships

[40] http://www.voithturbo.com/applications/vt-publications/downloads/1809_e_g_2161_e_steamtrac_2011-02-15_screen.pdf,

http://www.motorship.com/ news101/voith-enters-waste-heat-recovery-market

6 Benchmarking results

In this section, the benchmarking results from all the case studies above are summarised. The results are shown in Table 26. Compared to the baseline performance of road transport networks, an improvement of up to 8% in operating cost and 26% in CO_2 emissions can be achieved. The picture could change if the capital cost is included in the assessment and the return of investment is evaluated on a full corridor basis. For the analysed maritime cases, the introduction of energy efficiency measures can bring up to 20% reduction of CO_2 emissions. An improvement of about 38% on the average speed could be possibly achieved if better cargo handling systems were used. SOx after treatment systems can reduce the total transport chain SOx emissions by more than 73%. Natural gas fuels like LNG and CNG are the cleanest fossil fuels that can serve the shipping and road industries. The energy settlement systems in railways can provide with energy savings up to 15% and 30%. Finally, optimal design of waste heat recovery systems can provide economic benefits in large cargo flows with deep sea shipping.

Table 26 Detailed SuperGreen benchmark. Cost KPI: estimated fuel cost savings. Emissions KPI: emissions reduction potential. Average speed KPI: potential increase in speed of service. Frequency of service: potential increase of trips. Reliability of service: potential improvement of reliability (cargo safety and security, on-time delivery). The KPIs are: Cost, CO_2 emissions, SOx emissions, Average speed, Reliability and Frequency. In the case that the impact on a KPI could not be assessed due to data unavailability, the KPI is omitted from the Table for brevity.

Technology name		**Corridor**	**Mode of Transport**	**SuperGreen KPI**	**Impact compared to baseline [%]**
Hybrid trucks	VE03	Brenner	Road	Cost [euro/tn.km]	6% to 7%
				CO_2 emissions [gr/tn.km]	25%
Aerodynamic drag improvements	VE29	Brenner	Road	Cost [euro/tn.km]	3% to 4%
				CO_2 emissions [gr/tn.km]	10% to 26%
				SOx emissions [gr/tn.km]	13% to 25%
Low rolling resistance tires	VE33	Brenner	Road	Cost [euro/tn.km]	0% to 1%
				CO_2 emissions [gr/tn.km]	2% to 4%
Card-board pallets	CP01	Brenner	Multi-modal	Cost [euro/tn.km]	Positive impact
				CO_2 emissions [gr/tn.km]	
Waste heat recovery systems	FU26	Mare Nostrum	Maritime	Cost [euro / tn.km]	1% to 5%
				CO_2 emissions [gr / tn.km]	2% to 5%
				SOx emissions [gr/ tn.km]	1% to 5%
Exhaust abatement systems	EN21	Mare Nostrum	Maritime	Cost [euro / tn.km]	-4% to -1%
				SOx emissions [gr/ tn.km]	90% to 96%
Integrated short sea transport	BP08	Mare Nostrum	Maritime	Average speed [km/hr]	5% to 8%
Contra rotating propeller	EN61	Nureyev	Maritime	CO_2 emissions [gr / tn.km]	5% to 15%
				SOx emissions [gr/ tn.km]	4% to 16%

Mechanical azimuth thrusters	EN06	Nureyev	Maritime	CO_2 emissions [gr / tn.km]	0% to 20%
				SOx emissions [gr/ tn.km]	0% to 21%
Wind propulsion - Sails	FU25	Nureyev	Maritime	CO_2 emissions [gr/tn.km]	0% to 15%
				SOx emissions [gr/tn.km]	0% to 14%
LNG	FU08	Nureyev	Maritime	CO_2 emissions [gr / tn.km]	10% to 20%
				SOx emissions [gr/ tn.km]	98% to 100%
Cargo casette translifter	HT11	Nureyev	Maritime	Average speed [km/hr]	0% to 38%
				Frequency of service [times / year]	0% to 6%
				Reliability [%]	0% to 6%
Exhaust abatement systems	EN21	Strauss	IWW	Cost KPI [euro/tn.km]	0% to 1%
				CO_2 emissions [gr/tn.km]	-5% to 8%
Route optimisation systems	NA16	Strauss	IWW	Cost KPI [euro/ tn.km]	1% to 1%
				CO_2 emissions [gr/tn.km]	10% to 10%
				SOx emissions [gr/tn.km]	10% to 10%
LNG	FU08	Strauss	IWW	CO_2 emissions [gr / tn.km]	10% to 19%
				SOx emissions [gr/tn.km]	95% to 100%
Aerodynamic drag improvements	VE29	Cloverleaf	Road	Cost KPI [euro/ tn.km]	2% to 8%
				CO_2 emissions [gr/tn.km]	10% to 26%
				SOx emissions [gr/tn.km]	10% to 26%
Hybrid trucks	VE03	Cloverleaf	Road	Cost KPI [euro/ tn.km]	13% to 23%
				CO_2 emissions [gr/tn.km]	25%
				SOx emissions [gr/tn.km]	10% to 26%
EREX	BP13	Cloverleaf	Railways	Cost KPI [euro/ tn.km]	1%
Braking energy recovery & On-board energy storage systems	LU13 & LU14	Silkway	Railways	CO_2 [gr/ tn.km]	30% to 40%
Intelligent temperature unit	HC02	Silkway	Multi-modal	Reliability [%]	Positive impact
LNG & CNG (for road)	FU08 & FU03	Multi-corridor	Road	CO_2 emission reduction potential	11-23%
			Maritime		20-25%
			IWW		similar to maritime
			Hubs		positive
			Road	NOx reduction	Positive (similar to maritime)
			Maritime		90%
			IWW		similar to maritime
			Hubs		positive
			All modes	SOx	Tank-to-Wheel: ~0%
Route optimisation	NA16		Maritime	Fuel savings	3.5-8% depending on the measure (§5.2.1)

				Average speed	Positive influence
				Reliability	
			IWW	NOx, PM, CO2 emissions reduction potential	10%
Waste heat recovery	FU26		Maritime	Fuel savings	Differs depending on size and complexity. Indicatively, 7%
				Emissions reduction	Relative to fuel savings

7 Conclusions

In this report, the results of the SuperGreen Task 3.3 were presented. The objective was to create a benchmark of multi-modal green technologies, which shows their potential greening benefits and drawbacks compared to the conventional technologies. The impacts from applying various technological solutions on European transport corridors were estimated and compared to the current performance; thus, a benchmark of the green corridors with green technologies was created.

The green technologies and their application areas were identified in Tasks 3.1, 3.2 and the first stage of Task 3.3. The benchmark was created with respect to the SuperGreen Key Performance Indicators (KPIs) of Task 2.2 [Paalsson et al., 2010], namely the relative cost (Euro/tn.km), the CO_2 and SOx emissions (gr/tn.km), the average speed (km/hr), the reliability (%) and frequency of service (times per week or year). The current corridor performance (baseline) was derived from SuperGreen Task 2.4 [Ilves et al., 2010].

The benchmark was created via a stepwise methodology. The KPIs were decomposed into factors, linking them with the performance specifications of the green technologies. Then, the green technology performance was analysed independently of the application area with regards to factors of the KPIs. Finally, the greening impacts were assessed with respect to the current corridor performance for selected case studies.

A set of 59 green technologies of all modes of transport (excluding air) and various technology categories was analysed with regards to the effects on the KPIs and the conventional technologies used in the corridor. An average percentage of 35% of positive influence on all KPI factors for all technologies was estimated, 39% of which was described in a quantitative manner. The baseline performance changes were shown on selected case studies, for which there was sufficient data availability. Each case was a combination of a green technology and a set of corridor segments and nodes.

6.2 Suggestions for future research

The work performed on the benchmarking of green corridors with green technologies led to the following conclusions:

- The creation of a benchmark of green corridors with green technologies is possible. However, a clear quantitative definition of all KPIs is required, including the reliability and quality of service. Detailed factorisation of each KPI is needed in order to assess as many as possible aspects for all the indicators. In addition, other social aspects should be included for all technologies, such as noise reduction, land use and safety.
- The need for statistical information on corridors' transport flows and their features is of great importance.
- A representative baseline is required. This would involve a large survey on long distance transport operations with multimodal coverage per corridor.
- Further work is necessary for the estimation of the performance changes of the technologies.
- Future research on the benchmarking of the green corridors should consider the adoption capacity of green technologies on an aggregated level (fleet basis). The inclusion of capital cost is of great importance in order to evaluate the return of

investment from each technology on a corridor level.
- Future analyses should create large cargo volume case studies for intermodal transport.
- Future studies should include indices related to regulatory barriers or benefits on national and/or community level, as well as the infrastructure capacity to support the adoption of the technologies.

To conclude, this work can serve as a basis for a detailed investigation of green technology applications on the European corridors, which will shed more light on their greening potential and will contribute to a solid understanding of the most promising solutions on a corridor level, for further practical implementation.

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