Green Technologies and Smart ICT for Sustainable Freight Transport

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Abstract Sustainable freight transportation is high on the European and international agenda. The EC White paper of Transport 2012 denotes technological innovation as a key part of the future strategy "to achieve a faster transition to a more efficient and sustainable European transport system". In the context of the 60 % GHG emission reduction target for the EC transport sector, deployment of sustainable fuels, energy-efficient propulsion systems and smart information systems will be needed. Green corridors, a new EU concept for long-distance and perhaps large-flow transport networks, is planned to serve as platform for demonstration and later adoption of environmental-friendly, innovative transport solutions and intelligent transport systems. The EU project SuperGreen (1/2010–1/2013), 'Supporting EU's Freight Transport Logistics Action Plan on Green Corridors Issues', aimed to support the definition and benchmarking of green freight

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corridors through Europe with respect to environmental, technical, economic, social, and spatial planning aspects. In this framework, a set of representative EC freight corridors has been assessed and comparatively evaluated against the potential use of advanced technologies and intelligent information/communication technologies. This paper presents the methodology developed and applied for the assessment and benchmarking of corridors with advanced technologies. A set of more than 200 technologies has been assessed against their possible impact on the corridor performance. Advanced technologies for engine and propulsion systems, fuels and energy sources, navigation technologies, cargo handling systems, heating and cooling technologies, vehicles (road and rail vehicles, and waterborne vessels), best practices, and innovative units were analysed. Also smart Information and Communication Technologies (ICT) such as single window systems, expert charging systems, centralised and decentralised transport systems and others could achieve tangible benefits in terms of improving the corridor Key Performance Indicators (KPIs). Case studies and examples are presented.

Keywords Green corridors · Benchmarking · Green technologies · ICT

1 Introduction

In 2007, the European Commission (EC) introduced the green corridor concept for long distance transport networks, to promote environmental sustainability and energy efficiency in the transport industry [1]. Green corridors could serve as a platform to demonstrate the use of environmentally-friendly technologies, advanced information systems and logistic solutions towards sustainable transportation [2].

The objective of the SuperGreen project (1/2010–1/2013) was to support the EC in defining and benchmarking European corridors against their sustainability footprint and greening potential. The project targets were:

- To develop a corridor benchmarking methodology against key performance indicators (KPIs) on the environment, economy and service quality;
- To analyse the role of advanced technical measures, the so-called green technologies, and Information and Communication Technologies (ICT) towards the goal of greener corridors;
- To provide the EC with recommendations on green corridor, stemming from the experience of public and private transport stakeholders;
- To recommend policy strategies and future Research and Development (R&D) on green corridor development.

The purpose of this paper is to present the SuperGreen approach on the impact assessment of green technologies and ICTs on existing EC corridors. The current corridor performance, the so-called baseline, is compared to the case that green technologies and ICTs are implemented on the corridors.

The paper is structured as follows. Section 2 presents the SuperGreen project outline. In Sect. 3, the benchmarking of corridors with green technologies is described. Section 4 presents the benchmarking of corridors with ICTs. Section 5 summarises the conclusions of this work.

2 The SuperGreen Project

SuperGreen[1] is a 3 year Coordination and Support Action research project co-funded by the 7th EC Framework Program and the project partners. It was kicked-off in January 2010 and finished in January 2013. The project consortium consisted 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 main project phases were:

- Identification of European corridors;
- Definition of corridor KPIs;
- Evaluation of baseline corridor KPIs;
- Collection of data on green technologies and smart ICT systems, suitable to be applied on the corridors to improve performance and solve bottlenecks;
- Benchmarking of green corridors with green technologies and smart ICT;
- Recommendations for R&D calls;
- Policy implications;
- Dissemination of results.

2.1 EU Corridor Baseline

The first project activity was to define a set of representative European corridors to test the project methodology. After a series of consolidation rounds, 9 corridors were screened out of 60 candidate ones, based on the TEN-T priority projects,[2] the Pan European Transport Network[3] and project partner's proposals. Particular attention was paid to the coverage of long distance routes serving large freight volumes by all transport modes apart from air. The SuperGreen corridors are shown in Fig. 1 [2, 3].

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

2 http://ec.europa.eu/transport/themes/infrastructure/index_en.htm.

3 http://ec.europa.eu/transport/themes/infrastructure/ten-t-implementation/extending/pan-european_corridors_en.htm.

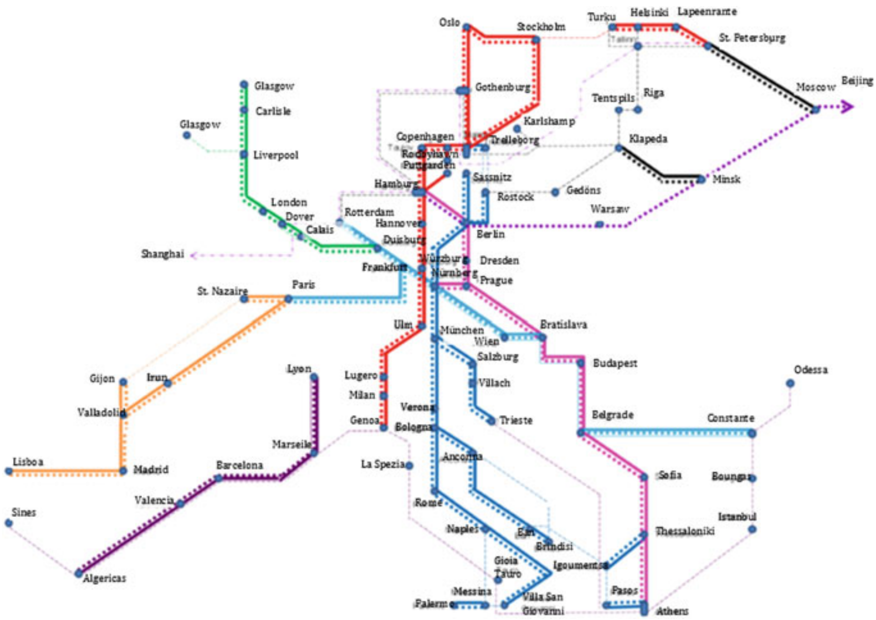

Fig. 1 The SuperGreen corridor network [2]

Then, a methodology was developed to evaluate the baseline performance against sustainability KPIs and reveal areas for future improvement. Since no corridor benchmarking study was found in the literature, the methodology was drawn upon past experience on transport chains [2, 4, 5]. In this respect, the SuperGreen methodology examines a corridor by decomposing it into transport chains, calculating their KPIs, and, finally, aggregating the results at the corridor level. After a series of dedicated workshops, the following KPIs were identified [2]:

- Relative cost (€/tn.km);
- Average speed (km/h) (or transport time, in hours);
- Reliability (% of shipments delivered within acceptable time window);
- Service frequency (no of trips per year);
- CO_2 (gr/tn.km);
- SO_x (gr/tn.km).

Some extra KPIs were also identified, such as congestion, land use, traffic safety and noise. A quantitative definition of these KPIs was not considered and few data about them were collected. Thus, these extra KPIs were excluded from the baseline evaluation, although they were considered in the qualitative benchmarking of ICTs, as discussed in Sect. 4.

Table 1 presents the corridor baseline. Information about the transport chains was collected by means of a survey on transport operators over the corridors. The

Table 1 Baseline corridor benchmark [2]

Corridor	Mode	Cost (€/tn.km)	Av. speed (km/h)	Reliability (%)	Service frequency (no/year)	CO_2 (gr/tn.km)	SO_x (gr/tn.km)
Brenner	Inter-modal	0.03–0.09	9–41	95–99	26–624	10.62–42.11	0.02–0.14
	Road	0.05–0.07	19–40	50–99	104–2600	46.51–71.86	0.05–0.08
	Rail	0.05–0.80	44–98	50–100	208–572	9.49–17.61	0.04–0.09
	SSS*	0.04	23	100	52	16.99	0.19
Clover-leaf	Road	0.06	40–60	80–90	4.68	68.81	0.09
	Rail	0.05–0.09	45–65	90–98	156–364	13.14–18.46	0.01–0.02
Nureyev	Inter-modal	0.10–0.18	13–42	80–90	156–360	13.43–33.36	0.03–0.15
	SSS	0.05–0.06	15–28	90–99	52–360	5.65–15.60	0.07–0.14
Strauss	IWW**	0.02–0.44	–	–	–	9.86–22.80	0.01–0.03
Mare nostrum	SSS	0.003–0.2	17	90–95	52–416	6.44–27.26	0.09–0.4
	DSS***	–	–	–	–	15.22	0.22
Silk way	Rail	0.05	26	–	–	41	–
	DSS	0.004	20–23	–	–	12.5	–

*Short sea shipping
**Inland waterways
***Deep Sea Shipping

transport chain performance was evaluated using: (1) the survey results, (2) a literature review on baseline technologies and (3) the Ecotransit[4] tool, to calculate the vehicle emissions. The results are expressed as ranges of values that correspond to the minimum and maximum values of the transport chain KPIs [2, 3, 6].

2.2 *Benchmark Objective*

The next project milestone was two-fold:

- First, to assess the potential impact of green technologies to be applied on the corridors, in order to improve the KPIs and solve bottlenecks.
- Second, to define and exploit the role of ICT flows towards the goal of greener transport.

The next sections present the SuperGreen approach and the results for the benchmarking of corridors with green technologies and ICTs.

[4] http://www.ecotransit.org/.

3 Benchmarking of Green Corridors with Green Technologies

To develop a green corridor benchmark with green technologies, the steps below were followed:

Step 1: Survey on green technologies for all transport modes apart from air, on the basis of past and current research projects at national, European and international level.

Step 2: Screening of the technologies that could significantly improve the corridors KPIs and solve bottlenecks. This activity included a non-corridor specific assessment of the technology effects on the KPIs.

Step 3: Identification of green technology application areas over the corridors.

Step 4: Technology impact assessment on the corridor baseline (corridor-specific analysis) and development of a green corridor benchmark. This process required:

(a) Quantitative data on the technology impact, validated against real-life performance; and

(b) Detailed data about corridor transport routes, such as traffic volumes, frequency of service, delivery time and vehicle features.

Since such data were not available for all corridors, a limited set of benchmark scenarios was produced based on the baseline transport chains (Sect. 2) and the green technology review.

3.1 Green Technology Survey and Qualitative Assessment

A survey on green technologies was conducted, collecting data from manufacturers, research and academic works, and the project consortium. The survey resulted in a list of 200 representative technologies of the following categories: engine and propulsion systems, fuels and sources of energy, navigation technologies, cargo handling systems, heating and cooling technologies, vehicles and vessels, best practices, and innovative units with their treatment [7].

By applying a 6-level qualitative ranking scheme, the initial technology list was reduced to a smaller set of 58 technologies that could significantly improve the corridor KPIs, according to project expert judgment. The top and bottom ranks denoted mature technologies with positive potential and technologies with low impact to the KPIs, respectively [7].

Then, a matrix was created showing possible application areas for the 58 green technologies over the corridors. The matrix was populated based on expert judgement from both inside and outside SuperGreen. The results are publicly available through a web-based repository (http://88.32.124.84/SuperGreen/Login.aspx).

3.2 Benchmark Scenarios

After an extended review on industry and academic works [8–11], the impact of the 58 green technologies on the KPIs was quantified. The analysis was technology-specific and it was based on publicly available manufacturer data, technology success stories and research project results. To facilitate this assessment, the KPIs were further decomposed into factors and mapped to technology performance data [12]. For instance, a green technology that reduces fuel consumption can potentially help to reduce fuel cost, which is an important factor of the operating cost. It has to be noted that the selected factors reflect the size of available information and the targeted resolution of the analysis. Figure 2 presents an overview of the green technology impact on the KPI factors. The impact is expressed as the percentage of green technologies with positive, negative or neutral influence on the factors.

The development of the green corridor benchmark was based on the technology-specific analysis. The benchmark consisted of 20 scenarios; each scenario corresponded to a baseline transport route, combined with a green technology that would improve the route performance. Then, using simple algebraic calculations, the potential impact in route KPIs was estimated [12].

Tables 2 and 3 present the green corridor benchmark. Uncertainty regarding the baseline calculations and the technology impact may have affected the results. Due to lack of data about capital costs for some of the green technologies, the return of investment and its impact on the operating cost were not considered. This reduced the resolution of the analysis, to include only the effects on fuel consumption.

Compared to the baseline KPIs for road transport routes, an improvement of up to 7 % in operating cost and 26 % in CO_2 emissions can be achieved by aerodynamic truck design improvements and hybrid power systems. The picture would change if the return of investment is included in the analysis. For the maritime

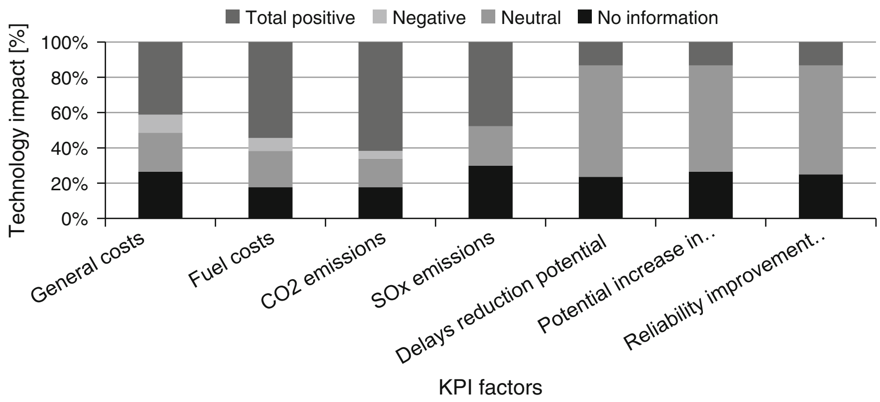

Fig. 2 Estimated impact of the green technologies on a set of KPI factors (horizontal axis). The vertical axis shows the percentage of technologies (number of technologies per total technology number)

Table 2 Green technology benchmark scenarios: Mare Nostrum, Nureyev, Strauss and silk way corridors

Scenario	Technology	KPI	Impact (%)
Mare Nostrum—SSS: container liner service between mediterranean ports	Waste heat recovery systems	Rel. cost (€/tn.km)	1–5
		CO_2 (gr/tn.km)	2–5
		SO_x (gr/tn.km)	1–5
	Exhaust abatement systems	Rel. cost (€/tn.km)	−4 to −1
		CO_2 (gr/tn.km)	−4 to −1
		SO_x (gr/tn.km)	90–96
	Integrated SS transport	Av. speed (km/hr)	5–8
Nureyev—SSS: container vessel serving a port-to-port connection linking Rotterdam and Helsinki	Contra rotating propeller	CO_2 (gr/tn.km)	5–15
		SO_x (gr/tn.km)	4–16
	Mechanical azimuth thrusters	CO_2 (gr/tn.km)	0–20
		SO_x (gr/tn.km)	0–21
	Wind propulsion–sails*	CO_2 (gr/tn.km)	0–15
		SO_x (gr/tn.km)	0–14
	LNG	CO_2 (gr/tn.km)	10–20
		SO_x (gr/tn.km)	98–100
	Cargo cassette trans lifter	Av. speed (km/hr)	0–38
		Serv. Freq.(no/year)	0–6
		Reliability (%)	0–6

(continued)

Table 2 (continued)

Scenario	Technology	KPI	Impact (%)
Strauss—IWW: JOWI class container vessel, serving Rotterdam-Duisburg segment	Exhaust abatement systems	Rel. cost (€/tn.km)	0–1
		CO_2 (gr/tn.km)	−5–8
	Route optimisation systems	Rel. cost (€/tn.km)	1
		CO_2 (gr/tn.km)	10
		SO_x (gr/tn.km)	10
	LNG	CO_2 (gr/tn.km)	10–19
		SO_x (gr/tn.km)	95–100
Silk way—rail: connection between China and Poland	Braking energy recovery and on-board energy storage	CO_2 (gr/tn.km)	30–40
	Intelligent temperature unit	Reliability (%)	Positive

The benchmark scenarios and the green technologies are described in columns 1 and 2, respectively. The technology effect on the baseline KPIs is shown in columns 3 and 4

Table 3 Green technology benchmark scenarios: Brenner and Cloverleaf corridors

Scenario	Technology	KPI	Impact (%)
Brenner corridor–road: route between Verona and Berlin operated by heavy duty EURO V type refrigerated trucks	Hybrid trucks	Rel. cost (€/tn.km)	6–7
		CO_2 (gr/tn.km)	25
	Aerodynamic drag improvements	Rel. cost (€/tn.km)	3–4
		CO_2 (gr/tn.km)	10–26
		SO_x (gr/tn.km)	13–25
	Low rolling resistance tires	Rel. cost (€/tn.km)	0–1
		CO_2 (gr/tn.km)	2–4
	Card-board pallets	Rel. cost (€/tn.km)	Positive impact
		CO_2 (gr/tn.km)	
Cloverleaf–road: fleet of Euro IV trucks of 24–40 t capacity case study, serving the link between London and Duisburg	Aerodynamic drag improvements	Rel. cost (€/tn.km)	2–8
		CO_2 (gr/tn.km)	10–26
		SO_x (gr/tn.km)	10–26
	Hybrid trucks	Rel. cost (€/tn.km)	13–23
		CO_2 (gr/tn.km)	25
		SO_x (gr/tn.km)	10–26
Cloverleaf–rail: electrified long train operating between Midlands and Duisburg	Energy settlement systems	Rel. cost (€/tn.km)	1

The benchmark scenarios and the green technologies are described in columns 1 and 2, respectively. The technology effect on the baseline KPI is shown in columns 3 and 4 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. SO_x after treatment systems can reduce the total transport chain SO_x emissions by more than 73 %. Fuels like liquefied natural gas (LNG) and compressed natural gas (CNG) are among the cleanest fossil fuels that can serve the shipping and road industries. The energy settlement systems in railways could provide with energy savings. Finally, the optimal design of waste heat recovery systems can provide with economic benefits in large deep sea shipping cargo flows. It is worth to mention that the results are case-dependent and cannot be generalised for any other transport route. Also, the benchmark does not imply any endorsement on the routes and/or the green technologies, by the SuperGreen consortium, or the EU Commission.

3.3 Implementation of Exhaust Gas Abatement Systems in the Mare Nostrum Corridor

In this paper, the benchmark scenario for exhaust gas abatement systems on the Mare Nostrum corridor is presented; any other scenario of Table 2 could be shown instead. The Mare Nostrum corridor includes Mediterranean and Black sea trade routes, with rail and road connections linking the ports to inland networks. The scenario is about a container liner service amongst the ports of Barcelona, Valencia, Gioia Tauro, Piraeus and Istanbul, operated once a week by feeder vessels of about 2,000 TEUs.

To estimate the green technology impact, a typical operating vessel profile must be considered. An average engine load of 75 % during the trip and 50 % at port was assumed. The mean distance sailed was 1,425 km, with a delivery time of 55 h and a speed of 14 knots. The time at port was 17 h. A typical freight loading factor of 70 % was considered.

3.3.1 Green Technology Description

Under the International Maritime Organisation (IMO) air pollution regulations [13], exhaust gas cleaning systems, like scrubbers, are one technical option to mitigate sulphur emissions, with alternative fuels like LNG or low-sulphur marine diesel oil being the other technically known options. Scrubbers can remove sulphur from the engine exhaust gas up to 99 % by using chemicals, seawater, or dry scrubbing technology. Due to the scrubber power needs, the overall fuel consumption increases, thereby increasing the CO_2 emissions [14]. The scrubber installation may require on-board vessel alterations, like additional tanks, pipes, pumps, effluent water treatment system. Extra operational costs may occur, if chemicals solvents are in use.

Currently, scrubbers are not widely used in the Mare Nostrum corridor. Such technologies have been installed in vessels sailing in the Baltic Sea, due to the regulatory regime in that region.

3.3.2 Benchmarking of Scrubbers on the Mare Nostrum Corridor

According to the literature [15], scrubber operation may increase fuel consumption by 2–3 %. This would influence fuel costs and CO_2 emissions. SO_x cleaning efficiency could be as high as 99 %. SO_x emissions reduction would depend on the engine loading and the operating profile of the scrubber.

For the Mare Nostrum scenario, the green technology impact was estimated:

- Relative cost: Assuming a range of values for the fuel consumption rate and the bunker oil price, the negative technology effect on fuel costs was estimated at about −1 to −4 %.
- CO_2 emissions: The negative effect on baseline CO_2 emissions was at the range of −1 to −4 %.
- SO_x emissions: For continuous scrubber operation, the SO_x emissions reduction could reach 96 %. In case that the scrubber is not operated below 50 % engine load, the reduction of emissions would be about 75 %.

4 Benchmarking of Green Corridors with Smart ICT

To develop a green corridor benchmark with ICTs, the steps below were followed:

Step 1: Conduction of a specialised expert ICT workshop (held in Genoa, Italy).
Step 2: Assessment of the results of the above ICT workshop.
Step 3: Non-corridor specific description of the ICT systems under investigation, including data about basic functionalities, cost, funding mechanisms, and other technical performance characteristics.
Step 4: Corridor-specific investigation on the existence of ICTs on the corridors and future implementation plans for ICTs, if any. Other relevant data could be also collected.
Step 5: Based on step 4, inter alia, investigation of potential impact of ICT on the KPIs of a corridor.
Step 6: Synthesis and interpretation of the results.

The above sequence of steps may look easier than it really is. As mentioned in Step 5, ideally one would like to obtain a precise quantification of the potential impact of a specific ICT on the corridor KPIs. However, our experience revealed that in many cases such a goal turned out very difficult or sometimes impossible to achieve, due to the following reasons:

(a) Data necessary to quantitatively compute the ICT impact on corridors generally proved to be difficult or elusive to obtain. This is due to reasons such as general unavailability or lack of information, unwillingness of operators or other sources to reveal such data (if any), and non-homogeneity in data quality. The problem of data availability (such as cargo flows) is recognised in the EU. In some cases, estimates of such data can be produced based on mathematical models. A fortiori, any linkage of such data with particular ICTs is even more complicated.
(b) In contrast to the green technologies (Sect. 3) that can have a direct and tangible impact on the corridor KPIs, the impact of ICTs on the greening of a corridor is of a different nature. For instance, an innovative propulsion system consumes less fuel, resulting in less CO_2 and SO_x emissions. On the other hand, a broadcasting ICT can result in no CO_2 emission reductions in and of itself, but it could do so, if it is appropriately used by the operator. Similarly, a ship may reduce speed, if it is known that there is congestion at the next port of call, a truck may use a different route, if an expert toll system is used, and so on. The same is true for most of the KPIs. The way such information is used (if actually used at all) is at the discretion of the human operator and as such does not lend itself to ease of measurement. The same is true for systems such as the European Railway Traffic Management Systems (ERTMS), expert charging systems, single-window systems and other ICTs examined. Actually, some of these ICTs (for instance, platooning) have not yet reached the implementation phase. Either way, the potential performance of these systems depends more on the way these systems are used and less on the systems themselves.

In that sense, it was proven difficult to connect all ICTs with the KPIs in a precise quantitative way and a qualitative evaluation was followed. Still, for some ICTs we managed to get some quantitative results, but as these are only indicative and case-specific, caution should be exercised in any attempt to generalise them. If anything, they can only be considered as clues as regards the validity of postulated conclusions.

Below we only give a summary of the results. Full details can be found by visiting the SuperGreen web site.

4.1 Qualitative Assessment

In the workshop held in Genoa, a dedicated questionnaire was constructed in order to collect data and evaluate the importance of a set of proposed ICTs:

- Adaptive speed control;
- Congestion charging;

- ERTMS;
- Freight transport information technology solutions (Fretis) or compatible system;
- Installation of sensors on-board vehicles;
- Single window systems;
- Platooning;
- River information systems;
- River tolls;
- Tracking units.

The ICTs were clustered in the following functional groups:

- Expert charging systems;
- Centralised transportation management systems;
- Decentralised transportation management systems;
- Broadcasting, monitoring and communication systems;
- Safety systems;
- E-administrative systems;
- Emissions footprint calculator systems.

Also, a first qualitative assessment of the ICTs impact on the corridors was performed. As expected, there was a large variation on the results, because of the different application areas and ICTs considered. For example, the Congestion Charging ICT seems to have an important effect on the congestion KPI and rather unimportant on the KPIs of Cargo Security and Safety.

4.2 Benchmark Scenarios

The next target was to develop the green corridor benchmark with ICTs. A set of 15 benchmark scenarios was constructed (Table 4), aiming to reveal the importance of ICT implementation on the corridors. The importance level had 5 grades, plus the ability to characterise the importance as "unknown". The benchmark scenarios were compiled by individual experts or subgroups of experts, during the Genoa workshop. The material was collected and processed, resulting in a corridor-specific ICT benchmark with respect to the KPIs. An example (only one among several) for the mean importance of the Congestion Charging ICT on the KPIs is shown in Fig. 3.

Table 4 ICT benchmark scenarios

Scenario no	Corridor	Mode	ICT
1	Mare nostrum	SCM	Tracking units
2	Brenner	Road	Expert charging
3	Brenner	Rail	ERTMS
4	Two seas	Road	Broadcasting
5	Silk way	Maritime	Emissions calc
6	Silk way	Rail	ERTMS
7	Edelweiss	Road	Emissions calc
8	Finis terrae	Maritime	JUP
9	Finis terrae	Rail	ERTMS
10	Strauss	IWT	RIS
11	Strauss	IWT	Expert tolls
12	Nureyev	Maritime	E-admin
13	Nureyev	Maritime	Icebreaker assignment/IBnet
14	Cloverleaf	Road	Platooning
15	Cloverleaf	Road	Safety-speed control

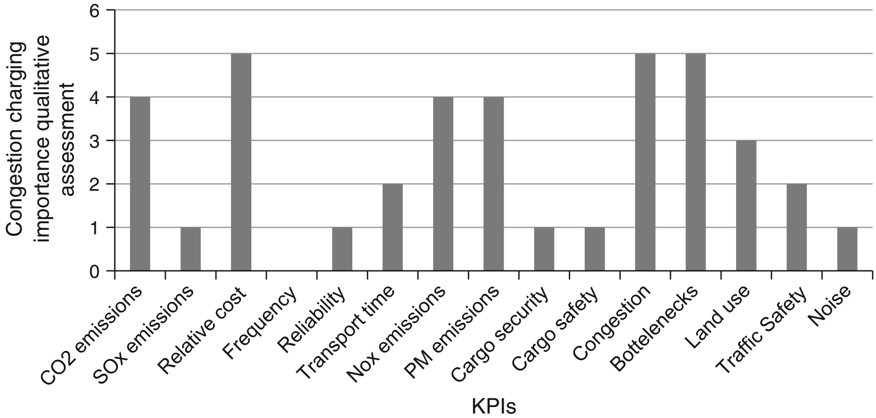

Fig. 3 Mean importance of Congestion Charging ICT on the corridor KPIs

4.3 *Implementation of Expert Charging ICT in the Brenner Corridor*

We have selected to present one example among the scenarios of Table 4, on the Expert Charging ICT over the Brenner corridor. This corridor concerns freight transport from Berlin, Germany to Palermo, Italy and Athens, Greece through the Italian peninsula. It involves crossing of the Alps through the Brenner Pass,[5] as

[5] Important route for road freight transport crossing the Alps.

well as crossing of the Ionian and Adriatic seas. It also includes the Tauern axis (Salzburg-Trieste).

4.3.1 General Description of Expert Charging ICT

EC countries are implementing various ICT regarding nationwide road pricing schemes, due to rising levels of traffic congestion and emissions. Some examples are:

- The road tax on vehicles (vignette) used in Central European countries, such as the German highway truck toll system, or the Swiss performance-related heavy vehicle fee (HVF), where the toll amount depends on the route, and the truck pollutant category, class (e.g. Eurocode), weight and number of axles.
- The Congestion Charging ICT, such as the Stockholm congestion tax, introduced in 2006 to reduce traffic congestion in Stockholm during peak hours, and the London congestion tolls. These systems surcharge the users of a transport network in periods of peak demand, to reduce traffic congestion.
- The "Pay as you drive" (PAYD) ICT, where the Automobile Insurance is determined by how much and for what purpose the vehicle is used.

Since congestion charging ICTs are designed mainly for urban applications and the PAYD ICT is used for insurance purposes, our analysis focuses in ICT systems similar to the German highway truck toll system.

4.3.2 Expert Charging ICT Status on Corridor

There are four countries involved in the corridor: Germany, Austria, Italy and Greece. In Germany, an expert charging system for trucks is already implemented, the so-called LKW-Maut. In January 2004, Austria introduced an electronic toll collection system for trucks over 3.5 t, using the Dedicated Short-Range Communication (DSRC) technology. In Italy, the toll price is proportional only to the distance travelled. In order to calculate the toll, the truck driver has to withdraw a ticket from an automatic dealer before entering the highway, returning it at the toll gate on exit. In case that the truck is equipped with a Telepass OBU (an automatic toll collection device), the ticket is not necessary. In the Greek segments of Brenner corridor, there is a toll for every specific highway, but not always based on distance travelled. This case by case charging is based on truck weight and emissions class. Greek e-toll systems use Radio-Frequency Identification (RFID) sensors and tags, in order to automatically detect passages from gateways. The process is also performed manually due tellers. The main anticipated benefit of such systems is the extent to which they can be used, to internalise the external costs of transport.

4.3.3 Benchmarking of Expert Charging ICT

As a result of the truck tolling program implementation in Brenner Corridor, freight companies will have an incentive to purchase vehicles with lower emission rates and shippers to use eco-friendlier transportation modes. The UK Commission for Integrated Transport cites [16]:

- 6 % decrease in the number of empty runs and
- 6 % modal shift to rail from road freight mode as a result of implementing the truck toll system.

We expect similar results for the Brenner corridor, including the segments in Italy, where it has not yet been introduced. Also, these factors are likely to decrease CO_2 emissions and other pollutants.

A negative consequence of the freight toll system is the shift of some trucks off the highways and onto other non-central roads, resulting in additional emissions, noise and congestion on these routes.

Last but not least, an indirect but potentially significant effect of expert charging ICTs can be that revenues generated by them can be used as 'offsets', that is, to invest in green technologies that can reduce emissions, either on the specific corridor, or elsewhere. Such 'out of sector' emissions reductions can be as significant as 'in sector' reductions.

Similar analyses were performed for the benchmark scenarios of Table 4, but are not reported here due to space limitations.

5 Conclusions

In this paper, the results of the SuperGreen project on the benchmarking of green corridors with advanced technologies and ICTs were presented. The main objective was to estimate the technology impact on the baseline performance of representative European corridors with respect to energy efficiency, environmental footprint, reliability and service quality. The benchmark also shows the technology potential benefits and drawbacks compared to conventional practices.

5.1 Green Technologies and Corridors

It was shown that there is wide potential for improving the performance of the European corridors. Green technologies are expected to have positive impact in corridor sustainability. Using the SuperGreen KPIs, that positive effect was estimated up to 35 %, a percentage of 39 % of which was described in a quantitative manner. The green technology effects on baseline performance were shown on 20 benchmark scenarios, for which there was sufficient availability of data.

This work revealed the need for adequate and consistent statistical information on transport corridor flows that would allow a precise quantification of the European corridor baseline. Future research on the benchmarking of the green corridors should consider the adoption capacity of green technologies on an aggregated level (fleet basis), including their return of investment. To facilitate the adoption of green technologies, future analyses should examine large-volume transport paradigms, considering indices related to regulatory barriers, benefits on national or community level and infrastructure capacity. Detailed investigation of green technology applications on the European corridors will shed light on their sustainability potential and contribute to a solid understanding of the most promising greening solutions.

5.2 *Smart ICTs and Corridors*

The introduction of ICTs in the SuperGreen corridors will generally have a positive effect in terms of cost, time, safety, security, environmental sustainability and reliability.

It is our belief that the results of this work support the general conclusion that the proposed ICTs have the potential to make logistics greener and constitute a "win–win" option for logistics stakeholders. The benefits would affect fuel economy, operation time variables, safety and reliability. At the same time, it was also seen that there are cases in which deployment of ICTs may have adverse impacts on some KPIs. Caution is necessary in these cases.

There was no clear forerunner in the benchmarking analysis, since there are multiple evaluation criteria. These KPIs are societal or private criteria affecting profitability, environmental impact and social safety and security. What is clear is that all the examined ICTs can provide vital benefits to all the stakeholders involved in the transport process. Another critical point apart from the installation of the systems is the integration with existing systems. Integration and smooth information flows are key points to maximise the positive effect of these systems.

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