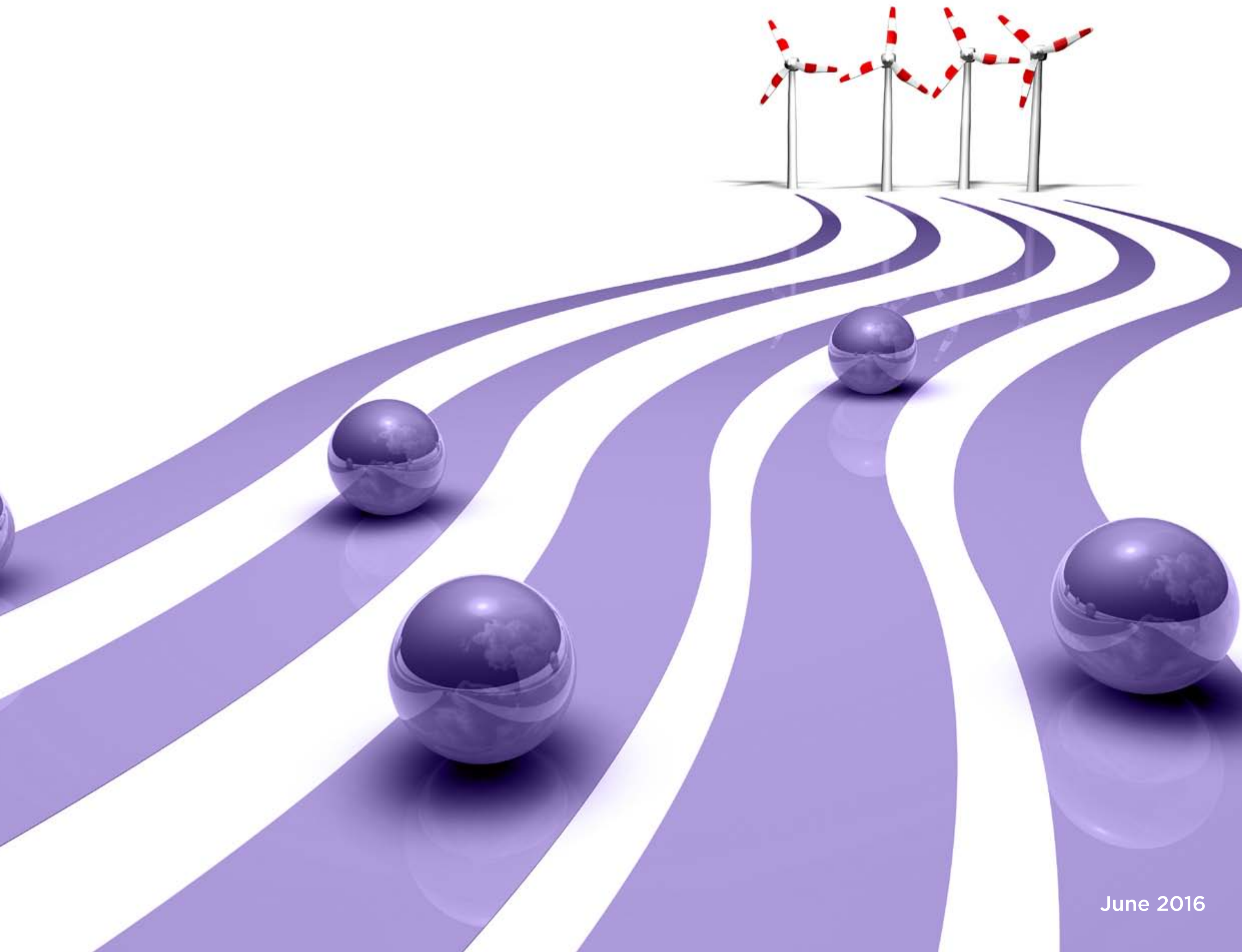
INTERNATIONAL UNION
OF RAILWAYS

Carbon Footprint of Railway Infrastructure

Comparing existing methodologies on typical corridors
Recommendations for harmonized approach



June 2016

978-2-7461-2500-1

CONTENTS

EXECUTIVE SUMMARY

The carbon footprint of transport infrastructure is often neglected when looking at the carbon content of passenger and freight trips. This is also the case for the railway sector, where there is limited incentive to mitigate the CO_2 emissions of railway infrastructure, even though carbon emissions inventories over the lifetime of railway infrastructures have been becoming more popular. Similarly, most eco calculation tools do not include infrastructure carbon content for any mode of transport as part of the CO_2 emissions of trips.

In order to investigate what a harmonized approach could look like, this report compares, qualitatively as a first step, ten existing reports and literature (the "methodologies") to gauge how the methodologies compare with each other in terms of calculation approaches, boundaries, standardization, applicability, etc. (Table ES1)

ELEMENTS ASSESSED	01 IFEU	02 UCB	03 RFF	04 ITALFERR	05 JBV	06 NTNU	07 CUENTAS	08 AEA	09 INECO	10 UIC
Stations	x	x	x	x				x		x
Tunnels/Bridges	x		x	x	x	x	x	x	x	x
Catenary	x	x	x	x	x	x	x	x		x
Signalling and telecommunications	x	x	x	x	x	x	x	x		x

Table ES1: Example of elements of railway infrastructure included in the assessment of the methodologies

Each methodology has been described in detail in a harmonized way, with reference to the original source, so that all statements can be tracked, and methodologies compared with each other in a similar way (See full methodology check list in Annex II). The most critical point encountered in assessing the data in a comprehensive way has been the lack of transparency of some methodologies, where assumptions are not communicated in the publicly available reports, and confidentiality issues impeded the sharing of underlying information to be analyzed in this report.

Following such in-depth review of the methodologies, the second phase of the study quantitatively calculated the effect of the methodology on results. Three typical corridors representative of the three most relevant types of railway traffic (high speed, suburban and freight) have been selected.

For each corridor, some of the selected methodologies have been applied to quantify the carbon footprint of the three cases, to explain the differences in results among the methodologies and to analyze the methodology most suitable for implementation in different cases. After performing all this analysis, the Ifeu / Tuschchmid (IFEU, 2010) study commissioned by UIC appears to be the most accurate, transparent, transposable methodology that could be used for most corridors and give accurate and reliable results with a reasonable amount of data needed. A sensitivity analysis on some key parameters shows that tunnels and bridges are the one key criterion to look at closely when calculating the carbon content of railway infrastructure.

When including the infrastructure carbon footprint on top of the CO_2 emissions during operation of the train, the rail sector remains largely competitive compared with other motorized modes (Figure ES1), on typical high speed corridors where trains compete with cars and planes. As the share of electrified passenger trains increases, and as the carbon intensity of electricity improves, the CO_2 emissions of trains can come close to zero. Green certificates also decrease the carbon intensity of train travel. Including the carbon footprint of the infrastructure would add credibility to the eco tools and show increased transparency towards a more comprehensive lifecycle approach for carbon emissions.

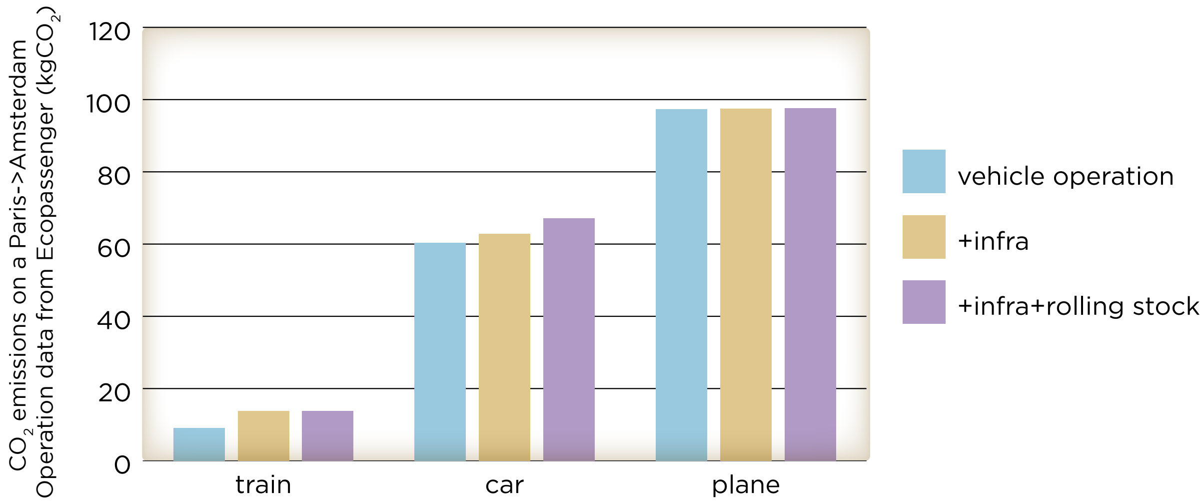


Figure ES1: CO_2 emissions of the main transport modes including operation, infrastructure and rolling stock on a typical European journey. Source: EcoPassenger.com and 01 – IFEU, Tuchschmid

The report also calculated the payback time necessary to mitigate the initial CO_2 emissions due to rail infrastructure construction, thanks to the modal shift from more carbon-intensive modes. For all three cases studies, the payback time is shorter than the average lifetime of the infrastructure for which some maintenance work is necessary. So building new railway lines saves CO_2 after one to three decades, mainly depending on the traffic assumption. Traffic is a key factor for a rapid payback, and so careful traffic estimation has to be performed during the planning phase of a new railway infrastructure.

Looking forward, the rail sector should add railway infrastructure calculations to Eco-tools to increase transparency and widen the boundaries, improving the consistency of the calculations. Given the high number of corridors included in Eco Passenger and Eco Transit tools, a rather simple approach is advised:

- For corridors that have a share of tunnels and bridges below 30%, a common, conservative and realistic value of around 50 tCO_2/km/year would be adopted following the values and the results using the IFEU/Tuschchmid methodology; on a case by case basis, lower emission factors could be used if railway operators could justify such lower values. To help put such a value into perspective, using total rail traffic (expressed in unit of transport UT) and global infrastructure length (IEA/UIC, 2015), 50 tCO_2/km/year of infrastructure would be equivalent to around 6 to 7 gCO_2/UT.
- For higher shares of tunnels and bridges, following the IFEU/Tuschchmid approach and the output tool would be the best way to get reliable and robust calculation of the carbon footprint of this kind of infrastructure.

Following such an approach, only the share of tunnels and bridges of each corridor would be needed, such information being available from the infrastructure operators, or using topography as a first proxy.

To further engage in carbon emission mitigation when maintaining or building new railway infrastructure, this report also advises including Carbon Arbitration Funds into the procurement of new railways. The Carbon Arbitration Funds would commit the bidders to performing detailed carbon emissions inventories and, more importantly, delivering on lowering carbon emissions during the construction phase of the railway infrastructure. Precedents in some European countries show a great potential for mitigating carbon embedded into the infrastructure in the most cost efficient way.

To conclude, including the carbon footprint of railway infrastructure in the Eco Tools would reward those making an effort to mitigate carbon emissions over the construction, re-construction and re-building of the line by using more carbon friendly techniques. It would create a win-win situation, where the rail sector reinforces its sustainability lead, and where infrastructure and railway operators are further committed to mitigating CO_2 emissions, and evaluating possible advantages of investments in railways as a solution to reduce carbon footprint in transport.

ACKNOWLEDGEMENTS

The report commissioned by the International Union of Railways has been produced by the independent consultant François Cuenot and coordinated by Gabriel Castañares Hernández, Senior Advisor of Energy and CO_2 to the Sustainable Development Unit of UIC.

Furthermore, the authors would like to acknowledge with much appreciation the crucial role of all the following UIC staff, members and partners in providing information and supervising the report:

> Nicholas Craven (UIC)

> Andrea Braschi (UIC)

> Iñaki Barrón (UIC)

> Takumi Ishii (UIC)

> Cheul-Kyu Lee (KRRI)

> Nozomu Ashida (JR Group)

> Freek Dankers (NS)

> Gerald Olde Monnikhof (ProRail)

> Malin Kotake (Trafikverket)

> Per Corshammar (Tüv Süd ApS)

> Lorenzo Radice (FSI)

> Henning Schwarz (DB)

> Matthias Tuchschmid (SBB)

> Fabian Scherer (SBB)

> Kjerkol Håvard (JBV)

> Alfonso Sanz Alduán (GEA21)

> Michelle Papayannakos (RSSB)

> Jonathan Casey (Atkins Global)

> Joachim Lémeri (Eiffage)

INTRODUCTION

The International Union of Railways (UIC) has a long history of quantifying the carbon emissions from the rail sector. Railways are among the most carbon efficient modes of mass transportation, with the highest share of electrification of all transport modes. Nonetheless, rail operators are keen to continue lowering the carbon impact of the railway sector, in order to make the sector an example and more attractive in drastically lowering carbon emissions for the whole transport sector.

One of the weakest and least harmonized approaches is the evaluation and estimation of the carbon content of the railway infrastructure over its life cycle. There have been some reports and study cases to estimate the carbon content of the railway sector's infrastructure, but the boundaries and the output results are not always consistent and often do not include the same parameters.

The tasks of this report commissioned by UIC are threefold:

> To gather the existing carbon footprint calculation approaches for rail infrastructure and to compare them in a qualitative, consistent and harmonized way, describing the parameters and indicators included.

> To apply a selection of methodologies identified for typical corridors, in order to assess the differences between the distinct approaches, and how they fare compared with each other, for different types of rail networks and operating conditions.

> To provide recommendations and potential best ways forward to develop a common approach for a carbon footprint methodology for railway infrastructure.

Building on this work, UIC could be in a position to offer their members common guidelines on carbon footprint determination for railway infrastructure. Such an agreed approach could be adopted by UIC members in order to provide incentives for green procurement and comparability for trip carbon content calculators.

THE TWO GOALS FOR EVALUATING THE CARBON FOOTPRINT OF INFRASTRUCTURE

The UIC's goal to have a better understanding of the different existing approaches to calculating the carbon content of railway infrastructure takes two forms:

Eco calculators

UIC and other stakeholders have deployed carbon footprint Eco calculation tools (also known as Eco Tools) to provide the carbon content for a given trip depending on the selected transport mode. Such tools (Ecopassenger.com for passenger services, EcoTransIT.com for freight, both developed by UIC) do not include the carbon content of the infrastructure (Figure 1). Including carbon emissions from infrastructure is not likely to alter the carbon competitiveness of the railway sector while making the communicated values more comprehensive, robust and transparent and thus increasing the credibility of these tools.

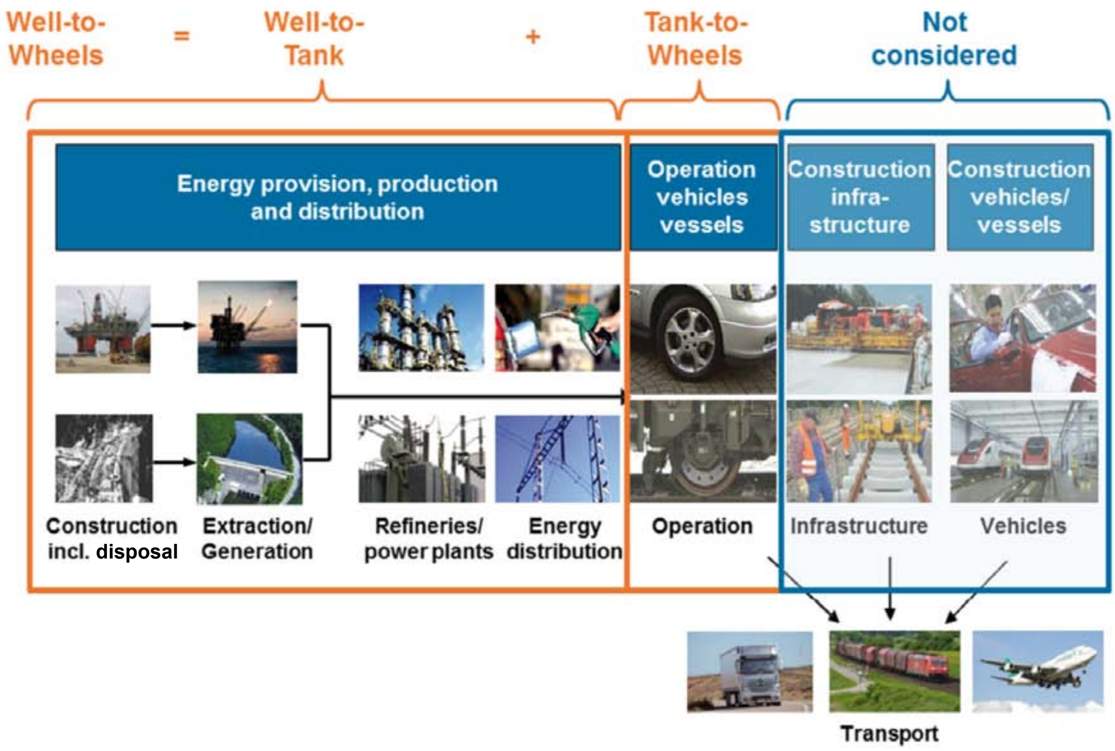


Figure 1: System boundaries for EcoPassenger and EcoTransit eco-calculators (Ifeu, 2015, Ifeu et al, 2014)

Green procurement

Quantifying the carbon content of existing and future rail infrastructure is only a first step. Engaging civil engineering companies in reducing their carbon emissions from building railway infrastructure through green procurement would provide a valuable asset to the rail sector for claiming ever lower carbon emissions for the services.

British Standards (BSI, 2012) include a methodology to calculate the carbon content of trips on the ticket (as already adopted in some countries to be displayed on transport tickets). Having conservative carbon content values for the infrastructure as default values would commit rail network providers to delivering a specific carbon content for any given infrastructure. This would increase knowledge and encourage a commitment to lowering carbon content during the construction phase of the rail infrastructure

Finally, Eco calculators and Green procurement are closely related, as including the infrastructure carbon footprint in Eco tools would offer a reward for best practices in carbon saving techniques to build the infrastructure. In addition, this would send a positive signal that low carbon construction of the infrastructure would be visible in Eco tools and rationalized.

PHASE I: COMPARING EXISTING METHODOLOGIES

The first and most intensive part of the project has been to gather, collect and compare the main existing methodologies for the carbon footprint of rail infrastructure. The list of studies and methodologies to be included in the comparative analysis has been provided by UIC (listed in Annex I).

The analyzed reports contain large discrepancies in the methods by which rail infrastructure was treated. Some studies cover a broad range of topics; the carbon content of rail infrastructure represents only a small part of the overall study scope. On the other hand, some studies go deeper into the rail sector and its infrastructure, down to minute details.

The first task of this phase has therefore been to harmonize the parameters, indicators and values included at the studies and to find out how they can be aggregated/disaggregated, knowing what the boundaries are and what is included in the calculation of infrastructure carbon footprint.

The list of reports / carbon footprint study cases of railway infrastructure analyzed in this report is given in Annex I. They are referred to below as "the methodologies". The methodologies have been read extensively to extract the most valuable information in relation to the carbon content of the railway infrastructure. A table summarizing each methodology is available in Annex II. The following parameters have been examined in particular:

- Transparency,
- Boundaries,
- Elements assessed,
- Applicability,
- Certification process.

All the parameters analyzed have been harmonized for every methodology in order to be able to perform a complete methodology comparison.

DATA TRANSPARENCY AND ACCESS

In order to be able to assess all the methodologies, the first step is to evaluate the extent to which the data were available and transparent. Many methodologies show just aggregated results without background information, or explanations about the process for obtaining the final values. Contact with the methodologies' authors did not always help in filling gaps in information, as some results are proprietary and so there was no possibility to share the full details of the numbering behind the published values.

Only three of the ten methodologies assessed have been rated as sufficiently transparent to provide a full understanding of what is behind the output values displayed in the publication (Table 1). The remaining methodologies could nevertheless be analyzed in some detail, but it was not possible to answer all the related questions.

		01 IFEU	02 UCB	03 RFF	04 ITALFERR	05 JBV	06 NTNU	07 CUENTAS	08 AEA	09 INECO	10 UIC
TRANSPARENCY	Illustration of calculation and assumption details	Medium	Good	Medium	Good	Bad	Bad	Bad	Bad	Medium	Medium
	Reporting of CO_2 emission factors	Good	Good	Medium	Good	Bad	Medium	Bad	Medium	Bad	Good
	Indication of the emission factor data sources	Good	Good	Medium	Good	Bad	Medium	Medium	Medium	Bad	Good

- Good: data fully available and traceable
- Medium: data source published but numbers not detailed
- Bad: no source or any detailed numbering

Table 1: Transparency rating of the methodologies

SYSTEM BOUNDARIES

To analyze the reports and studies, infrastructure carbon footprint has been split into four different phases:

1. Design: Planning railway construction mainly requires computers in engineering offices, a shorter phase in terms of time compared to the life time of the infrastructure.
2. Construction: Building railway tracks requires machines operating intensively for several years to adapt the topography to the rail line needs; material production and transport are also energy and carbon intensive activities.
3. Operation and maintenance: Infrastructure does not generally require any carbon intensive feature for the operation phase, except for the signalling systems along the tracks. Maintenance requires machines and operation that usually emit significant amounts of carbon.
4. Disposal: Removing rail infrastructure tracks and all related material can require a huge effort, usually powered by diesel machines producing significant amounts of carbon emissions.

The four phases of the life cycle and their subsequent carbon emissions are not covered by all the analyzed methodologies. Only three of them include the planning phase of the infrastructure construction, five methodologies contain the operation and maintenance phases (4 of them having both O&M) and only one methodology includes the disposal of the infrastructure (Table 2).

		01 IFEU	02 UCB	03 RFF	04 ITALFERR	05 JBV	06 NTNU	07 CUENTAS	08 AEA	09 INECO	10 UIC
BOUNDARIES	Planning			x	x						x
	Construction	x	x	x	x	x	x	x	x	x	x
	Operation		x	x		x		x	x		
	Maintenance	x	x	x		x			x		
	Disposal					x					

Table 2: System boundaries summary for each methodology

ELEMENTS ASSESSED

Railway infrastructure includes many features that could be included or excluded from the carbon footprint evaluation. Tracks, ballast and track foundation are always taken into account in the methodologies, but other elements such as catenary and signalling systems, or the stations are not always included; this scope of calculations would impact on the final results, as seen in Phase II. Most elements are covered by the vast majority of methodologies, but stations are nevertheless not always included; they are excluded in four methodologies (Table 3).

		01 IFEU	02 UCB	03 RFF	04 ITALFERR	05 JBV	06 NTNU	07 CUENTAS	08 AEA	09 INECO	10 UIC
ELEMENTS ASSESSED	Stations	x	x	x	x				x		x
	Tunnels/Bridges	x		x	x	x	x	x	x	x	x
	Catenary	x	x	x	x	x	x	x	x		x
	Signalling and telecommunications	x	x	x	x	x	x	x	x		x

Table 3: Elements of the railway infrastructure included in the assessment

APPLICABILITY OF THE METHODOLOGIES

The methodologies assessed are applied to specific corridors and operational conditions in specific regions. Methodologies are applied to certain types of rail transport, before or after the specified lines have been constructed on specific locations. Five methodologies can be applied to more than one single type of railway services, eight methodologies have been tested on forthcoming infrastructure, before and during its construction (expected results were usually published once the infrastructure construction was completed). Finally, excepting one methodology, all the rest only cover Europe (Table 4). Other methodologies might exist in Asian countries, but the language barrier is difficult to overcome with such methodologies usually not fully available in English (such as Korean Rail, 2012, summed up in Hyo-Jung Cha, 2013).

			01 IFEU	02 UCB	03 RFF	04 ITALFERR	05 JBV	06 NTNU	07 CUENTAS	08 AEA	09 INECO	10 UIC
APPLICABILITY (tested on)	What	Passenger - high speed	x	x	x	x	x	x	x	x	x	x
		Passenger - Intercity/ Regional	x	x		x	x			x		
		Freight	x			x	x			x		
	When	Ex post	x	x					x			x
		Ex ante			x	x	x	x	x	x	x	x
	Where	EU Countries	x		x	x	x	x	x	x	x	x
		Extra EU Countries	x	x								x

Table 4: Applicability of the methodologies

CERTIFICATION PROCESS

Assessing and quantifying the carbon content of infrastructure should follow strict and recognized international standards, in order to have similar approaches facilitating a comparison of the results.

Two existing standards have been adopted in the methodologies, ISO 14000 series is the most popular with 6 studies using it (Table 5), GHG protocol is a new standard that is gaining popularity, and the RFF study uses the French tool Bilan Carbone, a national approach for carbon content quantification.

	STANDARD
01 IFEU	ISO 14040
02 UCB	ND
03 RFF	ISO 140xx (Bilan Carbone)
04 ITALFERR	ISO 14064
05 JBV	ISO 14040, ISO 14044, ISO 14025
06 NTNU	ISO 14040, ISO 14044
07 CUENTAS	ND
08 AEA	ND
09 INECO	ISO 14064, GHG Protocol
10 UIC	ISO 14040

Table 5: Certification standard used by the methodologies

More information and details about where the analyzed parameters can be found in each methodology are available in Annex II.

To harmonize all the methodologies was a challenge, as most of them have different scopes, boundaries, applications, and above all levels of transparency. Nevertheless, data have been extracted as much as possible, though a satisfactory level of detail was often not available.

The second phase of the report contains a quantitative application of the methodologies to three typical corridors in terms of service operation: high speed, freight and suburban.

PHASE II: IDENTIFYING TYPICAL CORRIDORS AND APPLYING RELEVANT APPROACHES

For applying the methodology to specific corridors, a certain level of detail in the published data was required. The lack of data transparency was the biggest obstacle to applying the methodologies to specific corridors as intended in Phase II. Some of the methodologies turned out not to have the minimum data requirements to be applied to the typical corridor cases.

METHODOLOGY SELECTION

The initial aim was to apply the specific corridor cases to each methodology analyzed in Phase I. This has nevertheless not been possible as many methodologies were not detailed enough to extract meaningful information to be applied to a wide range of parameters as required for Phase II.

The methodologies 01 – IFEU, 03 – RFF, 06 – NTNU, 08 – AEA and 10 – UIC have been selected for Phase II to compare corridors with each other, as described in Annexes I and II. These methodologies were chosen based on their comprehensiveness and transparency.

Part of the analysis also looks at the results of the methodologies developed for specific corridors (for instance high speed rail lines) when they are applied to other types of railway lines and services.

04 – Italferr has published a more detailed account of their methodological approach that could have been added to the selected list. Unfortunately, the analytical work of this report was being done at the same time and the study was too late to be included in the analysis.

DESCRIPTION OF CORRIDORS

To assess the methodologies selected under different assumptions, three typical and very distinct corridors have been provided by UIC members to the author of this report. These are:

- A long high speed corridor built in the 70s in Japan.
- A freight line (that also carries a significant share of passenger services) in Sweden, on hilly terrain.
- A short suburban line built in the Netherlands, in a flat area.

These three very separate and different corridors have primarily been chosen for their data availability and drastically different line specifications that would potentially extrapolate the difference between methodologies.

Besides their application, these corridors also have different characteristics that make them interesting comparison points (Table 6).

	High Speed	Suburban	Freight
Line	Osaka-Fukuoka-Hakata (Japan)	Zaandam – Hoorn (part of Amsterdam – Hoorn) (The Netherlands)	Bothnia (Sweden)
Year opened	1975	1884	2007
Length of the line (km)	554	30	209
Lines (single | double)	Double	Double	Single
Bridges (km)	212	2	11
Tunnels (km)	350		25
Share of track profiles (UIC60 | S49 | S54)	UIC 60	UIC 54	UIC 60
Share of sleeper (concrete | wood | iron | ballastless slab)			
Concrete	50%	100%	100%
Wood			
Iron			
Ballastless slab	50%		
Share of Mast & overhead wiring (concrete | iron)			
Concrete	90%		
Iron	10%	100%	100%
Share of tunnel type (open pit | mining)			
Open pit			
Mining	100%		100%
Railway stations Unit (Intercity Junction | Local Junction | Local Stop | Freight)			736 m^2 per km of line of freight terminal
Intercity junction	19		
Local junction		1	
Local stop		2	
Freight			2
Number of sites for Maintenance Unit	13	1	

Table 6: Main characteristics of the selected corridors

Tunnels and bridges represent a key factor for the carbon intensity of the infrastructure; the corridors analyzed have distinct shares of tunnels and bridges that would impact on the results (Figure 2).

The high speed line corridor analyzed goes along the coast of Japan, through a mountainous area and crosses to another island, explaining the high share of tunnels and bridges due to very demanding topography.

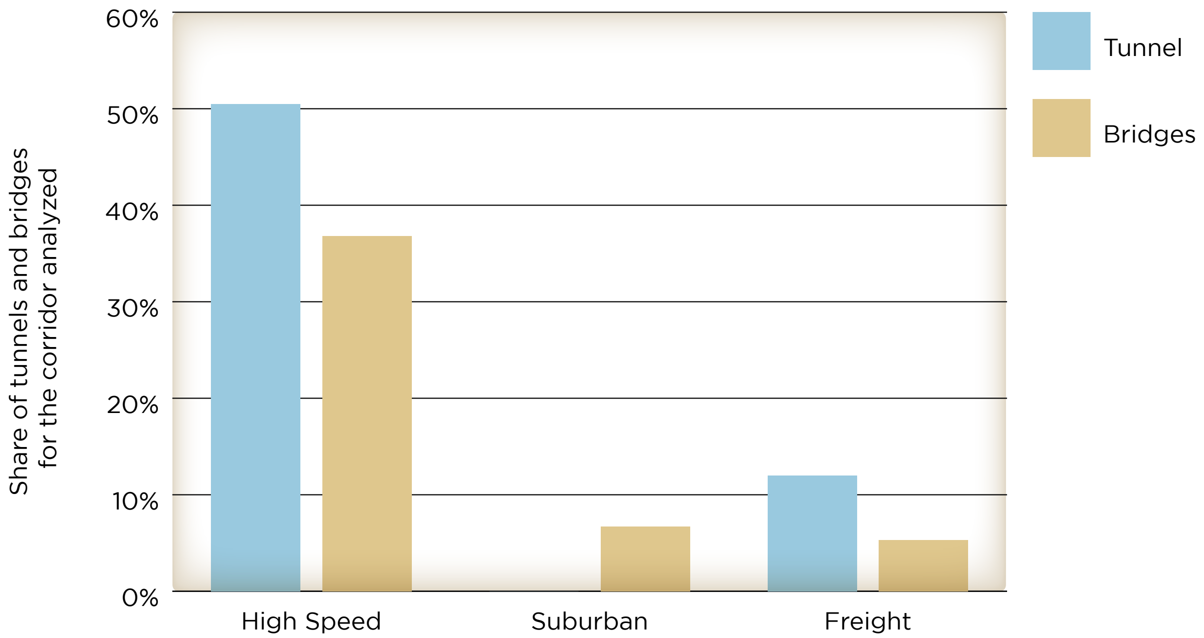


Figure 2: Tunnels and bridges share for the typical corridors

COMPARING CARBON CONTENTS

Because not all methodologies include the same components with different boundaries, a strict comparison is therefore not directly possible. The results highlight the different approaches and emission factors considered, as well as the differences in terms of methodology coverage, as detailed in Phase I of the report. With different methodologies leading to different results, each of the results has been broken down to analyse the origin of the difference qualitatively for each of the analyzed corridors.

For this comparison, IFEU methodology is taken as the reference for the comparison; indeed, it is the most transparent of all the studies, and many parameters could be adapted to a specific railway line.

High Speed corridor

The results on the high speed corridor show significant discrepancies from the lowest carbon footprint to the highest. The high percentage of bridges and tunnels is the main cause of the different results. In some cases, the impact of tunnels and bridges is not part of the methodology input, (e.g. RFF) and so the results have not been properly adapted to the specificity of the line due to a lack of data access. Both methodologies that were funded by UIC (IFEU and UIC) seem to be the most robust methodologies for this tunnel and bridge-dense corridor (Figure 3).

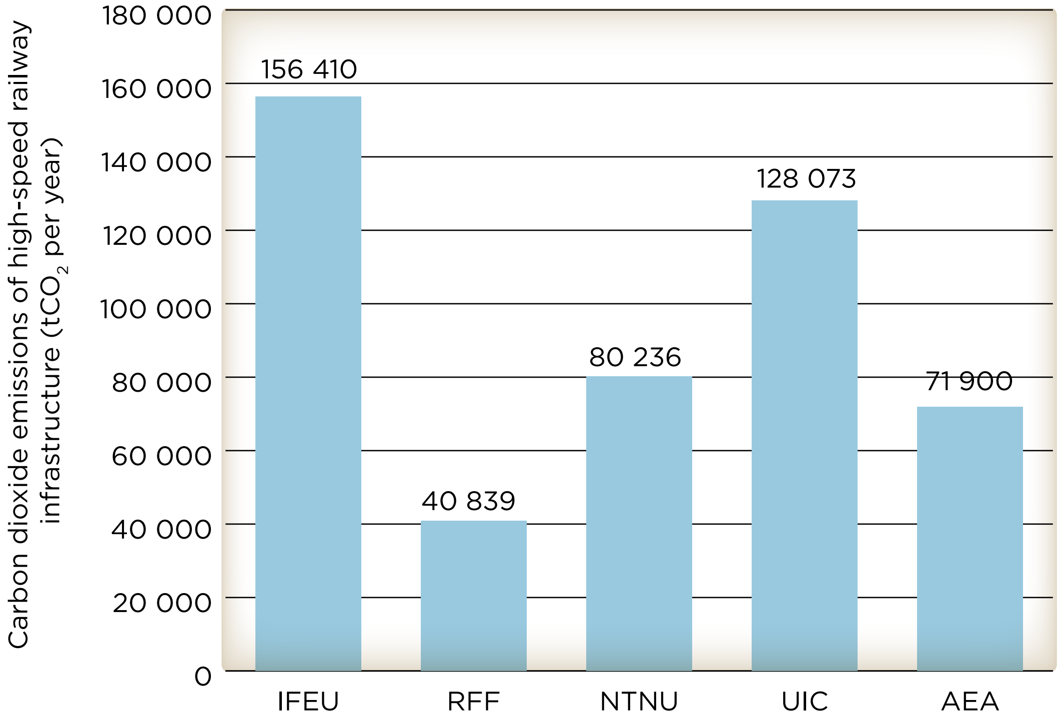


Figure 3: Comparison of methodologies on a high speed corridor

Suburban corridor

By contrast, the suburban corridor has been built in a flat environment, with almost no bridges and no tunnels. Comparing results with the previous high speed corridor will therefore also highlight the sensitivity of the various methodologies to tunnelling and bridging. IFEU and UIC are the most sensitive to tunnels and bridges, when comparing these to the results for the high speed corridor analyzed (which has a lot of tunnels and bridges).

Results are broadly consistent, apart from AEA which has higher values (Figure 4). This study has remarkably high emission factor values for the overhead poles and cables, even higher than for tunnels which would not be expected. So the values assumed in the AEA study should be treated with care, this study often being one of the extremes in two out of the three corridors studied.

The output values of the UIC methodology are low compared with all the rest. This study has been primarily focused on high speed infrastructure carbon footprint that could be the main reason for the misalignment with other methodologies. The fact that most of the emission factors are derived from specific case studies makes the methodology difficult to apply to other corridors.

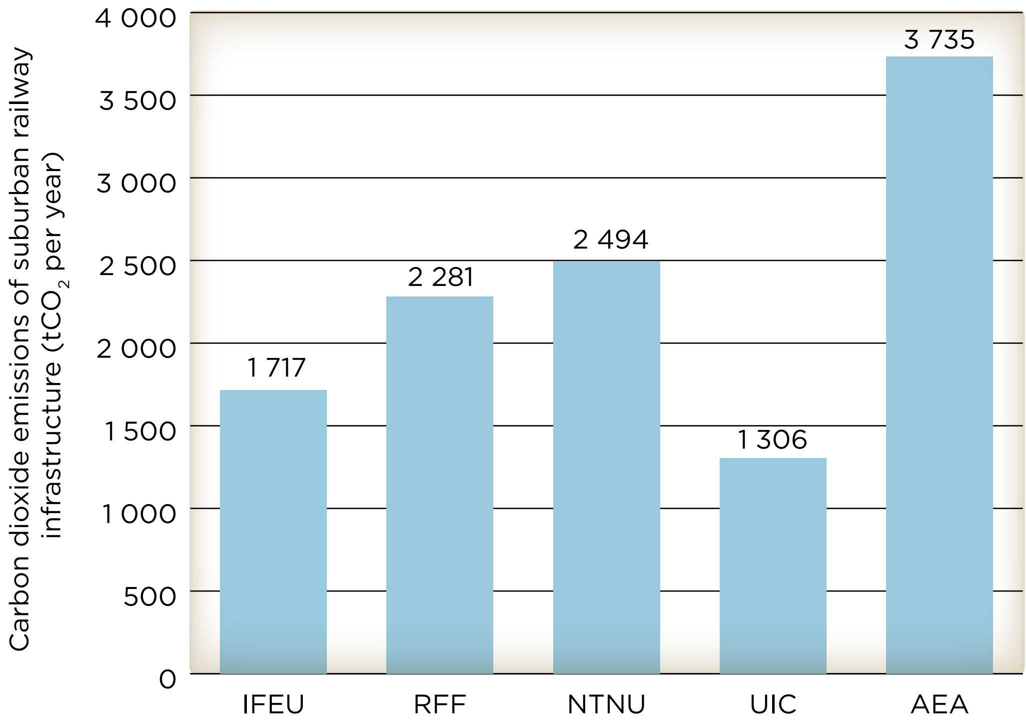


Figure 4: Comparison of methodologies on the suburban corridor

Freight corridor

The Swedish corridor is a single track along the coast, with a balanced share of tunnels and a small share of bridges (Figure 5). This new line has been built with a strict monitoring of the carbon embedded in it (IVL, 2010). The comprehensive study offers all the inputs needed to evaluate the corridor on the methodologies selected in the comparison assessment. This corridor has a high density of freight traffic compared to other lines in Sweden.

Figure 5: Map of the freight line corridor

The AEA methodology again shows different results, due to the elevated emission factors for overhead wire infrastructure. All the other studies are consistent, with the UIC study on the high side, again based on high speed infrastructure emissions factors. The NTNU study from Norway gets consistent results with the IFEU, whereas the RFF study revealed higher results, maybe also due to the fact that the application is for a high speed line (Figure 6).

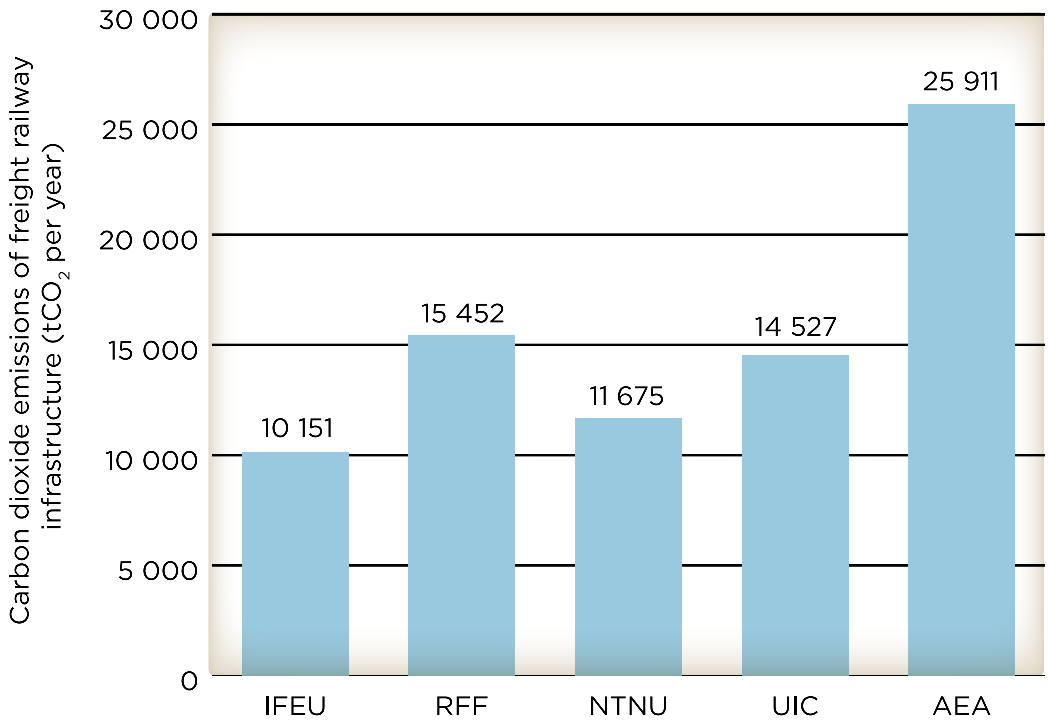


Figure 6: Comparison of methodologies on the freight corridor

Corridors in a nutshell

In order to have all corridors and all methodologies on the same plot, an indicator has been built by dividing each individual corridor value by its length to give carbon emission per km per year.

Some methodologies (mainly because of access restrictions) did not have many parameters that were user definable, such as RFF. In this case, the carbon content per km is similar. AEA also has a flat line, though many parameters are user definable; this is mainly due to the fact that the parameters that could be defined are not very different from each other. For example, concrete bridges have an emission factor of 3,133 tCO_2/km/year, while steel bridges are very similar with 3,038 tCO_2/km/year; so, according to AEA, building concrete or steel bridges does not have a significant impact on the carbon footprint of the railway infrastructure. The IFEU methodology contains a 100% difference in the carbon footprint of concrete versus steel bridges. The IFEU and UIC methodologies are pretty consistent and show a similar pattern, except for the freight line, which has a lower carbon intensity than suburban for IFEU and higher for UIC. The fact that the freight line is a single track is taken into account in IFEU, but not in UIC (analyzing only High-speed rail infrastructures), which could explain the divergence in per km results (Figure 7).

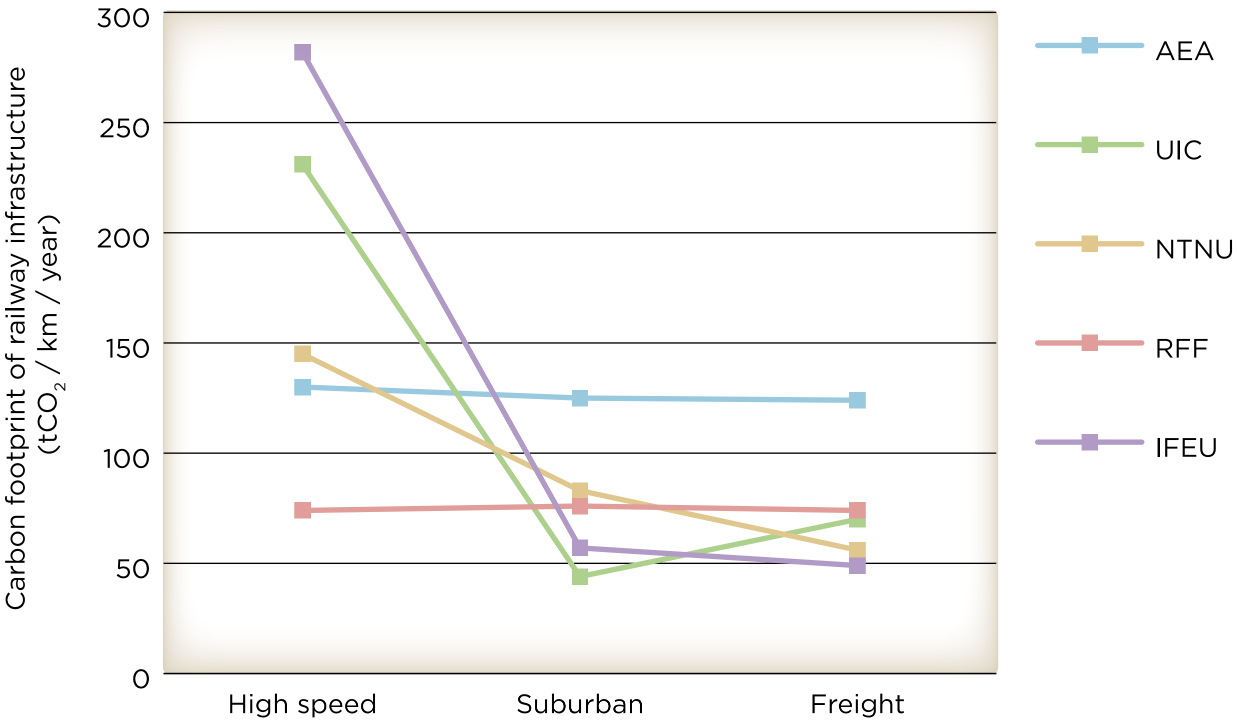


Figure 7: Corridors and methodology per kilometre comparison

Sensitivity analysis of critical parameters

Tunnels and bridges are a key parameter to the overall carbon footprint. The sensitivity to tunnels and bridges is crucial to the overall results, and this is valid for all the corridors analyzed. When a low share (with 5% of tunnels and 5% of bridges) and a high share (with 35% of tunnels and 35% of bridges) are simulated in the corridors chosen, all lines react in a similar way (Figure 8). This indicates that the location and type of the line is not the main reason for the differences shown in Figure 7.

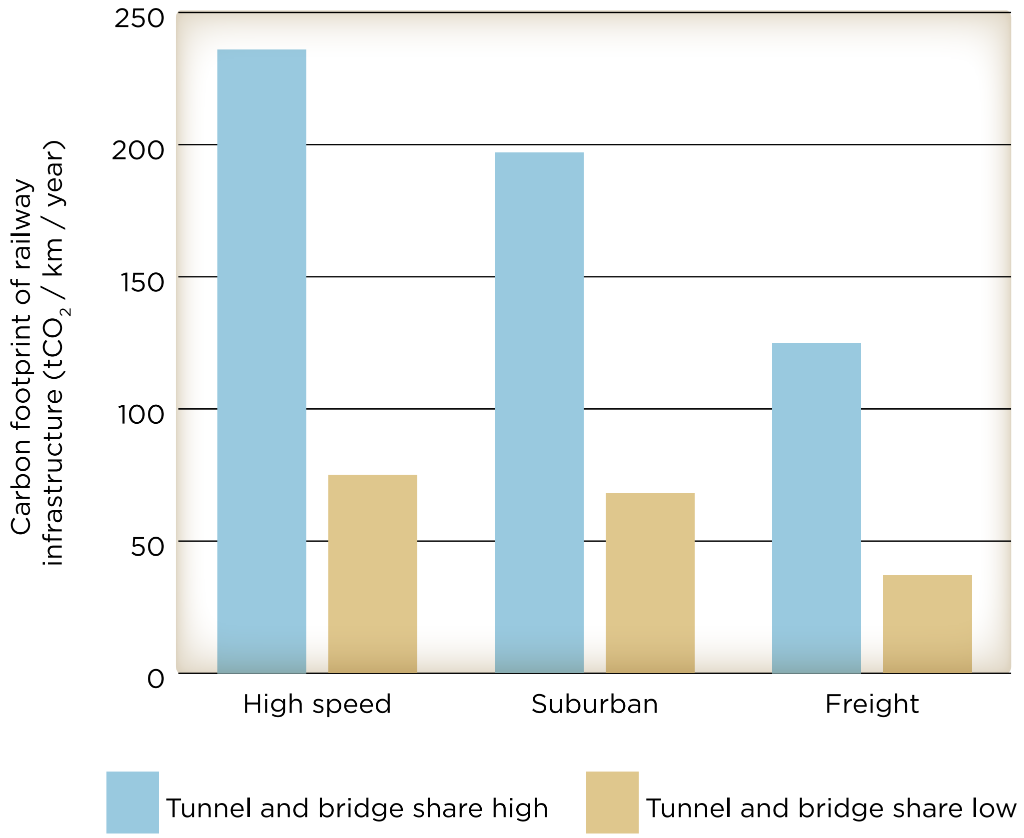


Figure 8: Carbon footprint sensitivity test on tunnel and bridge share for the selected cases

A similar sensitivity to the track foundation leads to a different outcome. Whether the track uses ballast or slabs to put the sleepers on makes a limited difference to the overall results of the three corridors used (Figure 9). One possible explanation would be that even though slab does require more carbon than ballast (most emission factors show that slab is about twice as carbon intensive as ballast, 5 tCO_2/km for ballast versus 11 tCO_2/km for slabs (as shown in 01 - IFEU), slabs last longer and therefore have a longer carbon amortization time, lowering the annually amortized carbon footprint. These emission factors are rather limited compared to other criteria such as tunnels and bridges, and are of the same order of magnitude as rail manufacturing.

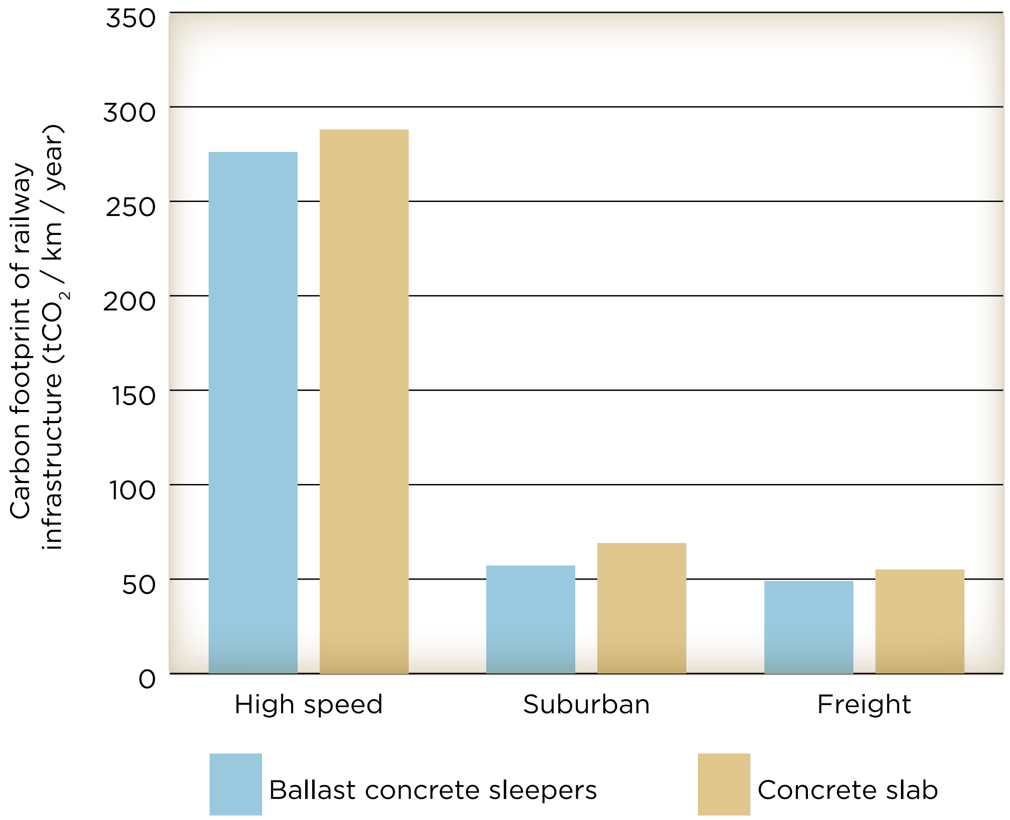


Figure 9: Carbon footprint sensitivity test on track foundation type for the selected cases

To look at the bigger picture, the infrastructure carbon footprint should be considered for each passenger-km or ton-km. For the three cases considered in this report, the infrastructure adds a significant emission to the operation of the train (Figure 10). The values calculated depend heavily on the traffic on the lines studied. Traffic information has been given by the companies operating the lines analyzed in this report, and so the values found are close to reality for the lines studied, not necessarily for the type of corridors they represent.

The Japanese high speed line is the least carbon intensive of the two passenger lines studied, despite the high share of tunnels and bridges. The data provided by Japan Railways showed very high traffic values for the line, highlighting the huge capacity of the high speed lines in Japan. Such high traffic has a big impact on the carbon intensity of the line per passenger.

The suburban case has more competition from other modes, but still has high traffic activity values showing that rail is competitive compared with other modes on suburban journeys (freight traffic has been ignored due to data availability issues).

Data provided by Swedish members show that the Bothnia line in Sweden has intensive freight train traffic on this line. Nevertheless, the line is also used by passenger trains. The carbon footprint of the Bothnia line is of the same order of magnitude as the passenger line, which shows the consistency of the calculation methodology (Figure 10). It is important to highlight the fact that this approach is very conservative as the passenger traffic also using the same railway line has not been taken into account when performing the calculations. It is estimated that this could have cut the carbon intensity by almost a factor of two.

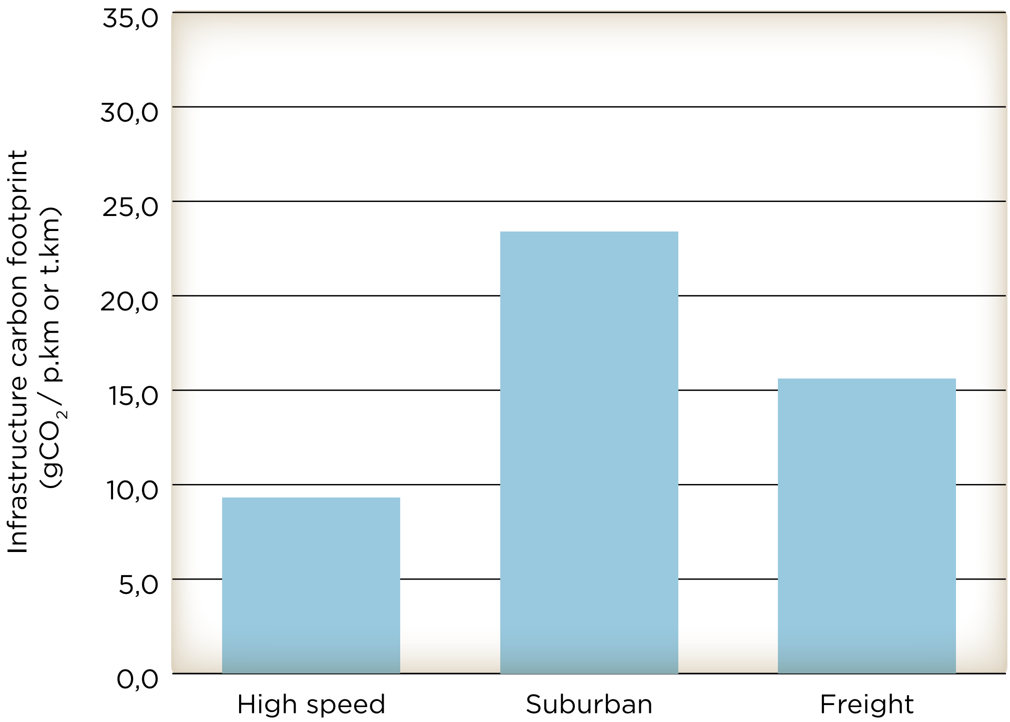


Figure 10: Carbon intensity of the railway infrastructure for the three corridors analyzed in this report

Comparison with other transport modes

In the EcoPassenger and EcoTransIT tools, only energy consumption for traction is taken into account to display CO_2 emissions. Rail is by far the least carbon intensive of the modes covered by the Eco Tools. Including the infrastructure and rolling stock embedded carbon might make a difference, as railway infrastructure is used less than road links or airports. Using EcoPassenger operation data for the rail, road and air transport modes, and adding the infrastructure and rolling stock carbon intensity, a comparison between modes, including operation, infrastructure and rolling stock embedded carbon has been performed on typical corridors (e.g. Paris <-> Amsterdam). Even though they almost double the CO_2 emissions, the extra emissions of the infrastructure and rolling stock do not drastically change the carbon competitiveness of railways compared with other modes (Figure 11).

So the benefits of including a wider range of elements in the carbon calculations outweigh the risk of the railways being less competitive due to their higher infrastructure carbon footprint compared with other alternative competitor modes. These results show the advantages of a modal shift to rail in terms of carbon emissions with a holistic scope.

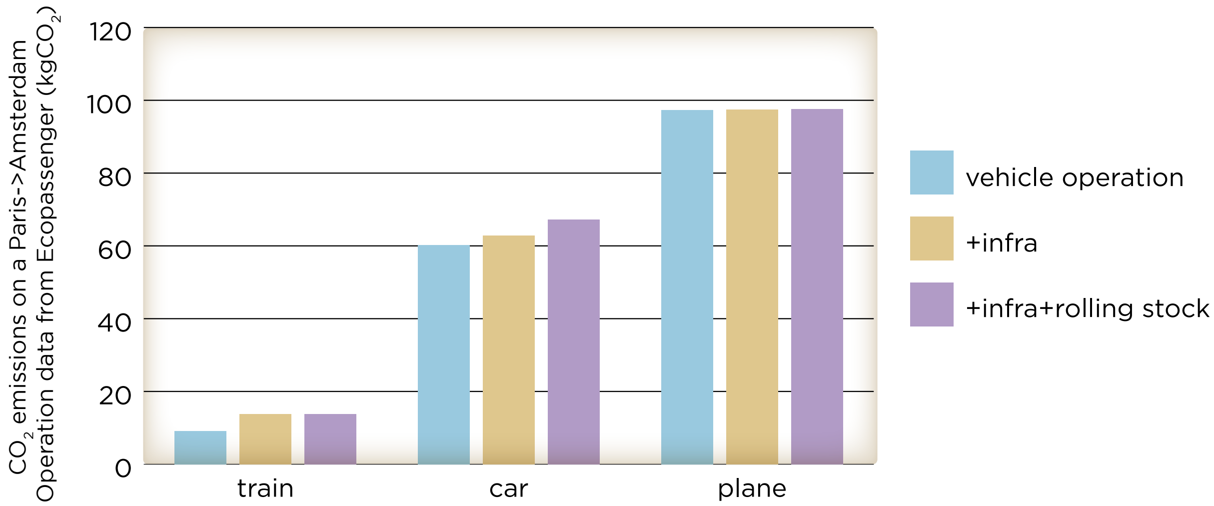


Figure 11: CO_2 emissions of the main transport modes including operation, infrastructure and rolling stock on the route Paris-Amsterdam, a typical High-Speed European journey (500 km approx.). Source: EcoPassenger.com and 01 – IFEU, Tuchschmid

Rail infrastructure payback times

Another way to look at how carbon emissions can be accounted for would be to look at how many years it takes to amortize a new infrastructure as a result of the modal shift to rail. As a new rail infrastructure is built, a modal shift from other modes will happen (together with induced demand, extra activity that is created because of the new rail infrastructure), saving CO_2 thanks to the higher efficiency of railways. Assuming modal shift and induced traffic for each of the three corridors (Table 7), the number of years needed to mitigate the carbon content of the infrastructure by saving CO_2 emissions from vehicle operation is calculated, using similar approaches from other literature (Renfe, 2013).

<table>
<tr><th rowspan="2"></th><th colspan="4">Traffic from</th><th rowspan="2">Induced traffic</th><th rowspan="2">Payback time (years)</th></tr>
<tr><th>Plane</th><th>Car</th><th>Bus</th><th>Trucks</th></tr>
<tr><td>High speed</td><td>50%</td><td>20%</td><td></td><td></td><td>30%</td><td>9.1</td></tr>
<tr><td>Suburban</td><td></td><td>40%</td><td>40%</td><td></td><td>20%</td><td>14.6</td></tr>
<tr><td>Freight</td><td></td><td></td><td></td><td>95%</td><td>5%</td><td>12.2</td></tr>
</table>

Table 7: Modal shift and induced traffic assumptions to calculate new infrastructure payback time

Passenger corridors, using the line and traffic data, show payback times of 10 years for the high speed corridor and 15 years for the suburban corridor. For freight, compared with passenger trains, the payback time is somewhere in the middle at around 12 years, showing consistency across type of transport. Again, it is important to stress that for the suburban and freight lines, part of the traffic has been ignored, making these values conservative and potentially much lower when all types of traffic are included.

Rail infrastructure also needs to be replaced or reconstructed after a certain amount of time. Looking at the average lifetime of the elements that constitute the infrastructure, it appears that each railway infrastructure has a different average lifetime before rebuilding/reconstructing has to be started.

Such average lifetime for the infrastructure depends on the composition of the rail infrastructure; for example, a high share of tunnels (which have a long lifetime compared with other railway infrastructure elements) will make the average lifetime longer.

The gap between the payback time and the average infrastructure lifetime can be considered as a good proxy for the carbon efficiency of the infrastructure; as long as the payback time is shorter than the average lifetime of the infrastructure, CO_2 emissions will be saved. In the three corridors analyzed, this is indeed the case. With the modal shift assumptions used, building a new railway saves a significant amount of CO_2 emissions (Figure 12).

In the case of the Japanese high speed corridor analyzed in the report, more than 1.7 ktCO_2 are saved per year and per kilometre of line because of the shift away from carbon intensive modes such as cars and planes. A long term view is nevertheless necessary for taking the appropriate investment decision covering the whole lifetime impacts and benefits of building new railway infrastructures that involve a significant amount of carbon emissions. Making sure traffic activity will be high, with a high modal shift away from other motorised modes is crucial and, today, most of such highly effective corridors have already been built in the developed countries of Europe and Asia. There is nonetheless a huge potential for highly carbon efficient high speed lines on other continents, e.g. in the Americas and developing Asia. For example, one of the studies analyzed in this report shows the potential of high speed rail in California (02 - UCB, 2008).

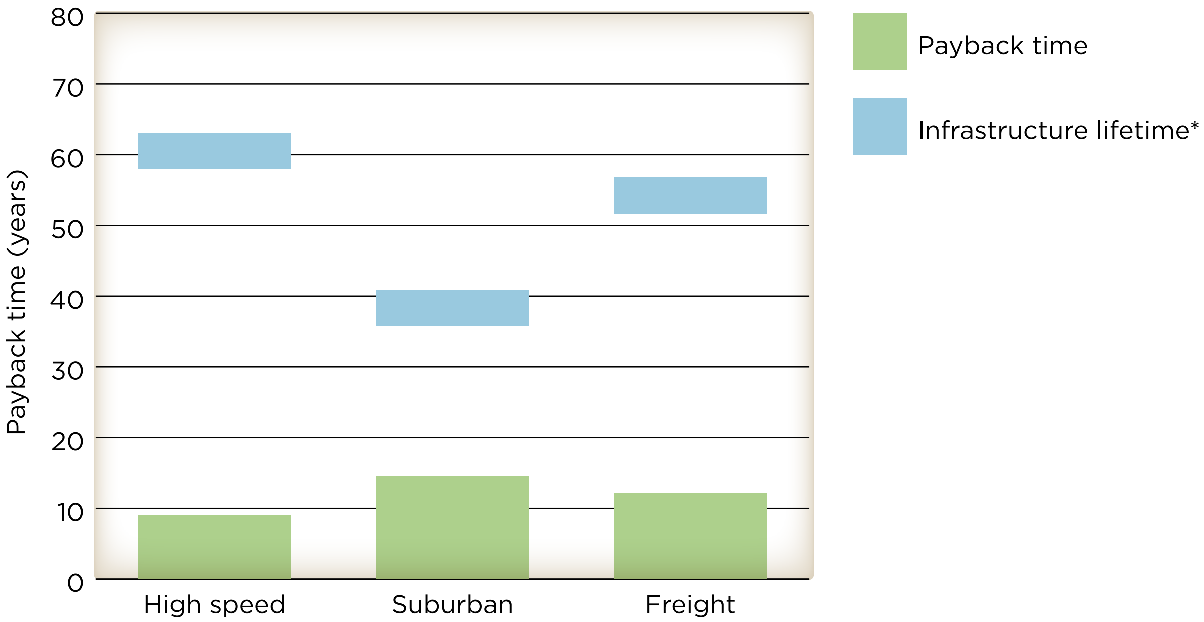


Figure 12: Payback times versus infrastructure average lifetime for the three corridors studied

* That is, the average lifetime of the infrastructure before starting re-building, re-construction of a part of the infrastructure. It has been calculated as the weighted average of the average lifetime of the rail infrastructure elements taking the carbon-intensity of each element into account. The greater the difference between the blue bar and the orange line, the bigger the carbon savings.

PHASE III: RECOMMENDATIONS FOR A COMMON METHODOLOGY TO CALCULATE THE CARBON FOOTPRINT OF THE INFRASTRUCTURE

USE IN A CARBON CALCULATOR

Figure 7 shows that for a typical corridor that is not too specific in terms of bridging and tunnelling a carbon emissions value in the range between 50 - 70 tCO_2/km/year is an acceptable approximation to give an order of magnitude with most of the analyzed reports. Only when there is a significant share of bridges and tunnels (over 30% of the line), there would be a need to use a more detailed methodology. The methodology of the IFEU report has been identified as the most accurate and consistent, after all the analysis performed in this report; according to this methodology a value of 50 tCO_2/km/year is acceptable as an order of magnitude. The AEA methodology is assumed not to be accurate enough to be considered a reliable methodology.

It is therefore recommended to include the carbon emissions of railway infrastructure into the Eco-Tools. Given the high number of corridors already included in the tools, a simplified approach is being proposed to UIC members for consideration:

- When the tunnel/bridge share is lower than 30% of the corridor's distance (which is expected to be the case most of the time), a standard emission factor of 50 tCO_2/km/year should be applied, aligned with the IFEU report. Considering an approach of carbon emissions per unit of transport (UT, the sum of passenger.km and ton.km) and the existing infrastructure at global level (IEA/UIC, 2015), a value of 6 to 7 gCO_2/UT would be a corresponding value which seems modest compared to the carbon intensity of other modes of transport.
- For higher shares of tunnels and bridges, apply the IFEU / Tuchschmid methodology at the highest possible level of detail in order to reach the most reliable emission factor.
- For line operators that could justify different emission factors to the general ones, a dedicated value should be adopted in the reporting and Eco-tools calculations, highlighting the transparency and solid background of the reporting and encouraging the use of carbon calculations to promote low carbon infrastructures.

There are already some existing best cases of Eco-tools including the life-cycle information. The Rail Carbon Tool of RSSB and Mobi Tool of SBB are two of the best examples of this LCA Eco-Tools (see boxes).

Rail Carbon Tool

The Rail Carbon Tool is a web-based tool that allows users to calculate, assess, analyze, report and reduce your rail project carbon footprint by evaluating low-carbon options using verified, centrally-available carbon factor data. This tool allows project managers to evaluate the carbon content embedded in railway infrastructure.

The tool, known as the Rail Carbon Tool, is licensed from Atkins by RSSB on behalf of the UK rail industry and it is managed by a cross-industry working group including Network Rail, TfL, Transport Scotland and HS2 and industry contractors and consultants. It is now being used by various parts of the railway in Great Britain enabling a growing proportion of the rail industry to measure accurately and efficiently the embodied and whole life carbon on projects, to ultimately achieve reduction in embodied carbon on GB rail projects, which has a well proven link to reduced costs.

Mobi Tool

Mobi Tool is a web calculator developed by SBB comparing journeys using different modes of transport covering a life-cycle assessment. The life-cycle inventory databases used by Mobi Tool and the related Environmental Timetable consider not only direct energy consumption but also all indirect environmental effects from production through to the final disposal of the materials. The comparison is based on information provided by the life-cycle inventory database created by a partnership of the Swiss Federal Institutes of Technology (ETHZ and EPFL, plus the Paul Scherrer Institute – PSI) and other bodies. The harmonized methodology and the use of the same reference values and background data ensure that the comparisons between the various modes of transport are fair.

The life-cycle inventory methodology takes account of the entire "end-to-end" chain of effects on the environment. Regardless of the chosen mode of transport, the vehicles must first be built, operated, maintained and then disposed of at the end of their life-cycle. Transport infrastructure (roads, tunnels, bridges) is also required, as are facilities such as railway stations, airports, office buildings, filling stations and electricity substations.

USE IN PROCUREMENT

In order to assess the carbon footprint of a future infrastructure, environmental product declarations (EPD) can be held in several ways. The European Commission is still trying to incentivize common and harmonized approaches to EPDs (EU, 2015). Having a standardized methodology dedicated to railway infrastructure seems still some way away. Relying on ISO standards and their derivatives (GHG protocol, Bilan Carbone) still leaves significant room for interpretation that is leading to some results differences, as identified in Phase II.

The methodologies analyzed all rely on standardized Life Cycle Analyses (LCA) methodologies, and results on similar corridors are to some extent different. This nevertheless offers a satisfactory level of accuracy.

When performing ex-ante carbon footprint calculations, the biggest challenge would be to make sure that the expected carbon emissions are not exceeded during the realization of the construction work: delivery of the promised CO_2 emissions still needs to be drastically monitored and improved.

An emerging solution seems to be very promising in order to incentivize both monitoring of ex ante and ex post CO_2 emissions and to offer cost competitive emission mitigation strategies: the carbon Arbitration Funds (see box). A share of the civil engineering budget is dedicated specifically to CO_2 emissions mitigation, giving priority to the most cost effective solutions.

The carbon arbitration fund

Measuring the carbon content of an existing or future infrastructure is the first step; a second phase is to actually reduce the carbon emissions during planning, and building the infrastructure itself will be the final stage. In order to engage civil engineering in reducing the carbon footprint of the building infrastructure, there are several experiences on the advantages of the inclusion of a small part of the construction budget dedicated to carbon saving activities. A small percentage of the infrastructure is placed in a carbon arbitration fund. Each team of civil engineers proposes ways to reduce the carbon content of their construction process, and the most cost effective process won a part of the dedicated budget. This is a best case of win-win strategy where saving carbon emissions often leads to cost savings.

Such practice should be more widespread when building railway infrastructure, for which even a modest share of the infrastructure total cost will represent a significant lever to mitigate the carbon content of the civil engineering work.

Such funds could be part of the procurement bid or be a requirement or obligation from the promoter; several cases have shown promising results, either on the public (Loiret, 2015) or the private sectors (l'usine nouvelle, 2013; le Loiret, 2015). Such processes are still in the early days and would deserve a great attention in the coming years to engage all parties involved in a virtuous circle.

Eiffage, the civil engineering company building the high speed line in the west of France, has been the first to experiment with carbon funds for the 200 km line. They have dedicated 6 million Euros to the carbon fund, for a 3 billion Euro infrastructure. The line is expected to be launched during the first half of 2017, so most of the civil engineering is now finalized. According to internal monitoring, the fund saved 14 000 tCO_2eq, and Eiffage have estimated an average cost of 375€/tCO_2eq saved. In such a strictly regulated environment, Eiffage has been faced with a big task to change construction regulations and habits. Even though Eiffage rated this experiment as not cost-effective (that was not their main aim), it considers the experiment a success and are willing to implement such schemes in a more automated way in the future.

About half of the proposed measures have been adopted, mainly in the earth moving and construction engineering fields. Some more emblematic actions have been adopted to replace poles, or to change GHG-intensive injection gas in substations by GHG-neutral gas nitrogen.

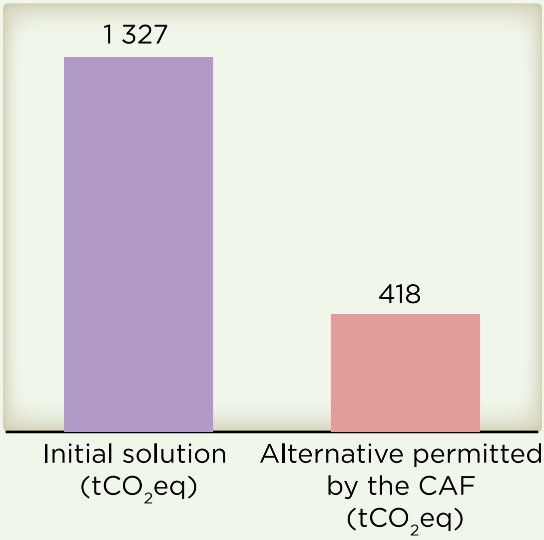
According to the author, such experiments would need to be further pursued and incentivized, as promoters are usually more focused on the use phase than on the construction phase.

Practical examples:

Solution 1

The substitution of the treated subformation level (made of quicklime and hydraulic binder) by a granular subformation made from surplus excavation was proposed for 24 km of a 35 km section and junction on the west of the city of Laval. This alternative presents a supplementary cost of 195 090€, and permits to avoid the emission of 909 tCO_2eq (reduction by 69% of total emissions).

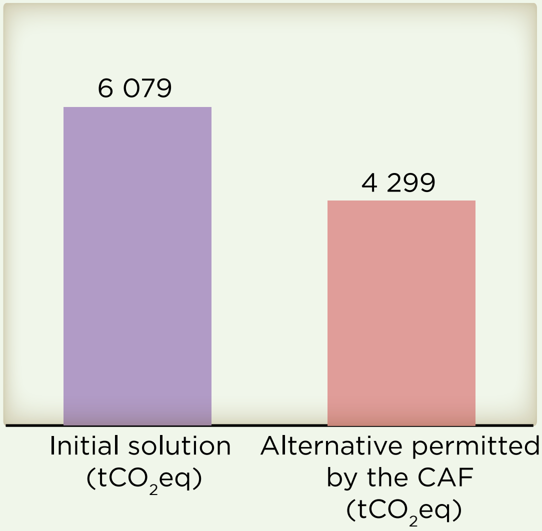
Subformation materials CO_2 emission on BPL West Laval section



Solution 2

The replacement of 5 transformers with less-emittive solutions was proposed. This alternative presents a supplementary cost of 100 000€ for a reduction of 1 780 tCO_2eq (56€ per tCO_2eq avoided).

CO_2 emission from the transformers of 2 BPL substations



CONCLUSION

Ten methodologies have been analyzed in this report in great detail in order to assess what is hidden inside and behind the neat figures and texts that are often published together with a specific case study. There is a wide range of methodologies used in the railway sector with different boundaries, different elements assessed, with a separate scope, different countries and, most importantly for this report, various degrees of transparency in the calculation and ease of access to the underlying data.

Overall, the IFEU / Tuchschmid methodology, funded by UIC, is the most transparent, versatile and comprehensive methodology that has been analyzed as part of this study. It nevertheless sometimes requires information that is not always available to the operator. Tunnelling and bridging, after line distance, is the principal parameter that needs to be known in order to evaluate the carbon content of a railway line. Below 30% of artificial ballast-less rail support (bridges, tunnels, other earth structures), an approximate emission factor of around 50 tCO_2/km/year of rail line can be assumed and approximated to a value of around 6 to 7 gCO_2/pkm or tkm. Above 30%, a more detailed methodology, ideally the IFEU / Tuchschmid, would have to be used to more accurately define the carbon content of the rail infrastructure.

A railway line operator that could justify lower values for their specific lines should be able to do so in order to increase visibility of lower carbon railway infrastructure and the investment in railways to reduce GHG emissions of the transport sector. An assessment procedure would need to be put in place with interested UIC members in order to independently validate the proposed values. This would also apply to major maintenance operations of railway infrastructure, such as ballast, sleepers, rail replacements during which lower carbon solutions might emerge.

Adding railways infrastructure carbon content to all the eco-calculation tools is not having a significant impact on the overall carbon competitiveness of the railway sector, when compared with the other modes of transport. It is therefore recommended to add these into the overall results in order to improve the transparency and the consistency of the results, even when calculated with conservative emission factors that would be improved and more precisely calculated for each corridor over time.

This would prove that the rail sector remains the most carbon-efficient motorized mode, when taking all elements of the life cycle analysis into account, supporting the development of new infrastructures based on the carbon performance of the whole life cycle, when the market demand and the subsequent number of services guarantee an effective carbon reduction by modal shift from more intensive energy consumer modes of transport.

For procurement, carbon footprint monitoring at the specific corridor level is common, and does not represent major standardization and harmonization challenges. The challenge now remains in making sure the carbon footprint of new infrastructure is considered with a scientific approach, and the expected CO_2 emissions reduction forecast during the procurement stage is delivered once the line is finished. Another option would be to give a financial incentive to lower the carbon emission of the construction phase by dedicating some of the infrastructure construction budget to emission reductions. Carbon Arbitration Funds offer a strong incentive to mitigate the carbon content of infrastructure using the most cost effective solutions for each specific corridor (See box "The Carbon Arbitration Fund").

It is now time to provide a strong incentive to rail infrastructure operators to lower their carbon emissions, as one of the last missing elements of the carbon life cycle of the rail sector. Combining the incentive of using Carbon Arbitration Funds during construction and maintenance with the added visibility of specific emission factors in the Eco-tools would be a win-win that would accelerate the carbon mitigation of railway infrastructure. Once again, the rail sector would lead the sustainability and environmentally-friendly debate and push other sectors to follow the rail example and best practices for a cleaner and more sustainable transport sector.

REFERENCES

BSI, 2012,
http://shop.bsigroup.com/ProductDetail/?pid=000000000030241098

European Commission, 2015, Environmental Product Declaration Schemes (EPDs),
http://ec.europa.eu/environment/ipp/epds.htm

Hyo-Jung Cha et al, 2013, Carbon Footprint of the Rail Infrastructure Construction for High Speed Line in Korea, 10th WCRR conference, Sydney, Australia

IEA/UIC, 2015, Railway Handbook 2013. OECD/IEA and UIC,
www.uic.org/IMG/pdf/iea-uic_2015-2.pdf

IFEU, 2015, EcoPassenger, Environmental Methodology and Data, Update 2015,
http://ecopassenger.hafas.de/hafas-res/download/Ecopassenger_Methodology_Data_update_151105.pdf

IFEU, INFRAS, IVE, Ecological Transport Information Tool for Worldwide Transports, Methodology and Data Update,
http://ecotransit.org/download/EcoTransIT_World_Methodology_Report_2014-12-04.pdf

IVL, 2010, Life cycle assessment of railway and rail transports: Application in environmental product declaration (EPDs) for the Bothnia line,
www.ivl.se/download/18.343dc99d14e8bb0f58b75d4/1445517456715/B1943.pdf

Korea Railroad Research Institute, 2012, 철도건설현장 탄소발자국 산정연구 Research on the Carbon Footprint of railway infrastructure, - final report -

L'usine Nouvelle, 2013, Eiffage réduit l'empreinte carbone de la LGV,
www.usinenouvelle.com/article/eiffage-reduit-l-empreinte-carbone-de-la-lgv.N195268

Le Loiret, 2015, le « fonds d'arbitrage carbone » du Loiret a permis d'éviter l'émission de 424 tonnes de CO_2,
www.decision-achats.fr/Thematique/marches-1036/commandes-publiques-10139/Breves/2015-fonds-arbitrage-carbone-Loiret-permis-eviter-emission-424-tonnes-CO2-262849.htm

Renfe, 2013, "Informe Anual 2012",
www.renfe.com/docs/informe_anual_2012.pdf

RSSB Rail Carbon Tool,
https://www.railindustrycarbon.com/KnowledgeBase/Account/LogOn?ReturnUrl=%2fKnowledgeBase%2f

SBB, Matthias Tuchschmid, Mobitool Report,
https://www.sbb.ch/content/dam/sbb/en/pdf/en_sbb-konzern/en_ueber-die-sbb/en_corporate-governance/Hintergrundbericht_e.pdf

ANNEX I - RAIL CARBON FOOTPRINT DOCUMENTS ANALYZED

01 – IFEU: Tuchschmid, 2011, Carbon footprint and environmental impact of railway infrastructure
www.mtuchschmid.ch/uic-infrastructure

02 – UCB: Chester M., 2008, Life-cycle Environmental Inventory of Passenger Transportation in the United States
www.its.berkeley.edu/publications/UCB/2008/DS/UCB-ITS-DS-2008-1.pdf

03 – RFF: RFF, ADEME and SNCF, 2009, 1er Bilan Carbone ferroviaire global
www.rff.fr/IMG/Bilan-Carbone-LGV-RR.pdf

04 – ITALFERR: FS/Italferr, 2012, Carbon Footprint in the design and construction phases. Consolidated with “CARBON FOOTPRINT IN CONSTRUCTION : The experience of Italferr”, engineering station n. 5 - May 2015,
www.italferr.it/cms-file/allegati/italferr_en/ArticoloImpontaclimaticarev070414FRAinglese.pdf

05 - JBV Trafikverket, 2012, The Follo Line - A Green Railway Infrastructure Project

06 – NTNU: GrossRieder, 2011, Life-Cycle assessment of Future High-Speed Rail in Norway

07 – ECOLOGISTAS: Sanz, et al, 2014, Las cuentas ecológicas del transporte en España
www.ecologistasenaccion.org/IMG/pdf/info_cuentas-ecologicas.pdf

08 – AEA: Hill, 2012, The role of GHG emissions from infrastructure construction, vehicle manufacturing, and ELVs in overall transport sector emissions
http://eutransportghg2050.eu/cms/assets/Uploads/Reports/EU-Transport-GHG-2050-II-Task-2-draftfinal1Mar12.pdf

09 - INECO, 2012, Huella de carbono de la construcción de una línea ferroviaria de alta velocidad

10 – UIC: Baron T. (SYSTRA), M. Tuchschmid, G. Martinetti and D. Pépion (2011), High Speed Rail and Sustainability. Background Report: Methodology and results of carbon footprint analysis, International Union of Railways (UIC), Paris, 2011
www.uic.org/IMG/pdf/hsr_sustainability_carbon_footprint_final.pdf
www.uic.org/IMG/pdf/hsr_sustainability_main_study_final.pdf

ANNEX II – DETAILED ANALYSIS OF THE METHODOLOGIES

CHECK LIST – 10 STUDIES ON CO_2 EMISSIONS FROM RAILWAY INFRASTRUCTURES

Methodological notes and reading guide

The scope of the checklist is to provide a synthetic overview of the main characteristics contained in 10 methodological proposals for the calculation of the carbon footprint related to the construction of railway infrastructure using an LCA approach.

The information reported in the check lists focuses only on infrastructure construction, even when the study includes the calculation of the carbon footprint due to the construction of rolling stock and/or the emissions related to the passenger/freight service operation.

The checklists contain all the information considered essential for the comprehension of the methodological proposal. The different fields of the checklist are explained below:

MAIN OBJECTIVE:

this field illustrates the main purposes of the methodological paper, indicating for example if it concerns only the calculation of CO_2 emission or other environmental impacts, if the methodology has been developed for a comparison with other transport modes, for existing or planned infrastructures and for a specific rail transport service (passenger rather than freight, high-speed rather than normal/intercity service).

REFERENCE DOCUMENT:

the title of the paper/document from which the information is derived.

GEOGRAPHICAL COVERAGE:

indicates where the methodology has been tested/ applied (EU –EU+EFTA- or Extra EU countries).

INVENTORY RESULTS AND INDICATORS:

reports the environmental indicators developed (only CO_2 and/or other pollutants) and the unit of measure used for the final outputs. In particular, it distinguishes between: absolute carbon emissions produced during the entire life cycle of the infrastructure (Tonnes of CO_2), emission normalized by infrastructure life time (Tonnes of CO_2 per year or per year km) or normalized by the production (Tonnes of CO_2 per pax- km or per Tonne km).

BOUNDARIES AND ELEMENTS UNDER ASSESSMENT:

the boundaries of the methodology are reported within the following macro-categories: Planning, Construction, Maintenance, Operation (e.g. energy consumptions of the stations or for signalling and communication) and Disposal (End of Life). The elements assessed in the infrastructure are listed (stations, tunnels, bridges, etc) and the relative lifetime parameter reported when available.

ENGINEERING ASSUMPTIONS:

describes the main assumptions relative to the building phase when declared, as, for example, the quantity of material used per km, per tunnel, etc.

METHODOLOGICAL APPROACH AND STANDARD:
reports, when available, the main standard followed (ISO and emission factors) and data source (e.g. Ecoinvent or Simapro database) and the methodological approach when declared.

NOTES:
general considerations on the methodology analyzed, with consideration of the final purposes of the present study.

When no information is available, the respective field of the checklist reports ND (Not Declared).

01 (IFEU 2011)

MAIN OBJECTIVE	Measuring carbon footprint and other environmental impacts of existing railway infrastructures, freight and passenger, both local-regional and high speed.
REFERENCE DOCUMENT	Matthias Tuchschmid, IFEU and Öko-Institut; *Carbon Footprint and environmental impact of Railway Infrastructure*; 2011
GEOGRAPHICAL COVERAGE	Tested both in EU and EFTA (Germany, Switzerland, France, Italy, Spain, Norway and Belgium) and extra EU countries (Japan and India). [pages 30-44]
INVENTORY RESULTS AND INDICATORS	Inventory results differentiated in [pages 10-12] For track: impact per year*km For buildings: impact per year*unit Indicators [pages 5-7]: Primary energy CO_2 Particulate matter (PM10) Non-methane hydrocarbons (NMHC) Nitrogen oxide (NO_x) Sulphur dioxide (SO_2) [presented in the output indicators, e.g. page 17]
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES Included [page 4]: Construction Maintenance Operation [NB page 18, only construction and maintenance is indicated] Not included: Planning Disposal Other specific aspects [page 8]: First mile/last-mile of the passenger (Before a passenger can board a train they need to get to the station using other means of transport (first mile). Similarly, the destination station is rarely the desired destination (last-mile). Infrastructure of stations/parking (Buildings and structures for smooth connection to public transport as buses and car parks to private transport are necessary. Within this study, it is assumed that these facilities are part of the respective network of public buses, private cars, respectively). Deforestation connected with infrastructure construction was not taken into account.

	LIFETIME [page 9] 60 years in line with PCR (Product Category Rules) (with the exception of: rail for tracks, sleeper 30-35 years; Building: Transformer Substation: Electrical Installations 15) ELEMENTS ASSESSED [pages 18-27] Normal track (single and double track, renewal of existing lines and new constructed lines, 4 types of sleepers, 3 types of rails) Bridges/viaducts (large and small, single and double track, concrete and iron) Tunnels (mining and open pit, single/double track) Embankments Catenary equipment (4 types) Substations Signals and communication (including signals, cable, buildings; not included are electronic solutions for new built lines, e.g. the use of European Train Control System on High Speed lines) Railway stations Maintenance centres Terminals Administration buildings Parking
ENGINEERING ASSUMPTIONS	Details about the construction data are given mainly in Schmied & Mottschall (2010) EARTHWORKS [page 19]: foundation layer of gravel and sand (magnitude 40 cm) Width for renewal of existing lines: 6.60 m (single track) and 11.00 m (double track) Width for new built lines: 8.60 m (single track) and 13.30 m (double track) Density of gravel and sand: 2.80 t/m^3 BRIDGE [page 20]: e.g. per metre of viaduct: 32.1 m^3 concrete, 3.51 t of steel and 26.17 m^3 of excavated earth TUNNEL [page 21]: e.g. per metre of mined tunnel: 37.2 m^3 concrete, 1.6 t of steel and 128 m^3 of excavated material SLEEPER [page 23]: e.g. per concrete sleeper: 32.1 m^3 concrete, 3.51 t of steel and 26.17 m^3 of excavated earth BALLAST (lifetime 25 years) [page 23]: For a double track of 1 000 m, around 2600 m^3 of crushed stone are needed RAIL [page 24]: in this study, 3 different rail types (in Germany) have been distinguished: UIC 60, S49 and S54 (the number stands for the weight in kg per m of rail). The profile S49 was mainly in use for older regional and narrow-gauge tracks in Germany, while the rail profile S54 can be found on main lines and especially station tracks. The heavier UIC profile has been used since the early seventies for heavily loaded and high speed lines.

	OVERHEAD SYSTEM (consists of the mast (concrete or iron), the catenaries and the overhead wiring) [page 25]: ND SIGNALLING & COMMUNICATION [page 26]: ND BUILDINGS [page 27]: Railway station: Junction for intercity trains (3 floors, 29 000 m² area for access to trains, 20 000 m² inside); Stop for local trains (1-2 floors, 2 000 m² area for access to trains, 600 m² area inside).
METHODOLOGICAL APPROACH AND STANDARD	Ecoinvent Database 2.2 (Emission factors) [page 8] Mainly based on a material flow analysis [page 8]
NOTES	Comprehensive and easy to apply methodology. On line calculator available at www.mtuchschmid.ch/uic-infrastructure (PSW: himalaya). Valid for all types of networks and transport service (local trains, intercity, high speed). In addition, the report includes the assessment of rolling stock construction and operation. Only CO_2 emissions, not Global Warming Potential (GWP) approach.

02 (UCB ITS DS 2008)

MAIN OBJECTIVE	Comparison between environmental impacts of road, rail and aircraft passenger transport. Both local-regional and high speed existing infrastructures.
REFERENCE DOCUMENT	Mikhail V Chester; Life-cycle environmental inventory of passenger transportation in the United States; Institute of Transportation Studies – University of California, Berkley; 2008.
GEOGRAPHICAL COVERAGE	Tested in USA (San Francisco Bay Area, Chicago, and New York City)
INVENTORY RESULTS AND INDICATORS	The inventory results are shown per Vehicle Lifetime (VL), per Vehicle-Mile travelled (VMT), and per Passenger-Mile travelled (PMT), and are differentiated per life-cycle component: station construction, station lighting, station escalators, station train controls, station parking lighting, station miscellaneous, station maintenance, station cleaning, station parking, track/power construction, track maintenance, insurance employees, insurance facilities. Indicators [pages 11-12]: GHG (CO_2, N_2O, CH_4) PM CO SO_2 NO_x VOC Pb

BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES Included: Construction Operation Maintenance Not included: Planning Disposal LIFETIME Ballast is assumed to have a lifetime of 25 years, concrete 50 years, track 25 years, power structures 35 years, substations 20 years [page 105] and parking 10 years (only wearing layers removed) [page 99]. ELEMENTS ASSESSED [pages 67-68] The assessment considers 5 trial railway systems: BART Bay Area Rapid Transit CAHSR California High Speed Rail GREEN LINE: Massachusetts Bay Transportation Authority Green Line Light Rail MUNI: San Francisco Municipal Railway Light Rail CALTRAIN: a diesel powered heavy rail Amtrak style commuter train operating on a single line from Gilroy to San Francisco The five systems exhibit vastly different infrastructure and operational configurations (diesel powered (only Caltrain) vs. electric powered; High Speed vs. Low Speed; heavy rail vs. light rail): BART: at peak operates 60 trains (assuming an average of 8 cars per train, 502 cars). There are 44 miles of surface track, 23 miles of aerial track, and 21 miles of underground track (including the 14 mile Transbay tube); MUNI: 127 light rail vehicle cars are operated by the organization; CALTRAIN: 34 locomotives (only diesel powered) and 110 cars (between 82 and 148 seats); BOSTON GREEN LINE: 144 cars in the fleet; CAHSR: (under construction) 700 miles of track, with 42 electric powered trains that will provide service with speeds averaging 220 mph. The following are considered: stations (construction; operation: station lighting, escalator, train control, parking lot lighting; maintenance and cleaning, station parking), and tracks (for each railway system a mix of 4 different typologies: at grade, retained fill, underground, and elevated or aerial). Not assessed, tunnel and bridge construction (lack of information). Also healthcare externalities are computed [pages 3-4 and 77-78]. Insurance cost covering operator health and casualty/liability with regard to the vehicles remains a significant portion of system operation. To provide this insurance, buildings are constructed, office operations are performed, energy is consumed, and emissions are produced.

ENGINEERING ASSUMPTIONS	[pages 67-76, 88-92] BART: there are 43 stations (14 aerial platforms, 13 at surface, and 16 underground). Aerial: 750 ft length, a pier cap cross sectional area of 275 ft^2, a platform cross sectional area of 100 ft^2; concrete requirement 520,000 ft^3. Surface: 440,000 ft^3 concrete. Underground: 770,000 ft^3 (1,100,000 ft^3 for shared stations with Muni). CALTRAIN: 34 stations. Platform 300 ft long and 12-15 ft wide. For each station: 27,000 ft^3 of concrete is required (18,000 ft^3 for the station and 9,000 for the sub-base). MUNI: 47 at grade stations and 9 underground stations. At grade: 100 ft length, 9,000 ft^3 concrete. Underground: like BART approach, with 310,000 ft^3 and 1,100,000 ft^3 of concrete per dedicated and shared station. GREEN LINE: similar to Muni, many street level at-grade stations, few underground and also 2 elevated stations (large use of steel). For at-grade total concrete requirement is estimated around 5,100 ft^3. Underground like Muni. CHASR: more than 25 (expected) stations next to track (similar Caltrain), platform length 720 ft. Concrete requirement 65,000 ft^3 (43,000 for the sub-base, 22,000 for the station). [further details 93-107]
METHODOLOGICAL APPROACH AND STANDARD	LCA database [page 68]: SimaPro 2006. LCA approach [page 9]: a hybrid approach is adopted, including EIO-LCA (the Economic Input Output Analysis based LCA that integrates economic Input Output analysis and publicly available environmental databases for inventory analysis of the entire supply chain associated with a product or service; based on Input-Output tables for US published in 1998. Emission factors: Fundamental energy consumption and emission factors are reported [page 130]
NOTES	US calibrated model (in terms of construction typologies, mobility model, electricity mix, etc.). Linked to 5 specific existing rail infrastructures (low replicability). The methodology incorporates the EIO-LCA from US 1998, based on Input-Output matrix not updated and not applicable to Europe or other countries.

03 (RFF-SNCF-ADEME, 2011)

MAIN OBJECTIVE	Measuring carbon footprint of new passenger high-speed rail infrastructures
REFERENCE DOCUMENT	ADEME, RFF, SNCF; 1er ferroviaire global Bilan Carbone - La Ligne à Grande Vitesse Rhin-Rhône au service d'une Europe durable; 2011
GEOGRAPHICAL COVERAGE	Tested in France-EU (Rhine-Rhône line).
INVENTORY RESULTS AND INDICATORS	Inventory results consist in the cumulative emissions deriving from the construction of the railway infrastructure (not normalized to the lifetime of the elements). Indicators: CO_2eq
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES [page 3] Included: Planning Construction Maintenance Operation Not included: Disposal LIFETIME [page 10] 30 years of operation/maintenance ELEMENTS ASSESSED [pages 6-11] Planning phase (110 tCO_2eq per million Euros of design phase) [page 6] Realization phase: Civil works: (internal energy of buildings dedicated to the High Speed Line LGV; Extraction and implementation of materials; Transport of materials by truck; Transport of persons; incoming materials; depreciation; ancillary works) Connections to the existing rail network Railway equipment (signalling, energy, wired arteries; Routes, catenary, works base; buildings; telecommunications; traction power; electrical substations; equipment signals and Hot Box Detector HBD) Railway stations and other railway buildings (main station; maintenance and technical stations) Operating and maintenance phase (30 years) Stations Infrastructure
ENGINEERING ASSUMPTIONS	N.D.
METHODOLOGICAL APPROACH AND STANDARD	Emission factors from ADEME. [page 4]
NOTES	Assessment based on specific characteristics of French high speed railway infrastructures

04 (ITALFERR 2011)

MAIN OBJECTIVE	Measuring carbon footprint of a railway infrastructure construction phase aimed at creating projects and programmes that allow significant CO_2 emissions reductions. For both passenger and freight transport and both local-regional and high speed (in principle, not specified in the paper).
REFERENCE DOCUMENT	F. Loffredo, P. Fedele, M. Severini; The climatic mark of railway infrastructural projects; Ingegneria Ferroviaria 3/2011.
GEOGRAPHICAL COVERAGE	Tested in Italy (Bari-Taranto line). [page 14]
INVENTORY RESULTS AND INDICATORS	Inventory results consist in the cumulative emissions deriving from the construction of the railway infrastructure (not normalized to the lifetime of the elements). Indicators [page 6]: CO_2
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES Included: Planning Construction (including the final approval and tests of the infrastructure) In particular: “Absorbers” neutralising carbon emissions (tree planting planned in the environment mitigation interventions) Renewable energy production Not included: Maintenance Operation Disposal LIFETIME Lifetime is not considered: assessment refers to the cumulative impacts of the whole construction process ELEMENTS ASSESSED [page 7-9] Data is grouped according to the seven emission (clearing) categories of CO_2: Emissions produced for the development of the project (equipment, various systems, paper consumption and use of transportation, office automation) Emissions generated by the production of materials (machinery and equipment used for the construction of materials at the production sites (plant, quarry, etc.)) Emissions deriving from transport of materials (transport means for materials from the production sites up to the building site (trucks, locomotives, etc.)) Emissions generated by processing at the building site (equipment, systems and work vehicles used at the building site for the processing and construction of the infrastructure) Emissions deriving from installations and building site management (fixed systems and mobile installations used at the building sites)

	Clearing due to the introduction of green works (new hedges or tree-shrub lots planned for in the environment and green arrangement interventions) Emissions avoided by using renewable energy systems (solar energy systems and/or wind power plants)
ENGINEERING ASSUMPTIONS	Data comes from the “Itemised Estimate” of the project. The methodology, as an alternative, makes use of a criterion based on the adoption of “Standard Sections” specifications for which the unitary emission has been preventively individually calculated. These typological sections are “average” transverse sections taken by the project designer as a reference and are related to entire parts of infrastructure with a unitary development (e.g. railway embankment with a single track and a height equal to 2 metres, tubular viaduct with 25 metre spans, double track tunnel, three span railway viaduct, double track cutting 3 metres deep, etc). No further specification. [pages 10-11]
METHODOLOGICAL APPROACH AND STANDARD	Compliant with ISO 14064. [page 4]
NOTES	Only CO_2 emissions (not Global Warming Potential approach). [page 6] Includes design and planning, the CO_2 removals from natural sink (green area) and the renewable energy production (solar and wind). A related document published in May 2015 “CARBON FOOTPRINT IN CONSTRUCTION: the experience of Italferr” has not been analyzed in such details, but was taken into account when assessing the methodology in Table 1 to 5. It contained more details about emission factor sources and calculation methodology.

05 (JBV 2009)

MAIN OBJECTIVE	Measuring environmental impacts connected with the construction of new rail infrastructures, for both passenger and goods transport
REFERENCE DOCUMENT	MiSA AS; New Double Track Line Oslo – Ski Life Cycle Assessment of the Follo Line – Transport - Technical report Life Cycle Assessment of the Follo Line – Transport; Rev 00A, 2011 Asplan Viak As; New Double Track Line Oslo – Ski Background report for EPD; Rev 00B; 2013 Asplan Viak As; New Double Track Line Oslo – Ski LCA Guideline for Railway Infrastructure Pilot project The Follo Line; Edition 00E; 2012 Asplan Viak As; New Double Track Line Oslo – Ski Life Cycle Assessment of the Follo Line-Infrastructure; REV 00A, 2011
GEOGRAPHICAL COVERAGE	Tested in Norway-EU (Follo Line, Oslo-Sky, currently the largest transport project in Norway).

INVENTORY RESULTS AND INDICATORS	Inventory results: Total impact Impact per pKm-tKm Indicators: [b) page 14 NB different list in different papers] CO_2eq Ozone depletion Terrestrial Acidification Eutrophication Particle matter Photochemical smog Human toxicity
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES [a page 7; b page 12-13] Included: Construction Maintenance Operation Disposal Not included: Planning LIFETIME [a) page 7; b) page 12] A total LCA for construction, operation, maintenance and disposal of the entire Follo Line within the 60 year calculation period. [page 38 specific lifetime for each component is reported] ELEMENTS ASSESSED Normal track (open section) Tunnel Bridges/viaducts Catenary equipment Substations Signals and communication
ENGINEERING ASSUMPTIONS	Pursuant to the Product Category Rules document (PCR 2009) for railway transport [a) page 8] Some specific engineering assumptions: c) pages 106-111
METHODOLOGICAL APPROACH AND STANDARD	The life cycle inventory and life cycle interpretation is modelled and analyzed in SimaPro using the inventory database Ecoinvent. [b) page 11] Compliant with ISO 14040, ISO 14044, ISO 14025. [d) page 21]
NOTES	Methodology developed for a very specific case (the Follo line), with heavy data and information requirements.

06 (NTNU 2011)

MAIN OBJECTIVE	Assessing environmental impacts of a future Norwegian high-speed rail infrastructure for passenger transport.
REFERENCE DOCUMENT	Carine Grossrieder; Life-Cycle assessment of Future Highspeed Rail in Norway; Norwegian University of Science and Technology Department of Energy and Process Engineering, 2011.
GEOGRAPHICAL COVERAGE	Tested in Norway-EU (the Oslo-Trondheim corridor)
INVENTORY RESULTS AND INDICATORS	Inventory results in: Impact per year*km Indicators [page 19]: Climate change (Global Warming Potential in CO_2eq) Ozone depletion Human toxicity Terrestrial acidification Freshwater eutrophication Water depletion
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES Included: Construction (only for this phase the emission factors are given) Not included: Planning Maintenance Disposal Operation Other specific aspects: [page 16] Deforestation connected with the infrastructure construction Service inputs such as insurance, banking and others LIFETIME Both 60 years and 100 years assumptions are assessed [page 22] ELEMENTS ASSESSED [page 20] Normal track Bridges/viaducts Tunnels
ENGINEERING ASSUMPTIONS	N.D.
METHODOLOGICAL APPROACH AND STANDARD	Ecoinvent 2.2 (for background systems) and SimaPro (for emission factors) [page 7] Mainly based on a material flow analysis
NOTES	The study also implements an up to 2070 scenario for the assessment of future infrastructures. No specific data on emission factors are given for single elements (but only for section typology: open, bridge and tunnel). Maybe more details could be found in "A Methodology for Environmental Assessment - Norwegian High Speed Railway Project Phase 2" by Asplan Viak, MiSA, VWI, and Brekke Strand (2011) and "Miljøbudsjett for Follobanen" by Korsmo, A.-R. and H. Bergsdal (2010). Based on a life-cycle inventory (LCI) for HSR in Norway performed by MiSA [page 14].

07 (CUENTAS 2014)

MAIN OBJECTIVE	Measuring environmental, social and economic impacts connected with different transport modalities in Spain. For passenger high speed infrastructures [Vol II page 160].
REFERENCE DOCUMENT	Alfonso Sanz, Pilar Vega, Miguel Mateos; Las cuentas ecológicas del transporte en España; Vol I + Vol II (methodology); 2014
GEOGRAPHICAL COVERAGE	Tested on transport infrastructures in Spain.
INVENTORY RESULTS AND INDICATORS	Inventory results: Total impact Indicators: [Vol I page 92] Energy consumption Emission of greenhouse gases (CO_2eq) Emissions of air pollutants (NO_2, PM10, PM2,5, O_3) Noise Occupation and fragmentation of territory
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES Included: [Vol I pages 15, 23, 84] Construction Operation Not included: Planning Maintenance Disposal (only vehicles) LIFETIME [Vol I page 84; Vol II pages 55-57] 50 years for all kinds of infrastructure. ELEMENTS ASSESSED [Vol II page 166] Earthwork Normal track Tunnels Railway platform facilities Additional works and others
ENGINEERING ASSUMPTIONS	N.D. [some partial information: Vol II pages 14-15, 164-165]
METHODOLOGICAL APPROACH AND STANDARD	Based mainly on energy consumption assessment per economic investment.
NOTES	A macro-scale holistic approach, aiming to assess gross impacts of different transport modalities in terms of environmental (energy consumption, CO_2 emissions, pollution, soil consumption and fragmentation, noise), social (health, wellbeing, equality and inclusion) and economic impacts.

08 (AEA-CE DELFT-TNO 2012)

MAIN OBJECTIVE	Measuring GHG emissions - both freight and passenger, both local-regional and high speed - resulting from future infrastructure construction and use, vehicle manufacturing, and end of life vehicles (ELVs) of different transport modes (Air, Rail, Road, Ship) and their possible influence on designing optimal routes to long-term GHG reductions from transport by 2050.
REFERENCE DOCUMENT	Nikolas Hill et al; The role of GHG emissions from infrastructure construction, vehicle manufacturing, and ELVs in overall transport sector emissions; Task 2 paper produced as part of a contract between European Commission Directorate-General Climate Action and AEA Technology plc; 1 March 2012 Final draft.
GEOGRAPHICAL COVERAGE	Not tested on specific countries. Applied to the EU overall infrastructures
INVENTORY RESULTS AND INDICATORS	Different inventory results for different phases are provided [pages 42-45] CO_2/km (construction) GJ/km (construction, maintenance) GJ or KWh/km*year (operation) CO_2/passenger (operation) Main indicators [pages V-VI]: Primary energy CO_2eq
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES Included [page 32]: Construction Maintenance Operation Not included: Planning Disposal LIFETIME [page 42] 15 years for gravel ballast; 30 years for rail, concrete ballast and catenaries; 50 years for concrete bridges; 60 years for ballastless track (both concrete and steel); 100 years for stations and tunnels. ELEMENTS ASSESSED [pages 30-31] Stations Ballast Gauge Tunnels Bridges Road crossing Catenaries Signalling and telecommunications
ENGINEERING ASSUMPTIONS	N.D.
METHODOLOGICAL APPROACH AND STANDARD	Four main life-cycle analyses were used; Heiberg (1992), Jonsson (2005), Schlaupitz (2008), Chester & Horvath (2008). [page 32] Emission factors from different sources were used [pages 10-17]: e.g. SimaPro2007, Inventory of carbon and energy database (Bath University), AEA/CE Delft (for Li-ion and NiMH batteries), AEA-GaBi software (for aluminium). Specific infrastructure emission factors were presented for each element [pages 42-45]
NOTES	Website www.eutransportghg2050.eu

09 (INECO 2012)

MAIN OBJECTIVE	Measuring carbon footprint associated with new passenger High-Speed rail infrastructures.
REFERENCE DOCUMENT	INECO; *Huella de carbono de la construcción de una línea ferroviaria de alta velocidad*; 2012
GEOGRAPHICAL COVERAGE	Tested in Spain-EU (specific line N.D.)
INVENTORY RESULTS AND INDICATORS	Inventory results: CO_2eq per km Indicators: CO_2eq. (Hybrid approach: only CO_2 for indirect emissions associated with the production and/or manufacture of concrete, steel, ballast etc). [page 3]
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES [page 3] Included: Construction Not included: Planning Maintenance Operation Disposal LIFETIME N.D. ELEMENTS ASSESSED [pages 5-6] Considers only elements concerning civil work, referring for more than 98% of total emissions; catenary equipment, signals and communication stations are not included. In particular are included: Platform construction (earthworks and civil works), Track assembly.
ENGINEERING ASSUMPTIONS	[page 8, 11-2] TUNNEL For excavation the type of land has been considered according to the RMR (Rock Mass Rating), which represents the index of rock quality parameters according to different terrain. In particular, middle ground with 35 < RMR < 50 has been selected for analysis. A free middle section average of 95 m^2 is assumed, with 30 cm of concrete lining. Two excavation work units are considered: mechanically and explosives, assigning a percentage distribution between 80% and 20%, respectively. BRIDGE It is estimated that 90% of the volume is concrete compared with 10% of pre-stressed concrete. RAIL Only double ballast track is considered, estimating that 6 m^3 of ballast is required per linear metre of double track. ASSEMBLY PHASE Taken into account are the spread of ballast, laying of sleepers, rail and track equipment and track raising necessary (to ensure the track geometry) and rail welding. This activity accounts for over 80% of the materials budget for execution of the project.

METHODOLOGICAL APPROACH AND STANDARD	In line with GHG Protocol and ISO 14046 (not compliant). [page 2] Ecoinvent 2.0 is used for indirect emissions. EMIL Cornier (guidelines 2009) for direct emissions.
NOTES	Very simple input data: [page 10] m of total length of the section m of tunnel m^3 of excavation (e.g. tunnel) m^3 (e.g. for landfill or embankments) m^3 of concrete Tons of steel

10 (UIC 2011)

MAIN OBJECTIVE	Measuring carbon footprint of new high speed rail (in comparison with road and air passenger transport).
REFERENCE DOCUMENT	T. Baron (SIESTA), M. Tuchschmid, G. Marinetti and D. Pelion (2011); High Speed Rail and Sustainability. Background Report: Methodology and results of carbon footprint analysis; International Union of Railways (UIC), Paris, 2011.
GEOGRAPHICAL COVERAGE	Tested both in EU (two lines in France, LGV Mediterranée from Valence to Marseille and South Europe Atlantic Project from Tours to Bordeaux) and extra EU countries (the newly built line from Taipei to Kaohsiung in Taiwan and "Beijing– Tianjin" in China).
INVENTORY RESULTS AND INDICATORS	Inventory results differentiated in: For track: CO_2 per year*km For buildings: CO_2 per year*unit Indicators: CO_2
BOUNDARIES AND ELEMENTS UNDER ASSESSMENT	BOUNDARIES [page 3] Included: Planning Construction Not included: Maintenance; Operation, Disposal and in particular: In general every element without direct relation to specific material flow (e.g. air conditioning devices in rolling stock); Deforestation connected with the infrastructure construction was not taken into account. LIFETIME [page 5] An average lifespan of 100 years has been considered for the construction of civil engineering (e.g. tunnels, buildings). NB: Product Category Rules for railways (PCR 2008) proposed a shorter lifespan of 60 years. Other specific lifespans: 25 years for ballast; 30 years for rail; 50 years for telecommunication and signalling equipment, equipment in general; energy provisions. ELEMENTS ASSESSED [page 9] Planning phase (energy for heating and electricity, paper, electronic device) Normal track (two types: ballasted track and slab track) Bridges/viaducts (three types: small bridge, large bridge and viaduct) Tunnels (three types: German Condition; LGV Med, SE-Atlantic) Energy (catenary posts, aerial cables and substation of the power system) and telecommunication (radio poles, communication cables and signs) Railway stations (two types: main station and secondary station)

ENGINEERING ASSUMPTIONS	EARTHWORKS [page 9-10] Anhydrite rock is used as body material for the track bed, approx. 38 t for 1 m of double track (average width 12 m, Density 2.8 t/m³, 1.15 m height). The quantity of quicklime (75%) and cement (25%) used for the soil treatment are provisional data from the South Europe Atlantique SEA HSR project. With quicklime, the soil can be dried and the consistency can be improved. Per metre of double track, about 1.2 t of quicklime and 0.4 t of cement have been used. Concerning transport of materials the following assumption has been made: 10% of the moved material (excavation & backfill) has to be transported over a distance of 50 km The anhydrite rock quicklime and cement are also transported over an average distance of 50 km 25% of the transport have been by truck (EURO5), 75% by rail transport (diesel) PLANNING 1 km double track requires 50 workers over 1 year; 10 Tonnes of paper will be printed off for 1 km of track; Electrical consumption per office desk is estimated at 1 000 KWh per year (Union for the Coordination of the Transmission of Electricity (UCTE)-electricity mix is assumed); the heating of the 1,500 m² office will be done by natural gas. TRACK CONSTRUCTION (BALLASTED OR SLAB TRACK) [page 11] 1. Ballasted track (concrete sleepers) It is assumed that the ballast (made from gravel) is 0.35 m thick and 6 m wide (density: 2 800 kg/m³). For 1 km of double track, 5 880 t of gravel is needed (in a different section of the study is reported: For a double track of 1 000 m, around 2 600 m³ of crushed stone are needed). The rail consists of UIC60-rail, so 1 metre of rail weighs 60 kg. For one km of double track, 240 tons of steel are needed. The concrete sleeper has an inter space of 0.6 m, for 1 km of double track 3333 pieces are needed. One piece weighs 200 kg (80% concrete, 20% iron) For the fence and the attachment of the rail on the sleepers, an additional amount of 28.7 tons of iron is needed. The lifespan of ballast has been considered as 25 years, the rails last about 30 years, whereas the other elements have an average lifespan of 50 years It is assumed that all material has been transported over a distance of 100 km, 25% by trucks and 75% by rail (diesel) 2. Slab track: Same assumption as above The slab track is made of concrete, for 1 km of double railway track an amount of 2,264 m³ concrete and 133 tons of iron is necessary.

	BRIDGE/VIADUCT [page 12] All material quantities are taken from the report by Schmied & Mottschall (2010). For 1 km of viaduct 1,983 tons of iron, 32,100 m^3 of concrete and 26,170 m^3 of excavation are needed. It is assumed, that the iron will be transported over a distance of 300 km, the concrete over 20 km and the excavated material over 5 km. For 1 km of a smaller concrete bridge, only 1,301 tons of iron and 14,000 m^3 of concrete are needed. The other assumptions are the same as above. For low viaducts over flat areas, it is assumed that around 1,650 tons of iron and 23,000 m^3 of concrete are needed for 1 km of viaduct. TUNNEL [page 13] 15 different tunnels (all mining tunnels) have been examined by Schmied & Mottschall (2010) and the specific material consumption has been calculated. Per metre of tunnel, around 37.2 m^3 concrete have been used, this includes all steps of the construction (e.g. also the concrete for securing the ceiling). Additionally 1,600 tons of steel for construction are needed, the building machines take another 140 litres of diesel. The drilling machine consumes about 2,200 MWh of electricity, assuming the European Electricity-Mix. ENERGY & TELECOMMUNICATION [page 15] A catenary post consist of 2 piles every 58 metres, -> 34.4 poles are needed for 1 km (weight 1 000 kg of iron, with a 1 m^3 concrete foundation The aerial contact line consists of copper, approx. 18 tons of copper are needed per km of a double track Per km of double track, about 18 km of cables are needed for signalling and telecommunication. No replacement of parts during their lifespan (50 years) is considered Only materials such as iron, copper and concrete are taken into account, no electrical devices are examined. BUILDINGS [page 16] It is assumed that a main station consists of 25,000 m^3 of concrete and more than 1,000 tons of iron. No further construction energy has been considered; it is assumed that the transport follows the same principle as the construction of bridges.
METHODOLOGICAL APPROACH AND STANDARD	Ecoinvent Database 2.0 (for emission factors). [page 4] Mainly based on an orienting material flow analysis in line with PCR (Product Category Rules) for rail infrastructure and rail vehicles and in close connection with the ISO standard 14025 (environmental declarations) and the ISO standard 14040 (Life Cycle Assessment). [page 3]
NOTES	Only CO_2 emissions (not Global Warming Potential approach). Includes design and planning, not included in the majority of other similar studies.

Published by: UIC-ETF
Coordination: UIC Sustainable Development Unit / Gabriel Castañares Hernández
Author: François Cuenot
Design: Coralie Filippini

ISBN: 978-2-7461-2500-1