Overview of transport infrastructure expenditures and costs

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Summary

This study is developed within the project ‘Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities’. The overall aim of this project is to assess the state-of-play of internalisation of external and infrastructure costs of transport in the EU Member States and some other countries. Additionally, options for further internalisation should be identified.

As input for this assessment, an overview of transport infrastructure costs is provided by this study. More specifically, this study aims to provide total, average and marginal infrastructure cost figures for road transport, rail transport, inland waterways transport (IWT), maritime transport and aviation in the EU28 Member States and some other Western countries (i.e. Norway, Switzerland, the US states California and Missouri, the Canadian provinces Alberta and British Columbia, and Japan). These infrastructure cost figures are estimated for 2016. For road, rail and IWT, the costs of the entire national (or state/province) transport network were estimated. For aviation and maritime transport, on the other hand, infrastructure costs for some specific ports and airports were estimated.

In addition to an overview of transport infrastructure costs, this study also assesses the development in infrastructure expenditures for road, rail and inland navigation transport over the period 1995-2016.

Transport infrastructure costs

For this study, infrastructure costs are defined as the direct expenses plus the financing costs. Annual infrastructure costs in 2016 are thus equal to the sum of the annual depreciation and financing costs. The transport infrastructure costs include investments in new infrastructure, renewal costs of existing infrastructure, expenditures on the maintenance of infrastructure, and operational expenditures enabling the use of transport infrastructure.

Total infrastructure costs

For road, rail and inland waterway transport, the total infrastructure costs in the EU28 amount to € 267 billion for 2016. The main part of these costs are caused by passenger cars and heavy goods vehicles, as is shown in Table 1. As for aviation and maritime transport, infrastructure costs are estimated for a selection of (air)ports, no total infrastructure costs figures at the EU28 level are provided by this study.

Average infrastructure costs

For passenger transport, the average infrastructure costs (in €/1,000 passenger kilometres) are higher for rail transport than for road transport (see Table 1). This is mainly explained by the higher fixed costs (e.g. construction costs) for rail infrastructure compared to road infrastructure. The average costs are highest for diesel passenger trains, which is due to the low occupancy rate of diesel trains (compared to electric trains)[1]. For road transport, the average infrastructure costs for buses and coaches are significantly higher as for passenger cars, which can be explained by the relatively high weight dependent infrastructure costs caused by these vehicles. Finally, the assessments carried out for 33 selected EU airports showed that the average infrastructure costs for aviation range from € 3 to € 41 per 1,000 passenger kilometres (with an (unweighted) average value for the selected airports of some € 18 per 1,000 passenger kilometres).

[1] This study does not take into account the different costs of a diesel and an electrified rail line but the cost of the overall rail network (which are allocated based on relevant cost drivers to electric and diesel trains).

Table 1 - Infrastructure costs for road, rail and inland navigation transport in the EU28[2]

Vehicle category	Total infrastructure costs	Average infrastructure costs	Marginal infrastructure costs
Passenger transport modes	**Billion €**	**€/1,000 pkm**	**€/1,000 pkm**
Passenger car	98	21	1.3
Bus	8	40	19.1
Coach	13	37	17.9
Motorcycle	3	18	1.1
High speed train	12	106	7.6
Conventional Electric passenger train	39	145	19.2
Diesel passenger train	18	270	35.2
Light commercial vehicles	**Billion €**	**€/1,000 vkm**	**€/1,000 vkm**
Light Commercial vehicle	20	41	2.7
Freight transport modes	**Billion €**	**€/1,000 tkm**	**€/1,000 tkm**
Heavy Goods Vehicle	42	23	7.2
Electric freight train	9	30	5.5
Diesel freight train	3	32	5.6
IWT vessel	3	19	1.3

Table 1 also shows the average infrastructure costs for road, rail and inland navigation freight transport. As for passenger transport, the highest costs are found for rail transport, followed by road transport and IWT. For maritime transport, this study only provides average infrastructure cost figures in € per tonne handled. Therefore, a direct comparison of the results with other transport modes is not possible.

Marginal infrastructure costs

Marginal infrastructure costs refer to the additional costs to the transport infrastructure manager caused by an additional vehicle kilometre (or call or LTO) on the network. In this study, the variable part of the average infrastructure costs (usage-dependent renewal and maintenance costs) are used as proxy for the marginal infrastructure costs.

The marginal infrastructure costs at the EU28 level are presented in Table 1 as well. For passenger transport, the highest costs are found for diesel trains. But compared to average cost figures, no large differences between road and rail transport exist. This can be explained by the fact that the marginal infrastructure costs are (in contrast to the average costs) not affected by the relatively high fixed costs of rail infrastructure. For aviation, marginal infrastructure costs are only calculated in terms of €/LTO in this study and a direct comparison with the other passenger transport modes is therefore not possible.

For freight transport, the highest marginal infrastructure costs are found for heavy goods vehicles, reflecting the relatively large variable part of road infrastructure costs. Marginal infrastructure costs for IWT are relatively low, as only a limited share of the infrastructure costs directly depend on the actual use of the inland waterways. Again, for maritime transport a direct comparison of marginal infrastructure costs with the other transport modes is not possible based on the results found in this study.

[2] EU27 total costs are presented in the accompanying Excel file

Development of infrastructure spending over time

This study also examined for road, rail and inland navigation transport the long-term (1995-2016) trends in infrastructure spending by governments and private transport infrastructure managers.
For road transport, infrastructure spending significantly increased between 1995 and 2007. Particularly in Central and Eastern European countries, there have been a significant increase in road investments in early 2000 as a response on the rising need for improvement of the road networks to facilitate economic development in these countries. The economic crisis has put a stop on this increasing trend, particularly in Southern and Eastern European countries, as budgets for investments and maintenance of existing roads have been cut. Since 2014, investment levels in Europe rise again, particularly in Central and Eastern European countries.

Compared to road transport, spending on rail infrastructure seems to be less significantly affected by the economic crisis, although also rail infrastructure spending decreased in general in the years after the start of the crisis. Rather different patterns are found for Western and Central/Eastern European countries. In Western European countries, spending shows a peak in 2003, followed by a reducing trend for the years afterwards. Since 2013 the expenditure levels are relatively stable. In Central and Eastern European countries, on the other hand, infrastructure spending has increased significantly since 2000, although the spending levels fluctuate significantly from year to year. This increased spending is possibly due to the need to improve the quality of the rail infrastructure in these countries.

Investments levels on inland navigation infrastructure has been rather stable over the period 1995-2016 in Western European countries. In Central and Eastern European countries investment levels have increased significantly between 1999 and 2009, followed by a sharp decrease between 2009 and 2012 (possibly (partly) explained by the economic crisis). As for operational and maintenance (O&M) expenditures, spending has been rather stable in Western Europe till 2010. But due to the economic crisis expenditures levels fall significantly between 2010 and 2014. In Central and Eastern Europe, O&M expenditures have decreased significantly in the late nineties and early 2000. This declining trend may be explained by the war in the former Yugoslavian republic, as a consequence of which the Danube was not really useable, discouraging Danube states to care about waterway maintenance.

Robustness of results

This study provides a state of the art overview on transport infrastructure costs and expenditures . However, there are some uncertainties with respect to the data and methodologies used to estimate the costs and expenditures. These uncertainties has to be kept in mind when interpreting the results of this study.

In general, direct comparisons between countries (or transport modes) should be made carefully, since data availability and quality vary significantly between countries (and modes). Furthermore, figures on total costs are more reliable than figures per vehicle category, as the allocation of total figures to vehicle categories does create some additional uncertainties. Finally, total cost figures are more reliable than average and marginal ones, as the latter have to deal with relatively large uncertainties in traffic performance data. With respect to the latter issue, particularly the scope of the road transport performance data used in this study affects the robustness of the final results. Road transport performance data from Eurostat has been used, which follows the nationality principle[3]. As this scope is not in line with the scope of infrastructure costs, the robustness of the average and marginal cost figures for road vehicles (and particularly HGVs) at country level is adversely affected.

3 According to this principle, transport performance reflects the activity of nationally registered vehicles regardless of where they drive. An alternative way to define transport performance is based on the territoriality principle, i.e. transport performance reflects the activity done by national and foreign vehicles within the territory of the country.

Glossary

Term	Explanation
Average infrastructure costs	Infrastructure costs per transport performance unit (e.g. Euro per pkm, Euro per tkm, etc.).
Bus	Passenger road motor vehicle designed to carry more than 24 persons (including the driver), and with the provision to carry seated as well as standing passengers.
CEEC	Central and Eastern European Countries, covering: Bulgaria, Croatia, Czech Republic, Estonia, Croatia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia.
Coach	Passenger road motor vehicles designed to seat 24 or more persons (including the driver) and constructed exclusively for the carriage of seated passengers.
Cost driver	Factor that expresses the responsibility or the causation of a vehicle for the level of total (infrastructure) costs. In the equivalency factor method (see: Equivalency factor method), cost drivers are called proportionality factors (see: Proportionality factors).
Enhancement costs/expenditures	Expenditures on (costs of) new infrastructure or expansion of existing infrastructure with respect to its functionality and/or lifetime.
Equivalency factor method	Approach used to allocate the total infrastructure costs to various vehicle categories, based on selected proportionality factors (see: Proportionality factor).
Expenditures (on infrastructure)	The actual amounts of money extracted annually from the public (or private) accounts to finance infrastructure. Infrastructure expenditures do not include financing costs.
Fixed costs/expenditures	Costs/expenditures that do not vary with transport volumes.
Gross Domestic Product (GDP)	Aggregate measure of production equal to the sum of the gross value added of all residents, institutional units engaged in production.
Ferry	A ship for conveying passengers and goods, especially over a relatively short distance and as a regular service.
Heavy Goods Vehicle (HGV)	Goods road vehicle with a gross vehicle weight above 3,500 kg, designed, exclusively or primarily, to carry goods.
High speed line (HSL)	Rail lines dedicated to high speed trains (see: High speed train).
High speed train (HST)	Trains designed to operate at a speed of at least 250 km/h on dedicated high speed lines (see: High speed line).
Infrastructure costs	The direct expenses on infrastructure plus the financing costs or - regarded from a different point of view - the opportunity costs for not spending the resources for more profitable purposes.
Investment (expenditure)	Expenditures on the enhancement (see: Enhancement costs/expenditures) and the renewal (see: Renewal costs/expenditures) of the infrastructure network.
Inland Waterway Transport (IWT)	Any movement of goods and/or passengers using inland waterway vessels which is undertaken wholly or partly on navigable inland waterways.
Landing and Take-Off (LTO)	Cycle of landing and take-off of an aircraft.
Light Commercial Vehicle (LCV)	Four-wheeled goods road motor vehicle with a gross vehicle weight of not more than 3,500 kg. Also known as van.
(Rail) line kilometre	One kilometre of rail line. A line is defined as one or more adjacent running tracks forming a route between two points.
Maintenance costs/expenditures	Costs/expenditures referring to the costs/expenditures of/for 'ordinary' maintenance. These are relatively minor repairs with an economic lifetime of less than 1 to 2 years.
Marginal infrastructure costs	Additional infrastructure costs caused by an additional vehicle kilometre (or LTO or call) on the transport network.
Motorcycle (MC)	Two-, three- or four-wheeled road motor vehicle not exceeding 400 kg of unladen weight. All such vehicles with a capacity of 50 cc or over are included.
Operational costs/expenditures	These costs/expenditures refer to the costs/expenditures of the organisation of efficient use of the infrastructure.

Term	Explanation
Operational and Maintenance (O&M) costs/expenditures	The sum of operational (see: Operational costs/expenditures) and maintenance (see: Maintenance expenditures/costs).
Passenger car	Road motor vehicle, other than a moped or a motorcycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver).
Passenger car equivalent (PCE)	Metric used to measure the impact that a single vehicle has on traffic variables (e.g. speed, density) compared to a single car.
Passenger kilometre (pkm)	Unit of measurement representing the transport of one passenger over one kilometre.
Perpetual Inventory Method (PIM)	Method to estimate infrastructure costs based on time series data on infrastructure expenditures. To estimate enhancement (see: Enhancement costs/expenditures) and renewal (see: Renewal costs/expenditures) costs, the annual depreciation costs are calculated by distributing the initial investments over the lifetime of the infrastructure. In addition, financing costs are calculated by using an appropriate interest rate. The sum of depreciation and financing costs equals enhancement and/or renewal costs. O&M costs (see: O&M costs/expenditures) are based on running expenditures.
Price index figure	Indicator measuring the weighted average of prices in a predetermined basked of goods (and/or services). Changes in this indicator are used to correct monetarised data for inflation.
Proportionality factor	Factor that express the responsibility or the causation of a vehicle for the level of total (infrastructure) costs. Used in the Equivalency factor method (see: Equivalency factor method). Also called cost driver.
Public Private Partnerships (PPP)	Long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance.
Purchase Power Standard (PPS)	Indicator reflecting the purchasing power of countries. This indicator is used to correct monetarised figures for differences in purchasing power of an euro across countries.
Renewal costs/expenditures	All costs/expenditures associated with the renewal of (parts of) the infrastructure. The renewed (parts of) the infrastructure will at least have a lifetime of more than 1-2 years. Renewal costs/expenditures doe include extraordinary maintenance with a lifespan of more than 1-2 years.
RoPax	Roll-On-Roll-Off Passenger ship. This ship is designed to carry passengers and wheeled cargo (e.g. cars, trucks, railroad cars), that are driven on and off the ship on their own wheels or using a platform vehicle (e.g. a self-propelled modular transporter).
Ship-kilometre	Unit of measurement representing the movement of a ship over one kilometre.
Tonne-kilometre (tkm)	Unit of measurement of goods transport which represents the transport of one tonne over one kilometre.
Total infrastructure costs	Total annualised infrastructure costs (considering both depreciation and financing costs) within a certain geographic boundary (e.g. EU28 or a country) associated to the relevant transport infrastructure (e.g. road network).
Train kilometre	Unit of measurement representing the movement of a train over one kilometre.
(Rail) Track-kilometre	One kilometre of rail track. A track is a pair of rails over which rail borne vehicles can run.
Transport infrastructure	The physical and organisational network which allows movements between different locations.
Usage elasticity	Indicators expressing the share of average infrastructure expenditures that can be considered marginal (or variable).
Variable costs/expenditures	Costs/expenditures that vary with transport volumes.
Vehicle kilometres (vkm)	Unit of measurement representing the movement of a vehicle over one kilometre.
WEC	Western European Countries, covering: Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, The Netherlands, Portugal, Spain, Sweden, UK, Norway, and Switzerland.

Country abbreviations

Abbreviation	Country
EU28	All 28 EU Member States
EU27	All 28 EU Member States excluding the UK
AT	Austria
BE	Belgium
BG	Bulgaria
HR	Croatia
CY	Cyprus
CZ	Czech Republic
DK	Denmark
EE	Estonia
FI	Finland
FR	France
DE	Germany
EL	Greece
HU	Hungary
IE	Ireland
IT	Italy
LV	Latvia
LT	Lithuania
LU	Luxembourg
MT	Malta
NL	The Netherlands
PL	Poland
PT	Portugal
RO	Romania
SK	Slovakia
SI	Slovenia
ES	Spain
SE	Sweden
UK	United Kingdom
NO	Norway
CH	Switzerland
CA-AB	Alberta (province in Canada)
CA-BC	British Columbia (province in Canada
US-CA	California (state in United States)
US-MO	Missouri (state in United States)
JP	Japan
WEC	Western European Countries, covering Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, The Netherlands, Portugal, Spain, Sweden, UK, Norway, and Switzerland
CEEC	Central and Eastern European Countries, covering Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia

1 Introduction

1.1 Background

Transport is a precondition for a proper functioning of our modern society, for the well-being of people and for the economy. At the same time, transport comes with various external effects, like air pollution, accidents and congestion. In addition, constructing, maintaining and managing transport infrastructure gives rise to significant costs. In contrast to the benefits, the external and infrastructure costs of transport are, without policy intervention, generally not borne by the transport users and hence not taken into account when they make a transport decision. By internalising the external and infrastructure costs (i.e. making these costs part of the decision making process) the efficiency of the transport system can be increased.

According to economic theory, marginal social cost pricing results in an efficient amount and allocation of transport. However, there are several alternative approaches of internalisation often applied and sometimes even more appropriate in the context of policy making. For example, charging vehicles at their average costs (‘average cost pricing’) ensures that total external and/or infrastructure costs are covered. Furthermore, average cost pricing may be considered more fair than marginal cost pricing, as vehicles have to pay for all cost they cause (and not only the marginal costs). Another alternative internalisation approach is Baumol pricing. This approach recommends to set taxes/charges at a level at which a certain objective (e.g. congestion level) is met. Finally, Ramsey pricing is a fourth often mentioned internalisation approach, which aims to choose charge levels in a way total revenues are maximised.

In practice, there are also large differences in the approaches considered to internalise infrastructure (and external) costs. For example, Directive 2011/76/EU (EC, 2011) prescribes that road infrastructure charges for Heavy Goods Vehicles in Europe have to be based on the principle of cost recovery, i.e. the weighted average infrastructure charge have to be related to the construction costs and the costs of operating, maintaining and developing the infrastructure network concerned. On the other hand, Directive 2012/34/EU (EC, 2012) requires that rail usage charges in the EU are based on the direct costs on a network-wide basis, i.e. the cost that are directly related to the use of the rail infrastructure.

So, both from a theoretical and policy point of view it is relevant to have an understanding of the total, average and marginal infrastructure costs of transport in Europe. However, evidence on transport infrastructure costs in Europe is scarcely available, particularly with respect to total/average costs. Road transport is, in this respect, an exception, as CE Delft (2016b) presents 2013 cost figures for the entire road network for all EU28 countries. Additionally, motorway infrastructure costs for HGVs and vans are estimated by CE Delft (2016a). Also Fraunhofer-ISI and CE Delft (2008) presents total/average road infrastructure cost figures, but these are based on less detailed (national) data and hence less robust. For the other transport modes, no recent studies are available that present total/average infrastructure costs for more than one country. Only UNITE (2003) do present total infrastructure cost figures for rail, aviation, inland shipping and maritime transport for 17 (mainly Western-European) countries, but these are figures for 1996 and 1998 only. At the national level, some studies are available (e.g. CE Delft and VU (2014) for the Netherlands, COWI (2004) for Denmark), but only on a limited basis.

Outside Europe, total/average transport infrastructure costs are scarcely studied as well. Transport Canada (2008) provides estimates of the total infrastructure costs in 2000 for road, rail, maritime and air transport, both at the country and province level. More recently, the Conference Board of Canada estimated the road infrastructure cost for the Canadian province Ontaria (The Conference Board of Canada, 2013). For the United States only one study on transport infrastructure costs was identified, i.e.

Delucchi (1998) calculated the road infrastructure costs for 1990/1991[4]. Finally, for Japan no study on transport infrastructure costs was found.

As for marginal infrastructure costs, results are mainly available from case studies. Particularly for road transport, rail transport and aviation several case studies have been carried out in European projects like CATRIN, GRACE and UNITE (CATRIN, 2009; GRACE, 2006; UNITE, 2003). More recently, studies like Nilsson et al. (2014), Nilsson et al. (2018) and Yarmukhamedov and Swardh (2016) have studied marginal road infrastructure costs, while marginal rail infrastructure costs have been assessed by studies like Andersson (2011), Odolinski et al. (2016), Nilsson et al. (2018), and Silavong et al. (2014). Finally, the marginal costs of airport infrastructure have been assessed by Martin et al. (2011). In contrast to the road, rail and aviation, the marginal infrastructure cost for inland shipping and maritime transport are only very scarcely studied. For inland shipping, only Ecorys and Metlle (2005) and CE Delft and VU (2014) do provide marginal cost figures, while for maritime transport fragmented evidence is available for some specific ports (e.g. Rotterdam from CE Delft and VU (2014), Antwerp from TRL et al. (2001)).

This study aims to fill the knowledge gap in the field of transport infrastructure costs, by presenting estimates of the total, average and marginal infrastructure costs for all transport modes and all EU countries (+ Norway and Switzerland). Furthermore, infrastructure costs for some non-European countries (US, Canada, Japan) are estimated as well for comparison reasons.

This study is part of a broader project on the internalisation of external and infrastructure costs of transport in Europe. This is explained in more detail in the following text box.

This report is produced with in the project 'Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities'. The overall aim of this project is to assess to what extent EU Member States and some other countries (i.e. Norway, Switzerland, US, Canada and Japan) have implemented the 'user-pays' and the 'polluter-pays' principles. It should provide an overview of the progress EU Member States have made towards the goal of full internalisation of external (and infrastructure) costs of transport and to identify options for further internalisation.

As part of this broad internalisation project, the following five deliverables are produced:

- *Overview of transport infrastructure expenditures and costs* (current report), which provides an overview of the infrastructure costs of all transport modes in all relevant countries.
- *Handbook on the external costs of transport - version 2018*, which provides an overview of methodologies and input values that can be used to provide state-of-the-art estimates for all main external costs of transport. Furthermore, this report present the total, average and marginal external costs for all relevant countries.
- *Transport taxes and charges in Europe - An overview study of economic internalisation measures applied in Europe.* This study provides an overview of the structure and level of transport taxes and charges applied for the various transport modes in the EU28 Member States (and the other relevant countries). Furthermore, this study presents the total revenues from transport taxes and charges for the various transport modes and countries.
- *The state-of-play of internalisation in the European transport sector*, which shows for all countries and transport modes to what extent external and infrastructure costs are internalised by current taxes and charges and which options for further internalisation are recommended.
- *Summary report*, providing an overview of the main findings of the other four deliverables.

[4] Although the number of studies on transport infrastructure costs in the US is limited, there are several studies providing data on transport infrastructure expenditures in the US, both at the federal and state level. For example, BTS (2017) present annual transport investments for the US as a whole. At the state level, studies like FDOT (2014) and Carnegie and Voorhees (2006) provide an overview of annual road expenditures for Florida and New Jersey, respectively. As will be explained in Chapter 2, these expenditure data is less useful than cost data for internalisation purposes.

1.2 Objective

The objective of this study is to provide total, average and marginal infrastructure cost figures for road transport, rail transport, IWT, maritime transport and aviation in the EU28 Member States and some other Western countries. Additionally, for road, rail and inland waterways transport, the development of infrastructure expenditures over time is assessed.

1.3 Scope of the study

1.3.1 Transport modes

In this study, infrastructure expenditures and costs[5] are estimated for road transport, rail transport, inland waterway transport (IWT), maritime transport and aviation. The vehicle types that are considered per mode are shown in Table 2.

Table 2 - Transport modes and vehicle types covered

Road transport	Rail transport	IWT	Maritime transport	Aviation
- Passenger car - Motorcycle - Bus - Coach - Van - Heavy Goods Vehicle (HGV)	- High speed passenger train (HSL) - Passenger train electric - Passenger train diesel - Freight train electric - Freight train diesel	- Inland vessel	- Freight vessel - Ferry	- Passenger aircraft - Freight aircraft[a]

a For freight aviation, only rough estimates of the total infrastructure costs are provided. No reliable estimates of average and marginal infrastructure costs for this type of aviation could be estimated. See Section 7.3 for more information.

As for the marginal infrastructure costs, figures for some additional reference vehicle types (in addition to the vehicle types presented above) are calculated. This is discussed in more detail in Annex H.

1.3.2 Geographical coverage

For road transport, rail transport and IWT we consider the infrastructure expenditures and costs for all relevant EU28 countries, Norway, Switzerland, Canada, US, and Japan. For Canada and the United States, as the management of transport infrastructure is institutionalised at the province/state level, infrastructure costs and expenditures are considered at the province/state level for these countries, i.e. California, Missouri (both US), and British Columbia and Alberta (both Canada)[6].

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5 External costs of transport (such as environmental costs) are assessed in a separate report, in the framework of the project mentioned in the text box in Section 1.1.

6 Both for the US and Canada, a front runner and laggard state/province with respect to the internalisation of external costs have been selected. For the US, California has been selected as a front runner state, among other things because fuel and vehicle taxes are among the highest in the US and broad enabling legislation for toll roads has been implemented. Furthermore, California is known for its progressive policies in the transport sector (e.g. regarding electric vehicles). Missouri, on the other hand, shows relatively low fuel and vehicle taxes as well as limited road charging legislation, suggesting a low level of internalisation. For that reason, Missouri is selected a laggard state. According to Corporate Knights (2015), British Columbia can be regarded as the Canadian province with the highest environmental performance for the transport sector, while Alberta is

In this study, we regularly present results differentiated to Western European countries (WEC), Central and Eastern European countries, Unites States and Canada (US + CA) and Japan. The WEC include: Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, The Netherlands, Portugal, Spain, Sweden, United Kingdom, Norway and Switzerland. The CEEC include: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.

For maritime shipping and aviation, infrastructure costs are not calculated at the national/regional level, but at the level of individual (air)ports[7]. The selection of (air)ports considered in this study is given in Table 3. This selection is made based on the following criteria:

- Airports:
  1. Of all considered countries the largest airport is analysed.
  2. In Canada and the US, the two largest airports are included.
  3. In Europe, the five largest airports, which are not already included in the criteria above, are considered as well.
  4. Only international airports (with international flights) are covered in the analysis.
- Maritime ports:
  1. All 24 maritime ports considered in the study *'Assessment of potential of maritime and inland ports and inland waterways and of related policy measures, including industrial policy measures'* (EY et al., ongoing) are covered. The maritime ports considered in this study provide a good representation of main EU ports with growth potential up to 2030. This ensures some coherence between the two studies.
  2. As not all countries were covered by the ports selected in Step 2, an additional set of ten ports was included to cover the main maritime ports for all European countries considered in this study.
  3. In order to provide a good representation of the main ferry/RoPax ports as well, an additional German port was added to the list.
  4. A sample of five over-seas ports in the US, Canada and Japan have been selected.

Table 3 - Airports and maritime ports covered

Country	Airport(s)	Maritime port(s)	
		Freight ports	Ferry/cruise ports
Austria	- Wien - Schwechat		
Belgium	- Brussels	- Antwerp	
Bulgaria	- Sofia	- Varna	
Croatia	- Zagreb Pleso	- Rijeka[1] - Split	- Rijeka[1] - Split
Cyprus	- Larnaka	- Limassol	
Czech Republic	- Prague Ruzyne		
Denmark	- Copenhagen - Kastrup	- Arhus - Helsingør (Elsinore)	- Arhus - Helsingør (Elsinore)
Estonia	- Lennart Meri Tallinn	- Tallinn	- Tallinn
Finland	- Helsinki - Vantaa	- Helsinki	- Helsinki
France	- Paris – Charles de Gaulle - Paris - Orly	- Calais - Le Havre - Marseille	- Calais - Le Havre - Marseille

ranked lowest. Therefore, British Columbia (front-runner) and Alberta (laggard) has been selected as Canadian provinces in this study.

7 As all relevant data to estimate the infrastructure costs are available at the (air)port level only.

Country	Airport(s)	Maritime port(s)	
		Freight ports	Ferry/cruise ports
Germany	- Frankfurt - Munich	- Hamburg - Bremerhaven	- Hamburg - Travemünde
Greece	- Athens Eleftheriios Venizelos	- Piraeus	- Piraeus
Hungary	- Budapest Liszt Ferenc		
Ireland	- Dublin	- Dublin	- Dublin
Italy	- Roma - Fiumicino	- Genova - Trieste[1] - Venice[1]	- Genova - Trieste[1] - Venice[1]
Latvia	- Riga	- Riga	- Riga
Lithuania	- Vilnius	- Klaipeida	- Klaipeda
Luxembourg	- Luxembourg		
Malta	- Luga	- Marsaxlokk	
Netherlands	- Amsterdam - Schiphol	- Rotterdam	- Rotterdam
Poland	- Warsaw Chopina	- Gdansk	- Gdansk
Portugal	- Lisboa	- Sines	
Romania	- Bucharest Henri Coandă	- Constanta	
Slovakia	- Bratislava M.R. Stefanik		
Slovenia	- Ljubljana Brink	- Koper[1]	- Koper[1]
Spain	- Barcelona – El Prat - Adolfo Suarez Madrid – Barajas - Palma de Mallorca	- Algeciras - Barcelona - Bilbao - Valencia	- Algeciras - Barcelona - Bilbao - Valencia
Sweden	- Stockholm - Arlanda	- Goteborg	- Goteborg
United Kingdom	- London - Heathrow - London - Gatwick	- Felixstowe	
Norway	- Oslo - Gardermoen	- Oslo	- Oslo
Switzerland	- Zurich		
Canada	- Toronto/Lester B Pearson Intl. Ont. - Vancouver International B.C.	- Vancouver - Montreal	- Vancouver - Montreal
United States	- Atlanta Hartsfield – Jackson International - Los Angeles International	- Los Angeles - Savannah	- Los Angeles
Japan	- Haneda Airport Tokyo	- Tokyo	- Tokyo

[1] The ports of Venice, Trieste, Koper and Rijeka are included under the North Adriatic Port Association (NAPA).

1.3.3 Transport infrastructure network

In this study, we consider the expenditures and costs for the entire transport infrastructure networks relevant for the transport modes presented above. This implies, for example, that for road transport the costs of the entire road network (including motorways, urban road and other roads) are covered. Furthermore, it implies that for aviation and maritime transport the total (air)port infrastructure is considered. Additionally, for road transport and rail transport assessments for specific parts of the network (i.e. motorways and high speed lines, respectively) are carried out as well.

1.3.4 Transport performance

To estimate the infrastructure cost figures, several types of transport performance data (e.g. vehicle-kilometres, tonne-kilometres, passenger-kilometres) have been used. For the purpose of this study a consistent set of transport performance data have been composed, mainly based on EU aggregated sources (like Eurostat and COPERT). For maritime transport and aviation, (air)port specific transport performance data (e.g. number of calls, LTOs) are collected from port authorities and annual reports of the considered (air)ports directly.

Road transport performance data is taken from Eurostat, following the nationality principle, i.e. transport activity is allocated to countries where the vehicle is registered. In an alternative approach, the territorial principle, transport activity is allocated to the countries where the activity actually takes place. For example, kilometres driven by Polish vehicles in Germany are accounted to Poland if the nationality principle applies, and to Germany if the territorial principle applies. The territorial principle would have been more consistent with the scope of the infrastructure costs. However, as a detailed EU-wide data set on road transport performance based on the territorial principle is not available, the official Eurostat data set based on the nationality principle has been used for this study. This choice (i.e. to apply road transport performance data based on the nationality principle) affects the results of this study. This is discussed in more detail in Section 2.5.

1.3.5 Base year

Infrastructure costs are presented for 2016. For road transport, rail transport and IWT, infrastructure expenditures for the years 1995-2016 are presented as well.

1.3.6 Price level

All financial figures are expressed in Euro price levels of 2016. Data from sources where price levels from other years were used, are translated to price level 2016 by using relevant price index figures (from Eurostat). Furthermore, all financial figures are adjusted for differences in purchase power between countries (by using Purchasing Power Standards (PPS) from Eurostat), in order to allow for direct comparisons between counties. This implies that all financial figures are shown for the EU28 average price level.

1.3.7 Funding of transport infrastructure

As discussed in Annex F, data on the institutional character (public or private) of the funding of transport infrastructure is hardly available and hence we were not able to assess this issue in a quantitative ways. Based on ITF (2018) it may be concluded, however, that the majority of transport infrastructure is financed from public money; the share of private investments in total road and rail investments is probably well below 10% for most countries. See Annex F for more details.

1.4 Outline of the study

In Chapter 2, we present an overview of the general methodology used to estimate the infrastructure expenditures and costs for the various transport modes. Using this methodology, the infrastructure expenditures and costs are estimated in Chapter 3 (road transport), Chapter 4 (rail transport), Chapter 5 (IWT), Chapter 6 (maritime transport), and Chapter 7 (aviation).

2 Methodological overview

2.1 Introduction

In this chapter we present an overview of the general methodology used to estimate transport infrastructure expenditures and costs for the various modes. Mode-specific methodological issues are discussed in the relevant chapters per mode (Chapters 3 to 7). We start this chapter by presenting the definition of transport infrastructure as it is used in this study (see Section 2.2). Next, infrastructure expenditures are defined and the approach to collect data on these expenditures is described (see Section 2.3). In Section 2.4, we define infrastructure costs and we present the general methodology to calculate these costs. Finally, in Section 2.5 the main uncertainties in the methodology and data and their implications for the reliability of the results of this study are discussed.

2.2 Defining transport infrastructure

In this study, transport infrastructure is defined as the physical and organisational network which allows movements between different locations (HLG, 1999). This definition is a bit broader than the definition presented in EC Regulation no. 851/2006 (EC, 2006) (i.e. 'transport infrastructure is all routes and fixed installations being routes and installations necessary for the circulation and safety of traffic'). The latter definition focusses on the physical aspect of transport infrastructure, while the definition used in this study also includes the organisational aspects (e.g. traffic police, traffic management). As these organisational aspects are necessary elements of an efficient and effective transport system, we consider them as crucial elements to take into account when estimating transport infrastructure costs. Furthermore, as some transport charges (partly) cover these organisational aspects of infrastructure costs (e.g. some of the airport charges), considering infrastructure costs including the organisational cost elements is preferred when comparing them to tax/charge revenues.

In the next chapters we translate this general definition of transport infrastructure into working definitions for the various modes. It should be mentioned, however, that the infrastructure expenditure data collected for the various transport modes and countries is not always fully consistent with these working definitions (e.g. as the sources from which the data is collected apply slightly different definitions or as for part of the infrastructure no expenditure data is available).
In Section 2.5, the impact of these issues on the reliability of the results of this study are discussed in more detail.

2.3 Infrastructure expenditures

2.3.1 Defining infrastructure expenditures

The actual amounts of money used annually from public (or private) accounts to finance transport infrastructure are called infrastructure expenditures (CE Delft, 2016b). An overview of expenditures provides an understanding of the direct impact of transport infrastructure on these budgets. However, infrastructure expenditures do not provide a complete picture of the economic costs of transport infrastructure, as is explained in the following text box. For that reason, infrastructure costs are estimated in this study as well.

Although infrastructure costs provide a better reflection of the actual economic costs of transport infrastructure, there are two reasons for considering infrastructure expenditures in this study as well.

First, data on infrastructure expenditures is required as input for the estimation of infrastructure costs (see Section 2.4). Secondly, data on infrastructure expenditures may provide an overview of the temporal pattern of spending on transport infrastructure (e.g. have maintenance expenditures on road increased or decreased over the last 20 years), which may be relevant from a policy perspective. For these reasons, we present time series data (for the period 1995-2016) for both investments and O&M expenditures on road, rail and IWT infrastructure in the next chapters. As time series data on infrastructure expenditures for maritime transport and aviation was not available for most (air)ports[8], these will not be discussed in Chapters 6 and 7.

Distinction between expenditures and costs
The total resources consumed by the construction, maintenance and operation of long life transport infrastructure can either be done by simply summing up expenses, or by using (real economic) costs. There is an important distinction between these two: expenditures do not take the financing costs or - regarded from a different point of view - the opportunity costs for not spending the resources for more profitable purposes into account, whereas costs do.
Financing (or opportunity) costs are expressed by the interest on capital. As the financing of infrastructure is an issue concerning both public and private investors, the use of full economic costs data is preferred to the summing up of expenditures in all cases.

A second argument for the use of economic costs as opposed to expenditures relates to the fact that infrastructure expenditures vary widely over time, e.g. due to long planning and construction phases of big projects. This implies they cannot accurately reflect the actual costs of transport infrastructure. For example, the investment expenditures in transport infrastructure built in 2000 are zero in 2016, but as the infrastructure is used in 2016 as well, part of these investments should be allocated to the transport users in 2016. This can be done by applying a cost accounting approach
(see Section 2.4).

In this study, we present both investments and operational and maintenance (O&M) expenditures on transport infrastructure (ITF, 2013b):
- *Investments* are expenditures on the enhancement and renewal of the transport infrastructure network. More specifically:
  - *Enhancement expenditures* are all expenditures on new infrastructure or expansion of existing infrastructure with respect to its functionality and/or lifetime.
  - *Renewal expenditures* are all expenditures associated with the renewal of (parts of) the infrastructure. The renewed (parts of) the infrastructure will at least have a lifetime of more than 1 to 2 years.

  Both enhancement and renewal expenditures can be undertaken at any time and are not directly dictated by the condition of the asses.
- *Operational and maintenance expenditures* do include two elements:
  - *Maintenance expenditures* are expenditures associated with ‘ordinary’ maintenance, i.e. maintenance that cannot be avoided. These activities do not change the performance of the infrastructure asset, but simply maintain it in good working order or restore it to its previous condition in the event of a breakdown. These are all relatively minor repairs with an economic lifetime of less than 1 to 2 years.
  - *Operational expenditures* are expenditures made to enable an efficient use of the infrastructure (e.g. lighting, traffic management).

In our assessments of transport infrastructure expenditures we will focus on investments and O&M expenditures for the five modes (road, rail, IWT, maritime transport and aviation). A further breakdown

[8] The fact that many maritime ports and airports are (partly) owned by private operators, collecting time series data on infrastructure expenditures is very difficult. Particularly as these data are often considered commercially sensitive data.

of these expenditures (i.e. to enhancement, renewal, maintenance and operational expenditures) will only be made for the purpose of estimating the infrastructure costs per vehicle category (see Section 2.4).

2.3.2 Collecting and assessing infrastructure expenditure data

To provide a complete and consistent set of data on infrastructure expenditures for all modes and countries, a three step approach has been applied:

1. Data collection from international aggregated sources:
   The collection of data has been started by assessing international aggregated sources, mainly from the OECD (road, rail and IWT) and Eurostat (rail and IWT). Both sources do provide data on annual transport infrastructure expenditures for a significant number of years, distinguishing between investments and maintenance expenditures. However, both sources do not provide a complete set of data, as this data is reported voluntarily by countries. Furthermore, the expenditure figures presented are not always complete (from the perspective of this study), e.g. by not covering operational expenditures. Furthermore, data on maritime transport and aviation are only presented at the country level (for a limited number of countries), while in this study we consider these modes from a (air)port level (see Section 1.3.2). A final complicating factor is that the scope of expenditures differ between countries, which complicates cross country comparisons. For these reasons the data collection from international aggregated sources have been complemented by data collection from national sources.
2. Data collection from national sources:
   In addition to the data collection from international aggregated sources, data on infrastructure expenditures have been collected from national sources as well. For that purpose annual reports of infrastructure managers have been assessed and relevant authorities (infrastructure managers, Ministries of Transport, airports, ports, etc.) and institutions (e.g. national statistical agencies) have been contacted. The data collected in this way have been used to complement and cross-check the data collected from the international aggregated sources.
3. Compiling of a complete and consistent dataset per mode per country:
   Based on the data collected in Step 1 and 2 a complete and consistent dataset is composed in this third step. Therefore, we have first transformed all data in euros, in constant prices of the year 2016 in order to make them comparable. Then, relevant crosschecks of data have been carried out and, as far as possible, a consistent dataset has been compiled. Data gaps identified have been filled by applying several methods, including:
   - extrapolating or interpolating time series data, which has been particularly useful for cases where limited data (e.g. only for a couple of years) is missing;
   - applying growth rates in expenditures from other, comparable countries to estimate missing data for some years;
   - using unit values (e.g. in €/kilometre network) from comparable countries.

More information on the data sources used for a specific mode or country and the methodologies applied to fill any specific data gap can be found in Annex A.

2.4 Infrastructure costs

2.4.1 Defining infrastructure costs

Infrastructure costs can be defined as the direct expenses plus the financing costs or – regarded from a different point of view – the opportunity costs for not spending the resources for more profitable purposes (Fraunhofer-ISI & CE Delft, 2008). Financing (or opportunity) costs are expressed by the interest on capital.

As for expenditures, a differentiation between investments (further differentiated to enhancement and renewal costs) and O&M costs (broken down to operational and maintenance costs) can be made. Infrastructure costs can further be classified by the way they are influenced by the infrastructure usage, i.e. transport volumes. This classification uses the definitions as introduced in Ecorys & CE Delft (2006) and applied in several studies (e.g. (CE Delft, 2016b; Ecorys & Mettle, 2005; ProgTrans; IWW, 2007)):
- *Variable costs*: costs that vary with transport volumes while the functionality of the infrastructure remains unchanged. Part of the maintenance and renewal costs belong to this cost category.
- *Fixed costs*: costs that do not vary with transport volumes while the functionality of the infrastructure remains unchanged, or costs that enhance the functionality of the infrastructure.
  All enhancement costs and operational costs are fixed infrastructure costs. Some of the maintenance and renewal costs are (partly) fixed costs.

In this study, we will estimate both total/average as well as marginal infrastructure costs. Total infrastructure costs refer to total annualised costs (considering both depreciation and financing costs) within a certain geographic boundary (e.g. EU28 or a country) associated to the relevant transport infrastructure[9]. Average costs are closely related to total costs, as they express the costs per transport performance unit (e.g. Euro per pkm, Euro per tkm, or Euro per vkm). Finally, marginal infrastructure costs refer to the additional costs to the transport infrastructure manager caused by an additional vehicle kilometre (or LTO or call) on the network. In this study we consider medium term marginal infrastructure costs, i.e. not only the maintenance expenditures caused by additional traffic demand are considered, but also renewal expenditures.

Finally, infrastructure costs can be categorised based on the institutional character of the costs. They can be financed from private, public or private public partnership (PPP) sources. A rough indication of the various financing sources in total infrastructure costs is estimated for all transport modes.

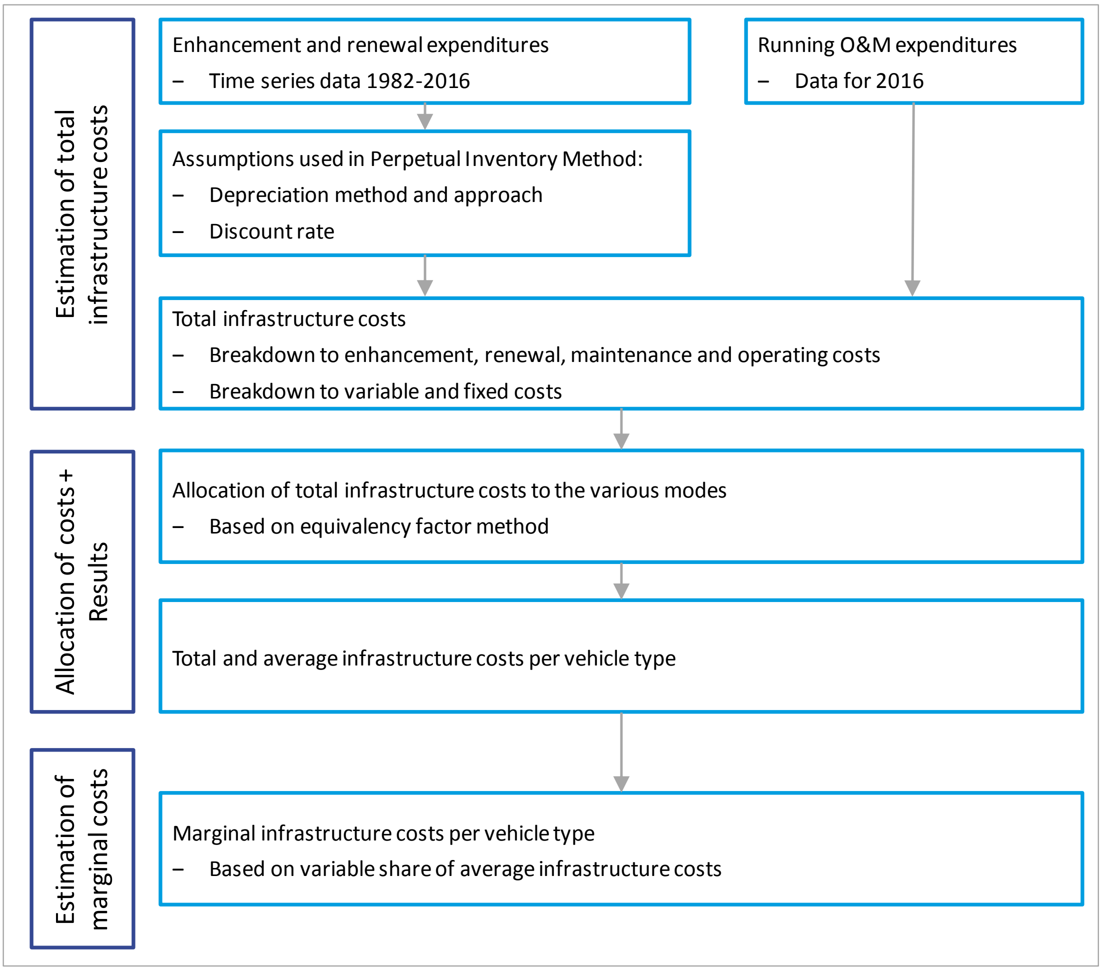
2.4.2 Estimating infrastructure costs: a general overview

A top-down approach is used to estimate infrastructure costs for the various transport modes (see Figure 1. This approach consists of three steps: first, total infrastructure costs per mode are estimated based on data on annual expenditures on transport infrastructure by using the Perpetual Inventory Method (see Section 2.4.3). The annual expenditures are capitalised (i.e. annual depreciation and financing costs are calculated) to estimate the total infrastructure costs (see Section 2.4.3). Alternative approaches to estimate infrastructure costs are the direct expenditures method and the Synthetic method. A detailed discussion on all three methods, their advantages and disadvantages and the reason to apply the PIM in this study is presented in Annex B.

Secondly, the total infrastructure costs are allocated to the various vehicle categories by applying relevant cost drivers (the so-called equivalency factor method). In this way the total and average infrastructure costs per vehicle type are estimated (see Section 2.4.4). Finally, the marginal infrastructure costs are estimated. In general, these are assumed to be equal to the variable share of the average infrastructure costs.

[9] Total infrastructure costs do differ from the capital stock. The latter is the current value of the transport network in a given year (ITF, 2013b) or, in other words, the sum of all historical investments that are not yet written off (Fraunhofer-ISI & CE Delft, 2008).

Figure 1 - General approach to estimate infrastructure costs



2.4.3 Methodology to estimate total infrastructure costs

Figure 1, different methodologies are used to estimate investment costs (i.e. enhancement and renewal costs) on the one hand, and O&M costs (i.e. operational and maintenance costs) on the other hand.

Investment costs

The estimation of investment costs is based on the Perpetual Inventory Method (PIM). This approach is widely used in transport infrastructure studies (e.g. by (CE Delft, 2016a; CE Delft, 2016b; COWI, 2004; ITS, 2001; The Conference Board of Canada, 2013; Transport Canada, 2008; UNITE, 2000)) and recommended by the ITF (2013b). The PIM approximates the value of the capital stock by accumulating and revaluing acquisitions less disposals of the type of asset in question over its lifetime, adjusted for changes such as depreciation (ITF, 2013b). In other words, it calculates the annual depreciation cost by distributing the initial investments over the lifetime of the infrastructure, and estimates interest/financing costs by using an appropriate interest rate. The sum of the depreciation and financing costs equal the investment costs. For a more detailed explanation of the PIM, see
Annex B.3.

The PIM is based on four assumptions:
- *Depreciation approach*: A variety of depreciation approaches can be used for the estimation of costs. The two most frequently used ones are the annuity approach, which assumes constant annual costs (depreciation + financing costs), or the linear approach, which assumes constant depreciation costs (and hence diminishing total costs). CE Delft (2008) and The Conference Board of Canada, 2013) shows that the differences in the results of both approaches are rather limited. For the purpose of this study, we will use the annuity approach as it can be applied in a practical manner.
- *Depreciation period*: The depreciation period is directly related to the life expectancy of the infrastructure. As the concept of infrastructure is very diverse, so is its life expectancy (e.g. 10-15 years for equipment, 90-100 years for earthworks). Unfortunately, data on that level of detail is not available in statistical databases. As a result, applying different values of life expectancy is not possible. In this study, we have therefore opted to use an average depreciation period of 35 years. This value was chosen as it can arguably be considered an EU average life expectancy for infrastructure assets (Fraunhofer-ISI & CE Delft, 2008; CE Delft, 2008). This length of depreciation period was also applied by The Conference Board of Canada (2013) to estimate the road infrastructure costs in Ontario (Canada).
- *Interest rate*: Although the interest rate has varied considerably in the last 35 years, we propose to use an interest rate of 4% for all EU Member States over that period. As explained in the Guide to Cost-Benefit Analysis of Investment Projects (EC, 2014), according to Article 19 (Discounting of cash flows) of Commission Delegated Regulation (EU) No 480/2014 (EU, 2015), for the programming period 2014-2020, the European Commission recommends that a 4% discount rate in real terms is considered as the reference parameter for the real opportunity cost of capital in the long term.
- *Inflation correction*: As mentioned in Section 1.3.6, all figures in this report will be expressed in Euro price level 2016. Therefore, all historic infrastructure expenditures are corrected for inflation. Additionally, figures are adjusted for PPP. This has been done based on Eurostat data.

Alternative approaches for aviation and maritime transport

As mentioned in Section 2.3.1, no time series data on infrastructure expenditures for aviation and maritime transport has been collected in this study. Therefore, alternative approaches has been applied to estimate the investment costs for airports and maritime ports. For aviation, these have been based on the depreciation costs that are presented by the airports themselves (e.g. in their annual reports), instead of applying the PIM approach based on time series of expenditure data.
As for maintenance and operational costs, these can be based on running expenditures for 2016 (as is the case for the other transport modes). For maritime transport, data on depreciation costs was rarely available from the annual reports of maritime ports. Therefore, maritime port infrastructure costs were directly based on the expenditures in 2016 (direct expenditures method, see Annex B)[10].

Operational and maintenance costs

Operational and maintenance costs are considered expenditure elements with a lifetime below one or two years. As a result, they are not capitalised, but rather the running costs (annual expenditures in 2016) are taken directly into account when computing total infrastructure costs.
Maintenance costs would preferably be based on the so-called ‘standard cost approach’ (CE Delft & VU, 2014; CE Delft, 2016b), which refers to the costs related to the minimum of maintenance measures required to ensure the long-term physical and functional integrity of existing infrastructure under current conditions (‘steady state level’). This approach corrects infrastructure spending that is systematically below (or above) what is needed for maintenance and hence better reflect the actual costs caused by infrastructure users. However, data on expenditures according to the standard cost approach is often not available. Therefore, we use the actual maintenance expenditures to estimate maintenance costs.

[10] This also implies that financing or capital costs of investments in port infrastructure were not covered in this study.

2.4.4 Methodology to allocate costs to vehicle types

In order to calculate the infrastructure costs per vehicle category, the total costs need to be allocated to the various vehicle categories (as defined in Figure 1). In this study, we have applied the widely-used equivalency factor method for this allocation task[11]. This method defines certain proportionality factors (cost drivers) for each cost category which express the responsibility or the causation of the vehicle for the level of total costs (Fraunhofer-ISI & CE Delft, 2008; CE Delft, 2008). Examples of proportionality factors may be the number of vehicle kilometres, number of tonne-kilometres, axle-load weighted kilometres, etc. Based on the selected proportionality factors the total infrastructure costs are allocated to the various vehicle categories.

The choice of proportionality factors heavily affects the final infrastructure costs estimates per vehicle category. Therefore, these factors have been selected based on a literature review, considering both their theoretical power (i.e. are they relevant cost drivers) and their pragmatic applicability (i.e. is all data available to apply these factors). The conclusions of this literature review are presented in the various mode-specific chapters (while a more detailed description of the literature review for road and rail transport is given in Annex E).

2.4.5 Methodology to estimate marginal infrastructure costs

To estimate marginal infrastructure costs, several approaches can be applied (Fraunhofer-ISI & CE Delft, 2008; TML, 2016):
- *Econometric approach*: based on time or cross section data on annual road costs or expenditures and traffic volumes, econometric models are estimated assessing the relationship between traffic volumes and costs.
- *Engineering approach*: using engineering cost functions and maintenance models, the length of maintenance periods is estimated based on data on traffic volumes and infrastructure characteristics. Based on the estimated impact of traffic volumes on maintenance periods, marginal infrastructure costs can be derived.
- *Cost allocation approach*: assuming that the marginal infrastructure costs are equal to the variable average infrastructure costs[12], the marginal costs can be estimated by distinguishing between fixed and variable infrastructure costs when estimating the total/average infrastructure costs.

[11] Instead of the equivalence factor method an econometric approach or a game theory approach could have been used to allocate the total infrastructure costs to the various vehicle categories (Fraunhofer-ISI & CE Delft, 2008). The econometric approach relates cost data to traffic flow information across links over time. The resulting regression coefficients illustrate the cost shares for the different vehicle categories. Although theoretically solid, the significance of the results are in practice often low due to high co-linearities of flow data among different vehicle categories. Furthermore, this approach has not been applied in many studies before and hence no default unit parameters (i.e. share of costs to be allocated to a specific vehicle category) are available to be applied in this study. The second alternative approach uses game theory to construct a characteristic cost function, which is then applied to a continuum of players (mode users). The result of the cooperative game is that all users negotiate a fair share of total costs for themselves. As this approach haven't been applied to complete transport infrastructure networks yet, no default unit parameters are available to be used in this study.

[12] Based on literature review, Fraunhofer-ISI and CE Delft (2008) conclude that, despite the fact that most studies show decreasing marginal costs with traffic density, the degree of nonlinearity is in general weak and hence it may be concluded that marginal infrastructure costs are approximately equal to average variable costs.

As both the econometric and engineering approach are very data intensive, they are not applied in this study. Instead, we apply the cost allocation approach and use the variable average infrastructure costs as proxy for the marginal infrastructure costs (for the general vehicle categories presented in Figure 1, see Section 1.3.1).

2.5 Uncertainty

The results provided by this study are based on a lot of data, from different sources and varying quality. Furthermore, the methodologies used to estimate the infrastructure costs require several assumptions (e.g. on interest rates, depreciation period) which result in uncertainties as well. It is important to carefully consider these uncertainties and their impact on the results presented in this study.

Some important uncertainties with respect to the expenditures on transport infrastructure are:
- As there is no coherent framework for accounting transport infrastructure expenditures, differences may exist in the scope and definition of infrastructure expenditures used in the various countries (ITF, 2013a; ITF, 2013b). Although we have tried in this study to align the definition and scopes of infrastructure expenditures between countries (by assessing national data sources and cross-checking data from various sources), differences between countries still exists. Therefore, comparisons between countries should be made very carefully.
- The datasets on infrastructure expenditures and costs available for this study do contain some significant data gaps. Particularly data on transport infrastructure investments in Eastern European countries before 1995 is often missing. But also data on depreciation costs and/or maintenance costs for maritime ports is often not publicly available. In order to estimate infrastructure costs for all transport modes in all relevant countries, these missing data have been estimated. The specific approaches used for this estimation is explained in the mode-specific chapters (Chapters 3 to 7) and Annex A. It should be clear that these estimations cause a considerable amount of uncertainty in the infrastructure cost figures estimated in this study.
- Data on the breakdown of total investments (into enhancement and renewal expenditures) and total O&M expenditures (into operational and maintenance expenditures) as well as between fixed and variable expenditures is often not available at the country level. To deal with this issue in the most appropriate way we have assessed the available data and literature to come up with EU average default values for these breakdowns. Although this approach may increase the consistency between infrastructure cost estimates between countries, it may also ignore to some extent country-specific characteristics of the transport infrastructure (costs).

The main uncertainties with respect to the methodology and supporting data used are:
- The allocation of infrastructure costs per transport mode to the various relevant vehicle categories requires the selection of relevant cost drivers. The choice of cost drivers is, however, always a trade-off between theoretical plausibility (how well does the driver explains the differences in infrastructure costs between vehicle categories?) and pragmatic applicability (to what extent is all relevant data available to apply the cost driver). At a European scale, it is hardly possible to apply the most sophisticated cost drivers due to lack of data and hence some simplifications have to be made. In order to select the most appropriate cost drivers we have carried out a literature review (see the mode-specific chapters and Annex E) on cost drivers applied in transport infrastructure cost studies. However, it should be noticed that the final selection of cost drivers does affect the results per vehicle category and that applying an alternative of cost drivers would end up with different results.
- There have also been uncertainties with respect to the input data (e.g. vehicle kilometres, passenger kilometres, tonne-kilometres, average weight of vehicles, etc.) used for the calculation of the infrastructure costs per vehicle category. These input data have been based on reliable sources (see Section 1.3.4 and Annex C), but inconsistencies between sources and missing data cause some uncertainty in these data as well. The main uncertainty with respect to input data is related to the transport performance data used for road transport. As explained in Section 1.3.4, in this study we

use data from Eurostat, following the nationality principle, i.e. transport activity is allocated to countries where the vehicle is registered[13]. The use of these data affects the results of this study and in some cases hampers some of the assessments to be carried out in this study, since the scope of these data differs from the scope of the infrastructure expenditure/cost data, which is in line with the territorial principle. Particularly the results for HGVs may be significantly affected at country level. For example, in countries with a lot of transit traffic (e.g. Austria) a significant part of the infrastructure costs are caused by foreign vehicles. By using transport performance data based on the nationality principle, transport activity of these foreign vehicles is not taken into account in the calculations. This affects the calculation of average and marginal infrastructure costs (e.g. resulting in too high average and marginal cost figures for countries with a lot of transit traffic[14]), but also the allocation of road infrastructure costs to the various vehicle categories (as this is partly based on transport performance data). As a consequence the results for road transport, as found by this study, are not always comparable to the results found by previous studies (e.g. (CE Delft, 2016a; CE Delft, 2016b)).

Because of the uncertainties described above, the results presented in this study should be regarded as an indication of the transport infrastructure costs in the various (European) countries. More detailed national (or airport or maritime port specific) studies would be required to validate the results from this study.

Given the uncertainties described above, it can be concluded that figures on total costs are — in general — more reliable than figures per vehicle category, as the allocation of total figures to vehicle categories does create some additional uncertainties at country level. Furthermore, total cost figures are more reliable than average and marginal ones, as the latter have to deal with relatively large uncertainties in traffic performance data.

[13] In an alternative approach, the territoriality principle, transport activity is allocated to the countries where the activity actually takes place.

[14] As the total cost figures are divided by only part of the relevant transport performance data (i.e. by domestic vehicles).

3 Road transport

3.1 Introduction

In this chapter we discuss the road infrastructure expenditures and costs. We start this chapter by clearly defining what is covered by road infrastructure in this study (Section 3.2). In Section 3.3 we discuss road-specific methodological issues (in addition to the general methodology explained in Chapter 2) with respect to the calculation of road infrastructure costs. Finally, the results on road infrastructure expenditures and costs are presented in Sections 3.4 and 3.5, respectively.

3.2 Defining road transport infrastructure

Table 4 provides an overview of the road infrastructure items that are covered by the road infrastructure definition considered in this study[15]. With respect to the physical infrastructure, these items are in line with the definition used in EC Regulation no. 851/2006[16] and in ITF (2013b). Next to the physical infrastructure, we do also consider the organisation of the road network as part of the road infrastructure in this study (see Section 2.2). The relevant organisation items are presented in Table 4 as well.

Table 4 - Overview of road infrastructure items

Main categories	Sub-items
Land	All land occupied by the road
Roadworks prior to paving	Cuttings, embankments, drainage works, support and back filling
Pavement and ancillary works	Pavement courses, including waterproofing, verges, central reserve, gullies and other drainage facilities, hard shoulders and other emergency stopping areas, lay-bys and parking places on the open road (roads for access and parking and traffic signs), planting and landscaping, safety installations, etc.
Engineering structures	Bridges, culverts, overpasses, tunnels, structures for protection against avalanches and falling stones, snow screens, etc.
Traffic signs and signalling and telecommunications installations	All traffic signs, including interactive ones
Lighting installations	All roadside lights, energy costs
Toll collection installations	All infrastructure for collecting revenue as a result of use of the road infrastructure
Buildings, energy, vehicles, etc. used by the infrastructure department	
Traffic management	Traffic management, traffic police
Cleaning icy/snowy roads	

15 As mentioned in Sections 2.2 and 2.5, the expenditure data collected for various countries is not always fully consistent with the definition given in this Section. For example, it may be that expenditures on telecommunication installations are not (or only partly) included in the available data. Therefore, some differences in expenditure levels between countries may be explained by these differences in scope of the data.

16 One minor alteration is the exclusion of level crossings. This was done as level crossings are also included in the definition of rail infrastructure. To avoid double counting, we consider level crossing to be part of rail infrastructure and not road infrastructure.

Parking lots are considered to be part of the road infrastructure as well. However, since the data availability on expenditures on (public) parking places in Europe is rather poor[17], we are not able to consider these expenditures/costs in this study. Therefore, parking lots (others than on the open road) are excluded from the working definition of road infrastructure in this study.

3.3 Methodology to estimate road infrastructure costs

The road infrastructure costs have been estimated by using the general methodology discussed in Section 2.4. However, for some road-specific aspects this methodology has been further elaborated. These are:
- breakdown of total road infrastructure expenditures;
- breakdown to fixed and variable road infrastructure costs;
- allocation of total road infrastructure costs to various vehicle categories.

Breakdown of total road infrastructure costs

As explained in Section 2.4, total road infrastructure costs have been estimated based on time series data on investment expenditures (using the PIM-approach) and the running O&M expenditures (for 2016). For the purpose of estimating the variable part of the infrastructure costs as well as for allocating these costs to the various vehicle categories, a further breakdown to enhancement, renewal, operational and maintenance costs is, however, required (see discussions below). However, not for all countries these differentiated cost figures could be calculated, as no data on infrastructure expenditures at this level was available. Therefore, for these countries we first estimated the breakdown of total investments and O&M expenditures based on default parameters for the share of the various expenditure categories in the total expenditures (e.g. the share of enhancement expenditures in total investments). These default parameters were based on data for the countries for which this breakdown in expenditure data was available (see Table 5). For example, for Western European countries for which no breakdown of investments to enhancement and renewal expenditures as available, it was assumed that 75% of the investments are enhancement costs and 25% renewal costs.

Table 5 - Average share of enhancement and renewal expenditures in total investments

Country	Investments		O&M expenditures	
	Enhancement	Renewal	Operational	Maintenance
Austria	64%	36%		
Bulgaria			35%	65%
Croatia	92%	8%		
Germany			64%	36%
Estonia	54%	46%		
Finland	80%	20%	47%	53%
Ireland	91%	9%		
Latvia	92%	8%	22%	78%
The Netherlands	65%	35%	47%	53%
Poland	80%	20%	29%	71%
Slovakia				
Slovenia	60%	40%	28%	72%
Sweden	67%	33%	32%	68%
UK			42%	58%

[17] Consultation of the European Parking Association made clear that expenditure data on parking places is not available at the EU level.

Country	Investments		O&M expenditures	
	Enhancement	Renewal	Operational	Maintenance
Norway			34%	66%
Switzerland	77%	23%	35%	65%
Recommended default values WEC[a] + (US, CA and JP)	**75%**	**25%**	**40%**	**60%**
Recommended default values CEEC[a]	**75%**	**25%**	**30%**	**70%**

a See Section 1.3.2 to see which countries belong to the Western European Countries (WEC) and which to the Central and Eastern European Countries (CEEC).

Breakdown to fixed and variable road infrastructure costs

Data on a breakdown of infrastructure costs to fixed and variable parts is not available for the countries considered in this study, with the exception of The Netherlands. Based on detailed data, CE Delft and VU (2014) estimates that about 60% of the renewal costs and 30% of the maintenance costs can be considered variable. Based on some case studies for various European countries, also CATRIN (2009) and GRACE (2007) provides some estimates of the breakdown of renewal and maintenance costs into variable and fixed parts (see Table 6). Based on these three sources — which are quite well in line — we have defined some default parameters that are used to calculate the fixed and variable parts of the renewal and maintenance costs estimated for the countries considered in this study[18]. For operational and enhancement costs, we assume — in line with the three sources mentioned in Table 6 — that these are fully fixed.

Table 6 - Share of variable and fixed costs in road renewal and maintenance costs according to various sources

Study	Renewal costs		Maintenance costs	
	Fixed	Variable	Fixed	Variable
CE Delft and VU (2014)	40%	60%	70%	30%
CATRIN (2009)	n/a	n/a	50-70%	30-50%
GRACE (2007)	13-42%	58-87%	40-50%	50-60%
Recommended values	**40%**	**60%**	**60%**	**40%**

Allocation of total road infrastructure costs to various vehicle categories

As explained in Section 2.4.4, the total road infrastructure costs are allocated to the various vehicle categories with help of the equivalency factor method. Based on relevant cost drivers (proportionality factors) the various cost categories are allocated to the various vehicle categories. Based on a literature review, the following cost drivers have been selected (for more details, see Annex E.2):

- *Enhancement costs* are assumed to be 90% capacity dependent, as enhancement of roads is usually applied once their capacities are too low. These capacity dependent costs are allocated based on Passenger Car Equivalents (PCE)[19] kilometres. The remaining 10% of the enhancement cost are assumed to be weight dependent (e.g. the type and cost of pavement materials used depends on the number of HGVs using the road) and are allocated based on 4th power axle load[20] kilometres.

[18] Except for The Netherlands, for which we used the country-specific figures from CE Delft and VU (2004).

[19] Indicator measuring the impact that a single vehicle has on traffic variables (e.g. speed, density) compared to a single passenger car.

[20] Based on extensive tests, it has been found that road damages are proportional to the 3rd or 4th power of the vehicle's axle load (Doll, 2005). For that reason, weight dependent costs are allocated based on 4th power axle load kilometres.

- *Renewal costs:* the variable renewal cost are assumed to be weight dependent and are therefore allocated based on 4th power axle load kilometres. The fixed renewal costs are assumed to be capacity dependent and hence are allocated based on PCE-kilometres.
- *Maintenance kilometres:* the variable maintenance costs (e.g. road pavement damages) are assumed to be fully weight dependent and are therefore allocated based on 4th power axle load kilometres. Fixed maintenance costs (e.g. maintenance of road sides, road signals, etc.) are allocated on the approach developed by a detailed German analysis (ProgTrans; IWW, 2007): 50% of the costs are allocated based on PCE-kilometres, 35% based on vehicle kilometres and 15% are allocated to HGVs.
- *Operational costs* are, based on (ProgTrans; IWW, 2007) allocated based on vehicle kilometres (30%) and PCE-kilometres (70%).

Table 7 summarises the cost drivers used to allocate the various infrastructure cost categories.

Table 7 - Cost drivers road transport

Cost category	Cost driver
Enhancement costs	- PCE-kilometres (90%) - 4th power axle load kilometres (10%)
Renewal costs	- 4th power axle load kilometres (60%) - PCE-kilometres (40%)
Variable maintenance costs	- 4th power axle load kilometres (100%)
Fixed maintenance costs	- PCE-kilometres (50%) - Vehicle kilometres (35%) - Allocated to HGVs (15%)
Operational costs	- PCE-kilometres (70%) - Vehicle kilometres (30%)

To allocate the road infrastructure costs based on the cost drivers defined above, assumptions have to be made on some vehicle characteristics (e.g. PCE, axle load) and data on vehicle kilometres had to be collected. The vehicle characteristics assumed are presented in Annex C. In this Annex, we have also further explained how the cost drivers are used in this study.

3.4 Road infrastructure expenditures

3.4.1 Investments

Total investments in road infrastructure in the EU28 in 2016 were equal to about € 69 billion (PPS adjusted). As is shown, this investment level is almost comparable to the investments in 1995, but significantly lower than just before the economic crisis. This decreasing trend in road investments started in the Western European countries (in 2007-2008), while in the Central and Eastern European countries this drop in investments started in 2011. Over the last years (2014-2016), investment levels in Europe rise again, particularly in the CEEC.

Figure 2 - Investment index for road infrastructure in the period 1995-2016

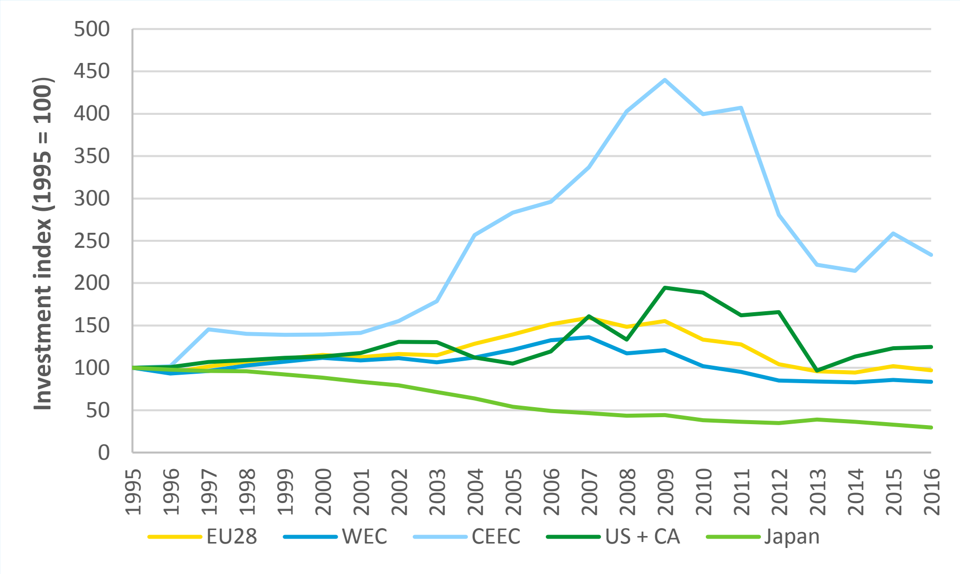


Figure 2 also shows the sharp increase in road infrastructure investments in CEEC between 2003 and 2011. This trend reflects the efforts to meet rising needs for road network capacity in these countries. Additionally, extensive funding from European programmes (mainly Cohesion and Structural funds) became available for these countries, such that they were able to finance these efforts.

Comparing the trend in investment levels in Europe with those in the US and Canadian states/provinces, we see in general the same pattern. The trend in the US + Canada is a bit more volatile, but this can be explained by the fact that it is composed based on data for just four states/provinces (compared to 28 countries for the EU28 index). Road Investment levels in Japan has decreased significantly over the past 20 years, due to general budget cuts by the end of the 1990’s and the reduction of the earmarking of gasoline tax revenues for development and maintenance of investments in roads in Japan (ITF, 2013a).

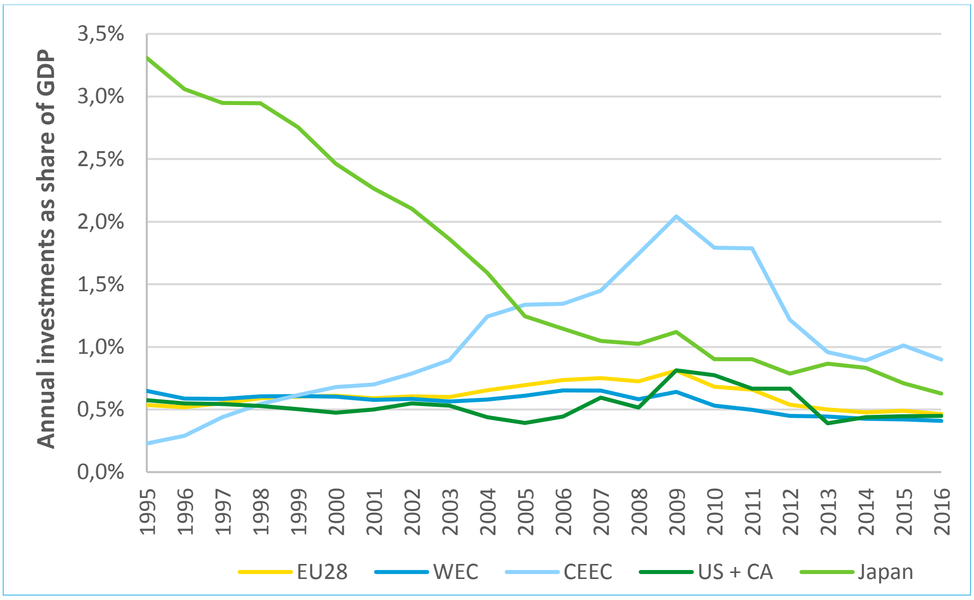
Road investments as share of GDP

Although the investment needs for road infrastructure depend on a number of factors (e.g. quality and age of the existing infrastructure and the geography of the country), presenting the investments as relative share of Gross Domestic Product (GDP) may provide a useful benchmark for comparing investment levels between countries.

As is shown in Figure 2, investments as share of GDP in the EU28 rose slightly between 1995 and 2009, followed by a decline due to the economic crisis. Different trends can be identified for WEC and CEEC. In Western European countries road investments are relatively stable over the period 1995-2009 (at about 0.6% of GDP) and afterwards fell to about 0.4% of GDP. Central and Eastern European countries, on the other hand, show a completely different pattern: a slight annual increase in the period 1995-2003, followed by a sharp increase till 2011, a significant drop till 2014 and rather stable afterwards. This pattern is in line with the developments described for these countries above.

The aforementioned reduction in road investment levels in Japan is clearly shown by Figure 3 as well. While in 1995 investment levels in Japan (relative to GDP) were considerably higher than in Europe, in 2016 they are almost on the same level. Finally, investment levels in the US states are just below the European level (at the level of about 0.3-0.4% of GPD).

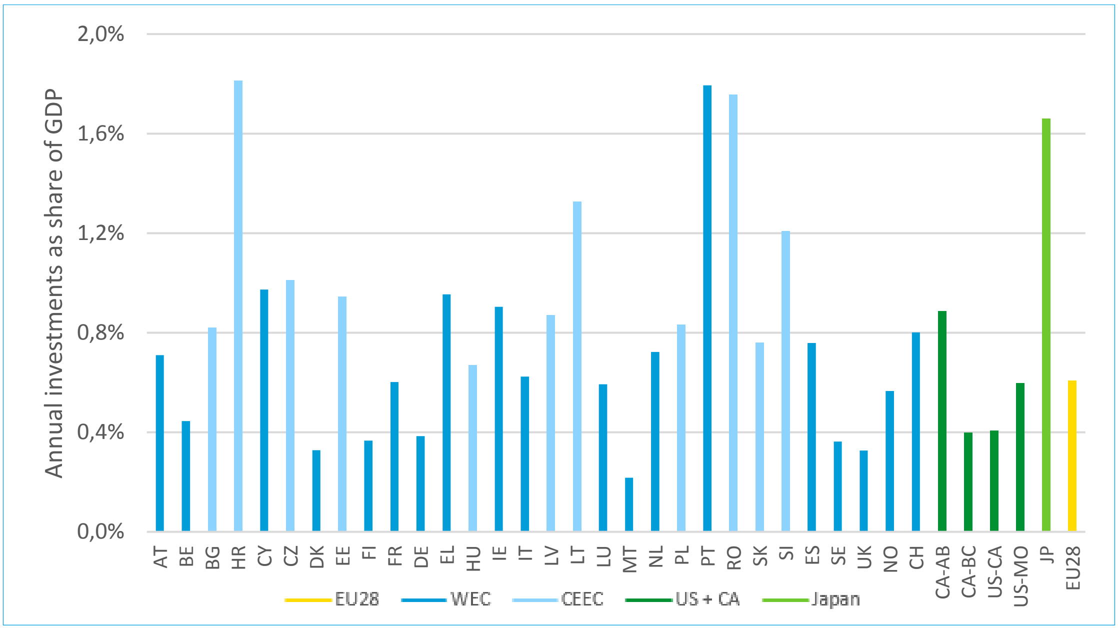
Figure 3 - Development in share of road infrastructure investments in GDP over time



The long-term share of investments as percentage of GDP is shown for individual countries in Figure 4. On average, EU28 Member States invest 0.6% of their GDP in road infrastructure. For Western European countries, this share lies between 0.2% and 1.0%. Exception are the investments in Portugal, which are on average 1.8% of GDP over the last 20 years. This high investment level can be explained by large investment programmes in the 1990s (mainly financed by European funds) and particularly the first decade of this century (with a significant role for public private partnerships)[21]. Since 2011 the investment levels have decreased significantly and current investments levels (as share of GDP) are even below the EU28 average.

[21] According to Pereira and Pereira (2017), several investment projects can be regarded as unnecessary and corruption in public-private partnerships are a matter of concern. These issues may also have contributed to the relatively high investment levels in Portugal.

Figure 4 - Road infrastructure Investments as share of GDP (average share for 1995-2016)



The share of road infrastructure investments in GDP is in general higher in CEEC than in WEC: between 0.7% and 1.3%. Both in Croatia and Romania the investment levels are even higher (1.8%).
The relatively high investment level in Croatia is mainly because of very ambitious investment programmes in the second half of the 1990s and the first decade of this century (WBG, 2004; WBG, 2015). These investment programmes were initiated to reconstruct war damaged infrastructure, to modernise existing and to build new infrastructure. In Romania, on the other hand, inefficiencies in the planning and construction phase are considered as a main explanation for the relatively high investment levels. A lack of (government) expertise in construction management, a lack of competition between construction companies, and a relatively high level of corruption, have resulted in high investment levels (IMF, 2015).

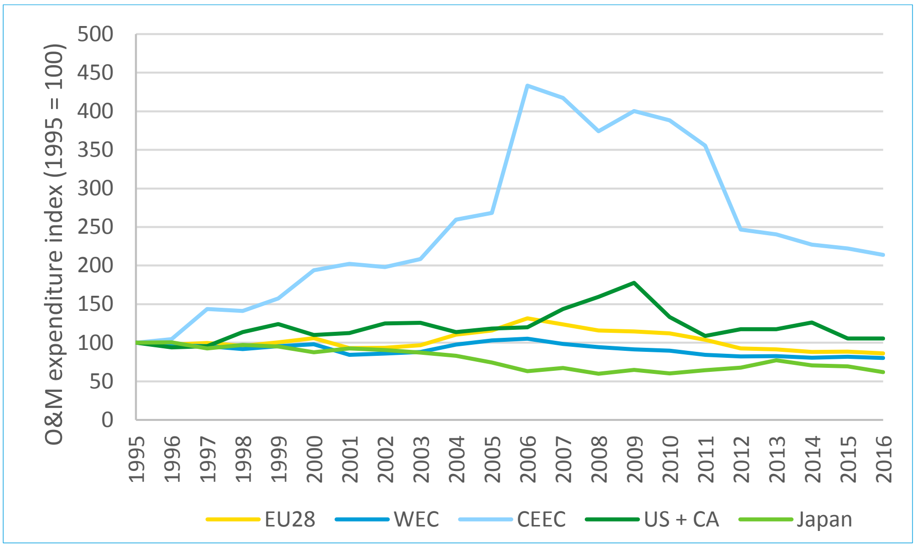
Comparing the results for the non-European and European countries, we find that investment levels in the US states and Canadian provinces are quite well in line with those in Western European countries. In Japan, road infrastructure investments as share of GDP are still relatively high, although considerably lower as in the past (see Figure 4).

3.4.2 Operational and maintenance expenditures

In 2016, the EU28 countries spent together about € 38 billion on the operational and maintenance of their road networks. This is slightly lower than in 1995, as is shown in Figure 5. O&M expenditures in the EU28 have been rather stable in the period 1995-2003, after which they increased till 2009. In the period 2009-2016 they are steadily decreasing, such that the current O&M expenditures are just 86% of the expenditures in 1995.

The trends in O&M expenditures differ significantly between Western European countries on the one hand and Central and Eastern European countries on the other hand. In Western European countries, O&M expenditures were rather stable in the period 1995-2007, but are decreasing in the years following. In Central and Eastern European countries, the level of O&M expenditures has rapidly increased from 1995 to 2007, followed by a slight decrease till 2011 and a sharp decrease in the following years (e.g. due to the economic crisis). Despite this decreasing trend, O&M expenditures in these countries were in 2016 still more than twice as high as in 1995.

Figure 5 - O&M expenditure index for road infrastructure in the period 1995-2016

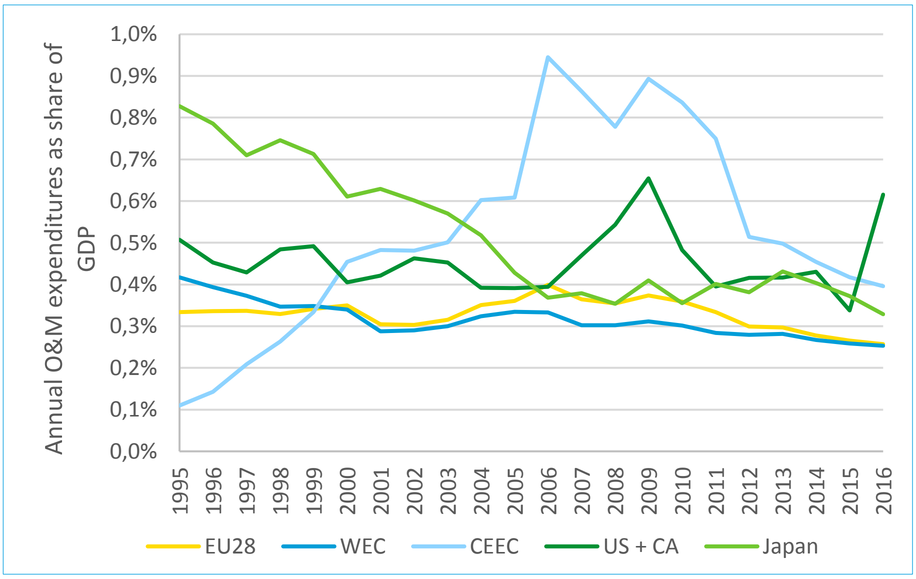


Comparing the development in O&M expenditures in Europe with the developments in the US and Canada doesn't show big differences. In Japan, O&M expenditures has decreased more significantly than in Europe: in 2016 O&M expenditures in Japan were only 60% of the 1995 levels.

Road O&M expenditures as share of GDP

The development of road O&M expenditures as share of GDP is shown in Figure 6. Between 1995 and 2016, the share of O&M expenditures in GDP has slightly decreased in the EU28 from about 0.4% in 1995 to just below 0.3% in 2016.

Figure 6 - Development in share of road infrastructure O&M expenditures in GDP over time

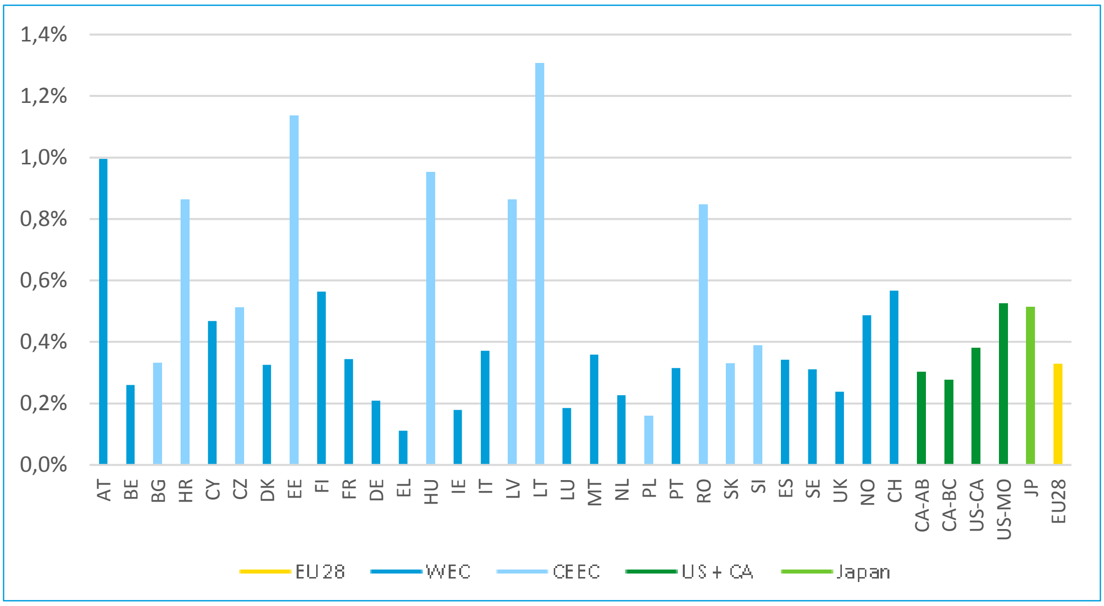


The trend in Western European countries is well in line with the EU28 trend. In Central and Eastern European countries, on the other hand, a sharp increase in O&M expenditure levels (compared to GDP) is found for the period 1995-2007, showing the rising need for good quality roads in these countries. However, due to the economic crisis, O&M budgets have been heavily cut in these countries (Steer Davis Gleave, 2014), resulting in decreasing shares of these expenditures in GDP.

The share of O&M expenditures in GDP in the US states is in general (slightly) higher than in the EU28. As explained before, the more volatile pattern in annual O&M expenditures in the US compared to the EU28 (or WEC) is caused by the fact that the US numbers are composed based on data for only two states. Finally, in line with the results found on road investments, Japanese O&M expenditures as share of GDP has decreased sharply over the last twenty years, but are still well above EU28 levels.

The higher share of O&M expenditures in GDP in Central and Eastern European countries compared to Western European countries is also shown by Figure 7, which shows the long-term average share of these expenditures in GDP for individual countries. In Western European countries, this share is smaller than 0.6% for all countries, except for Austria. In several Central and Eastern European countries, on the other hand, this share is above the 0.8% and even 1.3% in Lithuania. The shares of O&M expenditures in GDP in the US states and Canadian provinces and JP fall within the range found for the Western European countries.

Figure 7 - Road infrastructure O&M expenditures as share of GDP (average share for 1995-2016)

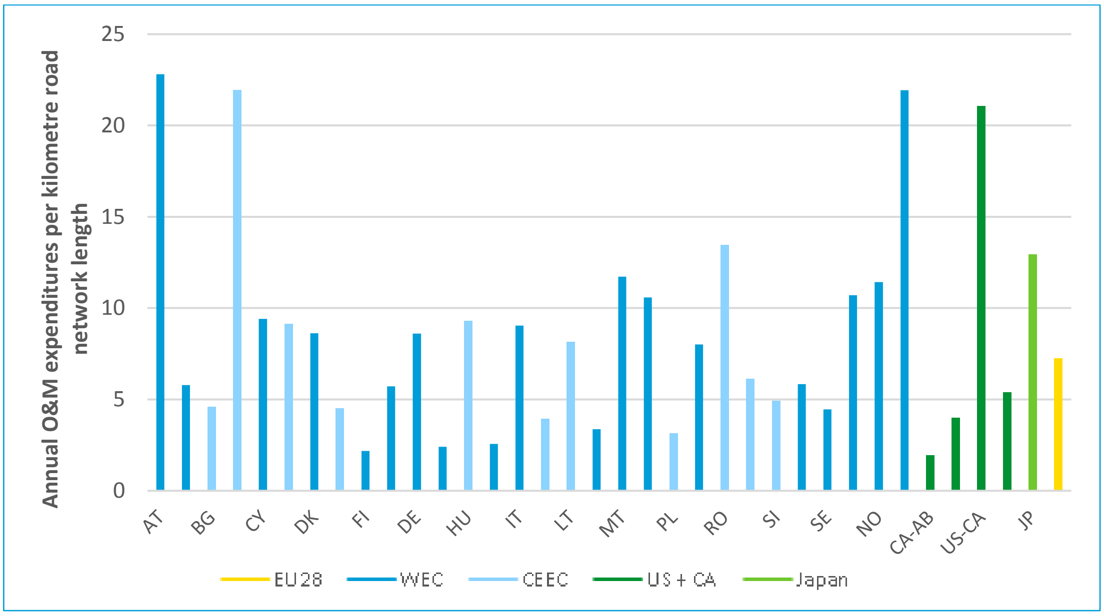


O&M expenditures per kilometre road network

The long-term average annual road O&M expenditures per kilometre of road network are presented in Figure 8. These expenditures are highest in Austria and Switzerland, for which there are several reasons. First, because of the mountainous landscape in these countries, the network complexity is relatively high (e.g. many tunnels and bridges). For example, tunnels and bridges make up about 17% of the total length of main roads in Austria, while in countries like France and Denmark this is only 1-2% (CEDR, 2010). As according to CEDR (2010) the maintenance costs of 1 km of bridge are on average ten times higher than the maintenance costs of 1 km of plain road (and for tunnels this is even more), the high complexity of the road networks is an important reason for the high O&M costs per kilometre network in Austria and Switzerland. Secondly, expenditures on winter maintenance will be above EU averages in these two countries. Third, the quality of the road network in Austria and Switzerland is relatively high (according to WEF (2016), Switzerland and Austria are ranked 7th and 8th worldwide with respect to the quality of their road network.

As for investments, relatively high O&M expenditure levels per kilometre of road network are found for Croatia and Romania. On the contrary, O&M expenditure levels per kilometre of road network are relatively low in countries like Finland, Estonia, Latvia and Sweden (but also for the Canadian provinces and Missouri). These countries have a large share of roads with very low traffic densities. The majority of the O&M expenditures are spent on a small share of the total road network, resulting in relatively low O&M expenditures levels per kilometre road network.

Figure 8 - Average annual road O&M expenditures per kilometre road network length in the period 1995-2016 (€ per km, PPS adjusted)



3.5 Road infrastructure costs

Based on the infrastructure expenditure data as presented in the previous section, we have applied the methodology as discussed in Chapter 2 and Section 3.3 to estimate the annual road infrastructure costs in the various countries and for the various vehicle categories. The annual infrastructure cost comprises the cost of depreciation and capital costs as well as the maintenance and operational costs for one particular year.

3.5.1 Total infrastructure costs

The total costs of the entire road network[22] for the year 2016 in the various countries are presented in Table 8. These costs were equal to about € 184 billion in the EU28. The main part of these costs are fixed (84%), while the remaining part is considered variable.

[22] The costs of motorways (total, average and marginal) are presented in Annex G.

Table 8 - Total road infrastructure costs in 2016 (billion €, PPP adjusted)

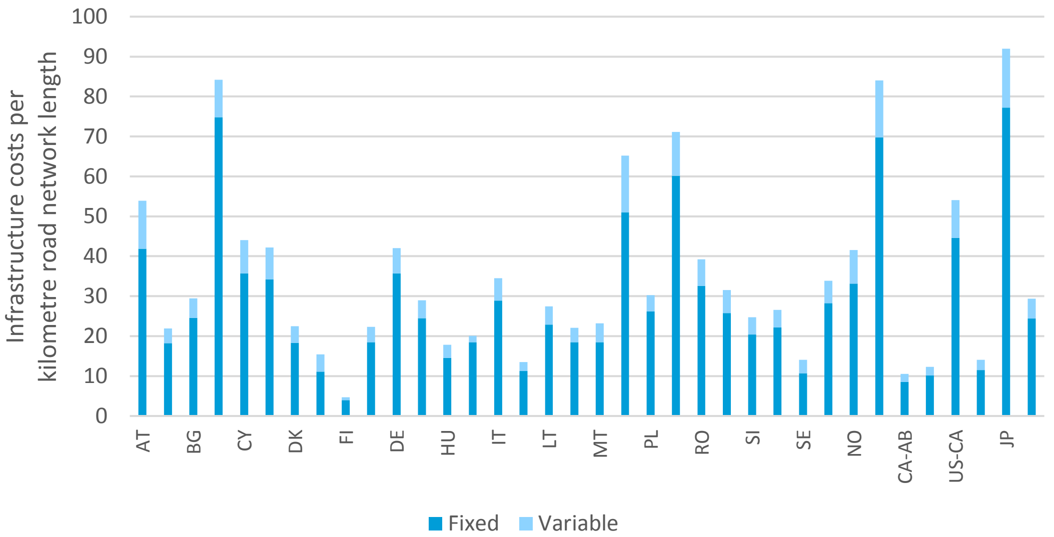
Member State	Investments costs	O&M costs	Total infrastructure costs		
			Fixed	Variable	Total
EU28	145.5	38.3	152.9	30.9	183.8
Austria	4.6	2,9	5.8	1.7	7.4
Belgium	2.7	0.7	2.8	0.6	3.4
Bulgaria	1.6	0.2	1.6	0.3	1.9
Croatia	1.5	0.7	2.0	0.3	2.2
Cyprus	0.2	0.2	0.4	0.1	0.4
Czech Republic	3.8	1.7	4.5	1.1	5.5
Denmark	1.0	0.6	1.4	0.3	1.7
Estonia	0.6	0.3	0.7	0.3	0.9
Finland	1.4	0.7	1.8	0.3	2.1
France	18.5	5.8	20.1	4.2	24.3
Germany	20.7	6.3	23.0	4.0	27.0
Greece	3.3	0.1	2.9	0.5	3.4
Hungary	2.1	1.5	3.0	0.7	3.7
Ireland	1.8	0.1	1.8	0.2	2.0
Italy	20.8	3.6	20.4	4.0	24.4
Latvia	0.7	0.3	0.8	0.2	1.0
Lithuania	1.7	0.6	1.9	0.4	2.3
Luxembourg	0.3	0.1	0.3	0.1	0.4
Malta	0.03	0.04	0.05	0.01	0.07
Netherlands	7.7	1.4	7.1	2.0	9.1
Poland	7.8	0.8	7.5	1.2	8.6
Portugal	5.9	0.4	5.3	1.0	6.3
Romania	6.9	1.1	6.6	1.3	8.0
Slovakia	1.3	0.4	1.4	0.3	1.7
Slovenia	0.8	0.2	0.8	0.2	1.0
Spain	14.5	3.2	14.8	2.9	17.7
Sweden	1.5	1.5	2.3	0.7	3.0
United Kingdom	11.6	2.6	11.9	2.4	14.3
Norway	2.0	1.9	3.1	0.8	3.9
Switzerland	4.1	2.0	5.0	1.0	6.0
Canada - British Columbia	2.1	0.4	2.1	0.5	2.5
Canada – Alberta	0.8	0.3	1.0	0.2	1.2
US - California	10.3	5.4	13.0	2.7	15.7
US - Missouri	2.1	0.9	2.4	0.5	3.0
Japan	104.4	13.0	98.6	18.8	117.4

a The infrastructure costs for Hungary and Slovakia are based on incomplete expenditure data for urban roads. For more information, see Annex A.2.

Table 8 provides an overview of the infrastructure cots per kilometre road network. For most countries, these costs are between € 20,000 and € 40,000 per kilometre road. In some countries (i.e. Estonia, Finland, Latvia, Sweden), the costs are considerably lower, which can be explained by the large share of unpaved and low density roads in these countries, for which both investment and O&M costs are very low.

In some other countries (i.e. Austria, Croatia, The Netherlands, Portugal, Switzerland and Japan) the infrastructure costs are significantly above € 40,000 per kilometre road network. For Austria and Switzerland, the high road network complexity (e.g. many bridges and tunnels), significant winter maintenance and the relatively high quality of roads are main explanations for these relatively high costs. In Portugal and Croatia, the large-scale investment programmes in the 1990s and the first decade of this century largely explains the high cost levels. High traffic densities (resulting in relatively large maintenance efforts required) combined with high quality levels mainly explains the high costs per kilometre road in the Netherlands. Finally, some important explanations of the relatively high costs in Japan are a high network complexity and low expenditure efficiency (e.g. investments in roads with very low utilisation rates (Monfort, 2015).

Figure 9 - Infrastructure costs per kilometre road network length (x 1,000 €/km, PPS adjusted)



Finally, the total road infrastructure costs per vehicle category are presented in Table 9. In most countries, passenger cars contribute most to the road infrastructure costs (ranging from 43 to 68%). Exceptions are Lithuania and Alberta, where HGVs are responsible for the largest share of the costs.

Table 9 - Total road infrastructure costs in 2016 per vehicle category (billion €$_{2016}$, PPP adjusted)

Member State	Passenger car	Motorcycle	Bus	Coach	LCV	HGV
EU28	98.06	2.93	7.07	13.48	19.42	42.83
Austria	3.73	0.07	0.23	0.87	1.05	1.50
Belgium	2.00	0.03	0.22	0.24	0.32	0.60
Bulgaria	1.07	0.005	0.14	0.13	0.07	0.48
Croatia	1.23	0.04	0.05	0.15	0.33	0.44
Cyprus	0.20	0.01	0.05	0.04	0.09	0.04
Czech Republic	2.47	0.11	0.18	0.49	0.55	1.71
Denmark	0.86	0.01	0.14	0.07	0.26	0.34
Estonia	0.46	0.001	0.10	0.08	0.04	0.23
Finland	1.27	0.02	0.13	0.09	0.18	0.46
France	12.93	0.29	0.88	2.13	3.89	4.16
Germany	16.93	0.25	0.98	1.15	1.28	6.43

Member State	Passenger car	Motorcycle	Bus	Coach	LCV	HGV
Greece	1.85	0.16	0.21	0.38	0.37	0.43
Hungary	1.57	0.06	0.16	0.42	0.45	1.00
Ireland	1.00	0.01	0.14	0.12	0.52	0.20
Italy	13.69	0.94	0.87	3.17	2.73	2.98
Latvia	0.45	0.001	0.04	0.04	0.06	0.37
Lithuania	0.97	0.02	0.11	0.02	0.16	1.02
Luxembourg	0.12	0.01	0.01	0.01	0.11	0.12
Malta	0.03	0.001	0.01	0.002	0.004	0.02
Netherlands	4.53	0.07	0.17	0.20	0.99	3.10
Poland	3.79	0.05	0.44	0.23	0.60	3.52
Portugal	3.02	0.05	0.17	0.32	1.20	1.51
Romania	3.93	0.02	0.62	0.50	0.77	2.19
Slovakia	0.72	0.01	0.09	0.05	0.16	0.70
Slovenia	0.48	0.004	0.01	0.07	0.10	0.30
Spain	9.17	0.62	0.38	1.51	1.16	4.88
Sweden	1.50	0.01	0.16	0.12	0.29	0.92
United Kingdom	8.09	0.08	0.36	0.88	1.67	3.18
Norway	1.90	0.03	0.19	0.14	0.66	1.02
Switzerland	3.86	0.08	0.55	0.23	0.38	0.91
Canada - British Columbia	1.10[b]	0.03		0.07[a]	N/A[b]	1.34
Canada - Alberta	0.73[b]	0.01		0.08[a]	N/A[b]	0.34
US - California	10.51	0.03	1.28	0.40	0.46	3.05
US - Missouri	2.04	0.01	0.39	0.02	0.06	0.47
Japan	72.40	2.12		20.93[a]	9.32	12.64

a It was not feasible to distinguish between busses and coaches, as there was no disaggregated transport performance data available for these two vehicle categories (needed to allocate the total costs to the various vehicle categories).

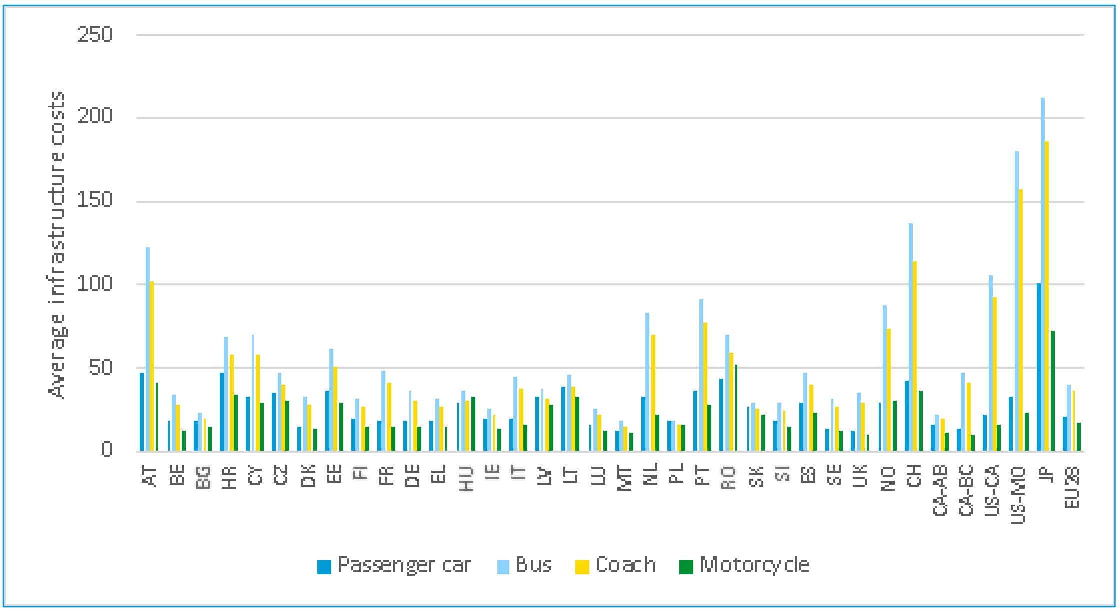
b The infrastructure costs for passenger cars in Alberta and British Columbia also includes the costs of LCVs. A split could not be made as there was no disaggregated transport performance data for these two vehicle categories.

3.5.2 Average infrastructure costs relative to transport performance

Passenger transport

Figure 10 presents the average infrastructure costs (in € per 1,000 passenger kilometres) for the four road passenger transport modes considered in this study. In (almost) all countries, the average infrastructure costs are highest for buses and coaches, followed by passenger cars and motorcycles. The relatively high infrastructure costs of buses and coaches is due to the large share of variable (weight dependent) infrastructure costs caused by these vehicles.

Figure 10 - Average infrastructure costs passenger transport in 2016 (€ per 1,000 passenger kilometre, PPS adjusted)



The average infrastructure costs for passenger cars in the EU28 are equal to € 21 per 1,000 passenger kilometres. Between countries, the average costs vary from € 13 to almost € 50 per 1,000 passenger kilometres. High average costs for passenger cars are found for countries with high infrastructure costs per kilometre road as well (e.g. Austria, Croatia, Portugal and Switzerland). Relatively high cost are also found for the Baltic countries, which can be explained by the low traffic density on the road network in these countries[23].

For motorcycles, the average infrastructure costs per 1,000 passenger kilometres in the EU28 are equal to € 18. Although the costs per vehicle kilometre for motorcycles is lower as for passenger cars (€ 19 vs. € 34 per 1,000 vkm, for the EU28), the lower occupancy rate of motorcycles compared to passenger cars results in average infrastructure costs per passenger kilometre that are almost similar for both modes. Differences between countries with respect to the average infrastructure costs can be explained by the same reasons as for passenger cars.

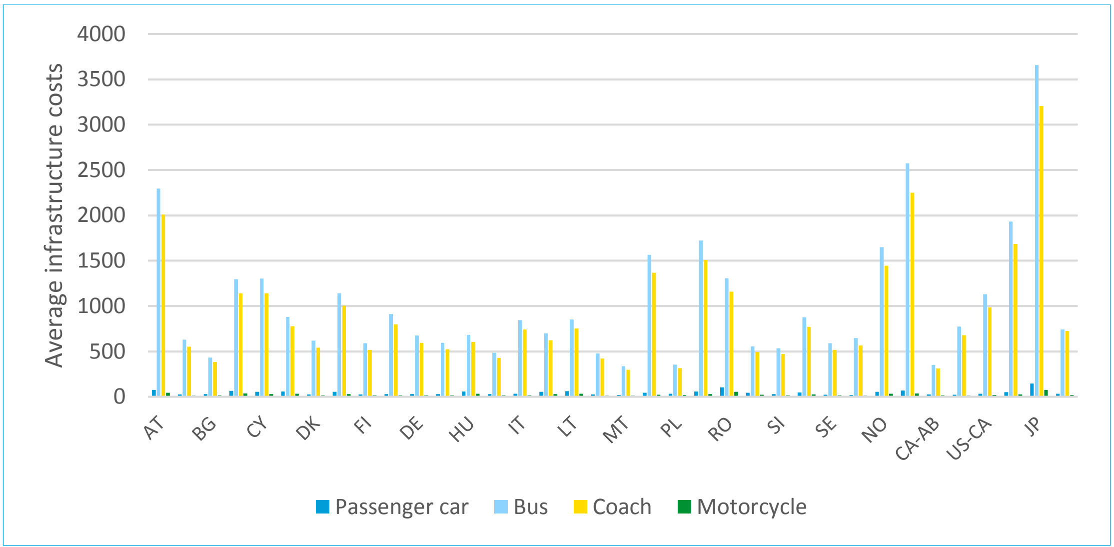
The average infrastructure costs for buses and coaches in the EU28 are about € 39 per 1,000 passenger kilometres. The highest costs are found for countries like Austria, Netherlands, Portugal, Romania, Norway and Switzerland. These are all countries with relatively high infrastructure costs per kilometre road network as well.

Considering the results for the non-European countries, we find relatively high infrastructure costs for passenger road transport in Japan. This can partly be explained by the high infrastructure costs per kilometre road network. Additionally, the utilisation rate of roads is lower than in many European countries, resulting in higher average infrastructure costs. For the US states, relatively high average infrastructure costs for busses and coaches are found. This can (partly) be explained by the on-average lower occupancy rates of busses and coaches (11 passenger vs. 19/20 passengers in EU countries), resulting in higher cost values per passenger kilometre.

[23] In these countries, the total infrastructure costs are allocated to a relatively limited number of passenger kilometres (by passenger cars), resulting in higher levels of average costs.

Finally, the average infrastructure costs in € per 1,000 vehicle kilometres are shown for the road passenger modes in Figure 11. As expected, the difference in average costs between buses and coaches on the one hand, and passenger cars and motorcycles on the other hand, is much larger than the average costs per passenger kilometre. For buses and coaches, the same occupancy rate is assumed for all European countries. For that reason, the relative differences between countries with respect to the average costs per vehicle kilometre is the same as for the average costs per passenger kilometre.

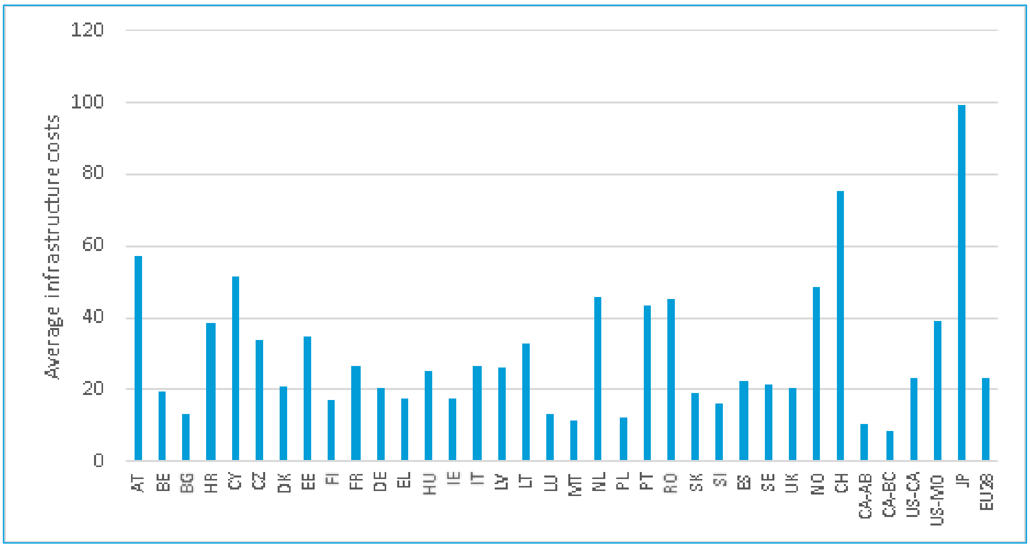
Figure 11 - Average infrastructure costs passenger transport in 2016 (€ per 1,000 vehicle kilometre, PPS adjusted)



Freight transport

Figure 12 shows the average infrastructure costs (in € per 1,000 tonne-kilometres) for HGVs.

Figure 12 - Average infrastructure costs HGVs (€ per 1,000 tonne-kilometre, PPS adjusted)

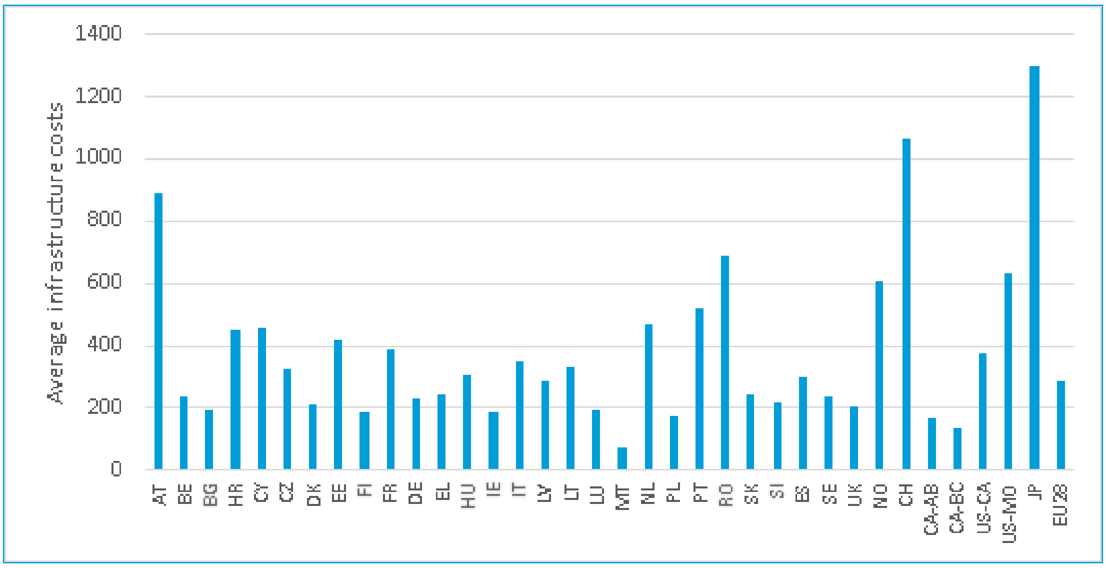


The average infrastructure costs of HGVs in the EU28 are about € 23 per 1,000 tonne-kilometres.

The results vary from € 57 per 1,000 tonne-kilometres in Austria to € 12 per 1,000 tonne-kilometres in Malta and Poland. In general, average infrastructure costs per tonne-kilometre are high in countries with high costs per kilometre of road network (i.e. Austria, The Netherlands, Portugal, Romania, Switzerland, Japan). Also for Norway and Cyprus relatively high average cost figures are found, which can be explained by the combination of relatively high infrastructure costs per kilometre road network and relatively low utilisation rates of the roads in these countries.

In Figure 13, the average infrastructure costs of HGVs in € per 1,000 vehicle kilometres are shown. Compared to Figure 13, the cost figures for Austria and Switzerland are significantly higher than for countries like The Netherlands, Croatia and Portugal (i.e. countries with relatively high HGV infrastructure costs per tonne-kilometre as well). This can be explained by the higher average load of HGVs in Austria and Switzerland.

Figure 13 - Average infrastructure costs HGVs (€ per 1,000 vehicle kilometre, PPS adjusted)

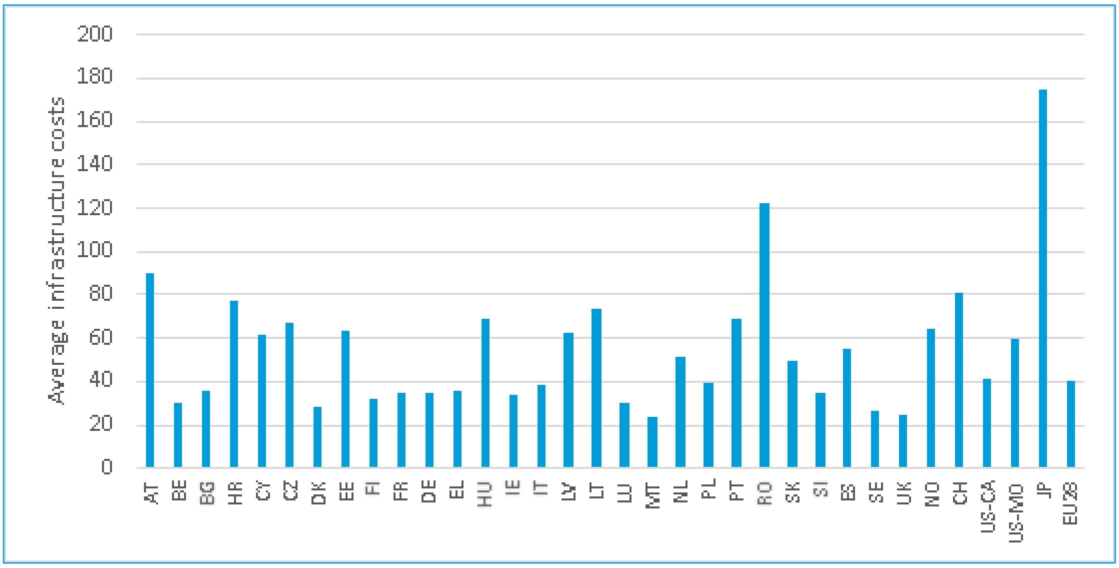


Light commercial vehicles

The average infrastructure costs for LCVs (in € per 1,000 vehicle kilometres[24]) are presented in Figure 14. For the EU28, these costs are equal to € 41 per 1,000 vehicle kilometre. The highest costs are found for Romania, which can, among other things, be explained by the relatively low traffic density on their networks. In countries like Austria, Croatia and Switzerland, the costs are high as well, which is in line with the high costs per kilometre road network in these countries.

[24] As LCVs are often used for services related transport (e.g. by plumbers), the average load of vans is relatively low. Therefore, presenting the average infrastructure cots in € per 1,000 tonne-kilometres would result in very high and meaningless values. Therefore, we only present these figures in € per vehicle kilometres

Figure 14 - Average infrastructure costs LCVs (€ per 1,000 vehicle kilometre, PPS adjusted)



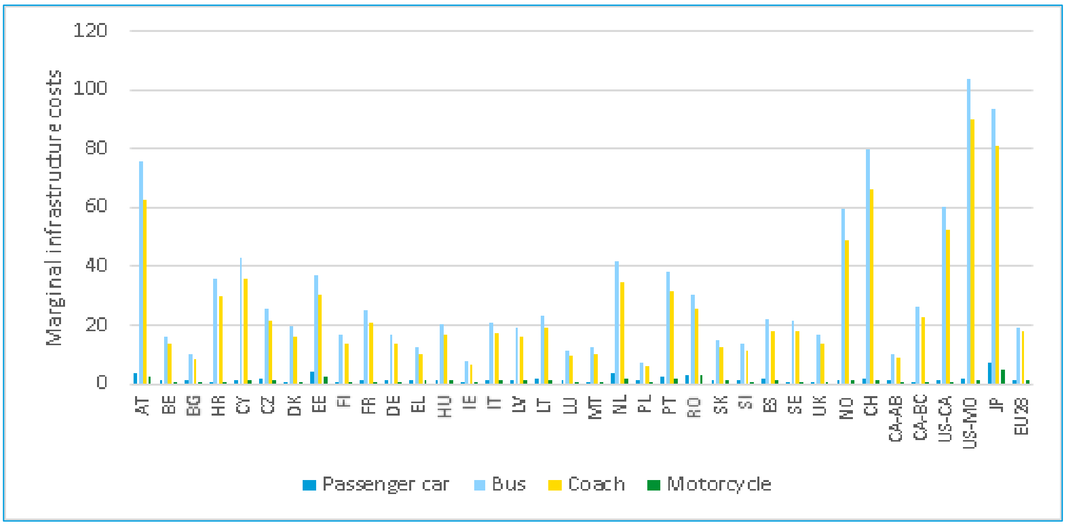
Note: No average infrastructure costs for the Canadian provinces Alberta and British Columbia have been estimated, due to a lack of transport performance data for these provinces.

3.5.3 Marginal infrastructure costs

Passenger transport

The marginal infrastructure costs for the road passenger modes are presented in Figure 15 (€ per 1,000 passenger kilometres). As for the average costs, the highest marginal costs are found for buses and coaches. The differences with passenger cars and motorcycles are, however, much larger than for average costs. This is explained by the fact that a large share of the marginal infrastructure costs are weight dependent maintenance (or renewal) costs and hence are mainly caused by heavy vehicles like buses and coaches.

Figure 15 - Marginal infrastructure costs road passenger transport in 2016 (€ per 1,000 passenger kilometres, PPS adjusted)



The marginal infrastructure costs for passenger cars in the EU28 are about € 1.3 per 1,000 passenger kilometres. Between countries, these costs range from € 0.4 per 1,000 passenger kilometres in Malta, to € 3.5 per 1,000 passenger kilometre in Austria. As for the average infrastructure costs, the highest marginal infrastructure costs for passenger cars are found for countries with high infrastructure costs per kilometre road as well (e.g. Austria, Netherlands).

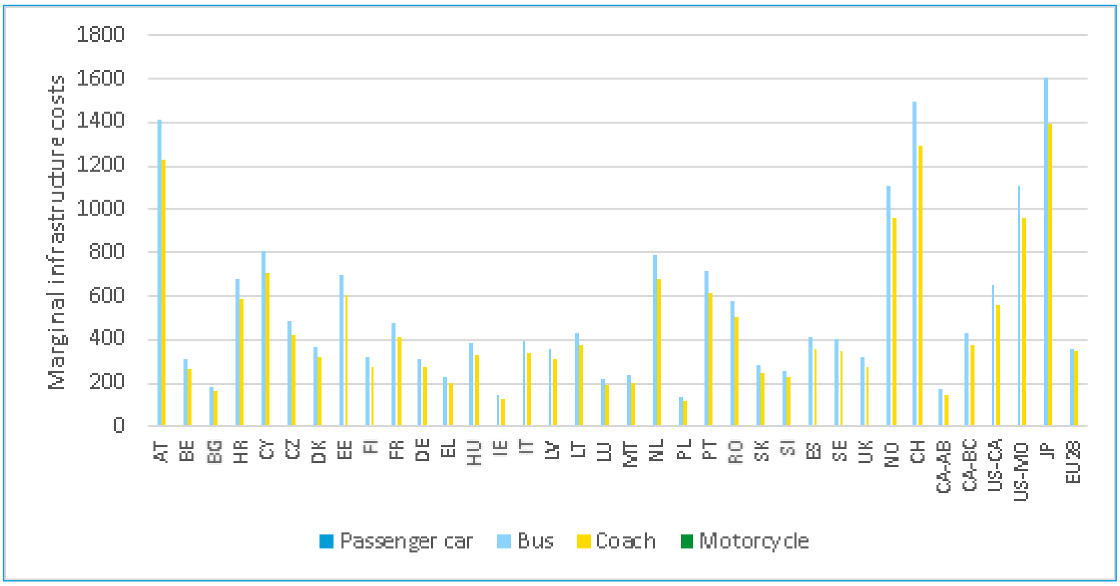
For motorcycles, the marginal infrastructure costs per 1,000 passenger kilometres in the EU28 are about € 1.1. Differences between countries with respect to the average infrastructure costs can be explained by the same reasons as for passenger cars.

The marginal infrastructure costs for busses and coaches in the EU28 are € 19 and € 18 per 1,000 passenger kilometres, respectively. The highest costs are found for countries like Austria, Switzerland and Norway. These are all countries with relatively high infrastructure costs per kilometre road network as well.

For the non-EU countries, relatively high marginal costs are found for passenger road transport in Japan. The high infrastructure costs per kilometre road network and the relatively low utilisation rates of Japanese roads are the main explanations for this finding. As for the average infrastructure costs, relatively high marginal cost figures are found for busses and coaches in the US states. This can be explained by the relatively low occupancy rates of busses and coaches in these states.

Finally, the marginal infrastructure costs of road passenger transport in € per 1,000 vehicle kilometres are presented in Figure 16.

Figure 16 - Marginal infrastructure costs road passenger transport in 2016 (€ per 1,000 vehicle kilometres, PPS adjusted)



Freight transport

The marginal infrastructure cost for HGVs are presented in Figure 17 (in € per 1,000 tonne-kilometres) and in Figure 18 (in € per 1,000 vehicle kilometres). In the EU28, these costs are on average equal to € 7 per 1,000 tonne-kilometres. As for average costs, the highest costs are found for Austria, The Netherlands, Norway, Switzerland and Japan.

Figure 17 - Marginal infrastructure costs HGVs in 2016 (€ per 1,000 tonne-kilometres, PPS adjusted)

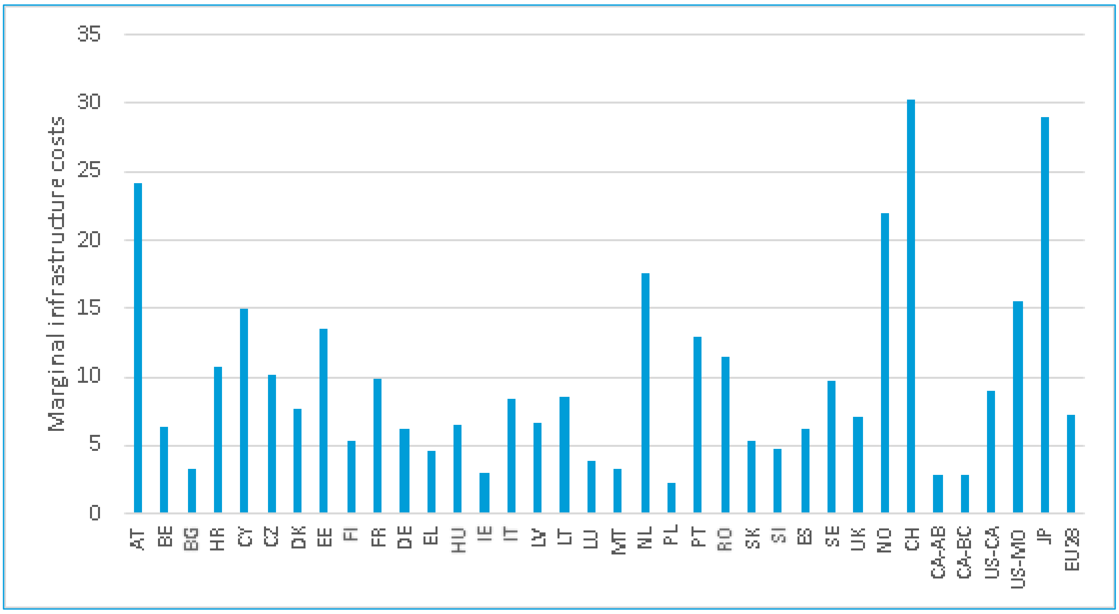
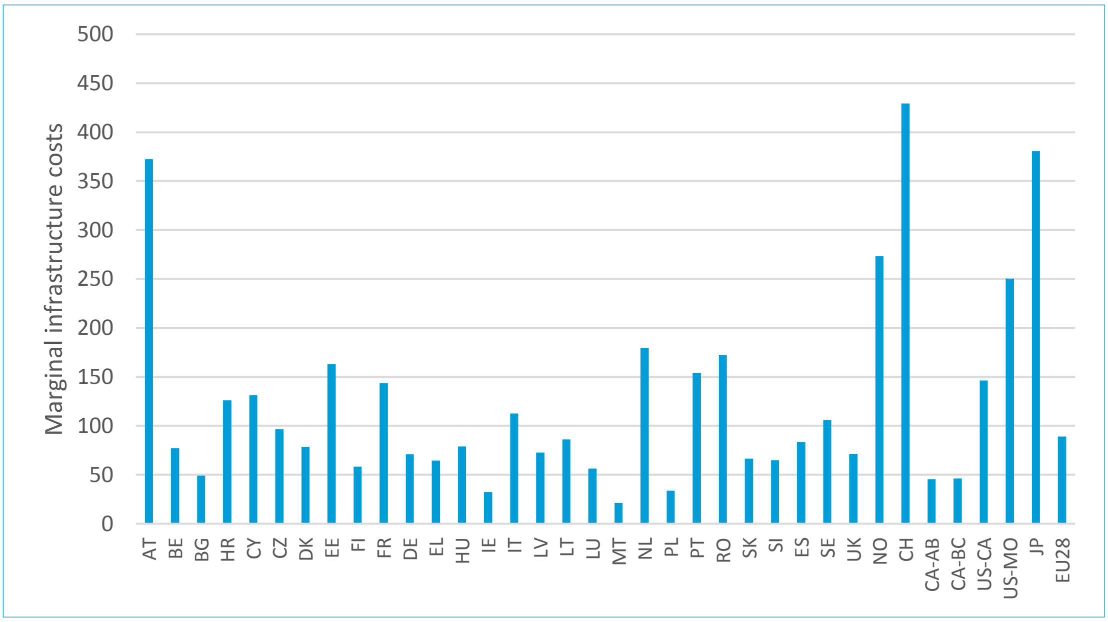


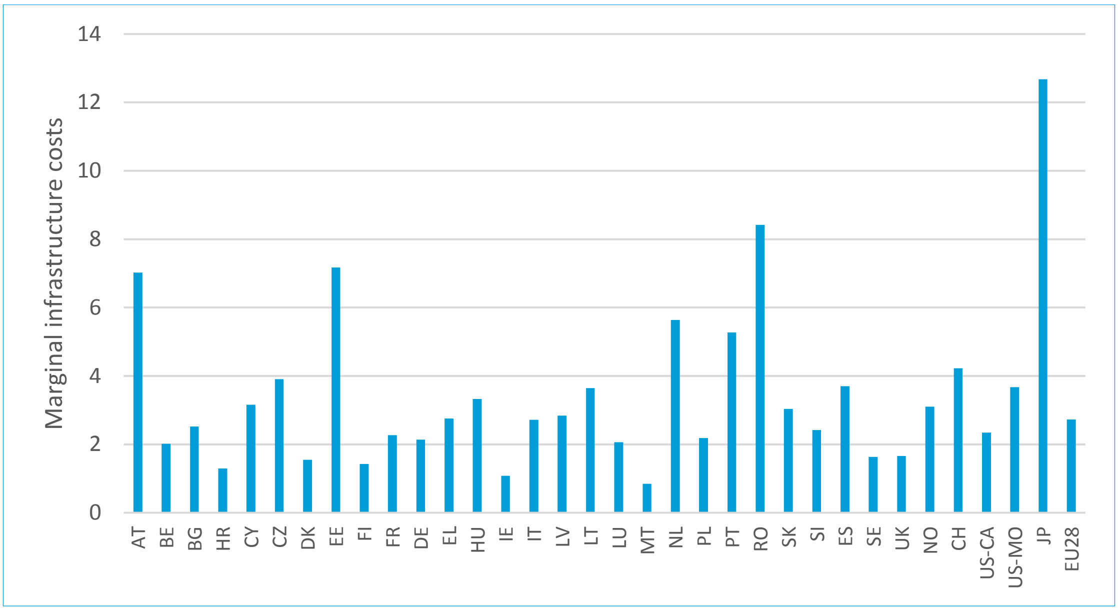
Figure 18 - Marginal infrastructure costs HGVs in 2016 (€ per 1,000 vehicle kilometres, PPS adjusted)



Light commercial vehicles

The marginal infrastructure costs of LCVs (in € per 1,000 vehicle kilometres) are presented in Figure 19. For the EU28, these costs are equal to € 2.7 per 1,000 vehicle kilometres. Between countries, the marginal infrastructure costs range from € 0.9 per 1,000 vehicle kilometres in Malta to € 8.4 per 1,000 vehicle kilometres in Romania. Differences between countries are quite well in line with differences in average costs and hence so are the explanations for these differences.

Figure 19 - Marginal infrastructure costs LCVs in 2016 (in € per 1,000 vehicle kilometre, PPS adjusted)



Note: No marginal infrastructure costs for the Canadian provinces Alberta and British Columbia have been estimated, due to a lack of transport performance data for these provinces.

4 Rail transport

4.1 Introduction

In this chapter we discuss the infrastructure expenditures and costs for rail transport. We do this for all countries considered in this study (see Section 1.3.2), except for Malta and Cyprus as these countries do not have a railways network. The infrastructure costs for high speed lines are considered for Belgium, France, Germany, Italy, Netherlands, Spain, UK and Japan[25].

In Section 4.2, we first clearly define what is covered by rail infrastructure in this study. Next, in Section 4.3 some rail-specific methodological issues (in addition to the general methodology explained in Chapter 2) with respect to the calculation of rail infrastructure costs are discussed. Finally, the results on rail infrastructure expenditures and costs are presented in Sections 4.4 and 4.5, respectively.

4.2 Defining rail infrastructure

An overview of the various rail infrastructure items that are covered by the rail infrastructure definition considered in this study is given in Table 10[26]. With respect to the physical infrastructure, these items are in line with the definitions used in EC Regulation no. 851/2006 and Directive 2012/34, as well as the with the definition applied in ITF (2013b). As explained in Section 2.2, in this study we also consider the organisation of the rail network as part of the rail infrastructure. The relevant organisational items are presented in Table 10 as well.

Table 10 - Overview of rail infrastructure items

Main categories	Sub-items
Ground area	All land area occupied.
Track and track bed	Embankments, cuttings, drainage channels and trenches, masonry trenches, culverts, lining walls, planting for protecting side slopes, four-foot way and walkways, enclosure walls, hedges, fences, fire-protection strips, apparatus for heating points, crossings, snow protection screens, etc.
Platforms	Passenger and goods platforms.
Engineering structures	Bridges, culvers and other overpasses, tunnels, covered cuttings and other underpasses, retaining walls, structures for protection against avalanches, falling stones, etc.
Level crossings	Level crossings both road-rail and rail-rail, including appliances to ensure the safety of road traffic.
Superstructure	Rails, grooved rails and check rails, sleepers and longitudinal ties, small fittings for the permanent way, ballast including stone chippings and sand, points, crossings, turntables and traversers (except those reserved exclusively for locomotives).
Access ways	For passengers and goods, including access by road.
Safety, signalling and telecommunications	Installations on the open track, in stations and in marshalling yards, including plans for generating, transforming and distributing electric current for signalling and telecommunications, buildings for such installations or plants, track brakes.
Lighting installations	Installations for traffic and safety purposes.

[25] For Sweden the European Statistical Pocketbook presents transport performance data for high speed trains, but no data on high speed infrastructure is presented. Therefore, no specific infrastructure costs for high speed trains in Sweden are estimated. For Poland, data on high speed rail infrastructure and high speed transport performance was available, but no data on high speed rail infrastructure expenditures was found. For that reason, no infrastructure costs for high speed trains in Poland are estimated.

[26] Notice that this is a working definition and that the infrastructure expenditures collected for the various countries are not always fully consistent with this definition. See Sections 2.2 and 2.5 for more details.

Main categories	Sub-items
Plants for transforming and carrying electric power for train haulage	Sub-stations, supply cables between substations and contact wires, catenaries and supports, third rail with supports.
Buildings used by the infrastructure department	Including a proportion with respect to installations for the collection of transport charges.
Organisation of rail network	Rail traffic monitoring and control, emergency and safety services, overhead infrastructure managers (personnel, energy).

As Table 10 shows, the applied definition of rail infrastructure does not include railway stations (except for passengers and goods platforms). Main parts of the railway stations can be regarded as commercial areas (e.g. shops, restaurants) and as rents are paid for the use of these areas the costs related to these areas can be regarded as being internalised. Furthermore, these infrastructure items are not directly related to transport performances. For these reasons, they are not included in this study.

4.3 Specific methodological issues to estimate rail infrastructure costs

To estimate the rail infrastructure costs, the methodology explained in Section 2.4 was applied. However, some aspects of this general methodology had to be further elaborated with respect to rail transport. These are:

- breakdown to fixed and variable rail infrastructure costs;
- allocation of total rail infrastructure costs to various train categories.

In the remainder of this section we will discuss these two issues in more detail.

Breakdown to fixed and variable rail infrastructure costs

Data on a differentiation between fixed and variable rail infrastructure costs is only available for a few countries (The Netherlands, UK). For the other countries we have estimated fixed and variable infrastructure costs based on default values on the shares of fixed and variable costs in total costs. Therefore, we have assessed relevant literature sources[27] and compared the results with the figures found for The Netherlands and the UK (see Table 11).

Table 11 - Share of variable costs in total infrastructure costs according to various sources

Country/study	Renewal costs	Maintenance costs
Results from data collection from EU aggregated and national accounts		
The Netherlands	21%	27%
UK	7%	18%
Results from literature study		
CATRIN (2009)	35%	20-45%[a]
UNITE (2002) - Finland, Sweden		17%
UNITE (2002) - UK	21-32%	21-32%
Silavong et al. (2014)		8-57%

[27] The studies reviewed estimated usage cost elasticities using econometric analyses. These elasticities express the share of average infrastructure costs that can be considered as marginal costs. As marginal costs are (assumed to be) equal to variable average costs, these cost elasticities are a measure of the variable part of the average infrastructure costs. Therefore we report the values found for the usage cost elasticities as the share variable costs have in the total infrastructure costs.

Country/study	Renewal costs	Maintenance costs
Odolinski and Nilsson (2016)		17-39%
Yarmukhamedov et al. (2017)	53%	
Finish Rail administration (2007)		12-27%
GRACE (2007)		16% (7-21%)
Andersson et al. (2012)	41%	
Andersson (2011)		5-18%
Recommended default values		
Default values	**35%**	- **20% by traffic density below 3 million tonne-kilometres per track-km per annum** - **30% by traffic density between 3 and 10 million tonne-kilometres per track-km per annum** - **45% by traffic density above 10 million tonne-kilometres per track-km per annum**

a CATRIN (2009) finds that the usage elasticity (i.e. variable part of total costs) depends on traffic density. Below 3 million tonne-kilometres per track-km per annum a value of 20% is recommended, for a traffic density between 3 and 10 million tonne-kilometres per track-km per annum a value of 30% is recommended, and for traffic densities above 10 million tonne-kilometres per track-km per annum t a value of 45% is recommended.

Based on the results shown in Table 11, we decided to make use of the values recommended by CATRIN (2009) as default values. As for maintenance costs, only this study provides values differentiated to traffic density, reflecting the fact that the share of variable costs in total maintenance costs increases with higher usage levels of the rail network. Furthermore, the results presented by CATRIN (2009) can be seen as an average of the values presented by the other studies. With respect to renewal costs, less evidence is available on the share of variable costs. The value recommended by CATRIN (2009) was chosen as it lies between the relatively low values found for the Netherlands and the UK and the higher values presented by (more) recent studies like Yarmukhamedov et al. (2017) and Andersson et al. (2012).

Little information is available on the variable part of the operational costs. Silavong et al. (2014) finds that about 65% of the operational costs are variable, but in this study only the costs of traffic management are considered. As the operational cost also cover more fixed elements (e.g. overhead costs rail infrastructure manager), this value seems too high to use in this study. As more evidence is lacking, we decided to assume the operational costs as 100% fixed. Finally, for enhancement costs we assumed that these are 100% fixed.

Allocation of total rail infrastructure costs to various train categories

The total rail infrastructure costs have been allocated to high speed trains, passenger trains (distinguishing electric and diesel trains[28]) and freight trains (distinguishing electric and diesel trains). The costs drivers used for this allocation has been based on a literature review. The selected cost drivers per cost category are presented in Table 12. For more details, see Annex E.3.

[28] This study does not take into account the different costs of a diesel and an electrified rail line but the cost of the overall rail network (which are allocated to electric and diesel trains based on the cost drivers mentioned in the following table).

Table 12 - Cost drivers rail transport

Cost category	Cost driver
Enhancement costs	- 100% capacity related: Allocated to passenger and freight trains based on train kilometres. - Costs related to high speed lines are fully allocated to high speed trains.
Renewal costs	- Variable costs allocated based on tonne km (both for passenger and freight trains). See Annex C.3 for more details on the tonne km data used). - Fixed costs area allocated based on train-km.
Maintenance costs	- Variable costs are partially (50%) allocated based on train-km and partially (50%) based on tonne-km. - Fixed costs are fully allocated based on train-km.
Operational costs	- Fully allocated on train-km.

The transport performance data (e.g. tonne-kilometres, train kilometres) used for this allocation of total infrastructure costs to various train categories can be found in Annex B.

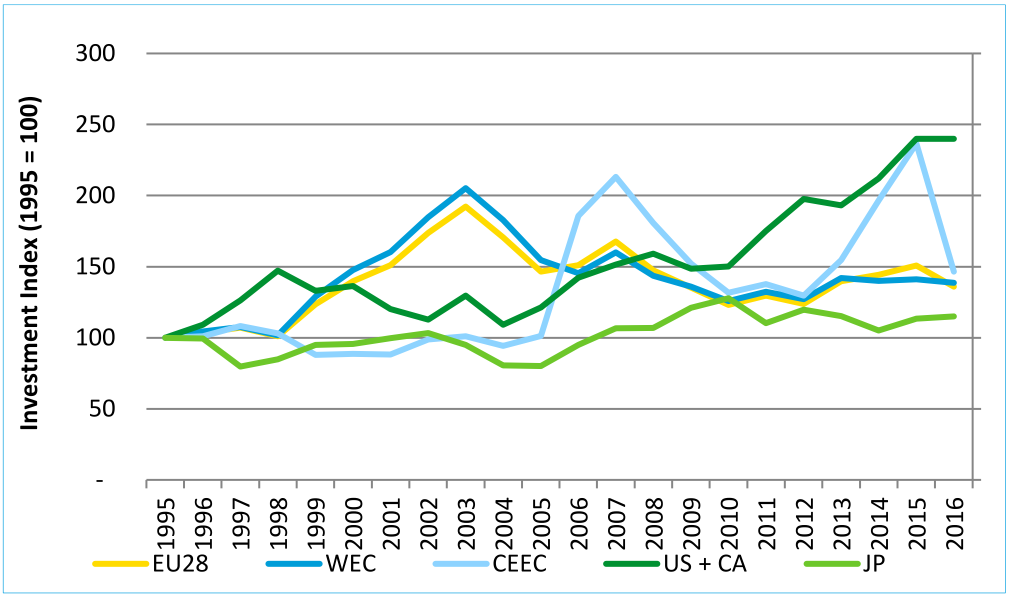
4.4 Rail infrastructure expenditures

4.4.1 Investments

The total rail infrastructure investments in the EU28 in 2016 were equal to about € 32 billion[29], of which 14% (€ 4.5 billion) was spent on high speed rail infrastructure. As shown in Figure 20, the level of rail infrastructure investments have changed considerably over the period 1995-2016. The overall pattern at EU28 level shows a peak in 2003, which was followed by a constant reduction trend until 2013. Since then the investment index is relatively constant. The declining trend was temporarily reversed in 2007 by stimulus spending, but after 2008, because of the effect of the economic crisis and need of fiscal consolidation, the efforts stalled in many countries. The impact of the stimulus spending is visible, but the trend indicates that the general volume has been broadly falling back to 2000 level and below pre-crisis level.

[29] According to the Fifth report on monitoring development of the rail market data (RMMS), the total rail infrastructure investments in 2014 at EU28 level was found equal to € 34 billion, of which € 7 billion for high speed lines (EC, 2016). It is worth observing that RMMS data cannot be fully compared with the data gathered for this study, because (i) referring to a different year and (ii) RMMS figures do not cover all Member States.

Figure 20 - Investment index for rail infrastructure in the period 1995-2016



As is shown in Figure 20, aggregate trends of Western European Countries (i.e., WEC) and Central and Eastern Europe Countries (i.e., CEEC) are markedly different. In general, investments on rail infrastructures depends on a number of factors. First, investment spending depends on the macro-economic condition under which the public effort is undertaken, but the need to invest is also influenced by the quality and age of the operated infrastructure, the landscape and geography of the country, the intensity and localisation of production activities, the residential choices and the level political commitment. All these driving factors may change significantly across (groups of) countries due the variety of local conditions (ITF, 2015; UNECE, 2016).

More specifically, in WEC the investment index for rail basically reflects the trend at the EU28 level. The stability of the investment index of the WEC of the recent years could depend on the ongoing construction and development plans of the high speed networks (in Denmark, France, Italy and Spain). Regarding CEEC, there are indications that difference with WEC has narrowed.
In particular, CEEC have been catching up with WEC, possibly due to the need to improve the quality of the infrastructures. The two peaks of 2006-2007 and 2015 show that investments spending has been more intense to recover from a worse initial situation and meet projected rail demand forecasts. Extensive funding from EC programmes (i.e., Cohesion and Structural funds) became available for CEEC countries, which were used to finance these efforts (Perchel, 2016). However, a recent study from the European Commission (EC, 2014) presents evidence that the stock of infrastructure in CEEC is still lower than the EU28 average, but the railway network appears over dimensioned in view of the actual dynamics of rail traffic.

Aggregate data for the four states of US and Canada which are analysed in this study show that the investment index for rail infrastructure increased significantly from 1995 to 2016, according to our estimates. In contrast to the rail investments in Europe, no decreasing trend is found since 2003 for the US and Canadian states/provinces. Finally, the pattern of the Japanese rail investment index is relatively stable through time and it remains mainly determined by the investing needs for continuous developments of the high speed network (ITF, 2015).

Rail investments as share of GDP

The analysis of the annual share of GDP allocated to rail infrastructure investments is a useful tool to infer to what extent the spending levels could have been affected by factors other than real investment needs, such as institutional budget allocation procedures or budgetary constraints.
The analysis over a long-term period, can also indicate the level political commitment for transport infrastructure spending through time.

Figure 21 shows that significant different patterns for the annual share of rail investments in GDP are found for WEC and CEEC, respectively. In WEC, the trend is very close to that observed at EU28 level through time and the annual investments as percentage of GDP constantly increased until 2003 from 0.20% to 0.35%. The sharp reduction immediately after was followed by a lower, but relatively constant, period of annual investment from 2005 to 2009. The reduction of the share accelerated afterwards, as effect of the crisis of the economy, to reach again the 1995 level. CEEC show a different pattern. As the annual investment share of GDP for this group of countries increases rather permanently over the period 1995-2005, a sharp increase is identified in 2006 followed by a U-shape trend until 2016. This is in line with the findings on the investment index and corroborates the correlation between EU funding after accession to the Union of CEEC and spending for improvements of quality and efficiency of the networks of this group.

For the US and Canadian states/provinces analysed in this study, the annual share of rail investment in GDP is found relatively stable over the period 1995-2016, with a slightly positive trend after 2004. This indicates that the annual expenditure of rail investment has been increasing at a higher pace than GDP annual growth. Compared to the EU, rail investments as share of GDP are at a considerably lower level in the US and Canadian states/provinces. In Japan, on the other hand, investments levels (as share of GDP) are generally comparable to those in the EU. The trend for Japan shows an oscillating pattern with a slightly negative trend over the period resulting from the outpacing increase of national GDP with respect to annual rail investments.

Figure 21 - Development in share of rail infrastructure investments in GDP over time

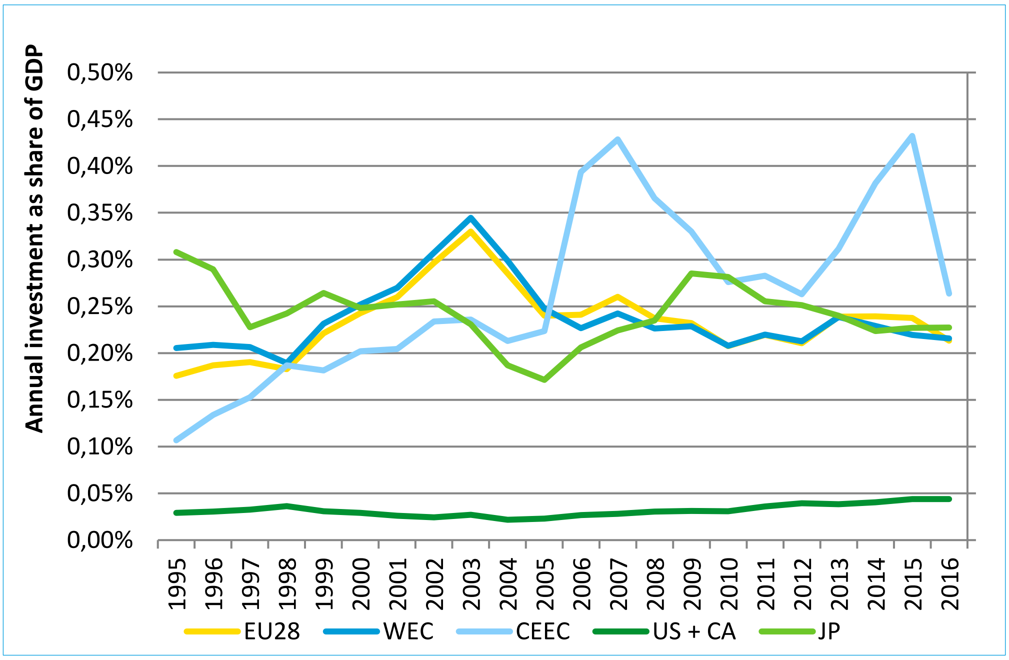
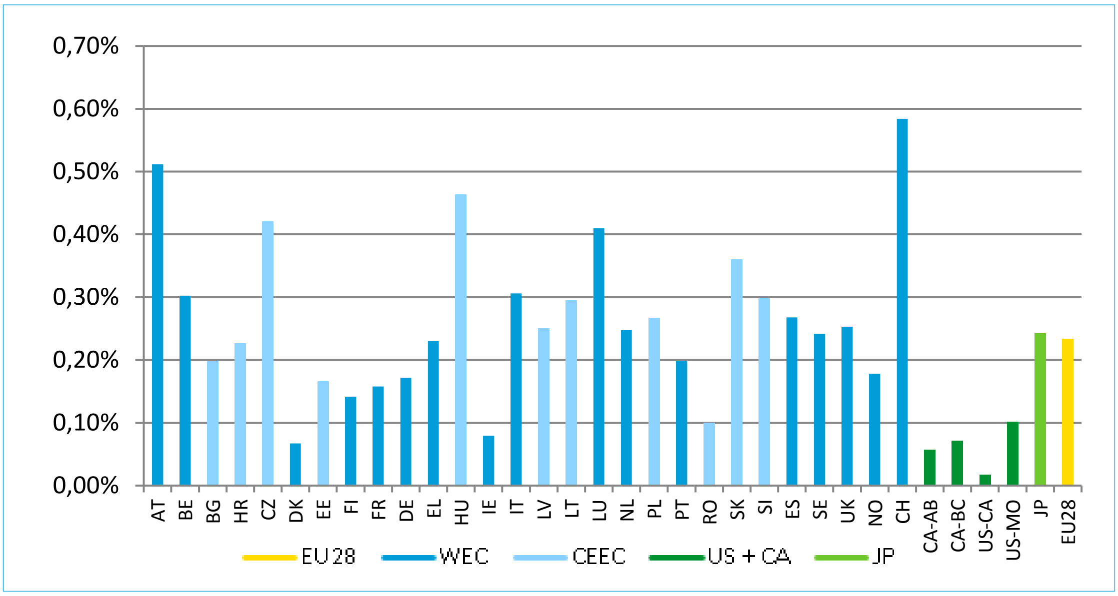


Figure 22 presents the long-term share of investments as percentage of GDP per country.

Figure 22 - Rail infrastructure Investments as share of GDP (average share for 1995-2016)



Note: There are no railways in Cyprus and Malta.

For EU28, the average annual share is equal to 0.23% and the values obtained are within a relatively broad interval of variation (i.e., from 0.07 to 0.51%). The highest average share of EU Member States is found for Austria, reflecting overall importance given to the quality of rail infrastructure[30], and more recently, the ongoing improvements of the network for Semmering Base Tunnel, Koralm Line, Brenner Base Tunnel and modernisation of stations (Reidinger, 2016). The high share of Luxembourg could be explained by the modernisation of the Brussels-Luxembourg-Strasbourg railway axis (EC, 2007).
Low average annual investments as share of GDP emerge for Denmark, due to the sharp contraction of investments observed from 1995 to 2010 and Ireland where investments are generally low, except for the period 2000-2007 for tracks modernisation (Doyle, 2016). Outside EU Member States, the annual investment share is higher only in Switzerland (i.e. 0.58%). This can be explained by large investment programme started in 1999 with the construction of the Lötschberg and Gotthard base tunnels to crossing the Swiss Alps.

The average annual investments as share of GDP lies slightly higher in CEEC countries than in WEC countries (0.28%). The interval of variation is also narrower (i.e., from 0.10 to 0.46%) in CEEC. Within this group, the variation can be explained by the different rate of completion of TEN-T conventional rail network, which according to EC scoreboard[31] is found high for the Czech Republic, Hungary and Slovakia and low for Romania. Degradation of the rail networks, inefficiencies and underdevelopment are also considered the main reasons for the relatively high investment needs in CEEC. In this respect, the EU cohesion policy is the main source of funding for rail infrastructure investments in the CEEC, from track modernisation and railway electrification, to ERTMS and signalling projects (Friebel, et al., 2007; Božičević, et al., 2008; Máthé, et al., 2013; Perchel, 2016).

[30] See also the scores on 'Investments and infrastructure' for Austria on the EC scoreboard

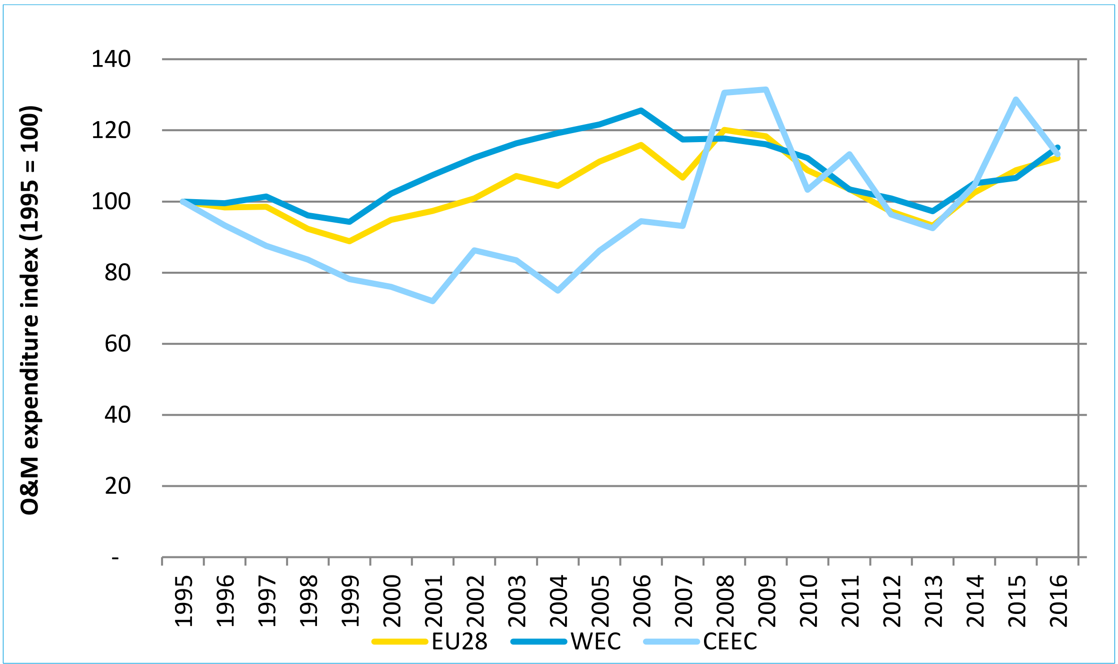
[31] See also EU transport scoreboard

4.4.2 Operational and maintenance expenditures

The O&M expenditures of rail transport in the EU28 in 2016 are about € 27 billion. Over the years, these expenditures seem to display quite cyclical variations (see Figure 23). The trend shows that O&M expenditure index initially decreases and then increases during the period from 1995 to 2006.
It steadily decreases in the years following and until 2013. More recently, the O&M expenditure index raises again. It is outside the scope of this study to review the maintenance programmes at country level, but such cyclical variation may depend on the timing of investment plans[32] and routine maintenance programmes carried out against deterioration of aging networks.

When it comes to distinguish between operational and maintenance expenditures in the EU28, their trends are found relatively similar to that of the total O&M expenditures, in terms of cyclical variations over time. It is worth observing that the share of the operational component is found reducing from 55 to 49% during the 1995-2016 period, while the maintenance component is found increasing from 45 to 51%. To some extent, this tendency may suggest a generalised deployment over the years of maintenance plans to address deterioration of the networks.

Figure 23 - O&M expenditure index for rail infrastructure in the period 1995-2016



Note: For the US and Canadian states/provinces as well as for Japan, only data for 2016 were available.

Comparing WEC and CEEC some differences emerge. In particular, before the economic crisis, the WEC group shows a markedly higher expenditure index, which is surpassed by the CEEC peak from 2007 to 2010. Afterwards, the economic downturn seems to have affected to a similar extent both groups that converged to relatively close trends after 2010, excluding the second CEEC peak of 2015.

[32] In the years following the actual deployment of an investment plan, a reduction of O&M expenditures would be expected because of the operation of new infrastructures.

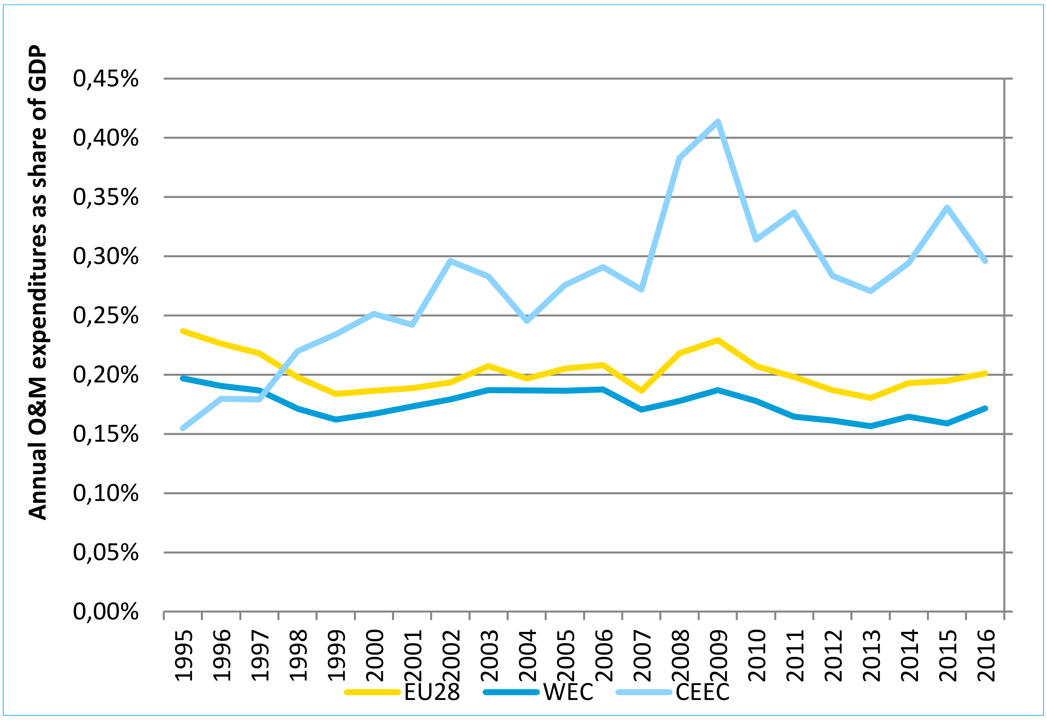
Analysing at country level, there are some WEC countries deviating from the general cyclical variation of O&M expenditure index. Notably, for Belgium, Ireland, Greece and Portugal a significant reduction has been found after 2010. Concerning CEEC, the annual O&M expenditure index shows a large decrease between 1995 and 2001, probably because there was no adequate maintenance after the fall of the former Eastern regimes. During this period, the overall quality of rail infrastructures decreased (Friebel, et al., 2007). The increase of O&M expenditure index from 2002 to 2010 can be explained by the deployment of programmes aimed to recover these deficiencies and overall underdevelopment levels. Such modernisation mainly concerned the main lines, and especially the elements of the CEEC networks part of the TEN-T (Perchel, 2016).

Finally, it is useful to briefly discuss the trends of operational and maintenance expenditures separately for WEC and CEEC, respectively. On the one hand, the results for the WEC is found relatively similar to the tendency found at EU28 level. This means, there is essentially an equal distribution between operational and maintenance cost components throughout the 1995-2016 period. On the other hand, for the CEEC it is found that the share of the operational component in total O&M expenditures is always higher compared to maintenance expenditures, even though a more balance distribution emerges over time (i.e., from 62-38% in 1995 to 53-47% in 2016).

Rail O&M expenditures as share of GDP

As Figure 24 illustrates, the annual O&M expenditures as share of GDP shows a relatively stable trend in the WEC over the period 1995-2009. It is followed by a slightly reduction after the start of the economic crisis. For CEEC, a significant increasing trend of annual O&M expenditure share is found for the period 1995-2009, which can be explained by the rising need for good quality rail infrastructures for this group of countries. However, due to the economic crisis, annual O&M budgets have been heavily cut, resulting in a significant reduction of these expenditures.

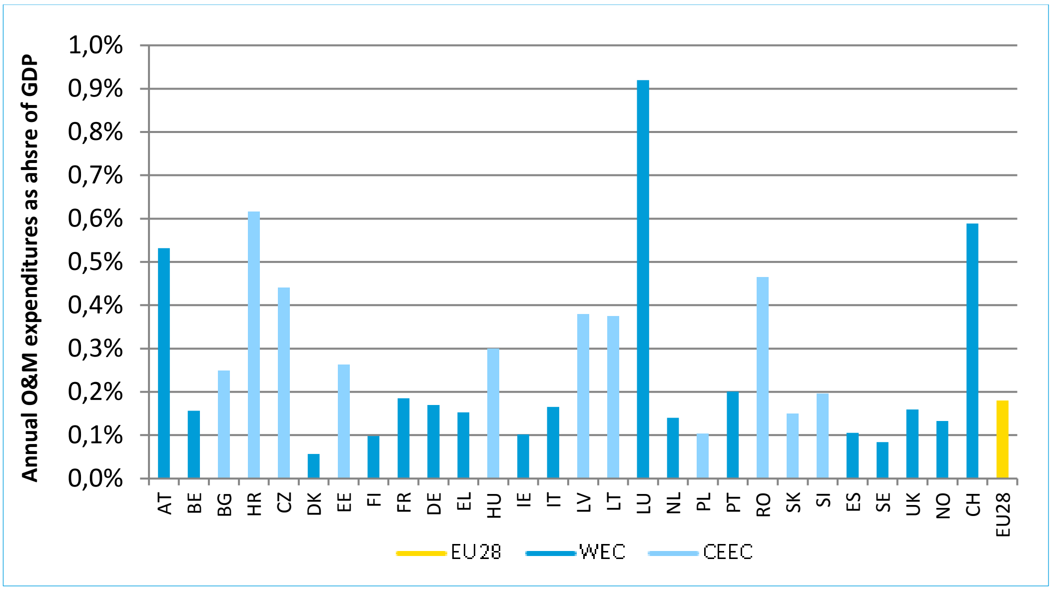
Figure 24 - Rail infrastructure O&M expenditures as share of GDP (average share for 1995-2016)



Note: For the US and Canadian states/provinces as well as for Japan, only data for 2016 were available.

Figure 25 illustrates the data by country. With the exception of Austria, Luxembourg and Switzerland, for most WEC, the share of annual O&M expenditures in GDP is smaller than or equal to 0.20%. Possible explanations for the higher shares in these countries are discussed in the next section.
On the other hand, for CEEC the annual O&M expenditure shares are larger or equal to 0.20%, except for Poland and Slovakia.

Figure 25 - Average annual rail O&M expenditures as share of GDP (average shares for 1995-2016)



Notes:

- figures for US+CA and Japan are based on data for 2016 only;
- there are no railways in Cyprus and Malta.

O&M expenditures per kilometre rail network

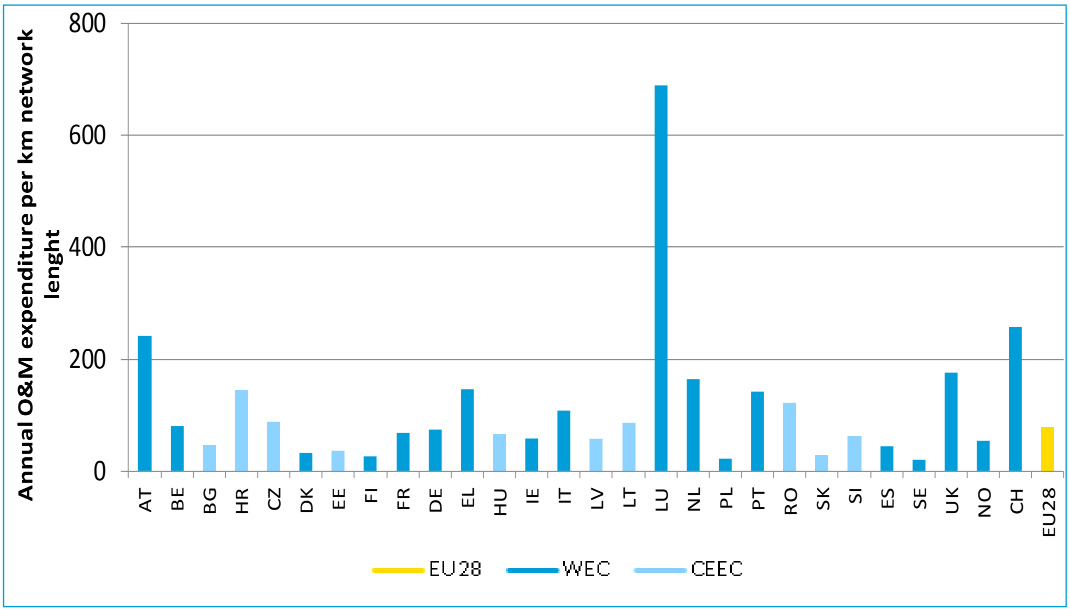
Figure 26 presents the O&M expenditures per kilometre of rail network of EU countries.
O&M expenditures are very high on Luxembourg rail, probably because of the impossibility to exploit economies of scale (Nash & Preston, 1992), having relatively high expenditure levels to manage a very small network of 275 km only. With the exception of this outlier, annual O&M expenditures per kilometre of network are highest in Austria and Switzerland, probably due to high intensity of use of both passengers and freight services, overall network quality and services punctuality and complexity to pass through the rugged landscape of the Alpine region (with a relatively large number of bridges and tunnels). For these networks another reason for the relatively high O&M expenditures per kilometre could be related to winter mountain maintenance activities.

Also in the Netherlands and UK O&M expenditures per kilometre rail network are relatively high due to the good level of traffic intensity and high expenditure levels. O&M expenditures on Italian rail network are relatively high as well, probably because of network complexities to cross not only the Alps, but also the Apennines, where the high speed line is operated through very long tunnels.
Concerning Croatia, Greece, Portugal and Romania, the networks have low or obsolete technical and technological standards, which may determine low efficiency levels and high maintenance costs. Another influencing factor for Croatia and Romania is the geographic complexity and territorial configuration (Božičević, et al., 2008; Máthé, et al., 2013).

The relatively low level of O&M expenditures per kilometre in countries like France and Germany can be linked to the large extension of their networks, which probably induce economies of scale per kilometre of rail, and to the investment level which may determine lower needs in terms of O&M expenditures for new infrastructures[33].

Finally, the O&M expenditures per kilometre in Japan are significantly above the average EU levels. However, it should be noted that the cost figures for Japan (as well as for US+CA) refer to 2016 values only and hence are not directly comparable to the figures for the European countries.

Figure 26 - Average annual rail O&M expenditures per track-km of rail network length[34] in the period 1995-2016 (x1,000 €/km, PPS adjusted)



Notes:

- figures for US+CA and Japan are based on data for 2016 only;
- there are no railways in Cyprus and Malta.

[33] It is also worth observing that the two countries shows different patterns regarding operational and maintenance costs. For France, maintenance expenditures are found always higher than operational expenditures over the 1995-2016 period. However, the level of past maintenance expenditures has been considered low and is expected to increase in the future (Raynaud, et al., 2017). For Germany, operational expenditures are the large majority of total O&M expenditures through time (i.e., 70% on the average for the 1995-2016 period), which could benefit from some scale efficiency in relation to the length of the network. However, according to figures in Arntz and Yasin (2017), the level of maintenance expenditures is expected to increase up to 2022 to catch up with the backlog.

[34] Annual O&M expenditures are expressed per track-km, assuming that the length of the tracks for the purpose of this calculation is equal to the sum of the lengths of single and double tracks (i.e., counting 1 for a single track line and 2 for a double track line). Another approach to estimate the annual O&M expenditure could be based on the line-km, namely assuming the length of the network not distinguishing with respect to the number of tracks. The advantage of using the track-km approach is that the average cost can be easily calculated on the basis of the infrastructure characteristics. On the other hand, the advantage of using a line-km approach is to consider some common costs that are afforded when maintaining a double track line.

4.5 Rail infrastructure costs

Based on the infrastructure expenditure data as presented in the previous section, we have applied the methodology as discussed in Chapter 2 and Section 4.3 to estimate the rail infrastructure costs in the various countries and for the various vehicle categories.

4.5.1 Total infrastructure costs

The total costs of the entire rail network in the various countries are presented in Table 13.
In 2016, these costs were equal to about € 80 billion in the EU28.

Table 13 - Total rail infrastructure costs in 2016 (billion €, PPP adjusted)

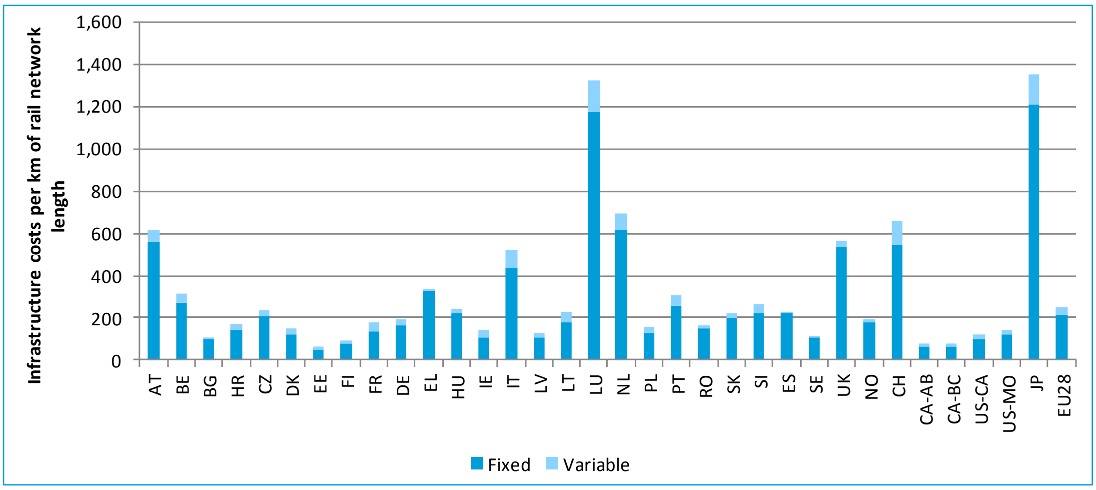
Member State	Investments costs	O&M costs	Total infrastructure costs		
			Fixed	Variable	Total
EU28	53.50	26.99	69.93	10.57	80.50
Austria	2.61	1.66	3.85	0.42	4.28
Belgium	1.78	0.38	1.84	0.31	2.16
Bulgaria	0.30	0.25	0.49	0.06	0.55
Croatia	0.19	0.30	0.41	0.09	0.50
Czech Republic	1.35	1.36	2.35	0.36	2.71
Denmark	0.39	0.13	0.42	0.10	0.52
Estonia	0.06	0.04	0.09	0.01	0.10
Finland	0.41	0.18	0.52	0.08	0.59
France	5.09	3.67	6.73	2.03	8.76
Germany	7.74	3.92	9.90	1.76	11.66
Greece	0.88	0.06	0.90	0.03	0.94
Hungary	1.52	0.70	2.03	0.19	2.22
Ireland	0.16	0.21	0.28	0.09	0.36
Italy	9.22	4.48	11.45	2.24	13.69
Latvia	0.11	0.17	0.23	0.05	0.28
Lithuania	0.22	0.31	0.42	0.11	0.53
Luxembourg	0.18	0.38	0.50	0.07	0.57
Netherlands	2.73	1.02	3.33	0.42	3.75
Poland	3.50	0.69	3.48	0.71	4.19
Portugal	0.71	0.26	0.82	0.15	0.97
Romania	0.53	1.66	2.01	0.19	2.19
Slovakia	0.83	0.35	1.05	0.12	1.17
Slovenia	0.23	0.18	0.34	0.06	0.40
Spain	5.23	0.73	5.75	0.22	5.97
Sweden	1.07	0.45	1.38	0.14	1.52
United Kingdom	6.46	3.45	9.34	0.56	9.91
Norway	0.52	0.48	0.92	0.08	1.00
Switzerland	2.50	1.58	3.37	0.71	4.08
Canada – British Columbia	0.16	0.55	0.59	0.12	0.71
Canada – Alberta	0.16	0.58	0.62	0.13	0.74
US – California	0.47	0.58	0.86	0.20	1.06
US — Missouri	0.38	0.55	0.76	0.17	0.93
Japan	14.93	34.88	44.56	5.26	49.82

Note: There are no railways in Cyprus and Malta.

Figure 27 illustrates the infrastructure costs per 1,000 track-kilometres of rail network. Excluding the specific case of Luxemburg, high costs emerge for countries operating networks in complex territories, like for Austria, Italy and Switzerland. Another case with high infrastructure costs concerns the Netherlands, which is probably determined by the relatively high total infrastructure costs, with respect to the small operated network. Furthermore, the high usage capacity of the Dutch rail network contributes to its relatively high costs. It is worth remarking that the highest infrastructure cost per 1,000 kilometres is found in Japan. Our estimation can be explained by the continued importance given to railway infrastructure developments, especially favouring high speed services.

With respect to the distribution of infrastructure costs between fixed and variable components, fixed costs are always the majority. In this respect, there is not a significant variation across countries. According our estimation, the share of fixed costs at EU28 level is equal to 87.6% and for WEC and CEEC, the shares are equal to 88,0% and 86,2%, respectively. For the US and Canadian states/provinces and Japan, we found shares similar to the European countries.

Figure 27 - Infrastructure costs per track-km of rail network length (x 1,000 €/km, PPS adjusted)



Note: There are no railways in Cyprus and Malta.

An overview of the total infrastructure costs per train category is given in Table 14. The allocation of the total rail infrastructure costs as presented in Figure 27 has been based on the equivalency factors presented in Table 14.

Table 14 - Total rail infrastructure costs in 2016 per train category (billion €, PPP adjusted)

Member State	HSL	Passenger conventional train electric	Passenger train diesel	Freight train electric	Freight train diesel
EU28	11.52	38.85	17.60	9.45	3.07
Austria	-	2.52	0.57	1.09	0.10
Belgium	0.31	1.53	0.10	0.17	0.05
Bulgaria	-	0.35	0.06	0.11	0.02
Croatia	-	0.18	0.19	0.07	0.06
Czech Republic	-	1.00	1.18	0.43	0.10

Member State	HSL	Passenger conventional train electric	Passenger train diesel	Freight train electric	Freight train diesel
Denmark[35]	0.03	0.19	0.27	0.01	0.02
Estonia	-	0.01	0.02	-	0.07
Finland	-	0.39	0.04	0.10	0.06
France	2.10	3.25	1.88	1.36	0.17
Germany	2.29	5.24	2.22	1.66	0.24
Greece	-	0.20	0.68	0.01	0.04
Hungary	-	1.05	0.83	0.27	0.07
Ireland	-	0.06	0.29	-	0.01
Italy	2.63	7.82	2.04	1.16	0.04
Latvia	-	0.01	0.03	-	0.24
Lithuania	-	0.01	0.08	-	0.44
Luxembourg	-	0.48	0.04	0.04	0.01
Netherlands	0.59	2.57	0.33	0.21	0.06
Poland	-	2.41	0.30	1.19	0.29
Portugal	-	0.55	0.26	0.10	0.06
Romania	-	0.91	0.76	0.37	0.16
Slovakia	-	0.51	0.35	0.25	0.07
Slovenia	-	0.15	0.08	0.13	0.04
Spain	3.22	1.89	0.50	0.28	0.07
Sweden	-	1.07	0.09	0.33	0.03
United Kingdom	0.34	4.52	4.39	0.09	0.57
Norway	-	0.65	0.17	0.14	0.04
Switzerland	-	3.49	0.07	0.51	0.01
Canada – British Columbia	-	-	0.10	-	0.64
Canada – Alberta	-	-	0.10	-	0.61
US – California	-	-	N/A	-	1.06
US - Missouri	-	-	N/A	-	0.93
Japan	5.76	18.56	18.59	4.94	1.95

Note: There are no railways in Cyprus and Malta.

Finally, Table 15 presents the shares of rail infrastructure costs per train category. It is worth noticing that in the Baltic countries the majority of the cost is allocated to freight trains, because of their higher intensity of use compared to the other European countries.

[35] HSL infrastructure costs refer to sections under construction, which implies that the average and marginal infrastructures costs relative to transport performance cannot be calculated.

Table 15 - Share of rail infrastructure costs in 2016 per train category

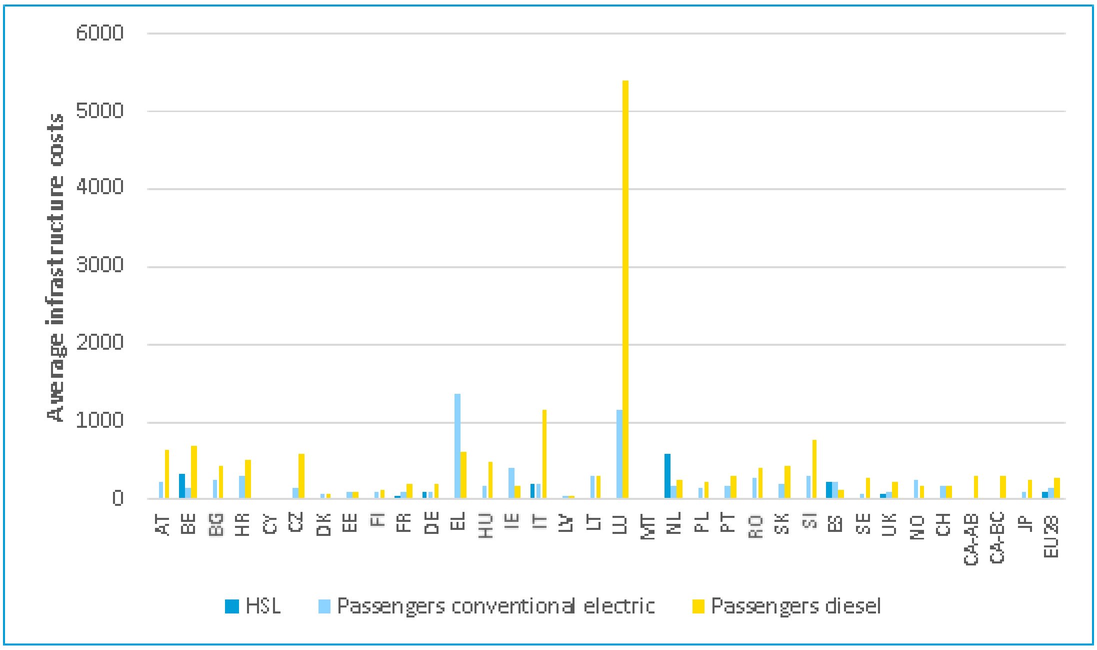
Member State	HSL	Passenger conventional train electric	Passenger train diesel	Freight train electric	Freight train diesel
EU28	15%	48%	22%	12%	4%
Austria	-	59%	13%	25%	2%
Belgium	14%	71%	5%	8%	2%
Bulgaria	-	64%	11%	20%	4%
Croatia	-	37%	38%	14%	11%
Czech Republic	-	37%	44%	16%	4%
Denmark	7%	36%	52%	3%	3%
Estonia	-	5%	23%	0%	72%
Finland	-	65%	7%	17%	10%
France	24%	37%	21%	16%	2%
Germany	20%	45%	19%	14%	2%
Greece	-	0%	93%	1%	6%
Hungary	-	47%	37%	12%	3%
Ireland	-	18%	80%	0%	2%
Italy	19%	57%	15%	8%	0%
Latvia	-	2%	11%	0%	87%
Lithuania	-	1%	15%	0%	84%
Luxembourg	-	84%	8%	7%	2%
Netherlands	16%	68%	9%	6%	2%
Poland	-	57%	7%	28%	7%
Portugal	-	57%	27%	10%	6%
Romania	-	41%	35%	17%	7%
Slovakia	-	43%	30%	21%	6%
Slovenia	-	38%	21%	32%	9%
Spain	54%	32%	8%	5%	1%
Sweden	-	70%	6%	22%	2%
United Kingdom	3%	47%	43%	1%	6%
Norway	-	65%	17%	14%	4%
Switzerland	-	86%	2%	12%	0%
Canada - British Columbia	-	-	31%	-	69%
Canada - Alberta	-	-	31%	-	69%
US - California	-	-	-	-	100%
US - Missouri	-	-	-	-	100%
Japan	12%	37%	37%	10%	4%

Note: There are no railways in Cyprus and Malta.

4.5.2 Average infrastructure costs relative to transport performance

Figure 28 presents the average infrastructure costs, expressed in € per 1,000 passenger kilometres for the three passenger train categories considered in this study.

Figure 28 - Average infrastructure costs rail passenger transport in 2016 (€/1,000 pkm, PPS adjusted)



Note: There are no railways in Cyprus and Malta. For the US states no data on the number of passenger kilometres was available.

In the large majority of the countries (i.e., 20 out of 29 or 70%), the average infrastructure costs for diesel passenger trains is estimated as the highest. This could be explained mainly by the low occupancy rate of diesel compared to electric trains (i.e., 60 against 150 passengers on average per train, respectively) and by the relatively high infrastructure costs allocated to this category against their low intensity of use (more often used for regional services). The infrastructure costs for HSL trains are in general lower than for conventional trains, except for Belgium and the Netherlands. In this respect, it is worth observing that if the actual number of high speed trains operated is low, the cost per passenger is high, even though the occupancy rate is high. For Germany, Italy and Spain the average cost of HSL trains is relatively similar to conventional passenger electric trains, while it is lower for France[36] and the UK, where the HSL network capacity is well used and the relatively high occupancy rate of HSL trains results in low average cost per passenger kilometre.

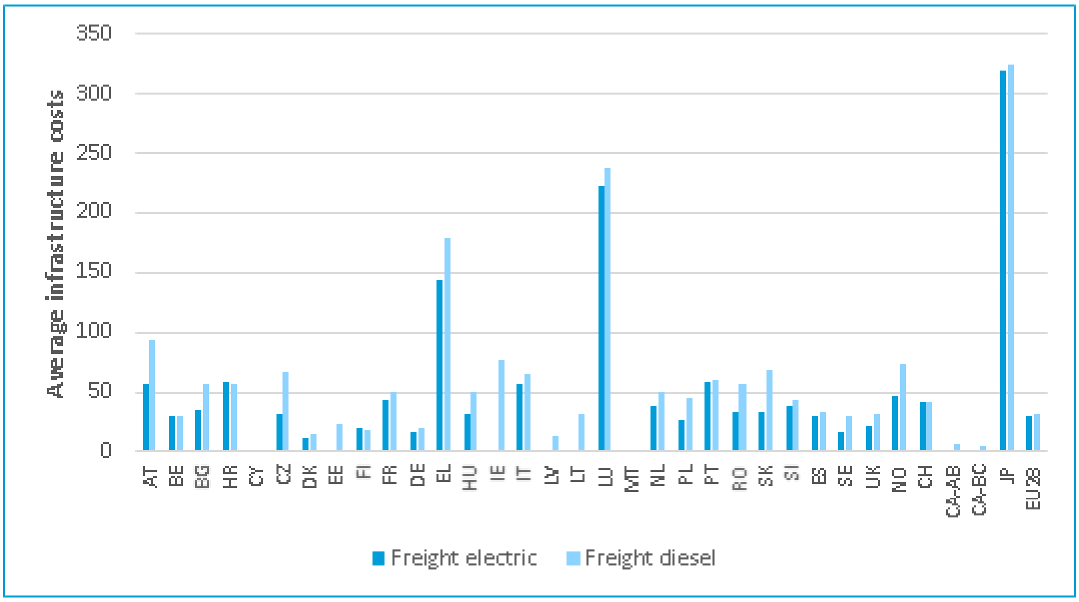
More in general, the highest average infrastructure costs for passenger trains are estimated for countries with relatively high network costs and associated with small networks or low intensity of use. The high traffic density on the rail network of France and Germany is an important reason for the lower average infrastructure costs in these countries.

Figure 29 shows the estimated average infrastructure costs, expressed in € per 1,000 tonne-kilometre, for freight trains. As for passengers, the average infrastructure costs are higher for diesel trains (i.e., 26 out of 29, or 89.7%), although the differences between diesel and electric trains are in general small. The reasons for the higher average infrastructure costs of diesel trains can be explained (i) by the different

[36] According to Trabo et al. (2013) France has relatively low HSL infrastructure costs. This can be explained by existence of less populated areas where HSL were constructed and also by the difference in construction procedures. In France steeper grades were designed rather than building tunnels and viaducts. In other countries HSL have been constructed in more densely populated areas, tackling various challenges during construction (e.g. Italy and Belgium). Land acquisition and labour cost are other influencing factors to be considered in explaining the differences.

average load (i.e., 512 against 494 tonnes per train, respectively) and (ii) again probably because of the lower intensity of use of diesel rail infrastructure (compared to electric rail infrastructure).

Figure 29 - Average infrastructure costs rail freight transport in 2016 (€/1,000 tkm, PPS adjusted)



Note: There are no electric freight trains in Estonia, Ireland, Latvia, Lithuania, and the Canadian/US states. Furthermore, there are no railways in Cyprus and Malta. Finally, no reliable data on rail tonne-kilometres was available for Missouri.

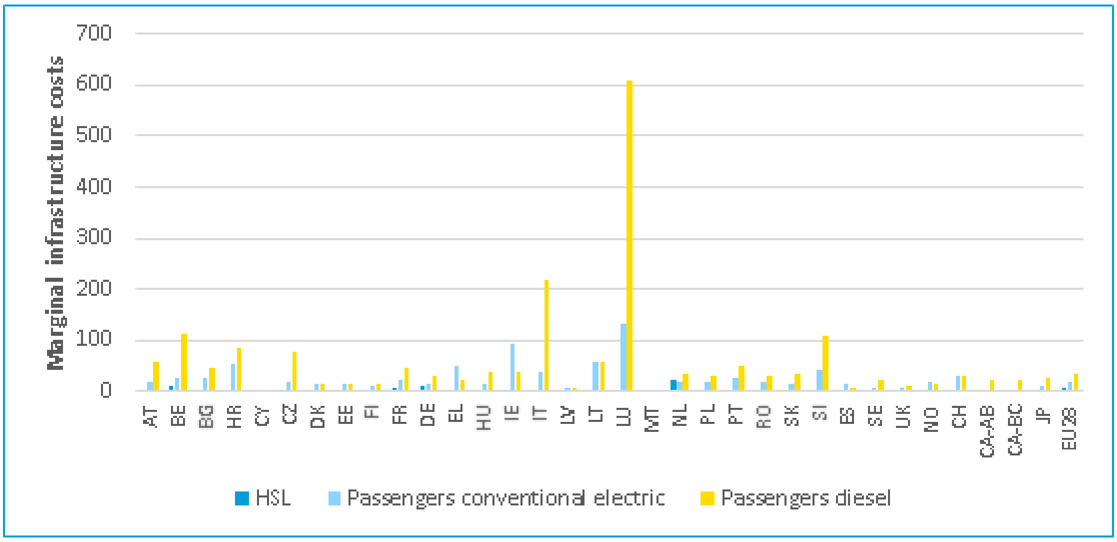
4.5.3 Marginal infrastructure costs

The marginal infrastructure costs for passenger trains are presented in Figure 30. As discussed in Section 2.4.5, they include all variable infrastructure costs, i.e. the variable part of the renewal and maintenance costs. The sizes of these variable parts are based on country specific data or the default values presented in Table 11. Subsequently these variable renewal and maintenance costs are allocated to the various train categories based on the cost drivers defined in Table 12[37].

In general, the same pattern as for average costs can be found. As regards the marginal infrastructure costs for HSL trains, they are lower than for electric conventional passenger trains, except in The Netherlands. As fixed infrastructure costs are no part of the marginal costs figures, the lower usage rate of HSL infrastructure (which is one of the main reasons for the relatively high average costs for these trains) does not affect the marginal cost levels per passenger kilometre. Instead, the on average higher occupancy rate of HSL trains results in lower marginal cost figures.

[37] The variable renewal costs are allocated based on tonne-kilometres. Therefore, the share of each train category in total rail tonne-kilometres is estimated and these shares have been used to allocate the variable renewal costs. With respect to variable maintenance costs a comparable approach is applied, using both tonne-kilometres and train kilometres as cost drivers (50% of the costs are allocated based on tonne-kilometres and 50% based on train kilometres).

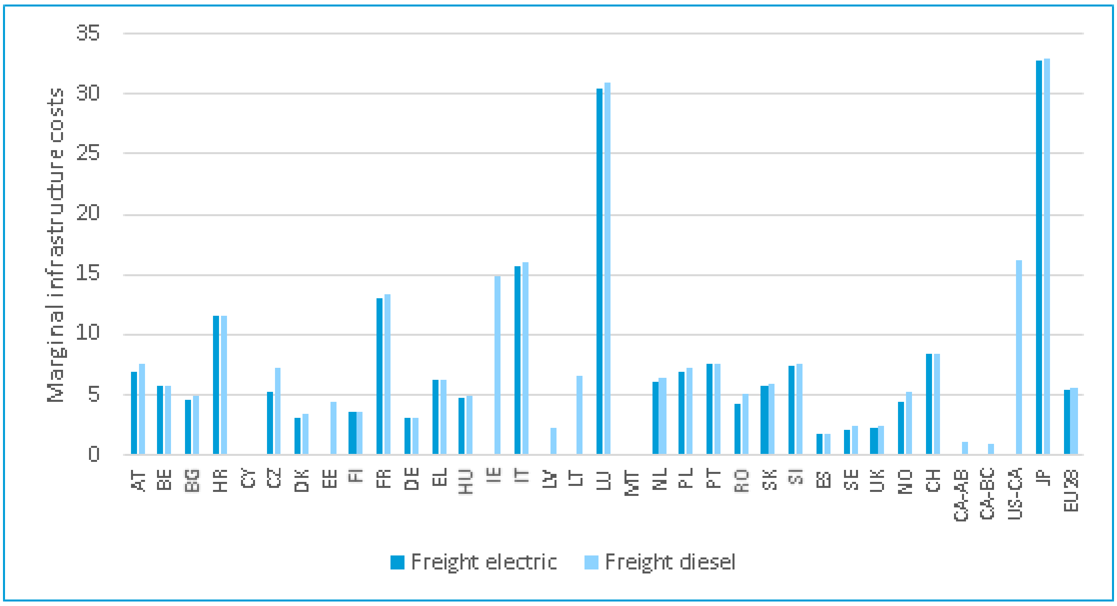
Figure 30 - Marginal infrastructure costs rail passenger transport in 2016 (€/1,000 pkm, PPS adjusted)



Note: There are no railways in Cyprus and Malta. For the US states no reliable rail passenger kilometre data was available.

Figure 31 presents the marginal infrastructure costs of rail freight transport in 2016. As for passenger transport, the pattern in marginal cost figures for freight trains is largely comparable with that for average costs figures.

Figure 31 - Marginal infrastructure costs rail freight transport in 2016 (€/1,000 tkm, PPS adjusted)



Note: There are no electric freight trains in Estonia, Ireland, Latvia, Lithuania, and the US/Canadian states. Furthermore, there are no railways in Cyprus and Malta. For Missouri, no reliable data on rail tonne-kilometres was available and hence no marginal cost figures could be estimated.

5 Inland waterway transport

5.1 Introduction

The infrastructure expenditures and costs for IWT are discussed in this chapter. We do this for seventeen European countries that have relevant IWT volumes, i.e. Austria, Belgium, Bulgaria, Croatia, Czech Republic, Finland, France, Germany, Hungary, Italy, Lithuania, Luxembourg, the Netherlands, Poland, Romania, Slovakia and Switzerland. For the non-European countries, we only consider the US state Missouri. No (significant levels of) transport by inland waterways Is performed in California, the Canadian provinces and Japan.

We start this chapter by presenting the definition of IWT infrastructure used in this study (Section 5.2). In Section 5.3 some IWT-specific methodological issues (in addition to the general methodology explained in Chapter 2) with respect to the calculation of IWT infrastructure costs are discussed. The results on IWT infrastructure expenditures are discussed in Section 5.4.
Finally, the results on IWT infrastructure costs are presented in Section 5.5.

5.2 Defining IWT infrastructure

Table 16 provides an overview of the various IWT infrastructure items that are covered by the definition of IWT infrastructure that is considered in this study[38]. As for road and rail transport, the physical infrastructure items mentioned in this table are in line with EC Regulation 851/2006 and ITF (2013b), with the exception that in this study we also take inland ports into account as part of the IWT infrastructure. As explained in Section 2.2, in this study the organisation of the IWT network is considered as part of the IWT infrastructure as well. The relevant organisational items are presented in Table 14.

Table 16 - Overview of IWT infrastructure items

Main categories	Sub-items
Land	The area of land occupied by the waterway.
Channel	Earthworks, canal basins and linings, sills, groynes, berms, tow-paths, service roads, bank protection, canal-carrying aqueducts, siphons and conduits, canal tunnels, service basins used exclusively for sheltering vessels.
Inland port	See definition of maritime ports in Section 6.2.
Water control structures	Works for waterway shut-off and safety, spillways for the discharge by gravity of impounded water, basins and reservoirs for storing water for feeding and regulating water level, flow gauges, level recorders and warning devices.
Barrages or weirs	Works constructed across the bed of a river to maintain sufficient depth of water for navigation and to reduce the speed of flow by creating pounds or reaches, associated structures such as fish ladders and relief channels.
Locks and similar structures	Navigation locks, lifts and inclined planes, including waiting basins and basins for water economy.
Mooring equipment and guide jetties	Mooring buoys, dolphins, mooring bitts, bollards, rails and fenders.
Movable bridges	

[38] Notice that this is a working definition and that the infrastructure expenditures collected for the various countries are not always fully consistent with this definition. See Sections 2.2 and 2.5 for more details.

Main categories	Sub-items
Safety, signalling, telecommunications and traffic control	Installations for channel buoying, signalling, safety, telecommunications, lighting and traffic control.
Toll collection installations	
Building used by the infrastructure department	
Organisation of IWT network	Traffic management, operational and monitoring of inland waterways installations (e.g. bridges, locks, inland ports), operational and monitoring of communication network of the waterways and shipping administration, emergency prevention, fire protection, search and rescue services, overhead infrastructure managers (energy, vehicles, etc.).

5.3 Specific methodological issues to estimate IWT infrastructure costs

For the calculation of the IWT infrastructure costs the general methodology explained in Section 2.4 has been applied. However, some aspects of this methodology have been elaborated with respect to IWT. These are:

- allocation of infrastructure costs to general water management functions;
- breakdown of total IWT infrastructure costs;
- breakdown to fixed and variable IWT infrastructure costs;
- allocation of infrastructure costs to freight and recreational/passenger vessels;
- allocation of infrastructure costs to inland freight vessels and to seagoing vessels;
- allocation of infrastructure costs of maritime ports to IWT.

In the remainder of this section we will discuss these issues in more detail.

Allocation of infrastructure costs to general water management functions

Not all costs related to investments, maintenance and management of inland waterways are caused by inland shipping. Costs of water management, flood protection, soil pollution prevention, recreational facilities on embankments, etc. cannot be allocated to inland shipping. Beside the above mentioned general water management functions, inland waterway infrastructure is sometimes used for energy production (as well). For instance the barrage in Iffezheim on the upper Rhine is built because of energy production. One can also discuss whether the Rhine canal upstream from Iffezheim was built because of the energy construction or because of inland navigation (see INFRAS and Planco, 2017).

In CE Delft and VU (2014) it was estimated that 19% of the costs of inland waterways in the Netherlands should be allocated to general water management. In UNITE (2002), it is estimated that 30% of all expenditures on the river Rhine (between Mannheim and Rotterdam) should be allocated to general water management, while Ecorys and Metlle (2005) estimate this to be about 20% for the Rhone river in France. For the Flemish inland waterways, TML (2017) assumes that about 25% of the expenditures are not IWT-related. Although there are no figures concerning the share of energy production in the IWT infrastructure costs in Germany, a share of about 20% of the costs relating to non-navigational purposes seems also plausible for Germany. Therefore, we decided to use a default value of 20% to estimate the infrastructure costs for non-navigational purposes in all countries (except for France, for which specific figures for the costs of general water management have been identified).

Breakdown of total IWT infrastructure costs

As for road and rail transport, a further breakdown of total IWT related infrastructure expenditures has been made. For some countries, such a breakdown was (partly) available from national accounts.

However, for other countries this breakdown has been estimated by using default values for the shares of the various expenditure categories in total infrastructure expenditures.

The default values to distinguish between enhancement and renewal costs have been based on data for Germany, France and The Netherlands (see Table 17)[39]. The data for these three countries show a comparable breakdown of investments and the German figures can be regarded as central values. Therefore, the recommended default values are set equal to the German figures.

With respect to the breakdown of O&M costs, default values for the shares of operational and maintenance costs are based on the results for eight countries. Although the results differ between countries (see Table 17), the shares of operational and maintenance costs in total O&M cost are comparable for main IWT countries like Germany, France and The Netherlands. As the figures for The Netherlands can be regarded central values, they are selected as default values.

Table 17 - Average share of enhancement and renewal expenditures in total investments and of operational and maintenance expenditures in total O&M expenditures

Country	Average share in total investments		Average share in total O&M costs	
	Enhancement	Renewal	Operational	Maintenance
Bulgaria	n/a	n/a	44%	56%
Croatia	n/a	n/a	34%	66%
Germany	53%	47%	22%	78%
Finland	n/a	n/a	8%	92%
France	40%	60%	38%	62%
Hungary	n/a	n/a	84%	16%
The Netherlands	66%	34%	33%	67%
Switzerland	n/a	n/a	86%	14%
Recommended default values	53%	47%	33%	67%

Breakdown to fixed and variable IWT infrastructure costs

In addition to the breakdown of total IWT infrastructure costs to the various cost categories, a differentiation between fixed and variable IWT infrastructure costs have been made. As these data is often not available from national accounts (only for the Netherlands), we have carried out a literature review on this issue. Only Ecorys and Mettle (2005) do provide some evidence, which is in line with the results found for the Netherlands (see Table 18).

Table 18 - Share of variable costs in total IWT infrastructure costs (differentiated to various cost categories) according to various studies

Country/study	Enhancement	Renewal	Maintenance	Operational
Netherlands (CE Delft and VU, 2014)	0%	15%	15%	
Ecorys and Mettle (2005)	0%	15-28%		

[39] These are three countries with relatively high inland navigation transport flows and hence it is uncertain to what extent the breakdown of investments in these countries are a good proxy for the breakdown in countries with more limited inland navigation transport flows. However, as there is no other evidence available, we do use these data to estimate the default values.

Both sources show that the renewal and O&M expenditures can be regarded for about 15% variable. To apply these parameters for other countries as well, we have made a correction for the utilisation of the network capacity. If the utilisation of inland waterways decreases, it may be expected that also the variable share in total infrastructure cost decreases. This relationship is estimated based on the Dutch data and is used to estimate specific shares of the fixed and variable costs in total infrastructure costs for every country. The resulting shares per country are shown in Table 19. Enhancement costs are assumed to be fully fixed.

Table 19 - (Estimated) shares of fixed and variable costs in renewal and O&M costs in the various countries

Country	Share of fixed costs	Share of variable costs
Austria	90.1%	9.9%
Belgium	86.7%	13.3%
Bulgaria	77.0%	23%
Croatia	98.3%	1.7%
Czech Republic	99.9%	0.1%
Finland	99.97%	0.03%
France	96.6%	3.4%
Germany	86.1%	13.9%
Hungary	98.1%	1.9%
Italy	99.9%	0.1%
Luxembourg	87.7%	12.3%
The Netherlands	85%	15%
Poland	99.95%	0.05%
Romania	85.7%	14.3%
Slovakia	91.7%	8.3%
Switzerland	83.0%	17%
Missouri (US)	85.0%	15%

Allocation of infrastructure costs to freight and recreational vessels

The total IWT infrastructure costs have been allocated to freight and non-freight (i.e. recreational/ passenger) vessels[40]. In CE Delft and VU (2014) this allocation was made based on the shares of freight and non-freight vessels in the total ship-kilometres on the Dutch inland waterways. This analysis showed that about 40% of the infrastructure costs should be allocated to recreational/passenger vessels. With respect to the fixed infrastructure costs, it is concluded that these can be (almost) fully allocated to freight vessels.

[40] Only the costs for freight vessels are relevant in this study and hence the infrastructure costs for recreational vessels have not been presented separately in this study.

Unfortunately, data on ship-kilometres differentiated to freight and recreational/passenger vessels is not available for the other countries. Only information about the numbers of passenger vessels is given by the Central Commission for the Navigation of the Rhine (CCNR). These numbers show that 75% of the cruise vessels in Europe are navigating on the Rhine, Danube and Elbe. Figures about daytrip boats or pleasure boats are missing. Hence the allocation of infrastructure costs to freight traffic and to passenger transportation might not be very different to the Dutch one. Therefore, as we cannot estimate country-specific parameters to allocate infrastructure costs, we will use the Dutch parameter (i.e. 40% of the variable costs are allocated to non-freight vessels).

Allocation of infrastructure costs to inland freight vessels and to seagoing vessels

Inland waterways are not only used by inland vessels. Seagoing vessels are also using parts of the inland waterways. Thus the renewal and O&M expenditures should be partly assigned to seagoing vessels. For estimating the share of costs which should be assigned to the sea going vessels the transport volumes of river-sea-transports have been used. Of course there are not river-sea -transports in all countries with inland navigation (see Table 20)[41].

Table 20 - Share of river-sea-transports (tons) on inland waterways

Country	Share seagoing transports
Belgium	0.78%
Germany	0.58%
Finland	78.30%
France	4.85%
Italy	*22.84%**
Lithuania	*78.30%**
Netherlands	20.00%
Poland	*78.30%**
Romania	22.84%

* Estimated.

Allocation of infrastructure costs of maritime ports to IWT

In some countries, inland vessels make use of maritime ports as well. This is, for example, the case in the Netherlands (e.g. Port of Rotterdam and Port of Amsterdam) and Belgium (Port of Antwerp and Port of Zeebrugge). In order to estimate the total infrastructure costs of IWT in these countries, part of the infrastructure costs of these maritime ports should (preferably) be allocated to IWT. However, since we do not cover all relevant maritime ports in this study, we were not able to consistently estimate this part of the IWT infrastructure costs. Therefore, we decided not to include the IWT related infrastructure costs of maritime ports in the total IWT infrastructure cost estimates. This may result in a (slight) underestimation of these costs[42].

[41] For the calculation of the share of sea-going transports Data from EUROSTAT and data from the market observation of the CCNR were used (CCNR , 2013; CCNR, 2017). The CCNR showed some figures about river-sea-transports in Europe. Transported tons were given for some European countries. For these countries a share of seagoing transports of the total transports on inland waterways had been calculated for the year 2012. Because there is no information about the transport performance of river-sea-shipping the transport volume was taken as an approximation. The results can be seen in Table 18. There had been no information for Poland, Italy and Lithuania. For Poland and Lithuania, Finland's share was taken as estimation for Poland and Lithuania (as they have a relatively similar short inland waterway network as in Finland). For Italy, the shares of Romania are taken as proxy.

[42] CE Delft and VU (2014) estimates that about 9% of the total IWT infrastructure costs in the Netherlands consists of costs related to maritime ports.

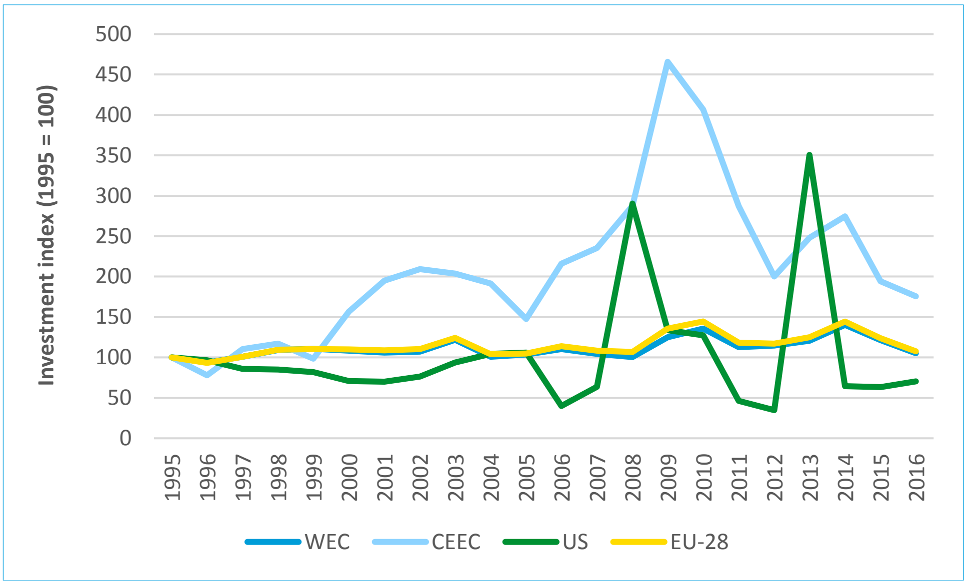
5.4 IWT infrastructure expenditures

In this section we present the main results for inland waterway infrastructure expenditures. The expenditures are just without the part for the general water management. The share of expenditures which belongs to recreation/passenger or seagoing vessels is still part of the expenditures in this section.

5.4.1 Investments

The total investments on inland waterways in the EU28 in 2016 are about € 1.6 billion. As is shown in Figure 32, this is well above the 1995 level.

Figure 32 - Investment index for IWT infrastructure in the period 1995-2016



- EU28 = Austria, Belgium, : Bulgaria, Croatia, Czech Republic, Finland, France, Germany, Hungary, Italy, Lithuania, Luxembourg, Netherlands, Poland, Romania, Slovakia.
- WEC = Western European Countries: Austria, Belgium, Finland, France, Germany, Italy, Luxembourg, Netherlands, Switzerland.
- CEEC = Central and Eastern European Countries: Bulgaria, Croatia, Czech Republic, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia.
- US = Missouri.

Figure **32 - Investment index for IWT infrastructure in the period 1995-2016**
Figure 32 also shows that the investment index of the EU28 and WEC[43] is quite stable over time, particularly when compared to the index of the CEEC. The investments expenditures of the CEEC are dominated by Czech Republic, Poland, and Romania. The share of these countries of the total investment expenditures in the CEEC is on average about 84% and never below 70%. Hence a change in the infrastructure expenditures in one of these three countries affects the investment index of the CEEC significantly.

The increase of the CEEC investment index in 1999 is based on relatively low investments in the period before 1999. A second increase occurred in 2006 but this one last 'only' until 2012.However, there is

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43 Notice that the definition of WEC (and CEEC and US) is different as for road and rail transport, as not for every country inland navigation is a relevant transport mode. The countries considered for inland navigation are shown in the note below Table 30.

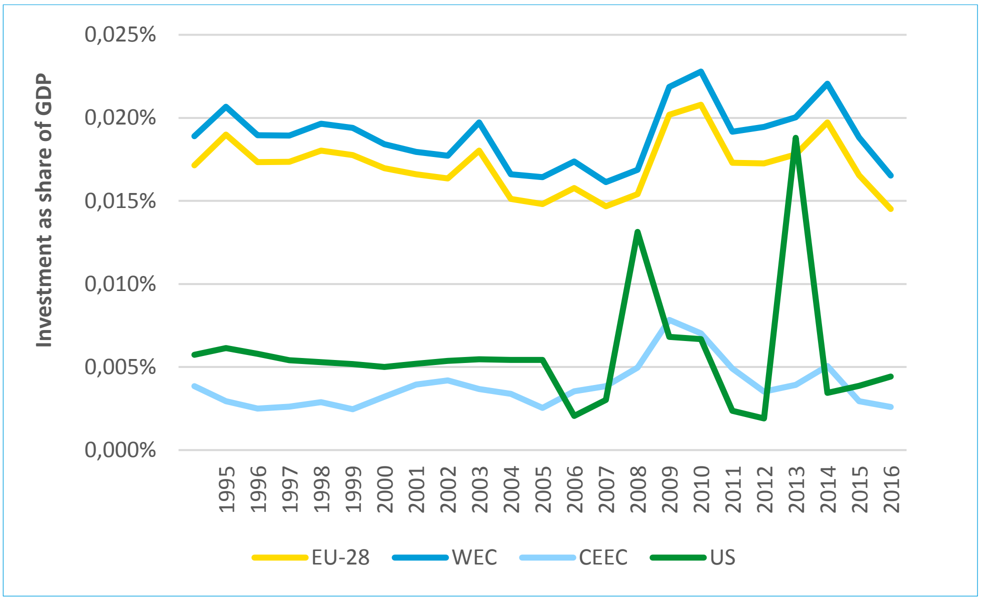
another effect as well. The exchange rate and deflator show bigger changes in the time from 1999. Thus there are two effects with impacts on the investment expenditure index of the CEEC. One is the lower investment in the early 1990s and the second is the exchange rate and deflator effect.

The EU28 consists for the inland waterways of the WEC and the EEC without Switzerland.
The investment index of the EU28 is lower than the investment index of the CEEC and higher than the index of the WEC. The EU28 is closer to the index of the WEC than to the index of the CEEC. This is caused by much higher investments in the WEC than in the EEC.
At first sight the investment index of the US seems to be very erratic, but there are only two years with extremely high investments compared to 1995 (2008, 2013). The US figures are based on the investments in one US state only (Missouri) and hence are by definition more volatile than the average figures for a group of countries.

Inland waterway investments as share of GDP

The development of the shares of investment expenditures in GDP for the WEC and the CEEC is shown in Figure 33.

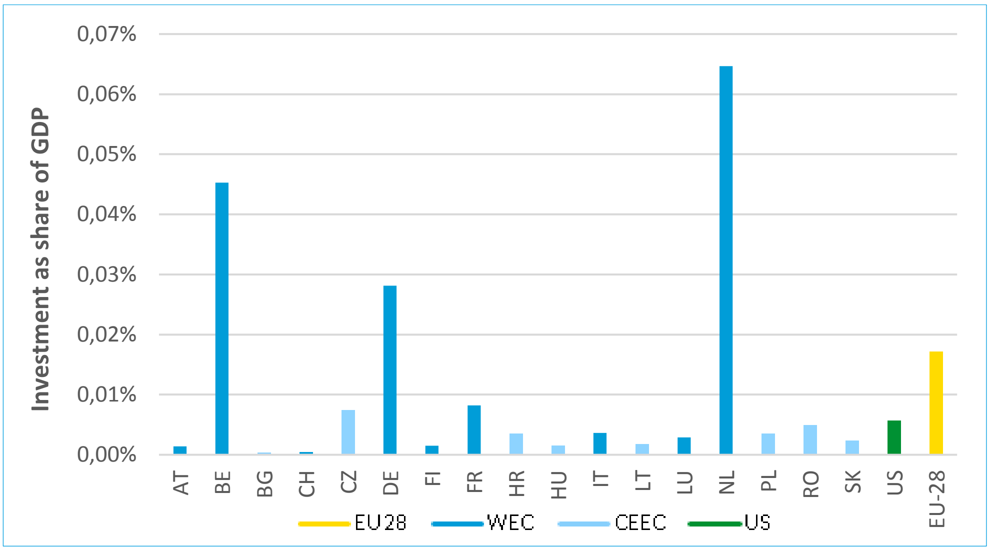
Figure 33 - Development in share of IWT infrastructure investments in GDP over time



The EU28 and WEC spent nearly the same share of the GDP in the inland waterway infrastructure over the entire period (between 0,015% and 0,02%). In the CEEC, the share shows similar volatility but on a lower level. As mentioned above, in the last years the investments in the important CEEC countries were lower than before. Hence the decline in the last years is mainly caused by this. In the earlier 2000s the investment in the CEEC grew more strongly than the GDP. Therefore the share of the annual investment in the inland waterway infrastructure has risen in this time.

A more detailed view of the share of investment expenditures of the GDP is given in Figure 34, which shows average share for 1995 to 2016 for the individual countries.

Figure 34 - IWT infrastructure Investments as share of GDP (average share for 1995-2016)



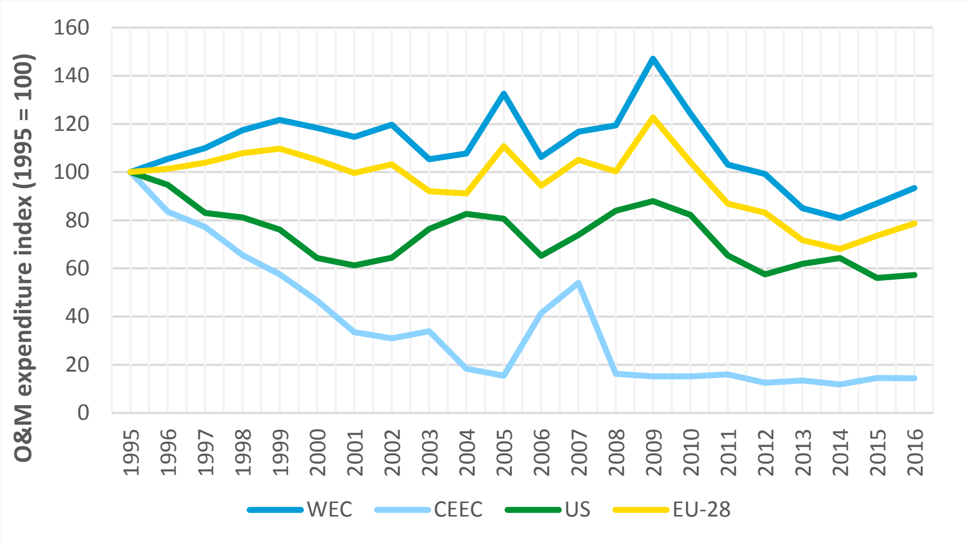
As mentioned above the Czech Republic, Poland and Romania are the countries of the CEEC with the highest investment expenditures in inland waterways. They are not only the countries with the highest absolute investment expenditures; they also spent, together with Croatia, the highest share of their GDP in inland waterways. Compared to some WEC countries (e.g. Austria) their shares are relatively high, which is mainly due to their relatively low GDP (PPP adjusted). This is particularly the case for Romania and Poland.

One also has to take into account the different sizes of the IWT network in the countries. For instance the IWT network in Italy, Finland or Lithuania is quite small and hence these countries invest a lower share of their GDP in inland waterways as for example Germany or Belgium. This explains some differences between the countries. By the same reasoning it can be (partly) explained that the share of inland waterways investment in GDP is higher in The Netherlands and Belgium than in Germany and France. The size of the inland waterway network in the latter two countries is relatively smaller (compared to their GDP) than in the Netherlands and Belgium.

5.4.2 Operational and maintenance expenditures

In 2016, the EU28 spent about € 1 billion (PPP adjusted) on the operational and maintenance of inland waterways. As shown in Figure 35, the development of the O&M expenditures in the EU28 have been rather stable up to 2009, followed by a significant drop between 2009 and 2014 (probably due to the economic crisis) and a slow uptake since 2014.

Figure 35 - O&M expenditure index for IWT infrastructure in the period 1995-2016

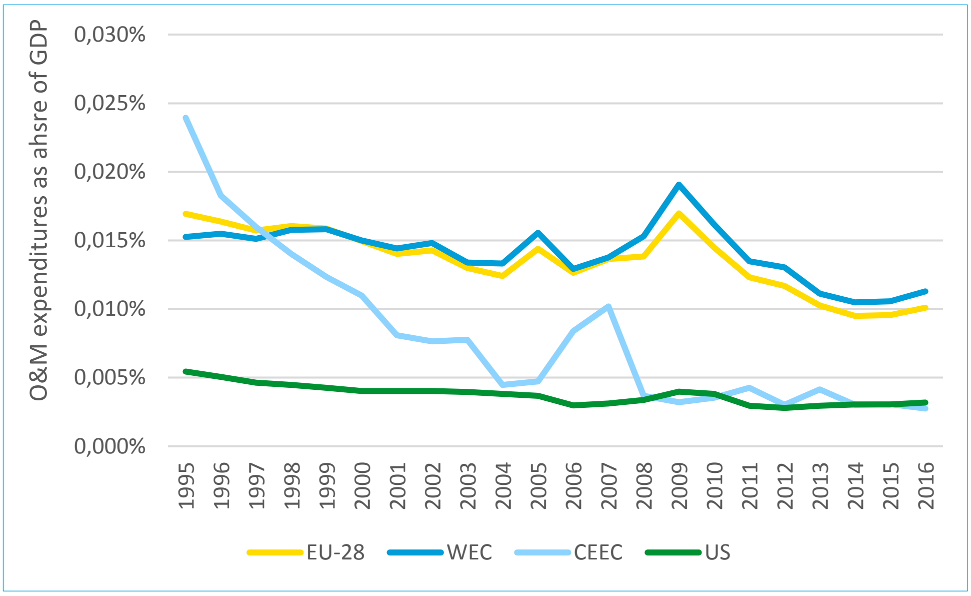


Until the economic crisis in 2010 the O&M expenditures of the WEC were at least as high as they had been in 1995. After the crisis the expenditures declined and started to rise again in 2014. In the CEEC the expenditures declined sharply between 1995 and 2004, to about 20% of the 1995 level. In the period 2004-2010 O&M expenditures increased slightly (to about 40% of the 1995 level), but fall again after 2011. The decline in the O&M expenditures in the end of the 1990s could be caused by the war in the former Yugoslavian republic. Because shortly after the war the Danube was not really useable, the Danube states might not have cared much about the waterway infrastructure. Finally, in Missouri (US) the O&M expenditures never reached the number of 1995 again though they had been relatively stable (between 60 and 80% of 1995 expenditure levels) since 2001.

Inland waterway O&M expenditures as share of GDP

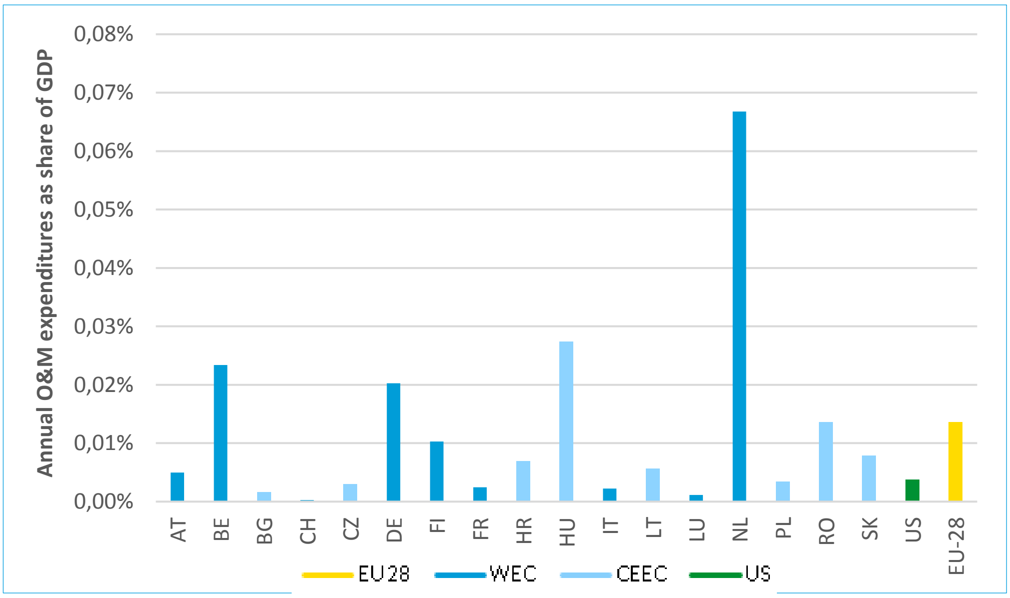
The share of O&M expenditures in GDPs shows similar trends as the O&M expenditures index for inland waterway infrastructure. This is shown in Figure 36. Both in the WEC and CEEC, the shares of the O&M expenditures in GDPs are going down since 1995 (only exceptions are the two peaks of O&M expenditures in the WEC in 2005 and 2009). The stronger decline in the CEEC is partly caused by the exchange rate development as well.

Figure 36 - Development in share of IWT infrastructure O&M expenditures in GDP over time



The average shares of the national O&M expenditures in GDPs show that the important inland navigation countries (i.e. Netherlands, Germany, Belgium) spend the highest share of their GDP for the O&M of the inland waterways (see Figure 37). The relatively high share of the GDP used for O&M expenditures in Hungary is caused by a relatively large inland waterway network and relatively low GDP. This relation also explains the difference between Germany and the Netherlands. The inland waterway network in the Netherland is 18% smaller than the German one, but the (PPP-adjusted) GDP is 79% lower. This relation also (partly) explains the differences between Germany, Belgium, France and the Netherlands.

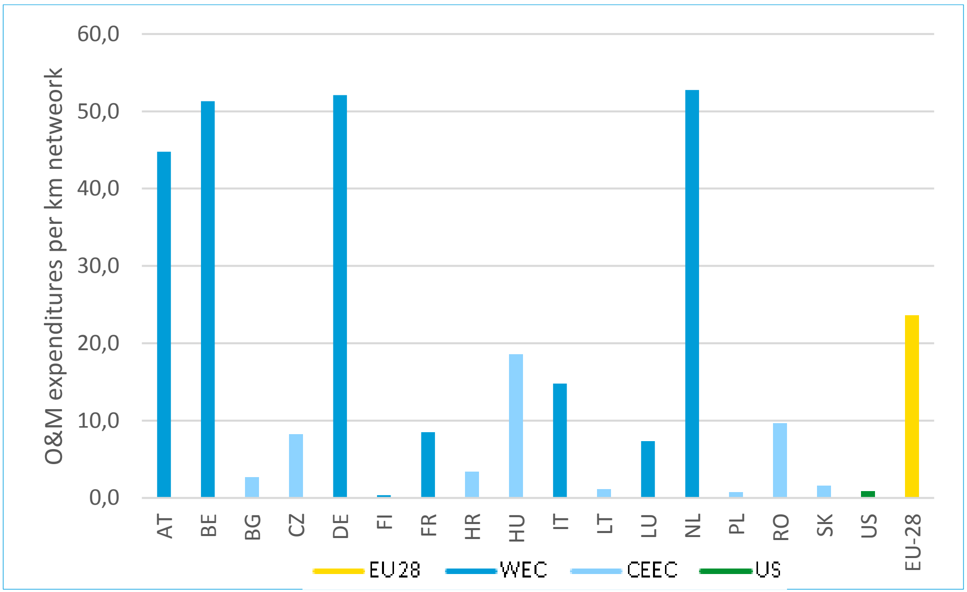
Figure 37 - IWT infrastructure O&M expenditures as share of GDP (average share for 1995-2016)



O&M expenditures per kilometre inland navigation network

The O&M expenditures per kilometre inland navigation network in the various countries is presented in Figure 38. As expected the O&M expenditures in Western European countries with relatively high utilisation rates of the inland waterways (e.g. the Netherlands, Germany, Belgium, Austria) are relatively high. As seen before, the level of O&M in CEEC is lower than in WEC, resulting in relatively low O&M expenditures per kilometre network (even in countries with relatively high utilisation rates, like Bulgaria and Romania).

Figure 38 - Average annual IWT O&M expenditures per kilometre IWT network length in the period 1995-2016 (in 1,000 € per km, PPS adjusted)



Note: Switzerland is missing, because of the extremely short IWT network length.

5.5 IWT infrastructure costs

The infrastructure costs of IWT are estimated based on the approach discussed in Section 2.4 and 5.3. The expenditure data as discussed in the previous section has been used as input for this estimation. As explained in Section 5.3, two corrections have been applied on these data before using them for the infrastructure cost estimations: some part of the expenditures have been allocated to recreation/ passenger vessels and some part to seagoing vessels. The remaining expenditures were used to calculate the infrastructure costs for freight IWT vessels.

5.5.1 Total infrastructure costs

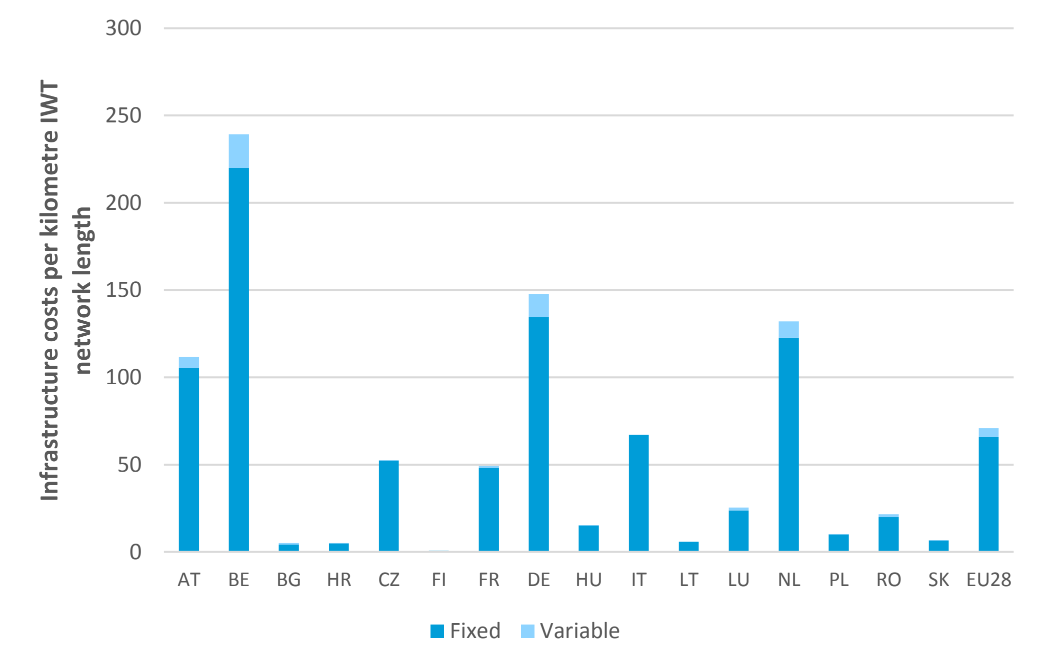
The total IWT infrastructure costs in 2016 are presented in Table 21. In 2016, these costs were equal to about € 2.8 billion in the EU28. The main share of these costs (88%) is fixed and the remaining part can be considered variable. The total infrastructure costs shown refer to the costs that can be allocated to the inland waterway freight traffic (i.e. the infrastructure costs that can be allocated to passenger IWT or seagoing vessels are not included).

Table 21 - Total IWT infrastructure costs in 2016 (million €, PPS adjusted)

Member State	Investments costs	O&M costs	Total infrastructure costs		
			Fixed	Variable	Total
EU28	2,079.7	783.8	2,663.0	200.5	2,863.5
Austria	30.8	8.4	37.0	2.2	39.2
Belgium	267.9	94.9	333.6	29.2	362.8
Bulgaria	0.8	1.6	1.9	0.5	2.4
Croatia	4.4	0.7	5.0	0.1	5.1
Czech Republic	30.2	7.4	37.6	0.02	37.6
Finland	4.4	1.6	6.0	0.001	6.0
France	186.2	51,2	231.9	5.5	237.4
Germany	766.7	367.1	1033.3	100.5	1,133.8
Hungary	24.6	3.9	28.2	0.3	28.5
Italy	89.1	15.6	104.6	0.04	104.6
Lithuania	2.1	0.5	2.6	0.0	2.6
Luxembourg	0.9	0.1	0.9	0.1	1.0
Netherlands	608.1	218.5	767.4	59.1	826.5
Poland	33.9	2.5	36.4	0.004	36.4
Romania	28.6	9.8	35.4	3.1	38.5
Slovakia	1.1	0.1	1.1	0.1	1.2
Switzerland	1.3	1.1	2.0	0.3	2.3
US - Missouri	9.5	1.1	10.2	0.4	10.6

The infrastructure cost per kilometre inland waterway network is given in Figure 39.

Figure 39 - Infrastructure costs per kilometre IWT network length (in 1,000 € per km, PPS adjusted)



The infrastructure costs per kilometre inland waterway are higher in Belgium than in Germany and the Netherlands. Compared to Germany (26%) this can be explained by a higher share of canals in Belgium (58%). Compared to the Netherlands (77%) this cannot be the explanation, as the costs per kilometre waterway in the Netherlands is even lower than in Germany despite the (much) higher share of canals. However, in the Netherland part of the inland waterway infrastructure is heavily used by seagoing vessels, such that a significant part (20%) of the renewal and O&M costs are allocated to maritime transport instead to IWT. In Belgium and Germany, on the other hand, only 1% of these costs are allocated to maritime transport. As a result the infrastructure costs per kilometre waterway that is allocated to IWT is lower in The Netherlands than in Belgium and Germany. Finally, this point and the importance of the Danube for Austria explain why the costs per kilometre waterway are relatively high in Austria.

5.5.2 Average infrastructure costs relative to transport performance

The average infrastructure costs are presented as cost per 1,000 tonne-kilometre in Figure 40. Because three countries have very high costs per vessel kilometre they are shown separately in Figure 41. The Czech Republic, Italy and Poland have a very low utilisation of their inland waterways. Hence the average costs are extremely high in these countries. For the same reason, but to a lesser extent, the average costs for Finland are relatively high. For the main Western European IWT countries, the average infrastructure cost are quite comparable, ranging from € 17 to € 35 per 1,000 tonne-kilometre. For the EU28, the average infrastructure costs of IWT equals € 19 per 1,000 tonne-kilometres.

Figure 40 - Average Infrastructure costs - Part 1 (€/1,000 tkm, PPS adjusted)

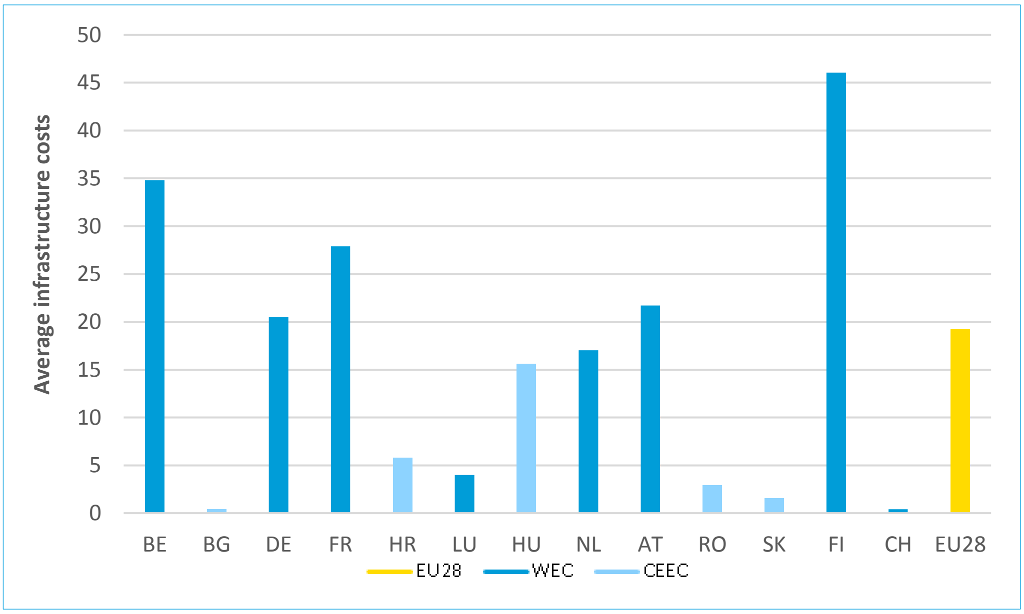
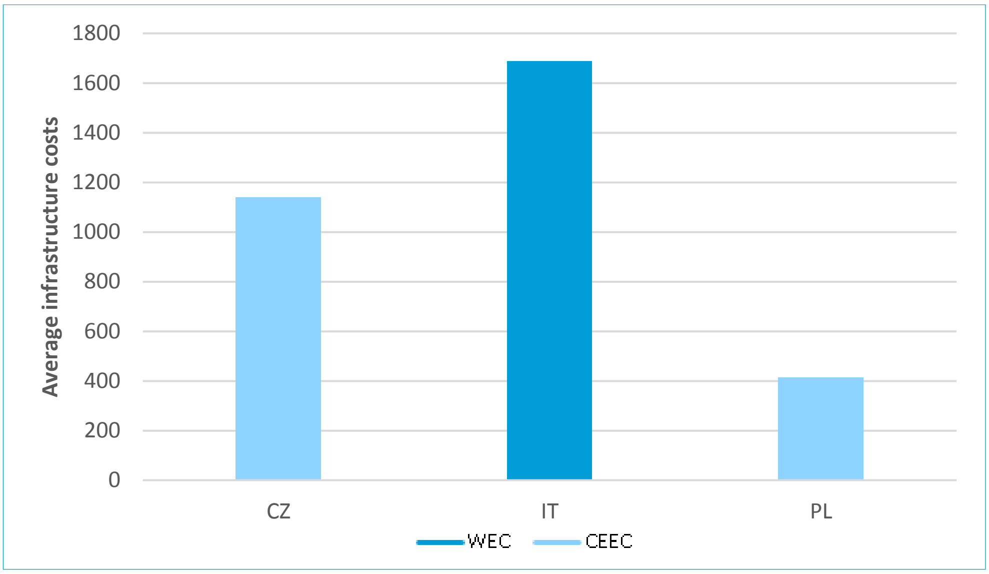


Figure 41 - Average Infrastructure costs - Part 2 (€/1,000 tkm, PPS adjusted)

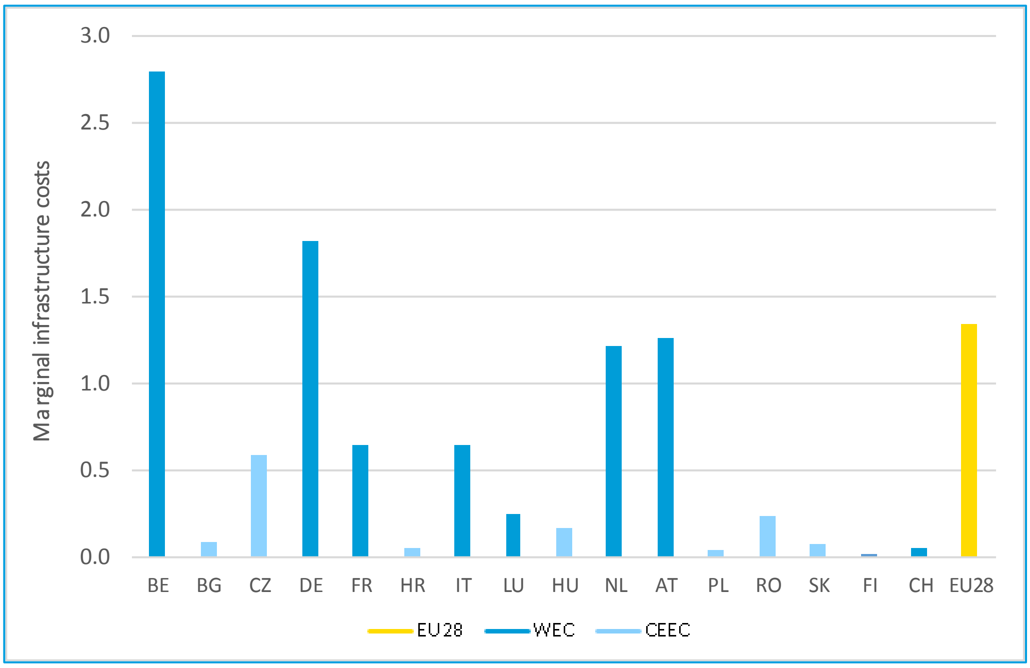


5.5.3 Marginal infrastructure costs

The marginal infrastructure costs are estimated as the variable part of the average costs.
As mentioned above the share of the variable costs are estimated with the help of the utilisation of the inland waterway network in the countries. Hence the figures show a different picture for the countries compared to the average costs.

The marginal costs are calculated per 1,000 tkm. Figure 42 shows the marginal costs for an average vessel in the countries. The countries with high marginal costs per tonne-kilometre are the countries with a high utilisation rate of the infrastructure (i.e. Belgium, Germany, The Netherlands).
As mentioned before the infrastructure costs in Belgium are relatively high compared to Germany and the Netherlands. The high share of canals and the low share of seagoing traffic explain this.
The average marginal infrastructure costs for the EU28 are well in line with the marginal costs in the large IWT countries and equals € 1.3 per 1,000 tonne-kilometre.

Figure 42 - Marginal Infrastructure costs (€/1,000 tkm, PPP adjusted)



6 Maritime transport

6.1 Introduction

In this chapter we discuss the infrastructure costs for maritime ports. In Section 6.2, we first present the definition of maritime port infrastructure used in this study. Specific methodological issues relevant for estimating infrastructure costs for maritime ports are discussed in Section 6.3. Finally, the results on maritime port infrastructure costs are provided and discussed in Section 6.4.

6.2 Defining maritime port infrastructure

Maritime ports are defined as the area of land and water made up of such infrastructure and equipment so as to permit, principally, the reception of seagoing vessels, their loading and unloading and the embarkation and disembarkation of passengers, crew and other persons and any other infrastructure necessary for transport operators within the port area. This definition is based on EC Regulation no. 2017/352, and is in line with ITF (2013b). In order to harmonise the definitions for infrastructure between the various transport modes, it was decided that any areas that are rented out commercially (e.g. warehouses for the storage of goods) are excluded, similar to the exclusion of commercial areas for rail infrastructure (see Section 4.2). Finally, the organisation of maritime transport in the port should theoretically be considered as part of the port infrastructure as well. However, as will be explained in Section 6.4 in more detail, we were not able to find data on expenditures on operational services like piloting and tugboats (mainly because these are privatized services executed by agencies other than the ports).

The various maritime port infrastructure items that are covered by the definition of port infrastructure are shown in Table 22. As mentioned in the previous chapters as well, the definition and related infrastructure items should be seen as a working definition. The infrastructure expenditures collected for the various ports do not always fully cover all the items listed in this table.
See Section 2.2 and 2.5 for more details.

Table 22 - Overview of maritime port infrastructure items

Main categories	Sub-items
Terminal related infrastructure	Berths/quays/docks Jetties Stacking yards Land reclamation Dolphins, mooring buoys
Access infrastructure	Access channels (including disposal of dredging material) Navigation aids (installations for buoying, signalling, safety, telecommunications, Lighting and traffic control, piloting) Turning basins Breakwaters Roads in the ports but outside terminal areas Rails in the ports but outside terminal areas Inland waterways in the ports
Buildings used by the infrastructure department	Buildings used by port authorities
Organisation of maritime port	Traffic management, piloting, tugboats

6.3 Specific methodological issues to estimate maritime transport infrastructure costs

The methodology to estimate the infrastructure costs of maritime ports is discussed in Section 2.4. As mentioned in Section 2.4.3, an alternative approach (compared to road, rail and IWT transport) is used to estimate the investment costs. Due to a lack of time series data on annual investments, the investment cost estimates are based on the depreciation costs that are partly provided by some of the maritime ports themselves (e.g. in their annual reports), instead of applying the PIM approach.

In addition to the general methodology to estimate the infrastructure costs, some issues specifically relevant for maritime transport have been elaborated in more detail. These are:
- estimation of missing data on total investments and/or O&M costs;
- breakdown to fixed and variable maritime port infrastructure costs;
- allocation of infrastructure costs to freight and passenger vessels;
- allocation of infrastructure costs of maritime ports to IWT.

In the remainder of this section we will discuss these issues in more detail.

Estimation of missing data on total investments and/or O&M costs

As mentioned above, data on total investments and/or O&M costs is missing for a significant number of the maritime ports considered in this study. More specifically, we were able to collect data on investments and O&M costs for fourteen ports only, while for five additional ports we found these data partly (see Annex A.5 for more details). As was discussed in Section 2.4.3, investment costs were estimated based on expenditures in 2016 only (direct expenditures method)[44].
Despite the theoretical weaknesses to estimate infrastructure costs based on investment data for one year only (see Section 2.4), we have used these data because more appropriate data was not available.

For twenty ports no data was publicly available or provided by the ports at all[45]. Therefore, we have made some estimations to provide rough figures on investments and O&M costs for these ports as well. To estimate the missing data on total investments and/or O&M costs, all 40 ports were first clustered in large, medium and small ports based on handled volumes. Within these clustered groups we identified ports for which both types of data were available, i.e. figures on investments and on O&M costs. Based on these figures the average investments and O&M costs were calculated, i.e.:
- per handled ton (€/1.000 ton); and
- per port call (€/call).

For ports for which the investments and/or O&M costs were not available, cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available. This leads to values for both investments and O&M costs calculated by port calls and handled volumes. The final values for investments and O&M costs for ports with missing data were finally estimated by using the average from values for port calls and for port volumes.

It should be noted that this approach to estimate missing data on total investments and/or O&M costs only provide rough estimates of the actual port infrastructure costs. These figures should therefore be considered carefully. The same is true for the splits and differentiations calculated, based on these already estimated figures.

[44] For some ports (i.e. Constanta, Helsinki and Travemünde), investment data for some more years were available. For these ports, average annual investments were used to estimate the 2016 investment costs.

[45] We have contacted all maritime ports considered in this study directly, but only part of them were willing to share data on investments and O&M costs.

Breakdown to fixed and variable maritime port infrastructure costs

The total maritime port infrastructure costs have been broken down in fixed and variable costs. This information is not available from the data that has been collected from the ports and therefore we have estimated default values on the share of the fixed and variable part of the infrastructure costs (see Table 23). Base for the estimation of the default values were the shares found for/provided by the mentioned Dutch and Belgian ports.

Table 23 - Share of variable costs in total maritime port infrastructure costs, differentiated to various cost categories

Port/Study	Enhancement	Renewal	Maintenance	Operational	O&M total
Rotterdam - CE Delft and VU (2014)	0%	0%	10%	0%	5%
Flemish ports - TML (2017)	0%	0%	15%	15%	15%
Recommended default values	0%	0%	10%	10%	10%

The recommended and used approach is to calculate 10% of the operation and maintenance cost as variable cost.

Allocation of infrastructure costs to freight and passenger vessels

Some of the maritime ports considered in this study are used by both freight and passenger vessels. For these ports, the total infrastructure costs should ideally be allocated to both types of vessels. The figures provided (if any) on port infrastructure cost do not allow to make this allocation of cost to freight and passenger handling. Therefore, the cost were split between the loading categories (freight and passenger) according to the number of port calls of the relevant vessel types[46].

This allocation approach implicitly assumes that the port infrastructure costs of freight and passenger vessels per port call are equal. There are some indications, however, that investments on freight transport are on average higher than for passenger transport (e.g. investments for a container berth are higher than for a passenger berth). Hence, the approach used may result in an overestimation of the infrastructure costs for passenger transport, while the costs for freight transport are underestimated. However, as no data is available on the cost differences between passenger and freight port infrastructure, we were not able to correct for these issues.

Allocation of infrastructure costs of maritime ports to IWT

As mentioned in Section 5.3, maritime port infrastructure is sometimes used by inland vessels as well (e.g. in Rotterdam and Antwerp). Therefore, part of the maritime port infrastructure costs should (preferably) be allocated to IWT instead of to maritime transport.

As the data from the ports is not available with the necessary level of differentiation (infrastructure cost by vessel type) again an estimation have been applied. Taking the number of calls of inland water vessels in relation to the total calls of vessels in a port would be even more problematic than using this approach for the split between freight and passenger vessels. The inland water vessels are much smaller and the required infrastructure is much less expensive compared to deep-sea vessels, so that this would lead to a severe over-estimation of related infrastructure cost. E.g., in Rotterdam the number of reported calls of IWT vessels is more the three times higher than deep-sea vessels and as a consequence of such approach three quarters of all infrastructure cost would be allocated to IWT. Therefor it is decided to use a different method, which uses ratios from a single port (Rotterdam) where indications on the share of

[46] Freight transported by RoPax ferries was allocated to freight transport in this assessment.

IWT in investment and maintenance and also the share of IWT vessels in the total number of calls is available. This allows calculating a ratio that says, that for each 1% share in port calls of IWT, the share in investments is 0.13% and in O&M costs is 0.67%.
For example, if IWT vessels contribute 5% to total port calls, it is estimated that 0.65% (5 x 0.13%) of the investments and 3.35% (5 x 0.67%) of the O&M costs could be allocated to IWT. The reader has to bear in mind that the results may only give a very rough indication, especially as already the base value for the application of these ratio had to be estimated in many cases (see above).

6.4 Maritime transport infrastructure costs

6.4.1 Total infrastructure costs

Within the scope of this study the infrastructure cost of 40 seaports were (in parts roughly) estimated. Despite all efforts spend on gathering respective reliable information from the ports, the data received was limited to only a few ports and with different definitions and aggregations. Most ports consider the information on infrastructure cost confidential. Hence, the feedback on figures for port infrastructure expenditures has been weak. The consortium has had no influence on the provision of these figures by port authorities. Therefore, to get figures for the missing ports, we have followed the approach described above by using port calls and port volumes — clustered by small, medium and large ports. The resulting cost estimates are presented in Table 24. The split of O&M cost into a fixed and variable part was calculated based on the information give in Table 23.

Table 24 - Total maritime transport infrastructure costs in 2016 (million €$_{2016}$, PPS adjusted)

Port	Total port infrastructure costs	Investments	Operation and Maintenance costs		
			Total	Of which fixed	Of which variable
Antwerp (BE)	82.7	74.9	7.8	6.7	1.2
Varna * (BG)	2.0	1.3	0.7	0.6	0.1
Limassol * (CY)	2.8	2.0	0.8	0.8	0.1
Hamburg * (DE)	296.6	240.3	56.3	50.7	5.6
Bremerhaven *(DE)	2.3	0.6	1.6	1.5	0.2
Travemünde (DE)	10.4	7.3	3.2	2.8	0.3
Aarhus * (DK)	20.2	14.4	5.8	5.2	0.6
Helsingør * (DK)	49.0	34.6	14.4	13.0	1.4
Tallinn (EE)	11.3	8.5	2.8	2.5	0.3
Algeciras * (ES)	33.2	21.7	11.6	10.4	1.2
Valencia * (ES)	31.8	20.2	11.6	10.4	1.2
Barcelona (ES)	74.6	16.8	57.8	52.0	5.8
Bilbao * (ES)	23.6	14.1	9.4	8.5	0.9
Helsinki (FI)	25.5	16.6	8.9	8.0	0.9
Marseille (FR)	52.9	33.6	19.2	17.3	1.9
Le Havre * (FR)	42.2	29.8	12.4	11.2	1.2
Calais * (FR)	42.2	29.8	12.4	11.2	1.2
Pireaus * (GR)	61.2	36.6	24.6	22.1	2.5
Rijeka (HR)	10.0	5.8	4.2	3.8	0.4
Split (HR)	7.6	6.7	0.8	0.7	0.1
Dublin * (IR)	43.9	29.9	14.0	12.6	1.4
Trieste (IT)	21.6	13.2	8.5	7.6	0.8
Genova (IT)	14.2	7.2	7.0	6.3	0.7
Venice (IT)	49.1	45.3	3.8	3.4	0.4

Port	Total port infrastructure costs	Investments	Operation and Maintenance costs		
			Total	Of which fixed	Of which variable
Klaipeda * (LT)	20.8	14.3	6.5	5.9	0.7
Riga * (LV)	18.1	12.3	5.8	5.2	0.6
Marsaxxlokk * (MT)	21.1	14.1	7.0	6.3	0.7
Rotterdam (NL)	210.4	158.0	52.4	49.7	2.6
Oslo * (NO)	11.0	7.9	3.2	2.8	0.3
Gdansk * (PL)	13.8	9.4	4.4	3.9	0.4
Sines (PT)	9.3	0.5	8.8	7.9	0.9
Constanta (RO)	26.5	25.2	1.3	1.2	0.1
Gothenburg * (SE)	62.4	42.2	20.3	18.2	2.0
Koper * (SK)	13.2	9.2	3.9	3.6	0.4
Felixstowe * (UK)	29.0	20.4	8.6	7.7	0.9
Vancouver * (CA)	47.7	45.1	2.6	2.3	0.3
Montreal * (CA)	25.5	17.4	8.1	7.3	0.8
Los Angeles (US)	65.8	55.6	10.2	9.2	1.0
Savannah * (US)	28.2	19.6	8.6	7.7	0.9
Tokyo * (JP)	108.8	69.1	39.7	35.7	4.0

Note: Ports for which no infrastructure costs or the necessary differentiations were available and hence for which the figures are only rough estimations are marked with*.

As described (knowing and highlighting the deficiencies) the total sum of infrastructure cost per port has been split to freight and passenger transport using the port calls of these main vessel types (see Table 25).

Table 25 - Total maritime transport infrastructure costs in 2016 per transport type (million €$_{2016}$, PPS adjusted)

Port	Freight transport	RoPax ferries/cruise vessels
Antwerp (BE)	83	-
Varna * (BG)	2	-
Limassol * (CY)	3	-
Hamburg * (DE)	289	8
Bremerhaven *(DE)	2	0
Travemünde (DE)	-	10
Aarhus * (DK)	4	16
Helsingør * (DK)	-	49
Tallinn (EE)	2	9
Algeciras * (ES)	12	21
Valencia * (ES)	25	7
Barcelona (ES)	41	33
Bilbao * (ES)	21	2
Helsinki (FI)	3	22
Marseille (FR)	30	23
Le Havre * (FR)	41	1
Calais * (FR)	-	42
Pireaus * (GR)	5	57
Rijeka (HR)	4	6
Split (HR)	3	5
Dublin * (IR)	11	33

Port	Freight transport	RoPax ferries/cruise vessels
Trieste (IT)	11	11
Genova (IT)	9	5
Venice (IT)	37	12
Klaipeda * (LT)	16	5
Riga * (LV)	17	1
Marsaxxlokk * (MT)	21	-
Rotterdam (NL)	206	5
Oslo * (NO)	5	6
Gdansk * (PL)	13	1
Sines (PT)	9	-
Constanta (RO)	26	-
Gothenburg * (SE)	10	53
Koper * (SK)	13	-
Felixstowe * (UK)	29	-
Vancouver * (CA)	44	4
Montreal * (CA)	25	1
Los Angeles (US)	61	5
Savannah * (US)	28	-
Tokyo * (JP)	98	11

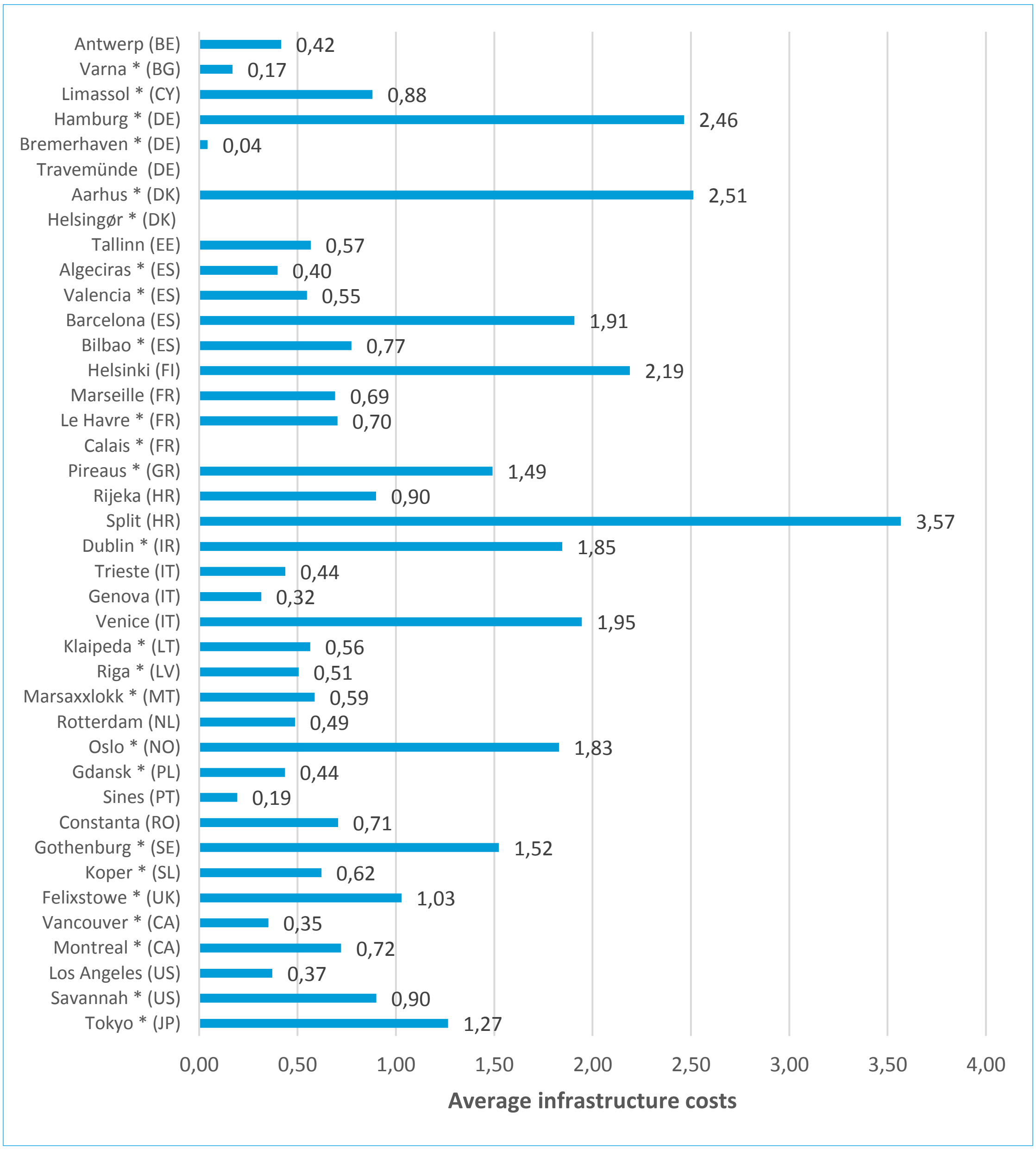
Note: Ports for which no infrastructure costs or the necessary differentiations were available and hence for which the figures are rough estimations are marked with*; freight vessels excl. RoPax.

6.4.2 Average infrastructure costs relative to transport performance

The estimated average infrastructure costs are calculated with the assumptions mentioned above as cost per freight ton (see Figure 43). As the figures on infrastructure cost were given by most ports (if any figures were sent) for the single year 2016 (depreciation cost were not reported or found at all) there may be a friction in the graph.

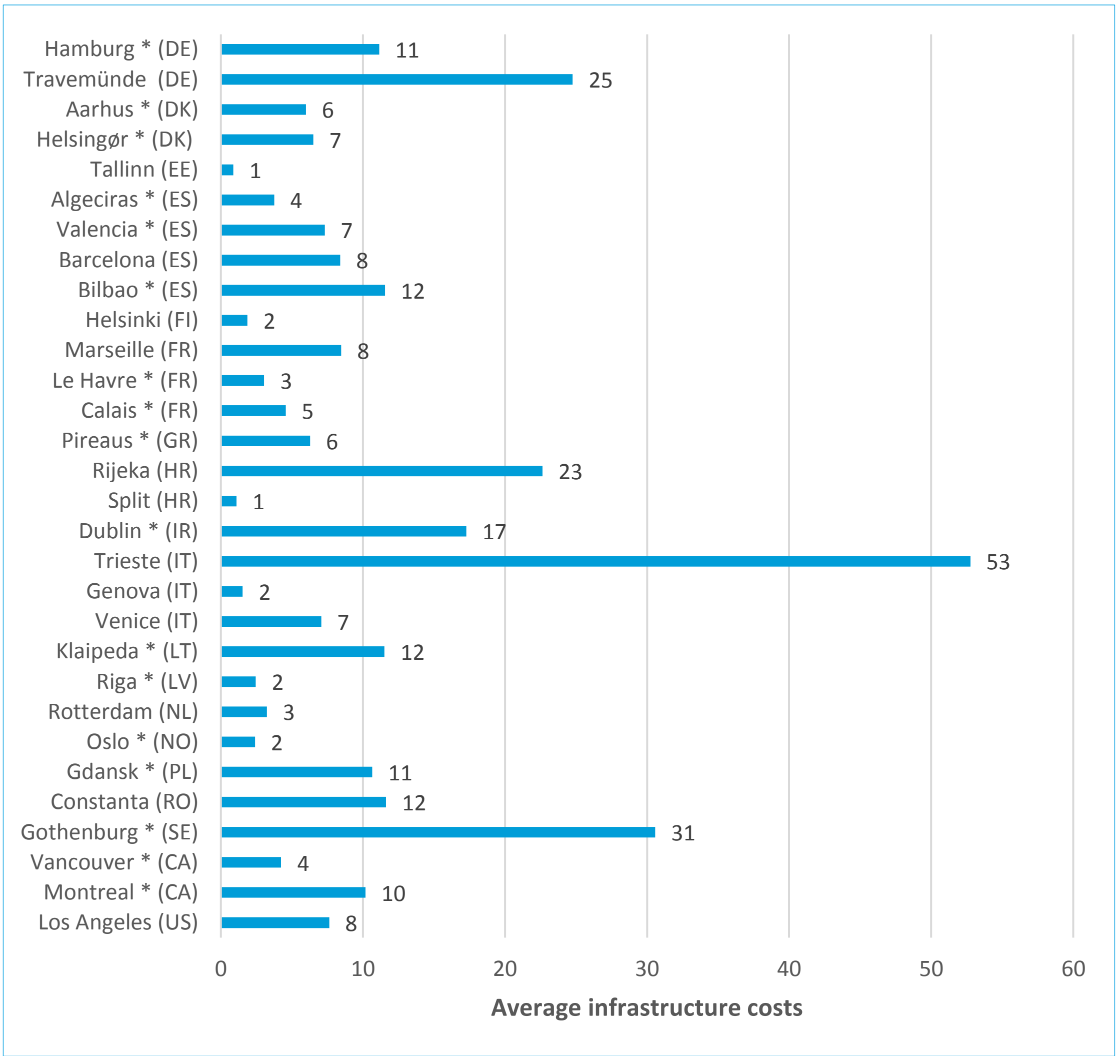
It would be possible to do the same calculation based on infrastructure cost and port calls, but this would lead to even more frictions and confusing results.

Figure 43 - Estimated average infrastructure cost in 2016 (€ per tonne, PPS adjusted)



The average infrastructure costs per passenger are shown in Figure 44. Again, the results found may be affected significantly by the fact that only expenditure data for 2016 was available for ports (if any data was available at all).

Figure 44 - Estimated average infrastructure cost per passenger embarked/disembarked in 2016 (€/passenger, PPS adjusted)

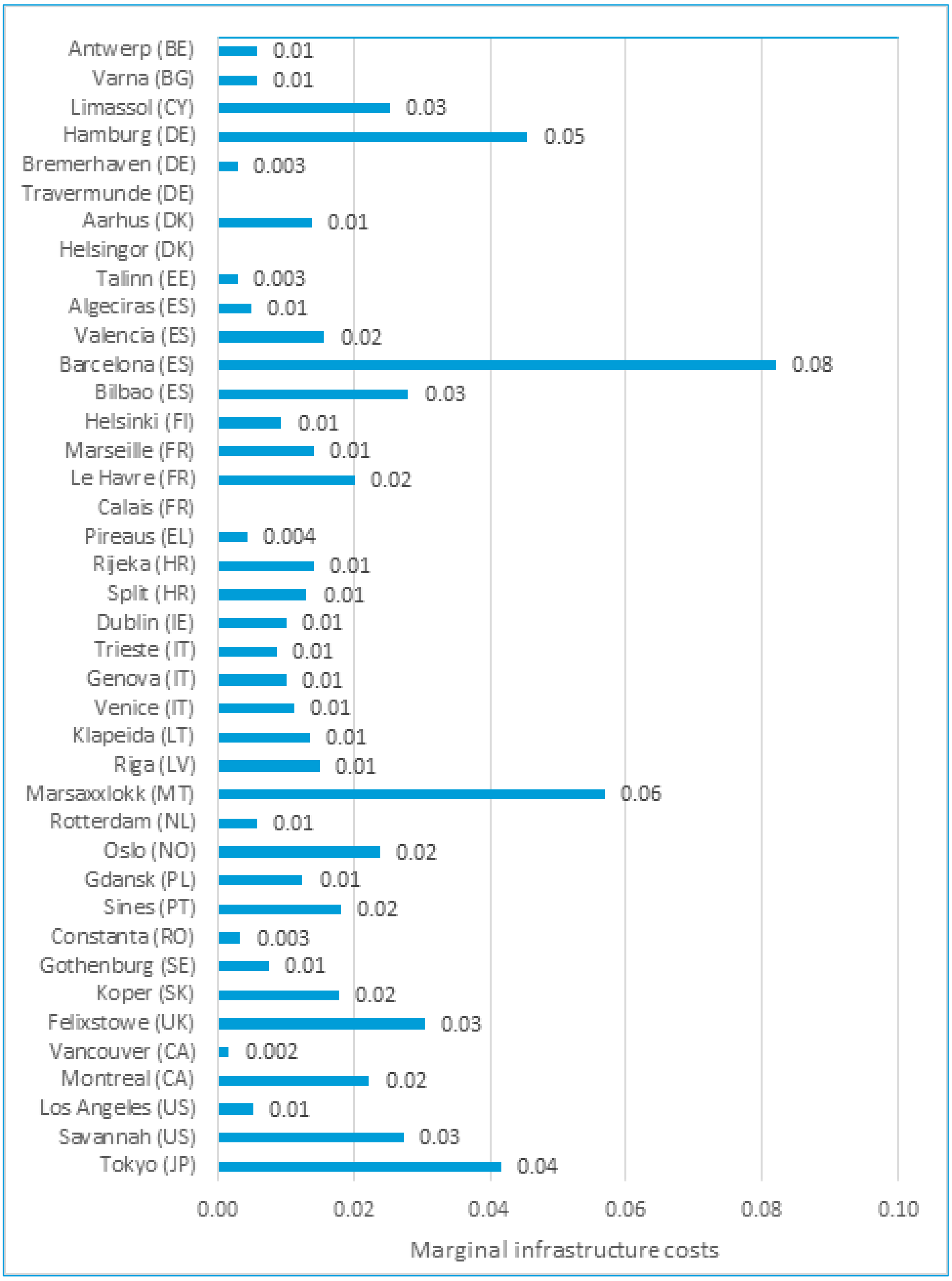


Note: Only ports relevant for passenger transport are presented. No data was available for Tokyo.

6.4.3 Marginal infrastructure costs

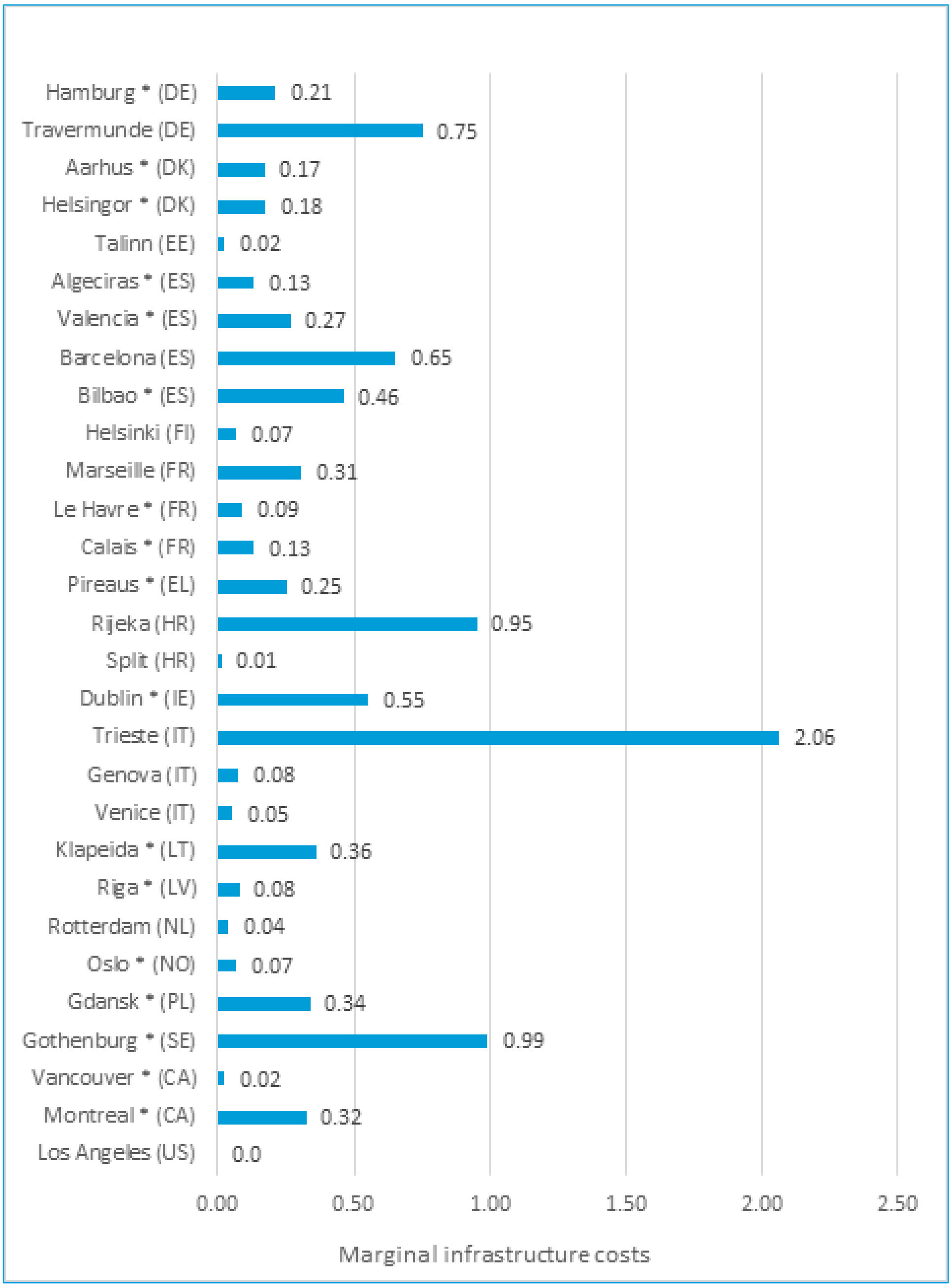
As mentioned above the shares of the variable/marginal costs are estimated with the help of the data from Rotterdam and the Flemish ports and the assumption that – based on this – the share of variable/marginal cost is about 10% of the operation and maintenance expenditures. If this is brought into relation with the number of tonnes handled per port in order to have an indication for the additional cost caused by an additional ton handled of an average freight vessel, Figure 45 results 2016.

Figure 45 - Estimated average marginal infrastructure cost in 2016 (€/tonne, PPS adjusted)



Finally, the marginal infrastructure costs for an average passenger vessel (in € per passenger) are shown in Figure 45.

Figure 46 - Estimated average marginal infrastructure cost in 2016 (€/tonne, PPS adjusted)



Note: Only ports relevant for passenger transport are presented. No data was available for Tokyo.

7 Aviation

7.1 Introduction

In this chapter we discuss the infrastructure costs of airports. In Section 7.2, we first define what is covered by airport infrastructure in this study. In Section 7.3 some aviation-specific methodological issues to estimate the infrastructure costs of airports are discussed in addition to the general methodology explained in Chapter 2. Finally, the results on airport infrastructure costs are presented in Section 7.4.

7.2 Defining airport infrastructure

In line with Directive 2009/12/EC, airport infrastructure is defined as "*any land area specifically adapted for the landing, taking-off and manoeuvring of aircraft, including the ancillary installations which these operations may involve for the requirements of aircraft traffic and services, including the installations needed to assist commercial air services".* Theoretically, we interpret the latter part of the definition "including the installations needed to assist commercial air services" as entailing check-in desks, waiting areas at the gates, and everything post customs excluding duty-free shops and other commercial areas. The waiting areas and check-in desks are seen as essential for the provision of commercial air services, whereas duty-free shops and other commercial areas are seen as convenient, yet not essential. In our definition, the latter – we name it "non-aviation" - are excluded for similar reasons as mentioned in the definition of maritime port infrastructure. The costs for these commercial areas are already internalised, as rent is being paid in exchange for the use of these areas. In Section 7.3 we explain, how we deal with this issue in practice.

The various airport infrastructure items that are covered by the definition presented above are shown in Table 26[47].

Table 26 - Overview of airport infrastructure items

Main categories	Sub-items
Land	The area of land occupied by the airport[48].
Runways	Runways for landing and take-off, taxiways, airport aprons, manoeuvring areas.
Airport terminal	Passenger and goods terminals, jet bridges, airport busses, automated people movers for between-terminal transfers, check-in desks, customs offices, waiting areas, gates.
Safety, signalling, telecommunications and traffic control	Installations for signalling, safety, telecommunications, lighting and traffic control.
Buildings used by the infrastructure department	Airport operation centre, ground handling facilities, etc.

[47] Notice that this a working definition and that the infrastructure expenditures collected for the various airports are not always fully consistent with this definition. See Section 2.2 and 2.5 for more details.

[48] In most cases, the cost for land is included in the cost for the airport operator. Nevertheless, in some cases the land is owned by the government and the airport can use it for free or at a reduced price. In this study, we assume that all cost for land are included in the airport operators cost.

In most cases, the cost for land is included in the cost for the airport operator. Nevertheless, in some cases the land is owned by the government and the airport can use it for free or at a reduced price. In this study, we assume that all cost for land are included in the airport operators cost.

7.3 Specific methodological issues to estimate airport infrastructure costs

As explained in Section 2.4.3, the airport infrastructure costs are mainly estimated on the basis of the financial statement in the annual reports of the airport operators. Considered are the 'operational costs' according to the definition of the financial statement, which includes all costs of running an airport[49]. Notice that these operational costs are much broader than the operational costs defined in this report[50]. In the following figures, financial cost are included as well, but they are not taken from the annual reports but estimated in the same way as for the other transport modes. In this way we assure that the financing costs are not affected by the owner structure (public versus private entities), as airports are — in contrast to the infrastructure of most other transport modes — mostly operated by private companies.

The data collected from annual reports have been processed in several ways in order to estimate the airport infrastructure costs. The main issues in this respect are:
- the separation of aviation and non-aviation costs;
- the separation of passenger and cargo costs;
- the breakdown to variable and fixed infrastructure costs;
- air traffic control costs.

In the remainder of this section we will discuss these issues in more detail.

Separation of aviation and non-aviation cost

The financial statement of airports does not distinguish between aviation and non-aviation costs, but only provide information about the total cost including non-aviation activities. However, the revenue from non-aviation activities is usually provided and can be used to estimate the size of the non-aviation costs, i.e. by making an assumption on the cost coverage ratio of non-aviation activities.
The main question is, what we assume about the cost coverage ratio of non-aviation activities.
The easiest assumption would be, that the cost is equal to the earnings. But based on confidential information owned by the project team and the rare public information (ARE, 2004; BSF, 2014), we know this would overestimate the cost. Based on our knowledge we assume that the cost of the non-aviation business is equal to halve of the non-aviation earnings.

Separation of passenger and cargo cost

One characteristic of aviation is the close relationship of passenger and freight transport: a large — often the main — part of air freight is transported as 'belly freight' in passenger planes. The marginal cost of freight transports is very low, since a large part of the cost of the flight are fixed costs. How to allocate the fixed cost to freight and passenger transport is a question of definition and always artificial. Therefore, it is understandable that gathering consistent freight cost data over the time or between different actors is very difficult (also due to confidentiality reasons). The only way to deal whit the issue is to use a key.

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[49] Including depreciation costs and O&M costs, but excluding financial costs, corporate taxes and profits.

[50] Actually, the operational costs as defined in this report are part of the operational cost as defined in the financial statement of airports.

The most common key is assuming that one passenger is equal to 100 kg freight (Doganis, 1992). But even if this key is broadly used in aviation, there are doubts about its validity (particularly with respect to estimating infrastructure costs). For example, Martin et al. (2008) showed with an econometrical approach, that it is likely that the airports cost for 100 kg freight is lower than that of one passenger. They argue, that the engagement of airports in passenger transport is wider than that in cargo transport. As an example, they mentioned, that cargo airlines operate cargo terminals often by themselves, whereas passenger terminals are operated by the airport operator. Since the focus of the study is not on the difference between cargo and passenger cost, unfortunately the study does not make a statement about the magnitude of the cost difference. Therefore, the common approach that one passenger is equal to 100 kg freight stays the best available approach and is applied in the following sections.

In the view of the project team the data quality of passenger transport is not affected substantially by applying this key, since at most airports the share of cargo is only between 1 and 10% of the total traffic volume (based on the approach that 1 passenger equals to 0.1 ton of cargo). Therefore, the cost key for the subtraction of cargo cost has only a minor impact on the passenger cost. In contrast to the costs allocated to passenger transport the validity of the costs allocated to cargo transport can be challenged, due to the arguments above. Generally speaking, due to the characteristics of aviation with a very high share of mixed transport (passengers and cargo in the same airplane), the differentiation in cargo and passenger transport does not properly reflect the nature of air transport.

The following section shows the estimated total cargo infrastructure cost according to the approach described above. It must be interpreted as a rough estimation. Due to the characteristics described above, the differentiation between investment and O&M cost as well as the average and marginal infrastructure cost per LTO are calculated for passenger transport only.

Breakdown to variable and fixed infrastructure costs

It is assumed that the share of variable cost in total infrastructure costs is one third. This assumption is based on the review of the financial statement of the selected airports and econometrical studies about the issues.

The review of financial statements of airports shows that they do not contain information about the share of transport-dependent (variable) and fixed cost. Nevertheless, they provide some hints. The financial statements contain more or less detailed information about the magnitude of different types of cost e.g. energy cost or marketing cost. Assuming for each cost category whether it is variable or fixed (e.g. energy cost is assumed variable, marketing cost is assumed fixed) leads to an indication of the magnitude of the share of variable and fixed cost. This assessment was made for ten airports. The share of variable cost was estimated to lie between 23 and 49% with a mean of 35%.

We have reviewed some literature that analyse the share of variable cost based on econometrical approaches. The range of the results differs between 11 (Link, et al., 2004) and 47% (Carlsson, 2003). The most recent known study is Mc Carthy (2014), which states that the variable share of costs is 34%. One reason for the wide range in the estimated share of variable costs between studies is the data availability: the elaboration of a big enough and consistent dataset is difficult (e.g. how is the non-aviation sector threated?). The other reason could lie in different structures of airports. According to the literature the share of variable cost:

- increase with the weight of international passengers compared to national passengers (Link, et al., 2004);
- increase with the weight of the share of full-service passengers compared to low cost passengers (Voltes-Dorta and Lei, 2013);
- decreases with the size of the airport (McCarthy, 2014).

Both the review of financial statements of airports as the review of the literature show that the mean share of variable cost in total infrastructure costs lies by about one third. The findings from the literature on the impact of the airport structure on the share of variable cost could not be confirmed by the analyses based on financial statements of airports. Therefore, we resign from composing different clusters of airports for which different shares of variable cost are assumed. There is no sufficient reliable database for such a clustering approach. This means as well, that the share of variable cost must be considered as an indication of the magnitude and not as exact numbers.

Air traffic control cost

Beside the airport operators also air traffic control agencies provide infrastructure services for air traffic. Air traffic control has two aspects:

- The control of the landing and taking of planes, called 'terminal navigation'. This aspect is directly linked to airports.
- The 'en route' control. If a plane flies from Rome to Munich it flies over Swiss territory and has to pay the Swiss air traffic control agency for the guidance over the Swiss territory. This service cannot be allocated to airports in a transparent way.

Since the en route service of a national air traffic control agency is not linked to the respective national airports, we focussed our efforts on the collection of the cost for the terminal navigation of the selected airports. However, the data availability in this field is very limited. On the one hand, there are countries which are not willing to give out any data due to political reasons (e.g. due to ongoing discussions about cost keys, etc.). On the other hand, there are technical limits. A large part of the cost of air traffic control is fixed and hence the allocation of costs to different airports is in fact difficult. Furthermore, it must be considered, that the air traffic control serves not only civil aviation but also military aviation. Also in the hypothetical case of a total absence of civil aviation a big part of air traffic control infrastructure would be needed for the military aviation. It can therefore be assumed, that the marginal cost of air traffic control for civil aviation is small, given that the services to military aviation must be provided. Another unsuccessful approach to collect data on air traffic control costs was to ask Eurocontrol for the data about the terminal navigation income for those airports for whom they collect terminal navigation fees. But due to confidentiality reasons they were not able to deliver these data.

Within the scope of this study it is therefore not possible to present a comprehensive picture of air traffic control cost for each selected airport. Nevertheless, in the next section we provide some tentative results on the magnitude of these costs, based on the results of the detailed assessment of a small number of airports.

7.4 Airport infrastructure costs

7.4.1 Total infrastructure costs

Within the scope of this study the cost of 34 airports were assessed[51]. For two airports (Tokyo Haneda (JP) and Larnaka (CY)), despite making a big effort to collect data, we did not manage to gain valid data. Therefore, no data are presented for these two airports.

Table 27 - Total airport infrastructure costs in 2016 (million €$_{2016}$, PPP adjusted)

Airport	Investments costs	O&M-costs	Total infrastructure costs		
			Fixed	Variable	Total
Vienna (AT)	218.7	335.6	371.4	182.9	554.3
Brussels (BE)	143.3	201.5	231.0	113.8	344.8
Sofia (BG)	1.7	77.9	53.3	26.3	79.6
Zagreb (HR)	0.9	55.2	37.6	18.5	56.1
Larnaka (CY)	N/A	N/A	N/A	N/A	N/A
Prague (CZ)	155.0	215.3	248.1	122.2	370.3
Copenhagen (DK)	88.6	128.9	145.7	71.8	217.5
Tallinn (EE)	22.4	29.0	34.4	17.0	51.4
Helsinki (FI)	67.0	152.9	147.4	72.6	220.0
Paris Charles de Gaulle (FR)	408.7	822.2	824.7	406.2	1,230.8
Paris Orly (FR)	154.1	310.0	311.0	153.2	464.1
Frankfurt (DE)	367.3	995.4	913.0	449.7	1,362.7
Munich (DE)	248.6	500.0	501.5	247.0	748.6
Athens (EL)	165.5	280.5	298.8	147.2	446.0
Budapest (HU)	132.7	118.8	168.5	83.0	251.5
Dublin (IE)	121.0	282.3	270.3	133.1	403.4
Roma (IT)	145.4	750.1	600.0	295.5	895.5
Riga (LV)	35.9	43.3	53.1	26.1	79.2
Vilnius (LT)	23.0	29.9	35.4	17.4	52.8
Luxembourg (LU)[a]	24.6	31.8	37.8	18.6	56.5
Luga (MT)	12.6	32.5	30.2	14.9	45.1
Amsterdam (NL)	292.5	543.7	560.2	275.9	836.2
Warsaw (PL)	57.4	88.9	98.0	48.3	146.3
Lisbon (PT)	147.0	212.8	241.1	118.7	359.8
Bucharest (RO)	103.1	178.0	188.4	92.8	281.1
Bratislava (SK)	29.9	25.9	37.4	18.4	55.8
Ljubljana (SI)	8.7	27.3	24.1	11.9	36.0
Barcelona (ES)	248.0	228.1	318.9	157.1	476.0
Madrid (ES)	299.3	275.3	385.0	189.6	574.6
Palma de Mallorca (ES)	157.7	145.0	202.8	99.9	302.7
Stockholm (SE)	58.0	129.8	125.8	62.0	187.8
London Heathrow (UK)	1,175.7	1,110.1	1,531.5	754.3	2,285.7
London Gatwick (UK)	247.6	335.9	390.9	192.6	583.5
Oslo (NO)	66.6	107.2	116.5	57.4	173.9
Zurich (CH)	158.9	163.9	216.3	106.5	322.8

[51] For Spain and Finland, only costs for the whole airport infrastructure of the country has been available, since in these countries one airport operator operates all airports The allocation to costs at the airport level has been done based on the number of flights.

Airport	Investments costs	O&M-costs	Total infrastructure costs		
			Fixed	Variable	Total
Toronto (CA)	170.2	222.7	263.2	129.6	392.8
Vancouver (CA)	106.8	99.6	138.2	68.1	206.3
Atlanta (US)	234.3	162.6	265.9	131.0	396.8
Los Angeles (US)	341.7	453.8	532.9	262.5	795.4
Tokyo Haneda (JP)	N/A	N/A	N/A	N/A	N/A

a Please be aware, that the airport of Luxemburg is mainly a freight airport. The assumption applied about non-aviation and fix and variable cost may not suit for this kind of airport and the data quality is therefore limited.

Assuming that the cost of one passenger equals the cost of 100 kg cargo, the total airport cost for passenger respectively cargo transport are estimated (see Table 28).

Table 28 - Total airport infrastructure costs in 2016 per transport type (million €$_{2016}$, PPP adjusted)

Airport	Passenger transport	Cargo transport[b]
Vienna (AT)	494.5	59.9
Brussels (BE)	281.1	63.7
Sofia (BG)	76.3	3.3
Zagreb (HR)	54.1	2.0
Larnaka (CY)	N/A	N/A
Prague (CZ)	349.5	20.8
Copenhagen (DK)	194.3	23.2
Tallinn (EE)	48.7	2.6
Helsinki (FI)	198.9	21.1
Paris Charles de Gaulle (FR)	949.6	281.3
Paris Orly (FR)	449.9	14.3
Frankfurt (DE)	1,011.2	351.6
Munich (DE)	748.5	0.1
Athens (EL)	427.1	18.9
Budapest (HU)	229.1	22.5
Dublin (IE)	384.8	18.6
Roma (IT)	863.5	32.1
Riga (LV)	76.0	3.2
Vilnius (LT)	51.6	1.2
Luxembourg (LU) [a]	15.2	41.3
Luga (MT)	43.7	1.4
Amsterdam (NL)	662.9	173.2
Warsaw (PL)	139.3	7.0
Lisbon (PT)	345.6	14.2
Bucharest (RO)	272.7	8.5
Bratislava (SK)	49.4	6.4
Ljubljana (SI)	31.6	4.4
Barcelona (ES)	464.0	12.0
Madrid (ES)	531.1	43.5
Palma de Mallorca	301.7	1.0
Stockholm (SE)	182.2	5.6
London Heathrow (UK)	1,899.0	386.7
London Gatwick (UK)	573.2	10.3
Oslo (NO)	165.1	8.8

Airport	Passenger transport	Cargo transport[b]
Zurich (CH)	279.1	43.7
Toronto (CA)	355.0	37.8
Vancouver (CA)	183.2	23.1
Atlanta (US)	374.3	22.6
Los Angeles (US)	621.8	173.7
Tokyo Haneda (JP)	N/A	N/A

a Please be aware, that the airport of Luxemburg is mainly a freight airport. The assumption applied about the allocation of cost to passenger and cargo transport may not suit for this kind of airport and the data quality is therefore limited.

b Please be aware that cargo cost data are calculated synthetically and data quality is limited.

As mentioned in Section 7.3, the total airport infrastructure costs as presented in Table 27 and Table 28 do not include the costs of air traffic control (i.e. cost of terminal navigation services), as due to lack of data these costs cannot be estimated in a consistent and reliable way for all airports. However, as is discussed in the following text box, these costs probably have a limited share in the total infrastructure costs of aviation. Roughly estimated these costs lie between 1 and 15% of the direct infrastructure costs of airports. As the costs of air traffic control are mainly fixed, the share in the variable (and hence marginal) infrastructure costs are considered to be even lower.

Air traffic control cost

As described in Section 7.3, the availability of reliable data on the cost of terminal navigation services is limited. In order to get an impression of the (relative) size of these costs, we have carried out some assessments for the airports for which some data on these costs are available. For 23 airports we estimated - on the basis of all available information - the cost for terminal navigation services or the income from the charges related to these services. The results on income were used as a proxy for the costs. Generally, the basis for the estimation of costs (or income) was the availed cost (or income) by the smallest number of airports including the airport of interest and assuming that the cost respectively income per LTO is the same at all airports. This is a very rough estimate and hence the reliability of the single data points is questionable. Particularly as it may be questioned to what extent the income from terminal navigation charges are a good proxy for the costs of these services, as in some countries public subsidies to finance air traffic control services are provided and hence charges are set lower than the costs. On the other hand, it is clear that using income of terminal navigation charges do not overestimate the costs, as the EU regulation on fees for air traffic control (Regulation 391/2013) (EU, 2013) do not allow terminal navigation charges above the cost for the terminal navigation at the respective airport.

Despite these weaknesses in the analysis applied, its results give an impression of the magnitude of the cost of terminal navigation services. We find that the cost for terminal navigation services lies between 1% and 15% of the cost for airport aviation infrastructure. The median value is 7%. Per LTO the cost lies between € 50 and € 460, with a median value of about € 210.

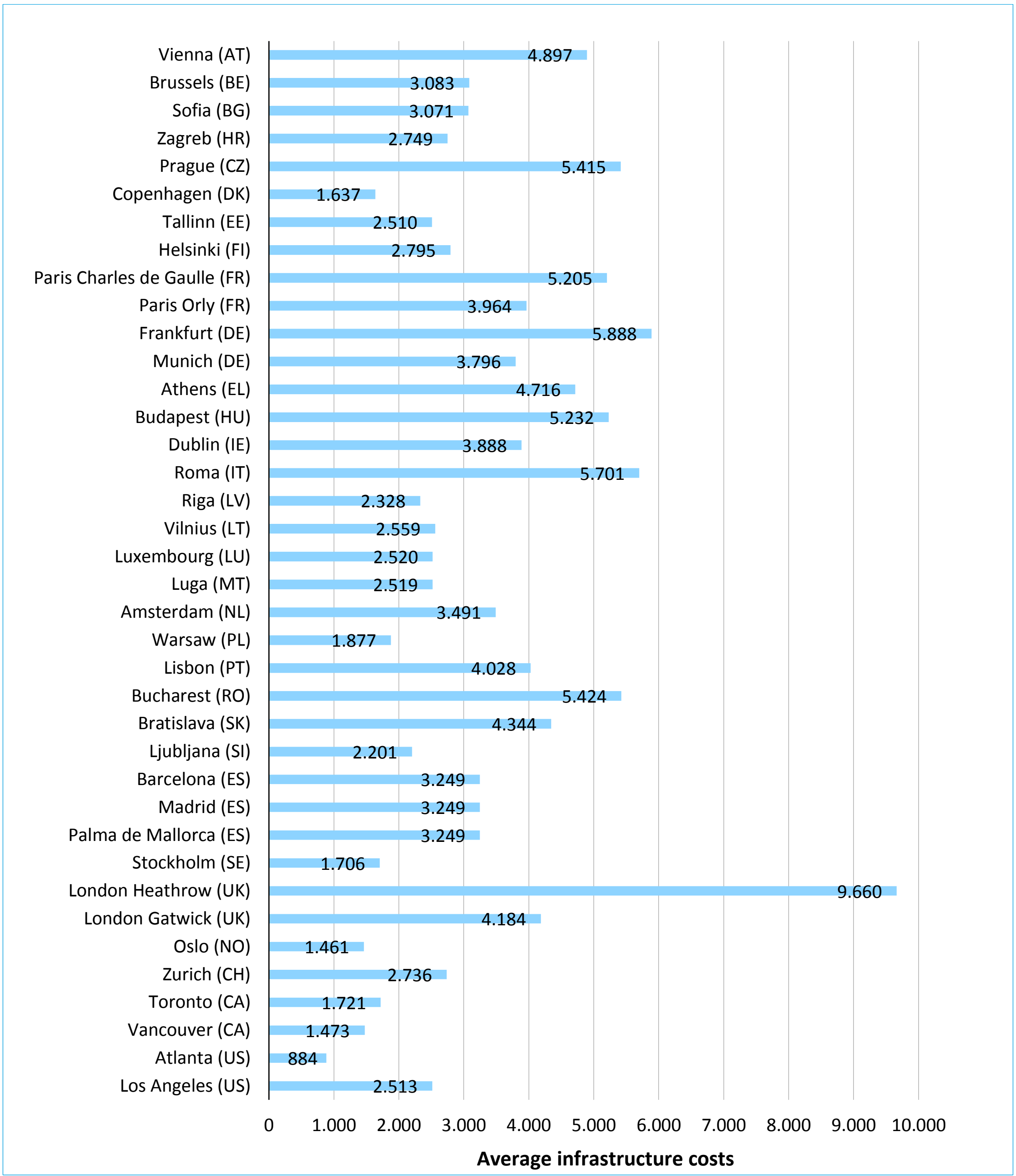
7.4.2 Average infrastructure costs relative to transport performance

The average airport infrastructure cost per LTO (measured in EUR 2016 and PPS adjusted) are presented in Figure 47. The highest cost per LTO is measured in London Heathrow, followed by Frankfurt and Rome. Also in the top five are Bucharest and Prague. The lowest cost level is found for Atlanta, followed by Oslo, Vancouver, Copenhagen and Stockholm. Two factors are key drivers for the cost levels (in €/LTO) found:

- The size of the average aircraft. The median airport transports 109 passengers per plane. In contrast, in London Heathrow we count 160 passengers per aircraft. At the lower bound we see small East-European airports, as Ljubljana or Tallinn, which count in average less than 60 passengers per aircraft. As number of passengers are an important driver of the infrastructure costs, it is evident, that airports with more passenger per plane have higher average cost per LTO than airports with less passenger per plane.

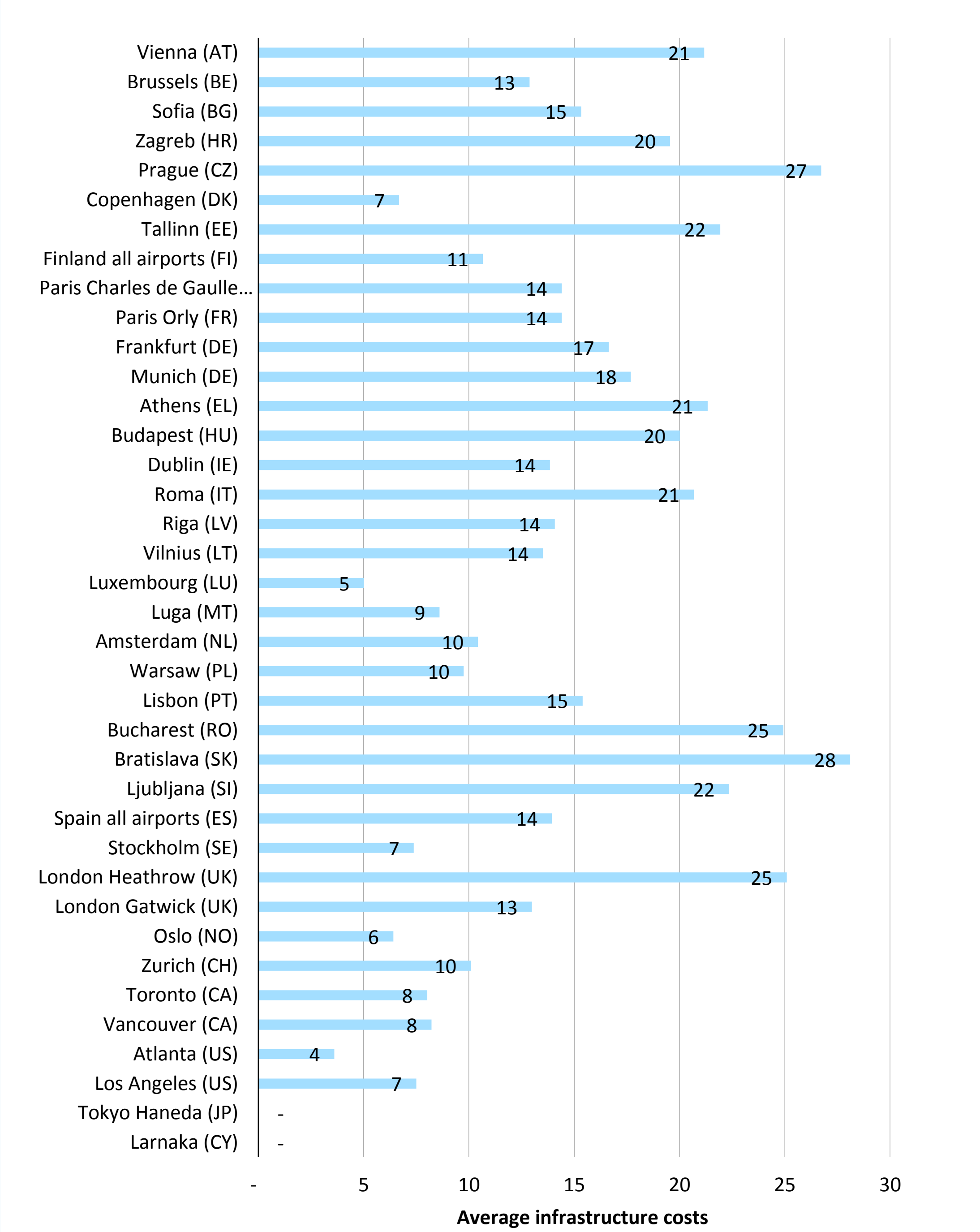
- The numbers are PPS adjusted. Due to the nature of the aviation business, intermediate goods for the production of air transport are often produced in an international setting. This means, that a substantial part of the cost of air transport is not connected to local prices. Furthermore, there is an international competition between hub airports. Hence, the price level of hubs is defined on an international level.

Figure 47 - Average PPS adjusted airport infrastructure costs per LTO in 2016 (€/LTO)



The impact of the number of passengers per aircraft on the average infrastructure costs per LTO can be illustrated by Figure 48, which shows the PPS adjusted cost per passenger. The highest cost is now measured at rather small airports like Bratislava, Prague, Bucharest, Ljubljana and Tallinn. This is a hint for economies of scale in the production of air transport infrastructure. London Heathrow still has relatively high average infrastructure costs, but it stays in the range of the top five. The lowest numbers are resulting for Atlanta, Oslo, Stockholm, Luxembourg, Copenhagen, and Los Angeles.

Figure 48 - Average PPS adjusted airport infrastructure costs per passenger in 2016 (€/passenger)



The ranking of the airports shifts again, if we do not adjust for PPS (in order to illustrate the impact of PPS adjustments on the average costs). This is illustrated in Figure 49.

Figure 49 - Average airport infrastructure costs per passenger in 2016 - not PPS adjusted (€/passenger)

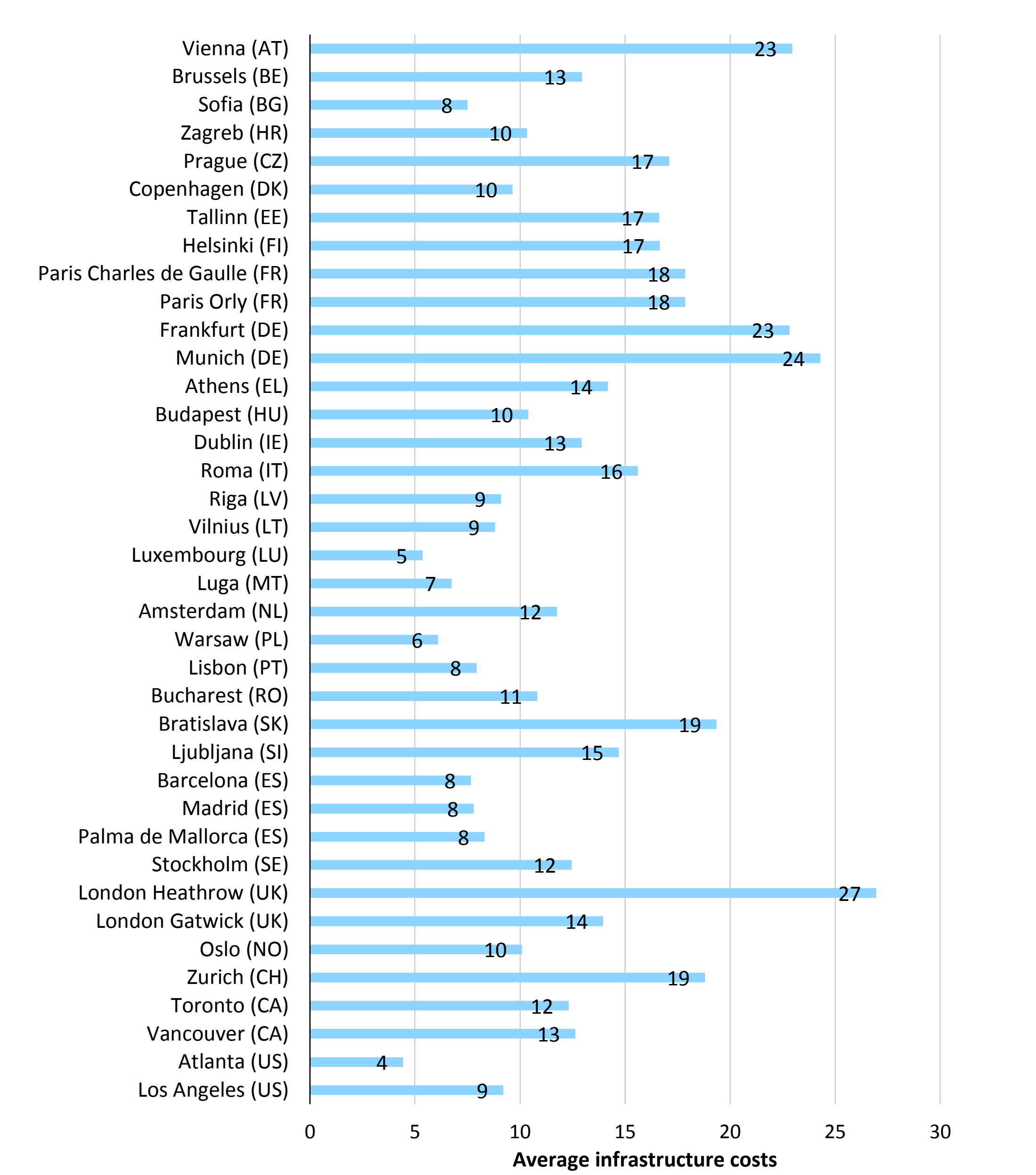
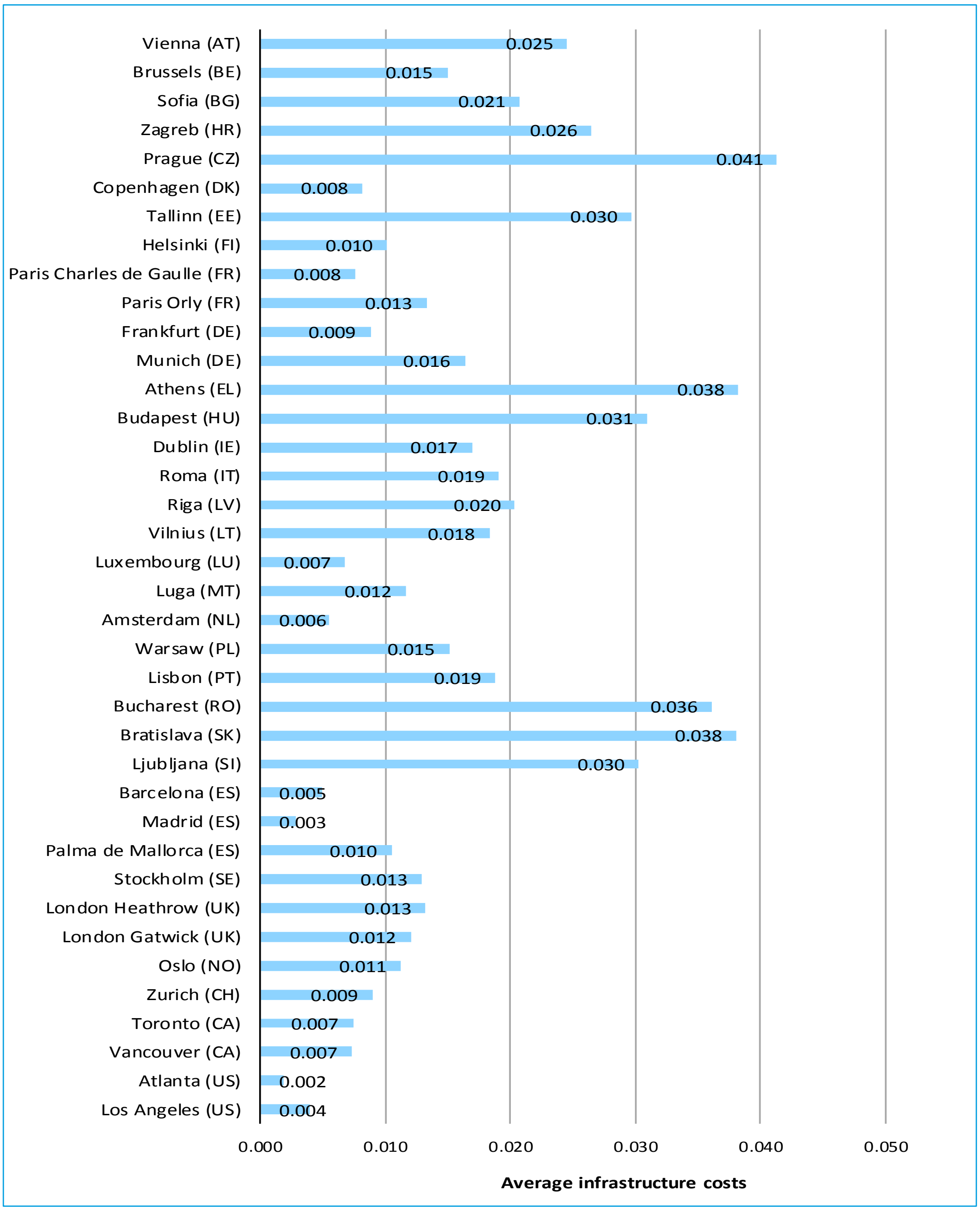


Figure 49 shows that by not adjusting for PPS, the most cost intensive airports are mainly hubs: London Heathrow, Munich, Frankfurt, Vienna, Zurich, Paris CDG and Paris Orly have cost above € 18 per passenger. This shows, that the infrastructure of a hub airport is more cost intensive than that of an airport which offers mainly point-to-point connections. Interesting is that Bratislava with € 19 per passenger and Amsterdam with € 12 per passenger do not fit in this pattern.
At the lower bound are Atlanta, Luxembourg, Warsaw, Luga, Sofia and Lisbon with cost below 8 €/passenger. As mentioned in Section 7.4.1, the data quality of Luxembourg airport is not as robust as

for other airports, since it is mainly a freight airport and it is unclear whether the keys used in the calculations fit for this kind of airport. With regard to non-European airports like Atlanta it is possible that some distortions appear due to different regulations, e.g. responsibility for airport security or regulation of the non-aviation business. However, this couldn’t be assessed in detail within the scope of this study Therefore, the comparability of European and non-European airports may be limited.

Finally, we also present the average infrastructure costs per passenger kilometre. However, the average costs per passenger kilometre are less representative since they are mostly influenced by the share of intercontinental flights (long-haul). Airports with low shares of intercontinental flights have much higher average costs per passenger kilometre.

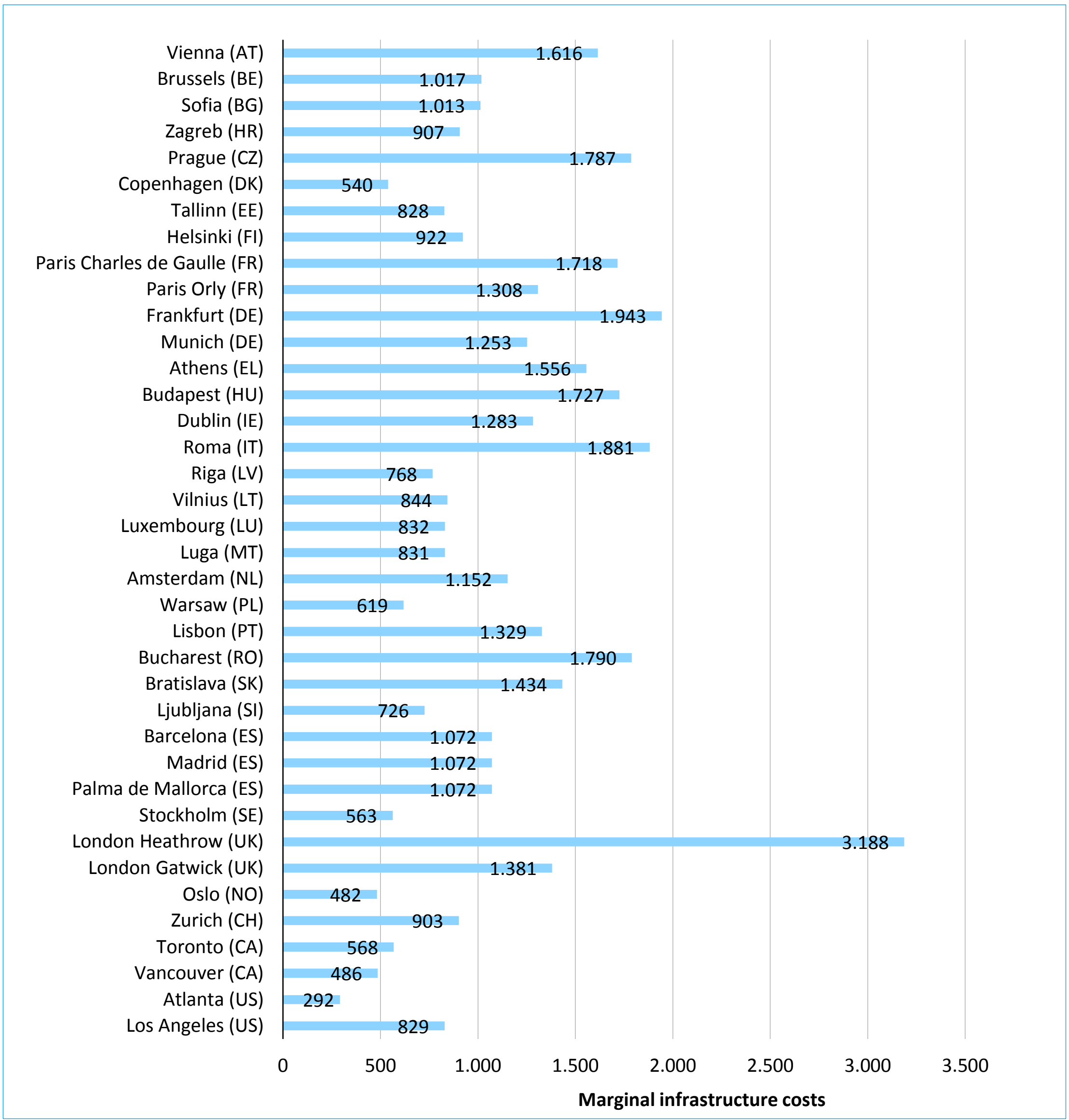
Figure 50 - Average PPS adjusted airport infrastructure costs per passenger kilometre in 2016 - (€/pkm)



7.4.3 Marginal infrastructure costs

Due to the methodology, the marginal costs are proportional to the average costs (see Section 2.4.5). The numbers per LTO are presented in Figure 51.

Figure 51 - Marginal airport infrastructure costs in 2016 (€/LTO, PPS adjusted)



The median of the PPS adjusted figures is 1,015 $€_{2016}$/LTO. Without PPS adjusting it would be 774 $€_{2016}$ per LTO. This is somewhat higher than the results found by McCarthy (2014), which states that the marginal cost per LTO is about 600 USD_{2005}/LTO or in Euro 637 $€_{2016}$/LTO. Given the median of the average PPS adjusted cost per passenger is 14 $€_{2016}$, the median average marginal cost per passenger is about 4 $€_{2016}$. This is a bit lower than the findings of Voltes-Dorta and Lei (2013), which presents marginal cost for 26 airports within UK. For London Heathrow and Gatwick they end up with 10.7 $€_{2016}$ and 5.5 $€_{2016}$ respectively, while we calculated 8.99 $€_{2016}$ and 4.65 $€_{2016}$ respectively (not PPS adjusted figures). Generally, we can conclude that our findings lie within the findings of the scientific studies.

8 Synthesis

8.1 Introduction

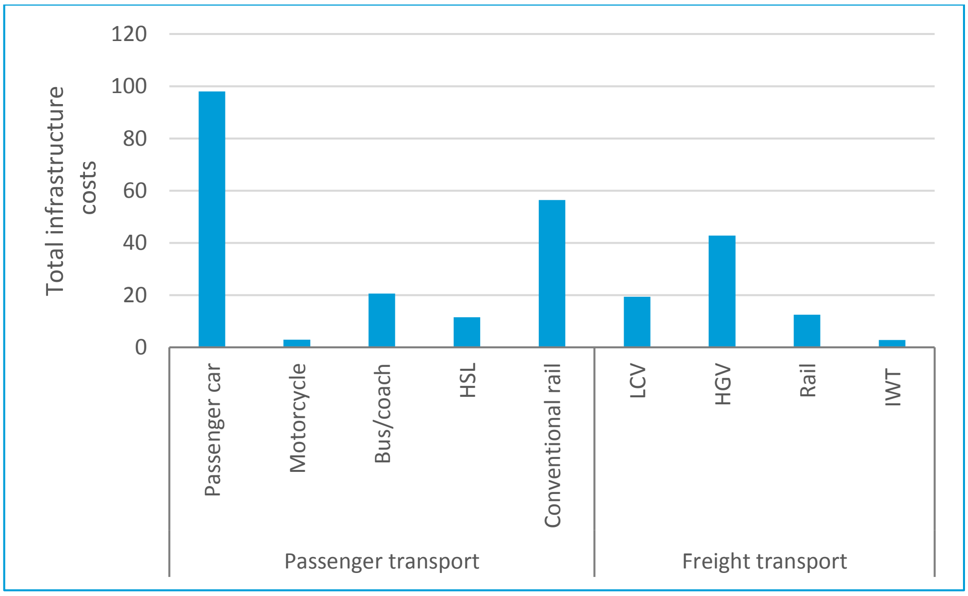
This chapter provides a synthesis of the results found in the previous chapters on infrastructure costs of the various transport modes. In Section 8.2, we first compare the total infrastructure costs of the various modes at the EU28 level. The same kind of comparisons are provided in Sections 8.3 and 8.4 for average and marginal infrastructure costs, respectively. Finally, in Section 8.5 some suggestions for further research are presented.

8.2 Total infrastructure costs

The total infrastructure costs for road, rail and inland waterway transport in the EU28 amount to €267 billion for 2016. The infrastructure costs for aviation and maritime transport are only calculated for a set of selected airports and ports. For the selected 33 EU airports the infrastructure cost amount to € 14 billion, while for the selected 34 EU ports the cost are estimated at 1.4 billion. However, based on this study it is not possible to determine what the share of these costs in the total infrastructure costs of aviation and maritime transport in the EU28 is.

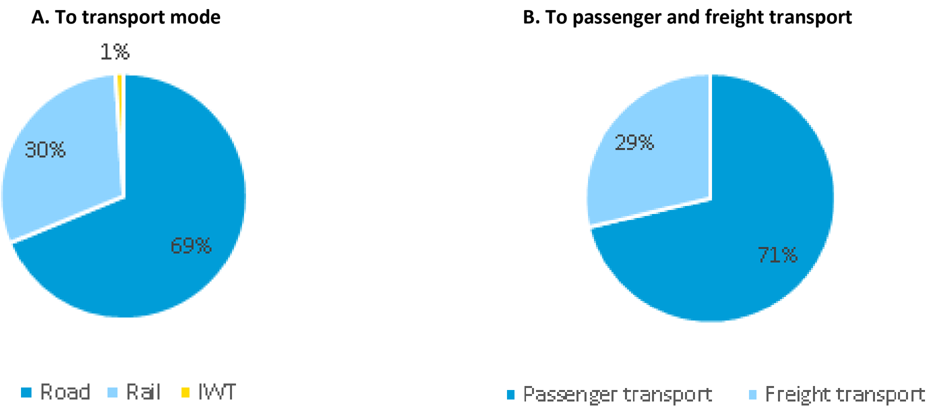
As is shown in Figure 52, passenger cars are responsible for the main share of the infrastructure costs in the EU28, which can be explained by the large share this vehicle category has in the total number of passenger kilometres. Also conventional rail and HGVs significantly contribute to the total infrastructure costs.

Figure 52 - Total infrastructure costs in 2016 for road, rail and inland waterway transport in the EU28 (billion €, PPS adjusted)



Road transport is the predominant mode and causes the most infrastructure costs: 69% of the total costs excluding aviation and maritime transport (see Figure 53). Also rail transport is causing a significant part of these costs, about 30%, while IWT is responsible for about 1% of the costs.
Figure 52 also shows that 71% of the infrastructure costs (excl. aviation and maritime transport) are caused by passenger transport, while 29% are due to freight transport.

Figure 53 - Composition of total infrastructure costs in 2016 for road, rail and inland waterway transport in the EU28



8.3 Average infrastructure costs

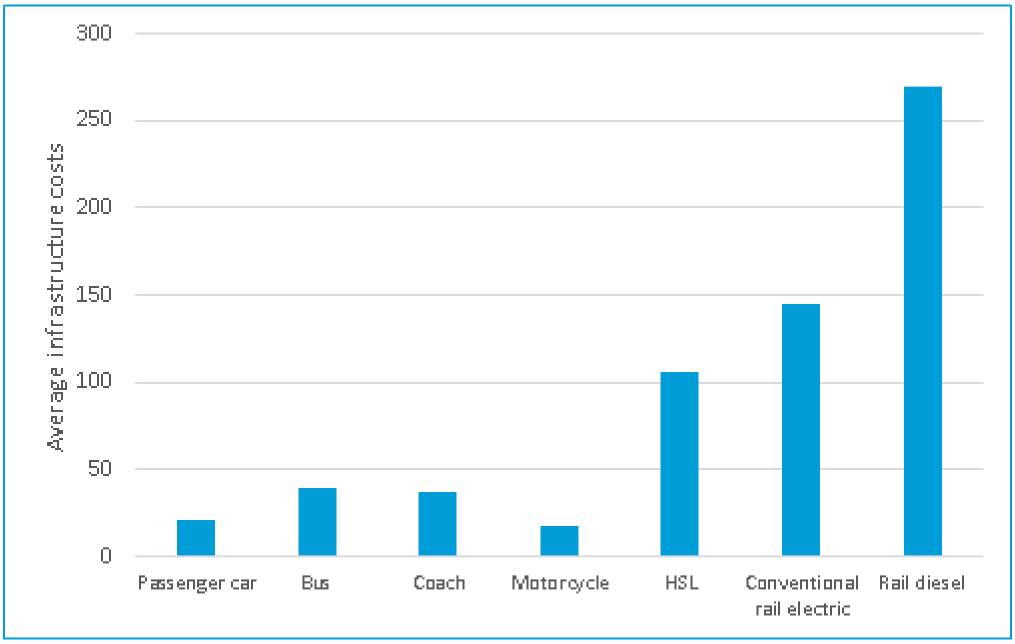
The average infrastructure costs of road and rail passenger transport in the EU28 are compared in Figure 54. These costs are higher for rail transport than for road transport. This is partly explained by the higher fixed costs (e.g. construction costs) of rail infrastructure compared to road infrastructure: the infrastructure costs per kilometre of road in the EU28 are about € 30,000, while the cost per track-kilometre rail amount to slightly more than € 200,000.

The highest average infrastructure costs are found for diesel trains, which is due to the low occupancy rate of diesel trains (compared to electric trains). The average infrastructure costs for HSL trains is at the EU28 level lower than for conventional electric passenger trains, although there are some countries (i.e. Belgium and The Netherlands) where the reverse is the case. As explained in Chapter 4, the variance in average infrastructure costs for HSL between countries can mainly be explained by the utilisation rate of the HSL network. Particularly in the Netherlands, the HSL network is poorly utilised compared to many other European countries.

As for road transport, the highest average infrastructure costs are found for buses and coaches, which can be explained by the relatively large share of variable (weight dependent) infrastructure costs caused by these vehicles.

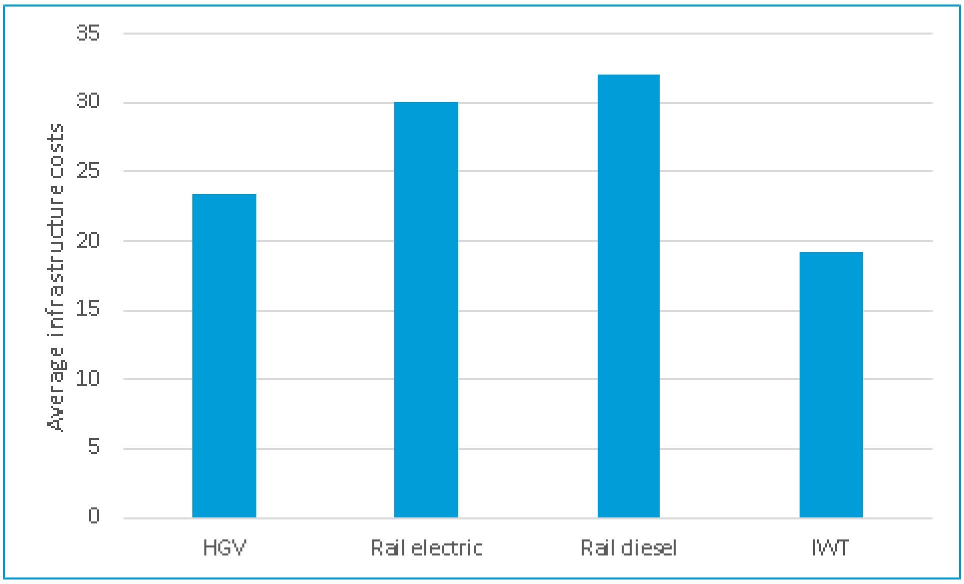
For aviation, no average infrastructure costs at the EU28 level are estimated in this study. The results of the assessments carried out for the selected 33 airports show, however, that the average infrastructure costs range from € 3 to € 41 per 1,000 passenger kilometres (with an (unweighted) average value for the selected airports of some € 18 per 1,000 passenger kilometres), which is comparable to the findings for passenger road transport.

Figure 54 - Average infrastructure costs in 2016 for road and rail passenger transport in the EU28 (€/1,000 pkm, PPS adjusted)



The average infrastructure costs for road, rail and inland navigation freight transport in the EU28 are shown in Figure 55. As for passenger transport, the highest costs are found for rail transport, followed by road transport and IWT. For maritime transport, no average infrastructure costs (in € per 1,000 tkm) were estimated at the EU28 level.

Figure 55 - Average infrastructure costs in 2016 for road, rail and IWT freight transport in the EU28 (€/1,000 tkm, PPS adjusted)

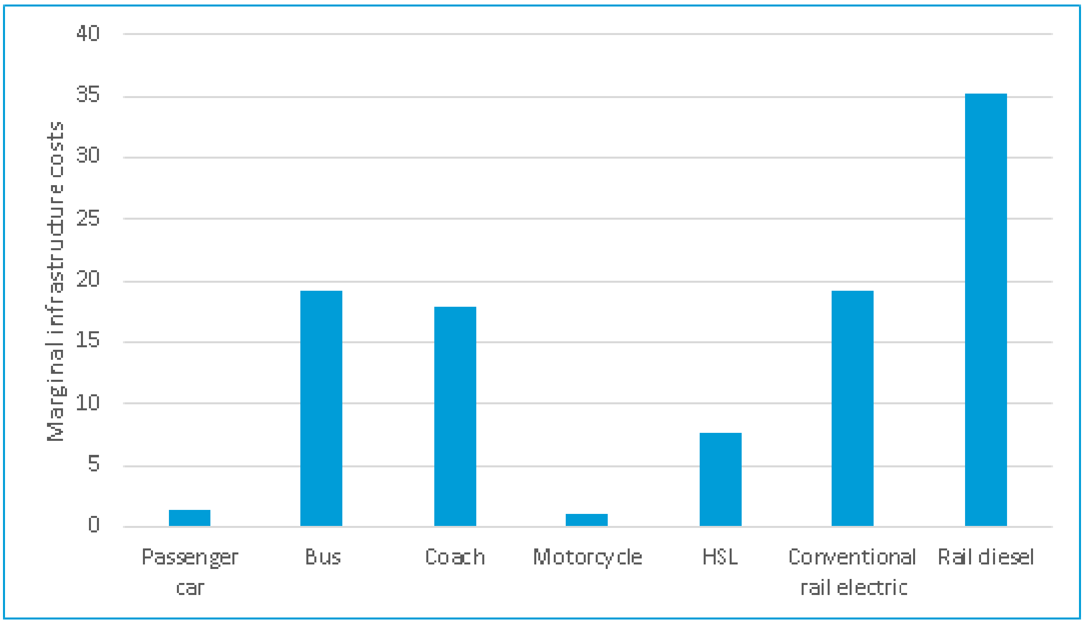


8.4 Marginal infrastructure costs

In this study, marginal infrastructure costs are defined as the variable part of the average infrastructure costs. They include the variable renewal and maintenance (and sometimes operational) costs. These costs are compared for passenger road and rail transport in Figure 56, showing that the highest costs are found for diesel trains. Compared to the results for average infrastructure costs, the marginal cost figures of road and rail transport are of the same order of magnitude. This can be explained by the fact that the relatively high fixed costs of rail infrastructure (the main cause of the high average infrastructure costs for rail) are not relevant for determining the marginal cost figures.

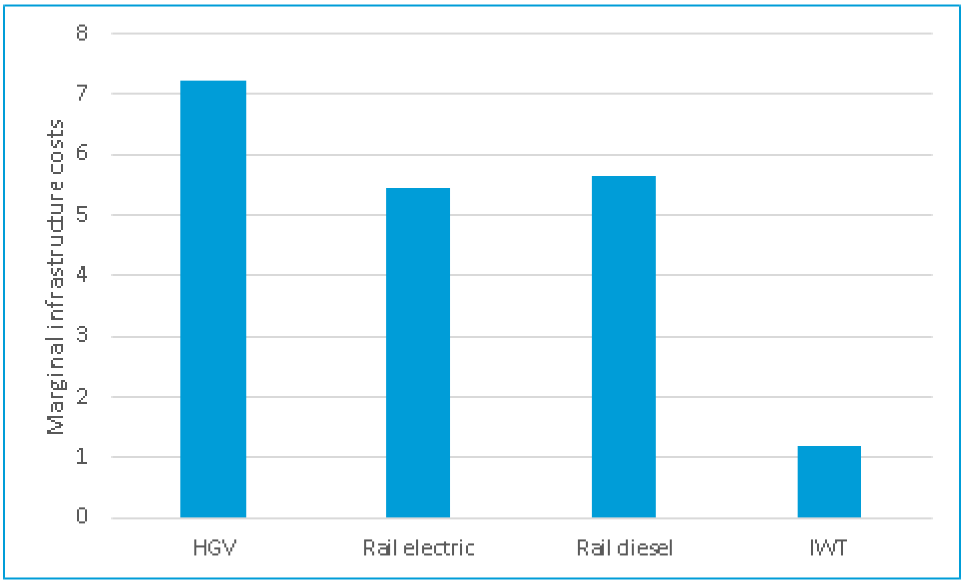
For aviation, marginal infrastructure costs are only calculated in terms of €/LTO in this study and a direct comparison with the other modes is therefore not possible.

Figure 56 - Marginal infrastructure costs in 2016 for road and rail passenger transport in the EU28 (€/1,000 pkm, PPS adjusted)



The marginal infrastructure costs of road, rail and inland navigation freight transport are shown in Figure 57. The highest costs are found for HGVs, reflecting the relatively large variable part of road infrastructure costs. Marginal infrastructure costs for IWT are relatively low, as only a limited share of the infrastructure costs directly depend on the use of the inland waterways.

Figure 57 - Marginal infrastructure costs in 2016 for road, rail and IWT freight transport in the EU28 (€/1,000 tkm, PPS adjusted)



8.5 Recommendations for further research

This study provides a state of the art overview on the infrastructure costs of transport. However, as discussed in Section 2.5 there are several uncertainties with respect to the data and methodologies used to estimate the infrastructure costs. To address these uncertainties further research on various topics is recommended. The main ones are:

- *Further harmonisation of the definition and scope of the transport infrastructure expenditure data collected in the various countries (and for the various transport modes).* The current set of expenditure data is not based on a coherent framework for accounting transport infrastructure expenditures, harming the comparability of these data between countries.
- *Constructing more complete and detailed datasets on transport infrastructure expenditures.* Long time series on transport infrastructure expenditure data are not easily available for all countries and all transport modes. Particularly for aviation and maritime transport these data is often not publicly available. Furthermore, detailed data on the breakdown of infrastructure expenditures (e.g. to investments and O&M expenditures) is often not available. Further assessments at the national or (air)port level (preferably in close cooperation with infrastructure operators) are recommended to improve the data base on transport infrastructure expenditures.
- *Further development of cost drivers to be used for the allocation of infrastructure costs per transport mode to the various vehicle categories*. More research on the relationship between infrastructure deterioration and the use of the infrastructure by vehicles may help to develop more detailed and robust cost drivers. Particularly for non-road modes there is considerable room for improvement on this issue.
- *Improving the accuracy and consistency of the transport performance data sets at the EU level.* There are considerable differences between various sources on transport performance data (e.g. vehicle kilometres, tonne-kilometres, passenger kilometres) in Europe. Improving and harmonizing these data would be recommended. Particularly for road transport, the composition of a consistent dataset based on the territorial principle would improve the assessment of road infrastructure costs a lot.

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A Data sources

A.1 Introduction

In this annex we present the sources from which data on transport infrastructure expenditures are collected. We only mention the sources from which the data have been actually taken. In many cases, alternative data sources have been used to cross-check the data, but these sources are not listed in this Annex. In addition to an overview of the data sources used, we also briefly discuss how missing data have been estimated.

A.2 Data sources road transport

The sources used for collecting data on road infrastructure expenditures are presented (per country) in Table 29. In this table also the methods applied to estimate missing data are briefly discussed.
For each country, the sources/estimation methods used for data on total investments and total O&M expenditures (for both the entire road network and motorways) as well as for the breakdown to more detailed expenditure categories (i.e. enhancement and renewal expenditures for investments, operational and maintenance expenditures for O&M expenditures) are presented (see Section 3.3 for more information on the approach used to estimate default parameters to make these breakdowns) . As the breakdown to fixed and variable expenditures is for all countries (except The Netherlands) based on the same EU average default parameters (see Section 3.3), it is not discussed specifically in Table 29.

Table 29 - Data sources used for road infrastructure expenditures

Country	Data description	Data source/Estimation approach
Austria	- Total expenditures on all roads	- Statistik Austria (2000-2013), BMWA + ASFINAG (1982-1999); Missing values for 2014-2016 estimated based on growth rate in expenditures (on motorways) according to the OECD.
	- Total expenditures on motorways	- ASFINAG (1998-2013), BMWA (1982-1997). Missing values for 2014-2016 estimated based on growth rate in expenditures according to the OECD.
	- Breakdown expenditures	- Based on detailed data from ASFINAG, BMWA and Administrations of the 9 Federal Countries for a selection of years. The breakdown of O&M expenditures to operational and maintenance expenditures for non-motorways has been based on EU average default parameters.
Belgium	- Total investments on all roads	- CE Delft (2016b) (1995-2013), ECMT (1982-1984; 1987-1994). Missing data 2014-2016 estimated based on growth rate in OECD figures. Missing data for 1985-1986 estimated based on interpolation.
	- Total expenditures on motorways	- Service Publique de Wallonie (2014-2016). Missing data 1982-2013 estimated based on same growth rate as in total investments.
	- Breakdown investments	- Based on EU default parameters.
	- Total O&M expenditures on all roads, including breakdown	- Total maintenance expenditures based on OECD (1995-2009; 2014-2016), CE Delft (2016b) (2010-2013). Operation al(and hence total O&M expenditures) estimated based on EU average default ratio operational and maintenance expenditures. - Total maintenance expenditures based on Service Publique de Wallonie (2014-2016). Operational (and hence total O&M

Country	Data description	Data source/Estimation approach
	- Total O&M expenditures motorways, including breakdown	expenditures) estimated based on EU average default ratio operational and maintenance expenditures.
Bulgaria	- Total investments on all roads - Total investments on motorways - Breakdown investments - Total O&M expenditures on all roads - Total O&M expenditures on motorways - Breakdown O&M expenditures	- All roads excluding urban roads: Road infrastructure Agency of Bulgaria (2006-2016); Missing data for 1982-2005 are estimated based on same growth rate in investments as in Poland. Missing data for urban roads estimated based on unit investments (€/km urban road) from Poland. - OECD (2006-2016); Missing data for 1982-2005 estimated based on same growth rate in motorway investments as in Poland. - Based on EU average default parameters. - All roads excluding urban roads: road infrastructure Agency of Bulgaria (2006-2016); Missing data for 1995-2005 are estimated based on same growth rate in expenditures in Czech Republic. Missing data for urban roads estimated based on unit expenditures (€/km urban road) from Poland. - OECD (2006-2016). - Based on EU average default parameters.
Croatia	- Total investments on all roads - Total investments on motorways - Breakdowns investments - Total O&M expenditures on all roads expenditures on motorways (including breakdowns) - Total O&M expenditures on motorways (including breakdowns)	- All roads excluding urban roads: OECD (1995-2016), ECMT (1993-1994). Missing data for 1982-1992 are estimated based on extrapolation. Missing data for urban roads based on unit expenditures (in €/km urban road) from Poland. - HUKA (1995-2016); Missing data 1982-1994) estimated based on same growth rate as investments on all roads. - Based on detailed data from HUKA (1995-2016). - All roads excluding urban roads: total maintenance expenditures from OECD (1995-2016). Missing data for urban roads based on unit expenditures (in €/km urban road) from Poland. Operational expenditures (and hence total O&M expenditures) have been estimated based on EU default ratio of operational and maintenance expenditures. - HUKA (1995-2016). For 1995-2015 the same breakdown of total O&M expenditures to operational and maintenance expenditures as for 2016 is assumed.
Cyprus	- Total expenditures on all roads - Breakdown expenditures categories - Total expenditures on motorways	- Eurostat (2002-2015); Missing data for 2016 assumed to be equal to 2015 expenditures. Missing data for 1982-2001 estimated based on same growth rate in expenditures as in Malta. - Based on EU average default parameters. - Estimated based on unit expenditures (€/km motorway) in Southern European countries and growth rate in total expenditures.
Czech Republic	- Total investments on all roads - Total investments on motorways	- Investments excluding investments on urban roads are from Transport Yearbook Czech Republic (1990-2016); Missing data for 1982-1989 estimated based on same growth rate in investments as in Poland. The investments on urban roads are based on unit investments (in €/km urban road) from Poland. - Directorate of Roads and Motorways (2003-2013), OECD (1995-2002); ECMT (1993-1994). Investments for 2014-2016 and 1982-1992 estimated based on same trend as for investments on all

Country	Data description	Data source/Estimation approach
	- Breakdown investments - Total O&M expenditures on all roads - Breakdown O&M expenditures all roads - Total O&M expenditures on motorways, including breakdown	roads. Investments for 1982-1992 estimated based on the same growth rate in motorway investments as in Poland. - Based on EU average default parameters. - Total maintenance expenditures from Transport Yearbook Czech Republic (1995-2016). Operational expenditures (and hence total O&M expenditures) estimated based on EU default ratio operational and maintenance expenditures. - Based on EU default parameters. - Directorate of Roads and Motorways (2004-2016).
Denmark	- Total expenditures on all roads and motorways - Breakdown expenditures	- Statistics Denmark (2016), Danish Road Directorate (1982-2015) Share of expenditures on motorways in expenditures on all roads is estimated based on OECD/ECMT data. This figure has been used to estimate the expenditures for motorways. - Based on EU average default parameters.
Estonia	- Total investments on all roads - Total investments on motorways - Breakdown investments - Total O&M expenditures on all roads, including breakdown - Total O&M expenditures on motorways - Breakdown O&M expenditures	- All roads excluding urban roads: Estonian Road Administration (2016), OECD (1995-2015). Missing data for 1982-1994 estimated based on the same growth rate as in Poland. Missing data for urban roads estimated based on extrapolation. - Estimated based on unit investments (€/km motorway) in CEEC countries and growth rate in total investments. - Based on detailed data for 2008-2012 from the Annual Yearbook of the Estonian Road Administration 2012. - Maintenance expenditures on all roads: Estonian Road Administration + Statistics Estonia (2016), OECD + Statistics Estonia (2012-2015). Maintenance expenditures on all roads excluding urban roads: OECD (1995-2011). Missing data for urban roads (1995-2011) estimated based on fixed share of maintenance expenditures on urban roads in total maintenance expenditures (based on 2012-2016 data). Based on the total maintenance expenditures the operational (and hence total O&M expenditures) are estimated based on a default ratio of operational and maintenance expenditures. - Estimated based on unit costs (€/km motorway) for Eastern European countries. - Based on EU default parameters.
Finland	- Total investments on all roads - Total investments on motorways - Breakdown investments - Total O&M expenditures on all roads, including breakdown	- OECD (1995-2016), ECMT (1982-1984; 1987-1994). Missing data for 1985-1986 estimated based on interpolation. - ECMT (1987-1995). For the other years, the average share of motorway investments in total road investments is assumed. - Based on breakdown for state roads (Finnish Transport Agency). - Total maintenance expenditures based on OECD (1995-2015) and extrapolation (2016). Based on share of maintenance expenditures in total O&M expenditures on state roads (Finnish Transport Agency), the total O&M expenditures on all roads are estimated. Operational expenditures are calculated by subtracting maintenance expenditures from total O&M expenditures.

Country	Data description	Data source/Estimation approach
	- Total O&M expenditures motorways - Breakdown O&M expenditures	- Estimated based on unit costs (€/km motorway) for Western European countries. - Based on EU default parameters.
France	- Total investments on all roads - Total investments on motorways - Breakdown investments - Total O&M expenditures on all roads - Total O&M expenditures on motorways - Breakdown O&M expenditures	- Ministry of Ecology, Sustainable Development and Energy (2003-2013), OECD (1995-2002), ECMT (1982-1984; 1987-1994); Missing data for 2016 and 1985-1986 estimated based on extrapolation and interpolation, respectively. - ASFA annual reports (1985-2016), correction for non-concessionary motorways based on CE Delft (2016b). Missing data for 1982-1984 estimated based on extrapolation. - Based on EU default parameters. - Ministry of Ecology, Sustainable Development and Energy + ASFA + APRR + SANEF + VINCI (2006-2013). Missing data for 2014-2016 has been estimated based on growth rate in maintenance expenditures according to OECD data. Missing data for 1995-2005 has been estimated based on same growth rate as in Germany. - ASFA+AFRA+SANEF+VINCI (2006-2013). Missing data for 2014-2016 has been estimated based on growth rate in maintenance expenditures on all roads. - Based on EU default parameters.
Germany	- Total expenditures on motorways and all roads - Breakdowns expenditures	- Statisches Bundesamt. - Breakdowns are based on the average breakdowns in Austria and The Netherlands.
Greece	- Total investments on all roads and motorways - Breakdown investments - Total O&M expenditures on all roads and motorways - Breakdown O&M expenditures	- OECD (2000-2015), ECMT (1987-1995). Investments in 2016 are assumed to be equal to 2015 investments. Missing data for 1996-1999 are estimated based on interpolation, while missing data for 1982-1986 are based on extrapolation. - Based on EU default parameters. - Maintenance expenditures: OECD (1995). Missing data 2016-1996 estimated based on growth rates in total maintenance expenditures. Operational (and hence total O&M expenditures) estimated based on EU average default ratio operational and maintenance expenditures. - Based on EU default parameters.
Hungary	- Total investments on all roads - Total investments on motorways - Breakdown investments - Total O&M expenditures on all roads - Total O&M expenditures on motorways	- NIF Nemzeti Infrastruktúra Fejlesztő (2016), OECD (1995-2015), ECMT (1987-1994). Missing data for 1982-1986 estimated based on growth rate in investments in Poland. *Only state investments are included (no data on investments from other sources available).* - OECD (1995-2000; 2004-2005; 2008-2016), ECMT (1987-1994). Missing data estimated based on the same growth rate in investments as for entire road infrastructure. - Based on EU default parameters. - All roads excluding urban roads: Hungarian Public Road Nonprofit PLC (2016), OECD (1995-2000; 2004-2015). Missing data 2001-2003 estimated based on interpolation. Missing data urban roads estimated based on unit expenditures (in €/km urban road) from Poland. - OECD (1995, 2004-2005, 2008-2015). Missing data estimated based on interpolation.

Country	Data description	Data source/Estimation approach
	- Breakdown O&M expenditures	- Data from Hungarian Public Road Non-profit PLC (all roads) and EU default values for share of operational and maintenance in total O&M expenditures (motorways).
Ireland	- Total investments on all roads - Breakdown investments - Total O&M expenditures on all roads, including breakdown - Total expenditures motorways - Breakdown expenditures motorways	- TII Annual Report (2016), OECD (1995-2015), ECMT (1982-1984; 1987-1994). Missing data for 1985-1986 estimated based on interpolation. - Based on TII Annual reports (2003-2016). For 1999-2002 the same breakdown is assumed as for the period 2003-2106, while for earlier years EU default values were used to make this breakdown. - Total maintenance expenditures for 1997-2015 available from OECD database. For 2016, same maintenance expenditures as in 2015 are assumed. Missing data for 1995-1996 are estimated based on extrapolation. Operational expenditures (and hence total O&M expenditures) are estimated based on default ratio of operational and maintenance expenditures. - Estimated based on unit values (€/km motorway) for Western European countries. - Based on EU default parameters.
Italy	- Total investments on all roads - Total investments on motorways - Breakdown investments - Total O&M expenditures on all roads - Total O&M expenditures on motorways - Breakdown O&M expenditures	- CNIT + ANAS + Ministerial reports on motorway concessionaires (2008-2015); CNIT (1995-2007), ECMT (1982-1984; 1987-1994). Missing data for 2016 assumed to be equal to 2015 and 1985-1986 estimated by interpolation. - CNIT + ANAS + Ministerial reports on motorway concessionaires (2008-2016); CNIT (1991-2007). Missing data for 1982-1990 estimated based on growth rate in investments all roads. - Based on EU default parameters. - CNIT + ANAS + Ministerial reports on motorway concessionaires (2008-2015); only for all non-motorway roads: CNIT (1995-2007). Missing motorway expenditures are estimated based on the same growth rate as for other O&M expenditures. - CNIT + ANAS + Ministerial reports on motorway concessionaires (2008-2016); Missing data is estimated based on approach discussed above. - Based on EU default parameters.
Latvia	- Total investments on all roads - Breakdown investments - Total O&M expenditures on all roads - Breakdown O&M expenditures	- Ministry of Transport (2016-2003). For the period 1995-2002, the OECD provides figures for state roads only. The figures on order roads have been estimated based on unit values (€/km road) from Poland. The missing values for 1982-1994 have been estimated based on the same growth rate as in Poland. - Based on detailed national data from the Annual report Latvian Road Administration 2012. For other years EU default values for share of enhancement and renewal expenditures in total investments have been assumed. - Ministry of Transport (2016-2003). For 1995-2002, O&M expenditures have been estimated by using the same growth rate as in O&M expenditures on Latvian state roads (from Ministry of Transport). - Based on data from Ministry of Transport. Breakdown of investment figures (2005-2016).

Country	Data description	Data source/Estimation approach
Lithuania	- Total investments on all roads - Total investments on motorways - Breakdown investments - Total O&M expenditures on all roads, including breakdown - Total O&M expenditures on motorways, including breakdown	- All roads excluding urban roads: Lithuanian Road Administration (2016), OECD (1995-2015), ECMT (1993-1994); Missing data for 1982-1992 estimated based on same growth rate as in Poland. Missing data for urban roads estimated based on extrapolation. - Lithuanian Road Administration (2016), OECD (1996-2015); Missing data for 1982-1995 estimated based on extrapolation. - Based on detailed data for Latvia (2005-2016) and EU default values on the share of enhancement and renewal expenditures in total investments. - Maintenance expenditures on all roads excluding urban roads: Lithuanian Road Administration (2016), OECD (1995-2015). Missing data for urban roads estimated based on unit expenditures (in €/km urban road) from Poland. Based on the total maintenance expenditures the operational (and hence total O&M expenditures) are estimated based on EU default ratio of operational and maintenance expenditures. - Maintenance expenditures on motorways: Lithuanian Road Administration (2016), OECD (1995-2015). Based on the total maintenance expenditures the operational (and hence total O&M expenditures) are estimated based on EU default ratio of operational and maintenance expenditures.
Luxembourg	- Total investments on all roads - Total investments on motorways - Breakdown investments - Total O&M expenditures on all roads and motorways, including breakdown	- OECD (1995-2015), ECMT (1982-1984; 1987-1994). Missing data for 1985-1986 estimated based on interpolation. For 2016 the same investment figure as for 2015 is assumed. - OECD (1995-2015). For 2016 the same investment figure as for 2015 is assumed. For 1982-1994 investments are estimated based on same growth rate as for investments on all roads. - Based on EU default parameters. - Maintenance expenditures available from OECD (1995-2015). For 2016 same figure assumed as for 2015. Operational expenditures (and hence total O&M expenditures) are estimated based on default ratio of operational and maintenance expenditures.
Malta	- Total investments on all roads - Breakdown investments - Total O&M expenditures, including breakdown	- OECD (1995-2014). Missing data for 2015-2016 estimated based on extrapolation. Missing data for 1982-1994 estimated based on same growth rate in investments as in Spain. - Based on EU default parameters. - Total maintenance expenditures from OECD (1995-2014). For 2015-2016, the same annual expenditures as for 2014 are assumed. Operational expenditures (and hence total O&M expenditures) are estimated based on default ratio of operational and maintenance expenditures.
The Netherlands	- Total expenditures on all roads and motorways (incl. breakdown)	- National accounts (2001-2016), Statistics Netherlands (1985-2000), CE Delft (2014) (1982-1984). Breakdowns of expenditures are based on DVS (2001) and DVS (2007).

Country	Data description	Data source/Estimation approach
Poland	- Total expenditures on all roads	- OECD (1995-2016), ECMT (1987-1994). The expenditures for 1982-1986 are estimated based on extrapolation.
	- Total expenditures on motorways	- GDDKiA (2008-2013), OECD (1995-2007), ECMT (1987-1994). For 2014-2016 the expenditures are estimated based on the growth rate in the relevant expenditures presented by the OECD. The expenditures for 1982-1986 are estimated based on extrapolation.
	- Breakdown expenditures	- Based on detailed data from GDDKiA for the period 2008-2013.
Portugal	- Total investments on all roads	- Association of Motorway Concessionaires + Annual reports national road infrastructure manager (2016 - 2013), OECD + Annual reports national road infrastructure manager (2012), Pereira & Pereira 2017 (1982-2011). Missing data on investments in urban roads for 2012-2016. These data were estimated based on average growth rate in urban road investments over the period 2000-2011.
	Total investments on motorways	- Association of Motorway Concessionaires (2016-2013), OECD (2012), Pereira & Pereira 2017 (1982-2011).
	- Breakdown investments	- Based on EU default parameters.
	- Total O&M expenditures on all roads (including breakdown)	- Total maintenance expenditures on all road excluding urban roads: Annual report national road infrastructure manager (2016), OECD (1995-2011, 2013-2014). Missing data for 2012 and 2015 estimated based on interpolation. Missing data for urban roads estimated based on share of O&M expenditures in total O&M expenditures from Steer Davies Gleave (2014).
	- Total O&M expenditures on motorways (including breakdown)	- Total maintenance expenditures from OECD (2012-2013). Maintenance expenditures for 2014-2016 estimated based on the same growth rate as for O&M expenditures on all roads. Operational expenditures (and hence total O&M expenditures) estimated based on EU default ratio between operational and maintenance expenditures.
Romania	- Total investments on all roads	- All roads excluding urban roads: National Institute of Statistics (2015-2016), OECD (1995-2014). Missing data for 1987-1994 are based on CE Delft (2016b), while missing data for 1982-1986 are extrapolated. Missing data for urban roads estimated based on unit investments (in €/km urban road) from Poland
	- Total investments on motorways	- National Institute of Statistics (2015-2016), OECD (2008-2014). Missing data for 1995-2007 estimated based on same trend as in investments on all roads. Missing data for 1982-1994 based on same growth rate as for investments on all roads.
	- Breakdown investments	- Based on EU default parameters
	- Total O&M expenditures on all roads	- All roads excluding urban roads: OECD (1995, 2001-2007). Missing data for 1996-2000) estimated based on interpolation. Missing data for 2008-2016 estimated based on interpolation. Missing data for urban roads estimated based on unit values (€/km urban road) from Poland.
	- Total O&M expenditures on motorways	Based on unit values (€/km motorway) for Eastern European countries
	- Breakdown O&M expenditures	- Based on detailed data from the National Road Infrastructure Company for 2015.

Country	Data description	Data source/Estimation approach
Slovakia	- Total investments on all roads - Total investments on motorways - Breakdown investments Total O&M expenditures on all roads, including breakdown - Total O&M expenditures on motorways, including breakdown	- Statistical Office of the Slovak Republic (2016), OECD (2015-1995), ECMT (1987-1994). Missing data for 1982-1986 are estimated based on extrapolation. *Only data for the main urban roads is included.* - Statistical Office of the Slovak Republic (2016), OECD (2015-1995). Missing data for 1982-1984 estimated based on extrapolation. - Based on EU default parameters. - Total maintenance expenditures are from OECD (1995-2016). Operational expenditures estimated based on default value for share of operational expenditures in total O&M expenditures. - Total O&M expenditures from National Motorway Cooperation (2005-2016). Total maintenance data on motorways available from OECD database (1995-2016). Operational expenditures (2005-2016) estimated by taking difference between total O&M expenditures and total maintenance expenditures. Operational expenditures (1995-2004) estimated are based on same growth rate as for maintenance expenditures. Total O&M expenditures (1995-2004) is calculated by summing operational and maintenance expenditures.
Slovenia	- Total expenditures on all roads and on motorways - Breakdown expenditures	- DARS and Direkcija Republike Slovenije za infrastrakstrukurg (2014-2016), OECD (1995-2013), ECMT (1992-1994); Missing data for 1982-1991 estimated based on growth rate in investments for those years in Poland. - Based on detailed data from Direkcija Republike Slovenije za infrastrakstrukurg for 2014-2016. For the other years European default values are used.
Spain	- Total investments on all roads - Total investments on motorways - Total O&M expenditures on all roads and motorways - Breakdown of total expenditures	- Ministerio de Fomento (1988-2016), linear interpolation (1984-1987), ECMT (1982-1983). - Ministerio de Fomento (1985-2016), figures for 1982-1984 estimated based on same growth rate in investments as for total roads. For motorways, national roads, departmental roads and regional roads: Ministerio de Fomento (1995-2016); for local roads: Ministerio de Hacienda y Administraciones Publicas (2002-2013), estimation based on same growth rate as for regional roads (2014-2016 and 1995-2001). - Based on EU default parameters.
Sweden	- Total expenditures on all roads - Total expenditures on motorways - Breakdown expenditures	- Statistics Sweden (1982-2013). Missing data for 2014-2015 extrapolated based on growth rate in expenditures on state roads (from Trafikverket annual reports). - Trafikverket (2009-2016), for the other years estimated based on the same growth rate in annual expenditures as for the entire road network. - Based on data received from Trafikverket on breakdown on state roads for the years 2014-2016.
United Kingdom	- Total expenditures on all roads and on motorways - Breakdown investments - Breakdown O&M expenditures	- Department for Transport (1982-2016). - Based on EU default parameters. - Based on detailed data from Department of Transport.
Norway	- Investments on all roads	- Annual report Norwegian Public Roads Administration + Statistics Norway (2016), OECD (1995-2015), ECMT (1982-1984 and 1987-1994). Missing data (1985-1986) estimated by interpolation.

Country	Data description	Data source/Estimation approach
	- Investments on motorways - Breakdown investments - Total O&M expenditures on all roads - Total O&M expenditures on motorways - Breakdown O&M expenditures	- Estimated based on unit investments (€/km motorway) from Sweden. - Same breakdown as for Sweden is assumed. - Annual report Norwegian Public Roads Administration + Statistics Norway (2010-2016), for 1995-2009 the same growth rate as for maintenance expenditures (from OECD) was assumed. - Based on unit values (€/km motorway) from Sweden. - Breakdown to operational and maintenance expenditures: total maintenance expenditures are available from OECD, operational expenditures are estimated by subtracting maintenance expenditures from total O&M expenditures.
Switzerland	- Total expenditures on all roads and on motorways - Breakdown expenditures	- Swiss Federal Statistical Office (1995-2014), ECMT (1982-1984; 1987-1994); Missing data for 2016-2015 estimated based on extrapolation. Missing data for 1985-1986 estimated based on interpolation. - Based on detailed data from Swiss Federal Statistical Office for the years 1995-2014.
Alberta (province in Canada)	- Investments on all roads and motorways - Breakdown investments - Total O&M expenditures on motorways - Total O&M expenditures on all roads - Breakdown O&M expenditures	- Estimated based on unit investments (€/km road) from Missouri (US). - Estimated based on EU default shares of enhancement and renewal expenditures in total investments. - Estimated based on unit expenditures (€/km road) from Missouri (US). - Expenditures for 2016 available from annual report Ministry of Transport of Alberta. Missing data for 1995-2015 estimated based on same growth rate as in Missouri (US). - Same breakdown as for Missouri (US) assumed.
British Columbia (province in Canada	- Investments on all roads and motorways - Breakdown investments - Total O&M expenditures on motorways - Total O&M expenditures on all roads - Breakdown O&M expenditures	- Estimated based on unit investments (€/km road) from Missouri (US). - Estimated based on EU default shares of enhancement and renewal expenditures in total investments. - Estimated based on unit expenditures (€/km road) from Missouri (US). - Expenditures for 2016 available from annual report Ministry of Transport of British Columbia. Missing data for 1995-2015 estimated based on same growth rate as in Missouri (US). - Same breakdown as for Missouri (US) assumed.
California (state in United States)	- Total expenditures on all roads - Total expenditures on motorways - Breakdown expenditures	- Federal Highway registration + Highway statistics (1982-2014). Expenditures for 2015-2016 estimated based on extrapolation. - Federal Highway registration + Highway statistics (1994-2014). Expenditures for 2015-2016 estimated based on extrapolation. Missing data for 1982-1993 estimated based on the same growth rate as for total expenditures on all roads. - Investments: estimated based on EU default shares of enhancement and renewal expenditures in total investments. O&M expenditures for all roads: breakdown available from sources mentioned above. For motorways, operational expenditures are estimated based on ratio operational and maintenance expenditures for all roads.

Country	Data description	Data source/Estimation approach
Missouri (state in United States)	- Total expenditures and breakdowns	- Same sources as for California (see above).
Japan	- Total expenditures on all roads - Breakdown expenditures	- Ministry of Land, Infrastructure, Transport and Tourism (1982-2015); Missing data for 2016 is estimated by assuming same expenditure levels as in 2015. - Based on EU default parameters.

A.3 Data sources rail transport

The data sources used to collect data on rail infrastructure expenditures are presented (per country) in Table 30. This table also briefly presents the approaches used to estimate any missing data. For each country, the sources/estimation approaches used for total investments and O&M expenditures are shown, as well as sources/estimation approaches on the breakdown of these expenditures to more detailed expenditure categories (i.e. enhancement and renewal expenditures for investments, operational and maintenance expenditures for O&M expenditures). As the breakdown to fixed and variable expenditures for all countries (except The Netherlands and the UK) are based on the same EU average default parameters (see Section 4.3), it is not discussed in Table 30.

Table 30 - Data sources used for rail infrastructure

Country	Data description	Data source/Estimation approach
Austria	- Total expenditures on all rail - Total expenditures on High Speed rail - Breakdown expenditures	- *Investments*: Annual report ABB Infrastruktur OB (2016), OECD (1995-2015), ECMT (1982-84 and 1987-94), missing data for 1985-86 estimated based on interpolation. *O&M*: annual report ABB Infrastruktur OB (2015-16), RMMS (2014-2016),1995-2013 estimated based on national default parameters using OECD values on maintenance expenditures. - *Investments*: estimated based on unit cost of HS line in Germany (Trabo et al., 2013), proportionally to HS network length and evenly distributed over the years 2008-2011. *O&M*: estimated based on default parameters (average HS weight in total O&M exp. in Germany). - *Investments*: Annual report ABB Infrastruktur OB (2016); O&M: Annual report ABB Infrastruktur OB (2014-16); remaining years estimated based on national average shares; *O&M*: RMMS (2014-2016), OECD (1995-2013).
Belgium	- Total expenditures on all rail - Total expenditures on High Speed rail - Breakdown expenditures	- *Investments*: Annual reports Infrabel (2005-16), Eurostat (1995-04), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation. *O&M*: RMMS (2015-2016), Eurostat (2010-2014), OECD (1995-2007), missing data for 2008-09 estimated based on interpolation. - *Investments*: RMMS (2015-2016), Infrabel (2005-2011), total expenditure for the period 1993-04 from Infrabel, allocated over years based on 'Meerjaren investeringsplan 2001-2012' (NBMS, 2001). *O&M*: RMMS (2015-2016), remaining years estimated based on national average shares. - *Investments*: Annual reports Infrabel (2005-2016); HS investments: RMMS (2015-16), 2012-2014 estimated as average of 2009-2011

Country	Data description	Data source/Estimation approach
		and 2015-2016 values, remaining years estimated based on national average shares. *O&M*: estimated based on Netherlands national average shares.
Bulgaria	- Total expenditures - Breakdown expenditures	- *Investments*: OECD (1995-2016), ECMT (1982-1984 and 1987-1994), missing data for 1985-1986 estimated based on interpolation. *O&M*: BG Railway Infrastructure Company (2015-2016); 2000-2014 estimated based on national default parameters using OECD values on maintenance expenditures; 1995-1999 estimated as average of 2000-2016 values. - *Investments*: estimated based on national average shares, using RMMS data for 2012-2016. *O&M*: BG Railway Infrastructure Manager (2015-2016), remaining years estimated based on national average shares.
Croatia	- Total expenditures - Breakdown expenditures	- Values based on data from Croatian Railways HZPP. - Values based on data from Croatian Railways HZPP; missing values for investments (1995-2006) estimated based on national average shares.
Czech Republic	- Total expenditures - Breakdown investments	- *Investments*: SZDC/OECD (1995-2016), ECMT (1993-1994), remaining years estimated based on extrapolation. *O&M*: SZDC (2014-2016), OECD (1995-2013). - *Investments*: estimated based on national average shares, using RMMS data for 2015-2016. *O&M*: SZDC (2014-2016), remaining years estimated based on national average shares.
Denmark	- Total expenditures on all rail - Total expenditures on High Speed rail - Breakdown expenditures	- *Investments*: Statistics Denmark (1995-2016), ECMT (1982-1984 and 1987-1994), missing data for 1985-86 estimated based on interpolation. *O&M*: Statistics Denmark (1995-2016). - *Investments*: construction costs of Copenhagen-Ringsted rail line, total cost evenly distributed over construction period (2010-2016). - *Investments*: estimated based on national average shares, using RMMS data for 2010-2016. *O&M*: RMMS (2010-2012), remaining years estimated based on national average shares.
Estonia	- Total expenditures - Breakdown expenditures	- *Investments*: values based on data from Estonian Railways manager EVR (1995-2016), ECMT (1990-1994), missing data for 1985-1986 estimated based on interpolation, missing data 1982-1989 estimated as share of 1990-1999 values. *O&M*: PMR own sources (2002-2016), missing data for 1995-2001 estimated based on extrapolation. - *Investments*: PMR own sources (2009-2011), remaining years estimated based on national average shares. *O&M*: PMR own sources (2002-2016), remaining years estimated based on national average shares.
Finland	- Total expenditures - Breakdown expenditures	- *Investments*: Finnish Transport Agency (1994-2016), ECMT (1982-1984 and 1987-1994), missing data for 1985-86 estimated based on interpolation. *O&M*: Finnish Transport Agency (1995-2016). - *Investments*: Finnish Transport Agency (2011-2016), remaining years estimated based on national average shares. *O&M*: Finnish Transport Agency (2014-2016), remaining years estimated based on national average shares.

Country	Data description	Data source/Estimation approach
France	- Total expenditures on all rail	- *Investments*: SNCF Réseau (1998-2016), OECD (1994-1997), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation. *O&M*: SNCF Réseau (1998-2016), missing data for 1995-1997 estimated as average of 1998-2003 values.
	- Total expenditures on High Speed rail	- *Investments*: SNCF Réseau (1998-2016), missing data for 1982-1997 estimated based on average weight of HS in total expenditures (years 1998-2016). *O&M*: RMMS (2011-2012 and 2014-2015), remaining years estimated based on national average share.
	- Breakdown expenditures	- *Investments*: RMMS (2008-2012 and 2014-2015), remaining years estimated based on national average shares. *O&M*: RMMS (2009-2010 and 2015), remaining years estimated based on national average shares. *HS O&M*: RMMS (2011-2012 and 2014-2015), remaining years estimated based on national average share.
Germany	- Total expenditures on all rail	- *Investments*: annual reports 'Deutsche Bahn Networks' (1992-2006 and 2016), OECD (2010-2015), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation; *O&M*: DB Netze AG Financial Statement 2016 and 2014, 1992-2006 estimated based on revenues from access charges (DB network) and CE Delft and ITS Leeds (2012) (non-DB network), missing data for 2010-12 estimated based on extrapolation.
	- Total expenditures on High Speed rail	- *Investments*: estimated based on unit cost of HS line in Germany (Trabo et al., 2013), proportionally to HS network length and evenly distributed over the 1988-2016 period; *O&M*: RMMS (2016), remaining years estimated based on default parameters (HS weight in total O&M expenditures in 2016).
	- Breakdown expenditures	- *Investments*: RMMS (2011), annual report 'Deutsche Bahn Networks' (1992-2006 and 2016), non-DB network estimated based on CE Delft and ITS Leeds (2009), remaining years estimated based on national average shares; *O&M*: RMMS (2014 and 2016), 1992-2006 expenditures based on revenues from access charges (DB network) and CE Delft and ITS Leeds (2012) (non-DB network), remaining years estimated based on national average shares; *HS O&M*: RMMS (2016), remaining years estimated based on national average shares.
Greece	- Total expenditures	- *Investments*: OSE Finance Department (2013-2016), OECD (2010-2012), Eurostat (1995-2009), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation; *O&M*: OSE Finance Department (2013-16), 1995-2003 and 2007-2009 estimated based on national average shares using Eurostat data on maintenance expenditures, remaining years estimated based on extrapolation.
	- Breakdown expenditures	- *Investments*: RMMS (2009-10, 2011-2012, 2015-2016), remaining years estimated based on national average shares; *O&M*: RMMS (2015-2016), remaining years estimated based on national average shares.
Hungary	- Total expenditures	- *Investments*: NIF National Infrastructure Development Company (2010-2016), OECD (1995-2009), ECMT (1987-1994), missing data for 1982-1986 estimated as average of 1987-2016 values;

Country	Data description	Data source/Estimation approach
	- Breakdown expenditures	*O&M*: 2016 data estimated based on data from national railways MAV and GySEV, Eurostat (2006-2015), missing data for 1982-1986 estimated as average of 1999-2003 values. - *Investments*: NIF(2016), RMMS (2009-2012, 2014-2015), remaining years estimated based on national average shares; *O&M*: MAV and GySEV (2016), RMMS (2009-2012, 2013, 2015), remaining years estimated based on national average shares.
Ireland	- Total expenditures - Breakdown expenditures	- *Investments*: RMMS (2015-2016), Irish Rail Annual Report and Financial Statements (2008-2014), OECD (1995-2007), ECMT (1987-1994), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation; *O&M*: 2016 data estimated based on data from national railways MAV and GySEV, Eurostat (2006-2015), missing data for 1982-1986 estimated as average of 1999-2003 values. - *Investments*: RMMS (2008-2010, 2014-2015), remaining years estimated based on national average shares; *O&M*: Irish Rail Annual Report and Financial Statements (2003-2013), remaining years estimated based on national average shares.
Italy	- Total expenditures on all rail - Total expenditures on High Speed rail - Breakdown expenditures	- *Investments*: RFI financial statements (2004-2016), National Accounts for Transport Infrastructures CNIT (1995-2003), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation; *O&M*: RFI financial statements (2011-2016), remaining years estimated based on national average shares. - *Investments*: RMMS (2015-2016), RFI financial statements (2004-2014), missing data for 1982-1992 estimated based on national default parameters (average HS weight in total Investments); *O&M*: missing data for 1995-2016 estimated based on national default parameters using data from RMMS 2016. - *Investments*: missing data for 1982-2016 estimated based on national default parameters, using RMMS data for 2008-2011, 2013, and 2015-16; *O&M*: RFI financial statements (2011-16), missing data for 2004-2010 estimated based on default parameters using RFI data on maintenance exp., missing data for 1995-2003 estimated based on extrapolations. *HS*/Investments: RMMS (2015-2016), missing data for 2004-2014 based on extrapolations; HS/O&M: estimated based on default parameters using RMMS 2016 data.
Latvia	- Total expenditures - Breakdown expenditures	- *Investments*: Latvian railways LDz and PMR own sources (2008-2016), Eurostat (1995-2007), ECMT (1993-1994), missing data for 1982-1992 estimated based on extrapolations; *O&M*: national railways LDz and PMR own sources (2008-2016), missing data for 1995-2007 estimated based on default parameters; - *Investments*: national railways LDz and PMR own sources (2008-2016), missing data for 1982-1992 estimated based on national average shares; *O&M*: Eurostat (2008-2013), missing data for 2014-2016 and 1995-2007 estimated based on national average shares.
Lithuania	- Total expenditures	- *Investments*: Lithuanian railways JSC and Railway infrastructure Directorate (1996-2016), missing data for 1982-95 estimated based on extrapolations;

Country	Data description	Data source/Estimation approach
	- Breakdown expenditures	*O&M*: Lithuanian railways JSC and Railway infrastructure directorate (2000-2016), missing data for 1995-1999 estimated based on extrapolations. - *Investments*: Lithuanian railways JSC and Railway infrastructure directorate (1996-2016), missing data for 1982-95 estimated based on national average shares; *O&M*: Lithuanian railways JSC and Railway infrastructure directorate (2000-16), missing data for 1995-1999 estimated based on national average shares.
Luxembourg	- Total expenditures - Breakdown expenditures	- *Investments*: RMMS (2008-13 and 2015-2016), OECD (2014 and 1995-2007), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation; *O&M*: national railways CFL financial statement (2014-2016), missing data for 1995-2013 estimated based on national default parameters. - *Investments*: RMMS (2008-2013 and 2015-2016), remaining years estimated based on national average shares; *O&M*: RMMS (2016), OECD (2014-2015), OECD (1995-2013).
The Netherlands	- Total expenditures (also HS) - Breakdown expenditures	- National accounts (1997-2016), Statistics Netherlands (1983-1996), CE Delft and VU (2004) (1982). - Breakdowns are based on annual national accounts and annual reports ProRail (rail infrastructure manager)
Poland	- Total expenditures - Breakdown expenditures	- *Investments*: RMMS (2015-2016 and 2008-2012), railway infrastructure manager PKP PLK (2013-14 and 2002-2009), OECD (2010 and 1990-2001), missing data for 1982-1989 estimated as average value 1990-99; *O&M*: PKP PLK (2016 and 2005-2009), OECD (2010-2015 and 1995-2004). - *Investments*: RMMS (2015), PKP PLK (2013-2014 and 2002-2009), OECD (2010 and 1990-2001), remaining years estimated based on national shares; *O&M*: PKP PLK (2016 and 2005-2009), remaining years estimated based on national shares.
Portugal	- Total expenditures - Breakdown expenditures	- *Investments*: INE National Statistics (1995-2016), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation; *O&M*: estimated based on national default parameters and data for maintenance (see below). - *Investments*: RMMS (2008-2013 and 2014-2016), remaining years estimated based on national average shares; *O&M*: infrastructure operator Infraestruturas de Portugal SA (2014-2016), RMMS (2011-2012), OECD (2001-2010), Eurostat (1995-2000).
Romania	- Total expenditures	- *Investments*: Romanian Railway Infrastructure manager CFR (2002-2016), OECD (1995-2001), ECMT (1987-1994), missing data for 1982-1986 estimated as average values (1987-2016); *O&M*: CFR Infrastructura (1999-2016); O&M/maintenance: CFR Infrastructura (2011-2016), RMMS (2008-2010), OECD (2001-2007), missing data for 1999-2000 estimated based on national default parameters, missing data for 1995-1998 estimated as average value (1999-2008).

Country	Data description	Data source/Estimation approach
	- Breakdown expenditures	*Investments*: estimated based on national average shares using RMMS values (2008-2013 and 2014-2016); *O&M*: for 2000-2016 see above, missing data for 1995-1999 estimated based on national average shares.
Slovakia	- Total expenditures - Breakdown expenditures	- *Investments*: Slovak Rail ZSR Annual report 2016, OECD (2015-1995). ECMT (1987-1994), missing data for 1982-1987 estimated as average of 1987-2016 values; *O&M*: Slovak Rail ZSR (1998-2016), remaining years estimated based on national default parameters using Eurostat (1999-2007) and OECD (1995-1998) values for maintenance. - *Investments*: estimated based on national average shares, using RMMS shares for 2008-2009 and 2014-2016; *O&M*: Slovak Rail ZSR (2008-2016), Eurostat (1999-2007) and OECD (1995-1998).
Slovenia	- Total expenditures on all rail - Breakdown expenditures	- *Investments*: Slovenian Ministry of Infrastructure (2016), Eurostat (1995-2015), ECMT (1994-1995), missing data for 1982-1993 estimated as average of 1992-2012 values; *O&M*: Slovenian Ministry of Infrastructure (2011-2016), missing data for 2000-2010 estimated based on national default parameters using OECD data on maintenance, 1995-1999 estimated as average of 2000-2006 values. - *Investments*: Slovenian Ministry of Infrastructure (2016), RMMS (2008-2010 and 2014-2015), remaining years estimated based on national average shares; *O&M*: Slovenian Ministry of Infrastructure (2011-2016), OECD (2000-2010), missing data for 1982-1993 estimated based on national average shares.
Spain	- Total expenditures on other rail - Total expenditures on High Speed rail - Breakdown expenditures	- *Investments*: Spanish Railways Renfe (2013-2014) and (2006-2007), RMMS (2015-2016 and 2008-2013), Eurostat (1994-2002 and 2004), ECMT (1982-1984; 1987-1994), missing data for 2003, 2005 and 1985-86 estimated based on interpolation. *O&M*: Renfe (2006-2016), missing data for 1995-2005 estimated based on national default parameters. - *Investments*: RMMS (2015-2016), missing data for 2000-2014 estimated based on unit cost of HS line in Spain (Trabo et al., 2013), proportionally to HS network length and evenly distributed over the 15 year period. *O&M*: estimated based on national default values, calculated using RMMS data for 2015-2016. - *Investments*: RMMS (2015-2016 and 2008-2013), remaining years estimated based on national average shares; *O&M*: Renfe (2006-2016), OECD (1995-2002 and 2004), missing data for 2003 and 2005 estimated based on interpolation.
Sweden	- Total expenditures	- *Investments*: Annual reports Trafikverket (2006-2016), Annual reports Banverket (2003-2005), missing data for 2001-2002 estimated based on Trafikverket information, Eurostat (1995-2000), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation; *O&M*: Annual reports Trafikverket (2006-2016), missing data for 2003-2005 estimated using information from annual reports Banverket, missing data for 1995-2002 estimated using information from Eurostat.

Country	Data description	Data source/Estimation approach
	- Breakdown expenditures	- For years 1995-2016 see above, missing values for Investments (1982-1994) estimated based on national average shares.
United Kingdom	- Total expenditures on other rail	- *Investments*: Infrastructure operator NetworkRail (1995-2016), 1994 estimated based on interpolation, 1982-1993 from "Gourvish, British Rail 1974-1997. From Integration to privatisation" *O&M*: NetworkRail (1996-2016), missing data 1995 estimated as average 1996-2000 values.
	- Total expenditures on High Speed rail	- *Investments*: RMMS (2015-2016), missing values for 2000-2014 estimated based on unit cost of HS line in UK (Trabo et al., 2013), proportionally to HS network length and evenly distributed over the 15 year period. *O&M*: NetworkRail (2016), remaining years estimated based on national default parameters.
	- Breakdown expenditures	- *Investments*: see above; *O&M*: NetworkRail (1996-2016), missing data for 1995 estimated based on national average shares.
Norway	- Total expenditures on other rail	*Investments*: Annual reports Jernebaneverket (2016-2016), Eurostat (2004-2014), OECD (1995-03), ECMT (1982-1984; 1987-1994), missing data for 1985-1986 estimated based on interpolation; *O&M*: Annual reports Jernebaneverket (2015-2016 and 2005), 2011-2014 and 2006-2008 estimated combining data from Eurostat and Jernebaneverket, 2009-2010 estimated based on interpolation, 2011-2014 and 2006-2008 estimated combining data from OECD and Jernebaneverket.
	- Total expenditures on High Speed rail	- *Investments*: missing data for 2004-2016 estimated based on data from Jernebaneverket Annual Reports (Flytoget 1995-1998); *O&M*: 2011-16 estimated based on data from Jernebaneverket Annual Reports, remaining years estimated based on national default parameters.
	- Breakdown expenditures	- *Investments*: 1995-2016 see above; remaining years estimated based on national average shares; *O&M*: estimated as based on national average shares.
Switzerland	- Total expenditures on all rail	- *Investments*: 2016 Annual Reports of BLS Netz AG and SBB, OECD (1995-2005), missing data for 1982-94 estimated based on extrapolation; *O&M*: Annual Reports of BLS Netz AG and SBB (2015-2016), remaining years estimated based on national default parameters using OECD data on maintenance.
	- Total expenditures on High Speed rail	- *Investments*: personal information on Lötschberg and Gotthard HS axis; *O&M*: estimated based on default parameters used for Investments.
	- Breakdown expenditures	- *Investments*: 1995-2016 personal information from Federal office for Transport; 1982-1994 estimated based on national average shares; *O&M*: Annual Reports of BLS Netz AG and SBB (2015-2016), OECD (1995-2014); HS/O&M: estimated based on national average shares.
Canada (Alberta and British Columbia)	- Total expenditures	- *Investments*: 1995-2016 estimated based on OECD country-level values, proportionally to the state share in total national freight track length, missing data for 1982-1994 estimated based on extrapolation;

Country	Data description	Data source/Estimation approach
United States (California and Missouri	 - Breakdown expenditures	*O&M*: estimated based on average unit O&M expenditure in Canada and USA, multiplied by the state rail network length. Unit expenditure assumed 100.000 €/km, estimating on data from ORR (2012) and COMPASS (2017). O&M expenditures assumed to be constant over time (1982-2016). - Estimated based on UK national average shares.
Japan	- Total expenditures on other rail - Total expenditures on High Speed rail - Breakdown expenditures	- *Investments*: OECD (1995-2014), missing data for 2015-2016 estimated based on extrapolation, missing data for 1982-1994 estimated as average of OECD (1995-2014) values; *O&M*: estimated based on average unit O&M expenditure in Japan, multiplied by the national rail network length. Unit expenditure estimated as 248 mJPY/km, based on data from Takikawa (2016). - Estimated based on national default parameters, using data from Japan Railway Construction, Transport and Technology Agency (JRTT). - Estimated based on national average shares, using data from Takikawa (2016).

A.4 Data sources IWT

The data sources used to collect data on IWT infrastructure expenditures are presented (per country) in Table 31. This table also briefly presents the approaches used to estimate any missing data.
For more information on the default values used to make the relevant breakdowns, see Section 5.3.

Table 31 - Data sources used for IWT infrastructure

Country	Data description	Data source/Estimation approach
Austria	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995; 2002-2012); 2016 was found in the Annual Report of viadonau; Data for the Years 1982-1985 were taken from: ECMT, Investment in Transport Infrastructure in ECMT Countries, 1988; Data for the Years 1985-1995 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the years 1996-2001 were estimated by regression on the basis of Eurostat Data about governmental investments. For the O&M expenditures the same sources were used in the same way. - The Breakdown was done with the default values.
Belgium	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1996-2016); Data for the Years 1982-1985 were taken from: ECMT, Investment in Transport Infrastructure in ECMT Countries, 1988; Data for the Years 1985-1995 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the years 1985-1986 were estimated by linear extrapolation. For the O&M expenditures the OECD-data were taken. - The Breakdown was done with the default values.
Bulgaria	- Total expenditures	- OECD-Data for Investments (2014-2016); Data for the years 1996-2015 were estimated by regression on the basis of Eurostat Data about governmental investments. For the O&M expenditures the OECD-data were taken for the years 2002-2016; Data for the years 1995-2001 were estimated by regression on the Basis of Eurostat data and the investment data.

Country	Data description	Data source/Estimation approach
	- Breakdown expenditures	- The Breakdown was done with the default values. The Breakdown of the O&M expenditures had been done with the help of Fairway Danube, National Action Plans, update May 2017.
Croatia	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1998-2013); Data for the years 1982-1997 and for the years 2014-2016 were estimated by regression on the basis of Eurostat Data about governmental investments. For the O&M expenditures the OECD-data were taken for the years 1998-2013; Data for the years 1995-1998 and the years 2014-2016 were estimated on the Basis of Eurostat data and the investment data. - The Breakdown was done with the default values.
Czech Republic	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995-2016); Data for the years 1993-1994 and were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the years 1982-1992 were estimated by linear extrapolation. For the O&M expenditures the OECD-data were taken for the years 1995-2002 and 2005-2016; Data for the years 2003-2004 were estimated by linear extrapolation. - The Breakdown was done with the default values.
Finland	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995-2016); Data for the Years 1982-1985 were taken from: ECMT, Investment in Transport Infrastructure in ECMT Countries, 1988; Data for the Years 1985-1994 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the years 1985-1986 were estimated by linear extrapolation. For the O&M expenditures the OECD-data were taken for the years 1995-2016. - The Breakdown was done with the default values.
France	- Total expenditures - Breakdown expenditures	- VNF data were taken for the investments. OECD-Data for were taken for the O&M expenditures. - Based on the same sources as total expenditures.
Germany	- Total expenditures - Breakdown expenditures	- Data from the Ministry of Finance. - Based on the same sources as total expenditures.
Hungary	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995-2016); Data for the Years 1987-1994 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the years 1982-1986 were estimated by linear extrapolation. OECD-Data for O&M expenditures (1995, 2004-2016); Data for the Years 1996-2003 were estimated by regression based on the Eurostat Data about governmental expenditures. - The Breakdown was done with the default values The Breakdown of the O&M expenditures had been done with the help of Fairway Danube, National Action Plans, update May 2017.
Italy	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995-2016); Data for the Years 1982-1983 were taken from: ECMT, Investment in Transport Infrastructure in ECMT Countries, 1988; Data for the Years 1986-1994 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the years 1984-1985 were estimated by linear extrapolation. OECD-Data for O&M expenditures (1995-2016);missing O&M expenditures for 2002, 2004, and 2006 were estimated by linear extrapolation. - The Breakdown was done with the default values.

Country	Data description	Data source/Estimation approach
Lithuania	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995-2016); Data for the Years 1993-1994 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the years 1982-1992 were estimated by linear extrapolation. OECD-Data for O&M expenditures (1995-2016). - The Breakdown was done with the default values.
Luxembourg	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995-2016); Data for the Years 1982-1984 were taken from: ECMT, Investment in Transport Infrastructure in ECMT Countries, 1988; Data for the Years 1995-1994 were estimated by linear extrapolation. OECD-Data for O&M expenditures (1995-2016). - The Breakdown was done with the default values.
The Netherlands	- Total expenditures - Breakdown expenditures	- *State inland waterways*: national accounts (2002-2016), Statistics Netherlands (1992-2001), CE Delft (2014) (1982-1991). Missing O&M expenditures for 1995-1997 are estimated by linear extrapolation. *Other inland waterways*: Statistics Netherlands (1998-2016), CE Delft (2014) (1982-1997). Missing O&M expenditures for 1995-1997 are estimated by linear extrapolation. - Based on the same sources as total expenditures.
Poland	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995-2016); missing data were estimated by linear extrapolation; Data for the Years 1985-1995 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the Years 1982-1984 were estimated by linear extrapolation. OECD-Data for O&M expenditures (1995-2016); missing data were estimated b regression based on the Eurostat Data about governmental expenditures. - The Breakdown was done with the default values.
Romania	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments, data from the Galati Lower Danube River Administration R.A., Administration of the Navigable Canals of Romania (1995-2016); Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the Years 1982-1984 were estimated by linear extrapolation. OECD-Data for O&M expenditures, data from the Galati Lower Danube River Administration R.A., Administration of the Navigable Canals of Romania (1995-2016). - The Breakdown was done with the default values.
Slovakia	- Total expenditures - Breakdown expenditures	- OECD-Data for Investments (1995-2016); missing data were estimated by linear extrapolation; Data for the Years 1985-1995 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the Years 1982-1984 were estimated by linear extrapolation. OECD-Data for O&M expenditure, missing data were estimated by linear extrapolation. - The Breakdown was done with the default values.
Switzerland	- Total expenditures	- OECD-Data for Investments (1995-2016); missing data were estimated by linear extrapolation; Data for the Years 1985-1995 were taken from: ECMT, Investment in Transport Infrastructure 1985-1995, Volume 2. 1999; Data for the Years 1982-1984 were estimated by linear extrapolation. O&M expenditure were estimated by a regression based on Eurostat data.

Country	Data description	Data source/Estimation approach
	- Breakdown expenditures	- The Breakdown was done with the default values.
Missouri (state in United States)	- Total expenditures - Breakdown expenditures	- Data for Investments (2011-2016) were given by Missouri Ports, missing data were estimated by linear extrapolation; O&M expenditure were estimated as a fixed relation to the investment. - The Breakdown was done with the default values.

A.5 Data sources maritime transport

The data sources used to collect data on maritime port infrastructure expenditures are presented (per port) in Table 32. This table also briefly presents the approaches used to estimate any missing data. The breakdown to fixed and variable costs is for all ports estimated based on the approach presented in Section 6.3. This is not repeated in Table 32.

Table 32 - Data sources used for maritime port infrastructure

Port	Data description	Data source/Estimation approach
Antwerp (BE)	Total expenditures and breakdowns	Annual report 2016.
Varna (BG)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Limassol (CY)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Hamburg (DE)	Total expenditures and new infrastructure expenditures & O&M	Annual report 2016, breakdowns are based on the average breakdowns.
Bremerhaven (DE)	Total expenditures and new infrastructure expenditures & O&M	Port authority, financial reports, breakdowns are based on the average breakdowns.
Travemünde (DE)	Total expenditures and breakdowns	Port authority, Mr. Siemensen by phone.
Aarhus (DK)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Helsingør (DK)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Tallinn (EE)	Total expenditures and breakdowns	Annual report 2016.
Algeciras (ES)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Valencia (ES)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Barcelona (ES)	Total expenditures and breakdowns	Annual report 2016.
Bilbao (ES)	Total expenditures and breakdowns	Annual report 2016, breakdowns are based on the average breakdowns.
Helsinki (FI)	Total expenditures and breakdowns	Annual report 2016.
Marseille (FR)	Total expenditures and breakdowns	Annual report 2016.
Le Havre (FR)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Calais (FR)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.

Port	Data description	Data source/Estimation approach
Pireaus (GR)	Total expenditures and new infrastructure expenditures & O&M	Annual report 2016, breakdowns are based on the average breakdowns.
Rijeka (HR)	Total expenditures and breakdowns	Annual report 2016.
Split (HR)	Total expenditures and breakdowns	Annual report 2016.
Dublin (IR)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Trieste (IT)	Total expenditures and breakdowns	Port authority, financial report.
Genova (IT)	Total expenditures and breakdowns	Port authority, financial report.
Venice (IT)	Total expenditures and breakdowns	Port authority, financial report.
Klaipeda (LT)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Riga (LV)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Marsaxxlokk (MT)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Rotterdam (NL)	Total expenditures and breakdowns	By questionnaire, port authority.
Oslo (NO)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Gdansk (PL)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Sines (PT)	Total expenditures and breakdowns	Annual report 2016.
Constanta (RO)	Total expenditures and breakdowns	Financial report 2016, port authority.
Gothenburg (SE)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Koper (SL)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Felixstowe (UK)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Vancouver (CA)	Total expenditures and new infrastructure expenditures & O&M	Annual report 2016, breakdowns are based on the average breakdowns.
Montreal (CA)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Los Angeles (US)	Total expenditures and breakdowns	Annual report 2016, Port of Los Angeles
Savannah (US)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.
Tokyo (JP)	Total expenditures and new infrastructure expenditures & O&M	Cost figures were estimated based on the available handled tons and on calls per port multiplied with the averages found for the ports for which data was available.

A.6 Data sources aviation

The data on infrastructure costs of airports are taken from the annual reports and/or websites of the relevant airports.

B Review of different cost estimation methods

B.1 Introduction

In general, three methods can be distinguished to estimate road infrastructure costs: the Direct expenditures method, the Perpetual Inventory Method (PIM) and the Synthetic Method (Fraunhofer-ISI & CE Delft, 2008; ITF, 2013b; The Conference Board of Canada, 2013). In this Annex we describe all three methods (in Annexes B.2 to B.4) and discuss their advantages and disadvantages. Based on this description, the method(s) to be used in this study is selected in Annex B.4.

B.2 Direct expenditures method

The direct expenditures method is based on observations of expenditures in the year that they occur, regardless of whether or not the expenditures are capital in nature (The Conference Board of Canada, 2013). In other words, the infrastructure costs in 2016 are assumed to be equal to the infrastructure expenditures done in 2016. Some studies (e.g. NTC, 2005) do use a three- or five-year average of expenditures to smooth out any major fluctuations in annual expenditures.

The direct expenditures method is applied by varies (particularly non-European) studies (e.g. (Craighead, 2018; FHWA, 1997; NTC, 2005; The Conference Board of Canada, 2013). Its simplicity is the main advantage of this method, as only data on current expenditures is required to calculate the infrastructure costs. However, it ignores the fact that current investments in transport infrastructure have little relation to current use of that infrastructure (ITF, 2013b; Fraunhofer-ISI & CE Delft, 2008; The Conference Board of Canada, 2013). Current investments are, in fact, for servicing transport demand in the next 30 to 50 years, and bears no obvious relationship to the infrastructure costs imposed by current traffic. Additionally, as explained in Section 2.3.1, the direct expenditures method may result in very volatile cost estimates over years (even if a long-year average is taken) due to the fact that investment projects can vary significantly from year to year.

B.3 Perpetual Inventory Method

The most widespread used approach to estimate infrastructure costs is the Perpetual Inventory Method (PIM). This approach has been applied in several EU wide studies (e.g. CE Delft, 2016a; 2016b), but also in various national studies, e.g. for Canada (Transport Canada, 2008), Denmark (COWI, 2004). The Netherlands (CE Delft & VU, 2014), Switzerland (BSF, 2014) and the UK (ITS, 2001).

The Perpetual Inventory Method (PIM) distinguishes between investments and operation and maintenance costs. The latter are, in line with the direct expenditures method, based on running expenditures. Investments, on the other hand, are generally calculated based on a long time series of investment expenditure data. For each category of investments (in this study enhancement and renewal costs), the initial expenditures are distributed over the lifetime of the infrastructure in order to calculate the annual depreciation costs. In addition, financing or capital costs are calculated by multiplying the value of the capital (current value of the total transport infrastructure considered) with an appropriate interest rate. The sum of depreciation and financing costs equal the investment costs. The calculation of depreciation and financing costs according to the PIM approach is illustrated by a simplified example in the text box.

Example: calculating investment cost using the PIM approach
Assume that in the period 2007-2016 annually € 1 million is invested in transport infrastructure and that each investment has an expected lifetime of 10 years. Furthermore, an interest rate of 4% is assumed.

To calculate the total depreciation cost for this transport infrastructure in 2016, the depreciation costs of each individual investment that has not yet been fully written down should be summed. Assuming a linear depreciation approach, the annual depreciation cost for each individual investment is equal to € 100,000, and hence the total depreciation costs in 2016 are equal to € 1,000,000.

To estimate the financing costs, first the economic value of the investments in 2016 (i.e. the value of the capital stock) should be estimated. The investment done in 2007 has been written down for 90%, so its economic value in 2016 is only € 100,000. By the same reasoning, it can be calculated that economic value in 2016 of investments done in 2008 is € 200,000, and so on. By summing the economic values of the individual investments, the total economic value of the transport infrastructure in 2016 can be calculated, i.e. € 5.5 million. Multiplying this total economic value with the interest rate (4%) gives the annual financing costs in 2016: € 220,000.

The total investment costs in 2016 are equal to € 1,000,000 + € 220,000 = € 1,220,000. Compared to the average annual expenditures (€ 1,000,000) these costs are considerably higher.

An alternative way to estimate the investment costs by the PIM approach is by using replacement cost indicators (Fraunhofer-ISI & CE Delft, 2008). By multiplying the current transport infrastructure assets with appropriate replacement costs, the total value of the infrastructure (and hence annual investment costs) can be calculated. To our knowledge this approach has only be applied in New Zealand (Booz Allen Hamilton, et al., 2005). Its main disadvantage is that there is no actual relationship between the current replacement costs and the existing assets (Fraunhofer-ISI & CE Delft, 2008).

The main advantage of the PIM approach it that it is compatible with the common accounting philosophies of public budgets (Fraunhofer-ISI & CE Delft, 2008; ITF, 2013b). It expresses the economic costs which past investment decisions and the existence of the infrastructure network cause in the accounting period. An important disadvantage of the PIM approach is the fact that long time series of investment data are needed, which are not always available. Additionally, as the PIM model reflect the depreciation of historical expenditures rather than physical assets, it abstracts from physically existing networks. Infrastructure assets that are full written down, are no longer considered by the PIM approach, even if such assets still have some economic value (and may require renewal costs in the near future).

B.4 Synthetic method

An alternative approach to estimate enhancement and renewal costs is by assessing future financing needs of the present infrastructure, the so-called Synthetic method (Fraunhofer-ISI & CE Delft, 2008; ITF, 2013b; The Conference Board of Canada, 2013). In the past, the Synthetic Method has been applied to estimate the road infrastructure costs in Germany (ProgTrans; IWW, 2007)) and Austria (Herry ; IW ; NEA , 2002).

The Synthetic method starts from a complete inventory of infrastructure assets for the base year. For every type of infrastructure asset a replacement value is estimated, reflecting the infrastructure's dimensions, load, location and the latest technical standards and specifications. Depreciation and interest costs are calculated taking into account the age, past and projected traffic loads and the physical condition of the asset. Operation and maintenance costs are, in line with the PIM approach, based on running expenditures.

An important advantage of the Synthetic method is that it takes the current condition of the transport infrastructure into account, such that investment backlogs can be reflected (Fraunhofer-ISI & CE Delft, 2008). Furthermore, it can react dynamically to different future scenarios of traffic demand developments. The Synthetic method can be considered a relevant decision support tool as it indicates the sum of money required to maintain the quality of the network at a certain level (in various transport demand scenarios). A disadvantage of the Synthetic approach is that it don’t provide a figures of the actual cost made to realise the existing transport infrastructure. Furthermore, the data requirement to apply the Synthetic approach are demanding, i.e. excessive data on physical infrastructure assets and their current condition is required to apply this approach.

B.5 Selected method(s)

Based on the review of methods presented above, the PIM approach was selected to be used in this study. This method calculates the current infrastructure costs based on actual historic expenditures, reflecting the actual cost caused by current use of transport infrastructure. The Synthetic Method, on the other hand, is more of a decision support tool as it indicates the amount of money that should be invested to maintain the quality of the network at a certain level. For that reason, the Synthetic method is not very appropriate to use in this study. Furthermore, the required data to apply this method (i.e. an inventory of the existing transport infrastructure assets) is not easily available for all relevant countries. In contrast, data on historic investments in road, rail and IWT infrastructure (as required to apply the PIM approach) is available (to some extent) for all relevant countries.

The PIM approach (and also the Synthetic method) is preferred to the direct expenditures approach, as it considers a cost approach instead of an expenditure approach. However, as is explained in Section 2.4.3, for maritime transport we have applied the direct expenditure approach. As for the maritime ports considered in this study no time series on investments was available, it was not possible to apply the PIM approach and applying the direct expenditures approach was the best possible fall-back option.

C Input data

C.1 Introduction

In this Annex the main input data used to estimate the infrastructure expenditures and costs figures are presented. These input data include transport infrastructure data (length of networks) and vehicle characteristics data (e.g. vehicle weight). The transport performance data used is discussed in Section 1.3.4.

C.2 Road transport

In this section we present the input data for road transport, addressing both vehicle characteristics and transport infrastructure data. With respect to the vehicle characteristics it is also explained how these are used to allocate the total road infrastructure costs to the various vehicle categories.

Vehicle characteristics

In order to allocate the total road infrastructure cost to the various vehicle categories, some assumptions on vehicle characteristics have been made. The assumptions used are presented in Table 33.

Table 33 - Vehicle characteristics road used to allocate total infrastructure costs

Vehicle category	Passenger Car Equivalent	Weight (tonnes)[a]	Number of axles	Axle configuration	4^{th} power axle load[b]
Passenger car	1	1.3	2	Single	3.6×10^{-5}
Motorcycle	0.5	0.4	2	Single	3.2×10^{-7}
Bus	2	15	2	Single	6.3×10^{-1}
Coach	2	13.5	2	Single	4.2×10^{-1}
Van	1.2	1.8	2	Single	1.3×10^{-4}
HGV 3.5-7.5t	1.7	5	2	Single	7.8×10^{-3}
HGV 7.5-16t	2.6	7.5	3	Single	1.2×10^{-2}
HGV 16-32t	3.9	16	4	Tandem	1.0×10^{-1}
HGV > 32t	4.7	20	5	Tridem	1.4×10^{-1}

Sources: CE Delft and VU (2014), Fraunhofer-ISI and CE Delft (2008), Eurostat; Adaptations made by CE Delft.

a The weight of HGVs is based on both loaded and empty rides.

b The fourth power axle load is calculated by using the following formulae: $\{K_i \; x \; (\frac{A}{10})\}^4$, where A is the actual axle load, i the number of axle groups and K a correction factor for the axle configuration (K = 1 for a single axle, 0.6 for a tandem axle and 0.45 for a tridem axle).

As explained in Section 3.3, road infrastructure costs are allocated based on vehicle kilometres, PCE-kilometres and 4^{th} power axle load kilometres. PCE-kilometres and 4^{th} power axle load kilometres are calculated by multiplying vehicle kilometres per vehicle category with the relevant PCE indicators and 4^{th} power axle loads (as presented in Table 33), respectively. For the allocation of a specific cost category (e.g. variable maintenance costs) to a vehicle category, the share of this vehicle category in total vehicle, PCE and/or 4^{th} power axle load kilometres is calculated and multiplied with the total size of the cost category. An illustrative example is provided in the following text box to explain the use of the vehicle characteristics in the allocation of road infrastructure costs.

Example: allocation of road infrastructure costs

Assume the variable maintenance costs of road infrastructure in a country are equal to € 100 million in 2016. Furthermore, assume that in this country only passenger cars and HGVs > 32 t make use of the road infrastructure. Total vehicle kilometres by passenger cars and HGVs are in 2016 equal to 3 billion and 5 million, respectively.

As explained in Section 3.3, the variable maintenance costs are fully allocated based on 4^{th} power axle load kilometres. Using the parameters from, the 4^{th} power axle load kilometres of passenger cars and HGVs can be estimated to be equal to 0.036 million and 0.68 million, respectively. The share of passenger cars in total 4^{th} power axle load kilometres equals about 5% and hence 5% of variable maintenance costs are allocated to passenger cars (and 95% to HGVs).

Transport infrastructure

Table 34 presents the length of the road network in the various countries.

Table 34 - Road infrastructure network length in 2016 (kilometres)

Country	Motorways	All roads
EU28	134,321	6,265,212
EU27	130,552	5,843,951
AT	1,719	138,207
BE	1,763	155,210
BG	2,379	64,350
HR	1,310	26,706
CY	272	9,855
CZ	776	130,657
DK	1,237	74,496
EE	147	58,828
FI	5,168	457,513
FR	11,599	1,088,746
DE	36,320	643,164
EL	1,589	117,352
HU	1,884	204,882
IE	916	98,898
IT	18,948	706,886
LV	-	70,829
LT	352	82,911
LU	969	17,394
MT	-	2,854
NL	2,756	139,124
PL	1,063	286,004
PT	18,915	88,310
RO	1,778	204,875
SK	463	54,857
SI	773	38,896
ES	15,336	667,056
SE	2,119	215,091
UK	3,769	421,261

Country	Motorways	All roads
NO	392	94,842
CH	1,440	71,520
CA-AB	4,448	240,948
CA-BC	7,040	94,140
US-CA	3,943	290,969
US-MO	2,220	212,124
JP	75,000	1,277,000

Sources :

- Motorways : EU Statistical Pocketbook. There are no motorways in Latvia and Malta.
- All roads: mainly based on EU Statistical pocketbook. However, for some countries figures from other sources are used or the figures from the EU Statistical Pocketbook have been corrected. More specifically:
  - Bulgaria: Urban roads are missing in figures presented by EU Statistical Pocketbook. Added based on Ecorys (2006).
  - Finland: Based on CIA (2018).
  - Germany: Urban roads are missing in figures presented by EU Statistical Pocketbook. Added based on Fraunhofer-ISI and CE Delft (2008).
  - Italy: Based on national statistics.
  - Lithuania: Based on national statistics.
  - Luxembourg: Urban roads are missing in figures presented by EU Statistical Pocketbook. Added based on Fraunhofer-ISI and CE Delft (2008).
  - Poland: Corrected based on national statistics.
  - Portugal: Urban roads are missing in figures presented by EU Statistical Pocketbook. Added based on Fraunhofer-ISI and CE Delft (2008).
  - Romania: Urban roads are (partly) missing in figures presented by EU Statistical Pocketbook. Added based on Robertson and Stanciu (unknown).

C.3 Rail transport

In this section we present the input data for rail transport, i.e. rail infrastructure data. The length of the rail networks in the various countries is given in Table 35. These figures refer to rail track-kilometres (and not rail line kilometres).

Table 35 - Rail network length (track-kilometres)

Country	Conventional rail
EU28	322,497
EU27	305,048
AT	6,928
BE	6,842
BG	5,007
HR	2,858
CZ	11,410
DK	3,525
EE	1,643
FI	6,605
FR	49,306
DE	59,673
EL	2,763
HU	9,157
IE	2,603
IT	26,231

Country	Conventional rail
LV	2,225
LT	2,322
LU	429
NL	5,434
PL	27,283
PT	3,155
RO	13,547
SK	5,250
SI	1,539
ES	26,068
SE	12,921
UK	17,449
NO	5,227
CH	6,215
CA-AB	9,233
CA-BC	9,740
US-CA	8,521
US-MO	6,368

Sources:
- EU countries: EU Statistical Pocketbook;
- Non-EU countries: UIC (Japan), national data (Canada and US).

C.4 IWT

In this section we present the input data for IWT, i.e. IWT infrastructure data. The length of the IWT network in the various countries is given in Table 36.

Table 36 - IWT network length

Country	IWT network
EU28	40,469
EU27	40,469
AT	351
BE	1,516
BG	470
HR	1,017
CZ	720
FI	8,127
FR	4,822
DE	7,675
HU	1,864
IT	1,562
LT	446
LU	37
NL	6,256
PL	3,655
RO	1,779
SK	172
CH	5
US-MO	1,658

Sources: Eurostat (EU countries) and State Transportation Statistics (Missouri). Switzerland estimated by INFRAS.

D Expenditures per inhabitant

D.1 Introduction

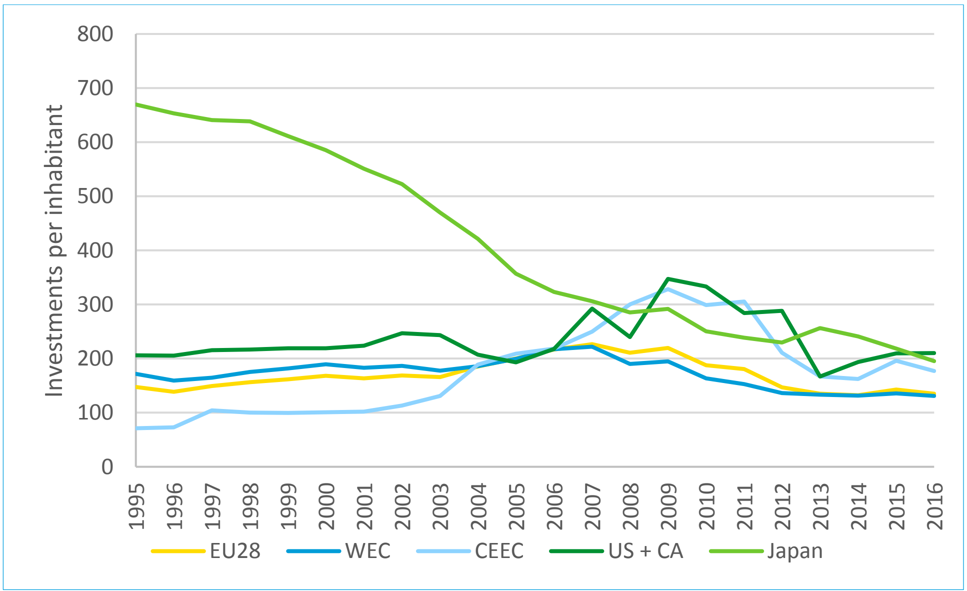
In Chapters 3, 4 and 5 infrastructure expenditures are presented as share of GDP as a benchmark for comparing expenditure levels between countries. An alternative benchmark is the road infrastructure expenditures per inhabitant of a country. Based on this benchmark the expenditure levels in (groups of) countries are compared in this Annex. This is done for road transport in Annex D.2, for rail transport in Annex D.3, and for IWT in Annex D.4.

D.2 Road transport

D.2.1 Investments

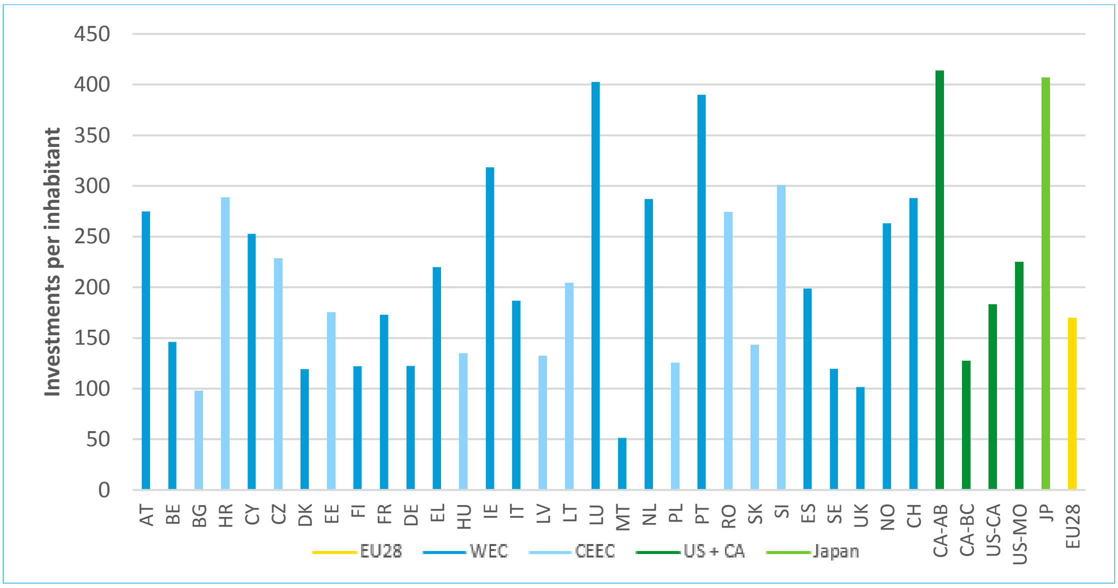
Figure 58 shows development of road investments per inhabitant over the period 1995-2016. The same trends as for the investments as share of GDP (see Section 3.4.1) can be identified. In the EU28 (and WEC), road investments per inhabitant increased slightly in the period 1995-2007 and fell afterwards (particularly due to the economic crisis). In the Central and Eastern European countries, investments per inhabitant increased particularly between 2002 and 2009, as these countries made great efforts (partly financed by European funding) to meet their needs for a high quality road network. After 2011 there was a sharp decrease in road investments per inhabitant in these countries, mainly as a result of the economic crisis. Finally, the declining trend in road investments in Japan is clearly shown by Figure 58: between 1995 and 2016 the investments per inhabitant declined from almost € 700 per person to about € 200 per person.

Figure 58 - Development of investments per inhabitant over time (€ per inhabitant, PPS adjusted)



The long-term average road investments per inhabitant are shown for the various countries in Figure 59. With respect to the European countries, Luxembourg has the highest investments per inhabitant. This can be explained by the relatively small number of inhabitants of Luxembourg. Also in Portugal the investments per inhabitant are relatively high, which is in line with the high investment levels in the end 1990s and the first decade of this century. The investment levels per inhabitant in both Portugal and Luxembourg are comparable with the levels in Japan.

Figure 59 - Investments per inhabitant (average for 1995-2016) per country (€ per inhabitant, PPS adjusted)



D.2.2 Operational and maintenance expenditures

The development of road O&M expenditures per inhabitant over the period 1995-2016 is presented in Figure 60. In the EU28 (and WEC), O&M expenditures per inhabitant have been rather stable over the period 1995-20007 and decreased in the period afterwards. In the Central and European we see an increase in O&M expenditures per inhabitant over the period 1995-2007, followed by a slight decrease between 2007 and 2011 and a sharp decrease in 2012. Since 2012, the O&M expenditures in these countries are at the same level as in the Western European countries. Figure 60 also shows that the road O&M expenditures per inhabitant in the US states are above average EU figures, probably because of the lower population densities. Finally, it is shown that O&M expenditures per inhabitant has fallen significantly in Japan, although this decreasing trend took mainly place between 1995 and 2005.

Figure 60 - Development of O&M expenditure per inhabitant over time (€ per inhabitant, PPS adjusted)

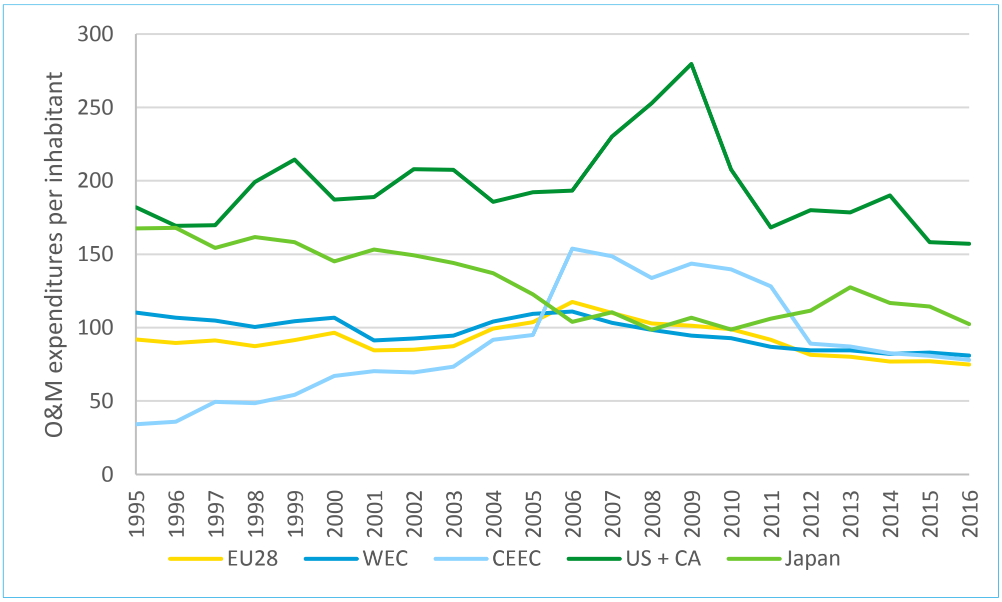
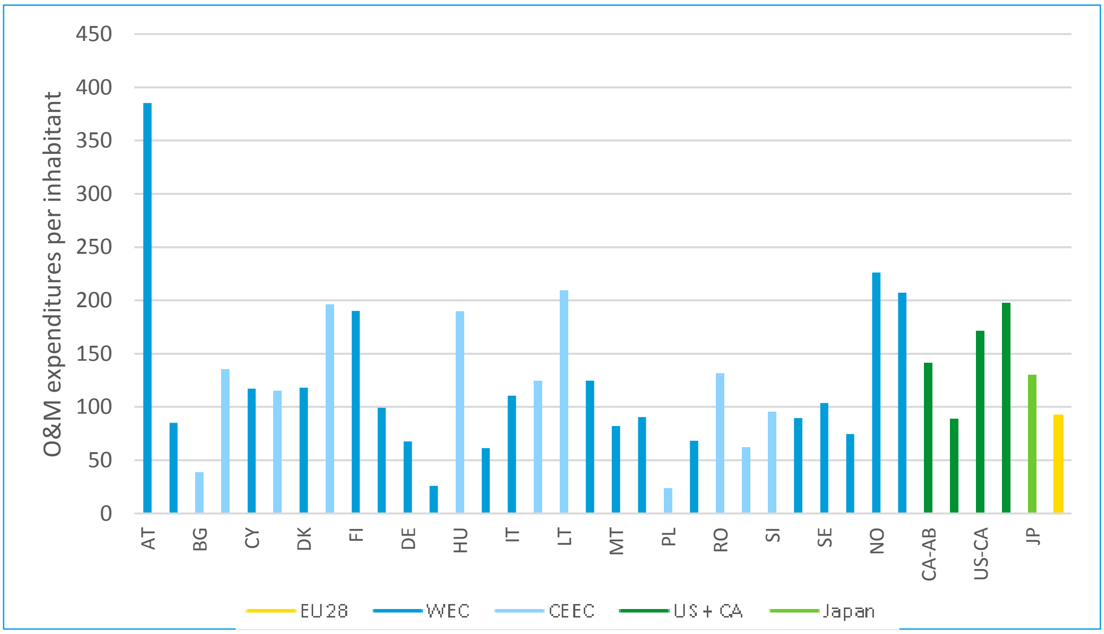


Figure 61 shows the long-term average O&M expenditures per inhabitant for the individual countries. These are highest in Austria, which is partly explained by the high O&M expenditures in Austria (see Section 3.4.2 for more details) and partly by the lower population density compared to countries like The Netherlands. Other counties with relatively high O&M expenditure levels per inhabitant are Norway, Switzerland, Lithuania, Estonia and Finland. These are all countries with relatively high O&M expenditure levels (e.g. per kilometre road network) and/or low population densities.

Figure 61 - O&M expenditures per inhabitant (average for 1995-2016) per country (€ per inhabitant, PPS adjusted)



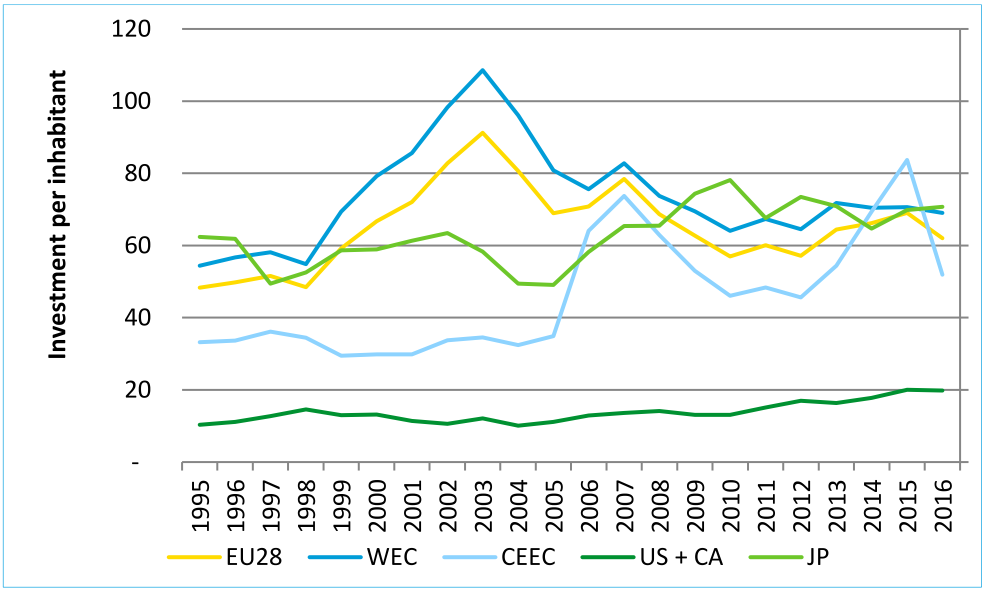
D.3 Rail transport

D.3.1 Investments

Figure 62 shows the development of rail investments per inhabitant over time. In the EU28 (and WEC) rail investments per inhabitant increased till 2003, followed by a sharp decrease between 2003 and 2010. Afterwards a slight increase in investments per inhabitant was found. In Central and Eastern European countries, investments per inhabitant were relatively stable between 1995 and 2005, followed by a sharp increase in 2006 and a kind of U-shape trend until 2016. As explained in Section 4.4.1, this trend shows the correlation between EU funding after accession to the Union of CEEC and spending for improvements of quality and efficiency of the networks of this group.

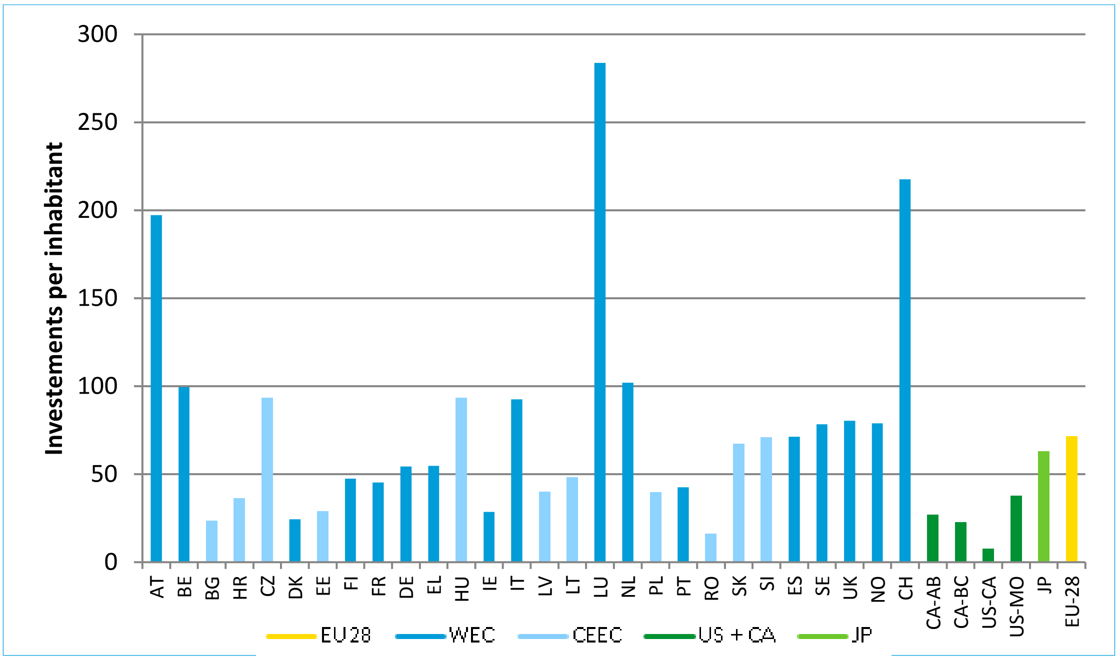
For the US and Canadian states/provinces, the annual rail investments per inhabitant are relatively stable over the period 1995-2005, followed by a slight increase until 2016. In these states/provinces, investments per inhabitant are, by the way, significantly lower than in European countries. In Japan, on the other hand, investments per inhabitant are at the same level as in Europe and showed a slightly increase over the entire period (particularly in the period 2005-2010).

Figure 62 - Development of investments per inhabitant over time (€ per inhabitant, PPS adjusted)



The long-term average rail investments per inhabitant are shown for the various countries in Figure 63. As we already mentioned in Section 4.4.1, investment levels in Austria, Switzerland and Luxembourg are relatively high (due to the realisation of some expensive railway projects).

Figure 63 - Investments per inhabitant (average for 1995-2016) per country (€ per inhabitant, PPS adjusted)

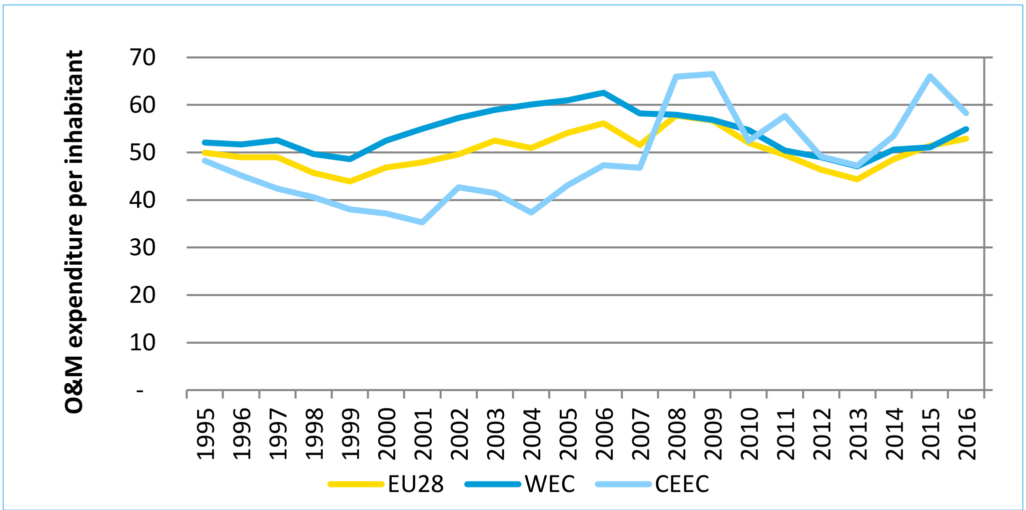


Note: There are no railways in Cyprus and Malta.

D.3.2 Operational and maintenance expenditures

Over the years, O&M expenditures per inhabitant show quite cyclical variations (see Figure 64). The trends of EU28 and WEC group are relatively similar. Initially the O&M expenditures decrease and then increases during the period from 1999 to 2006. Then, they steadily decreases in the years following and until 2013. More recently, the O&M expenditure per inhabitant raise again. In the CEEC our estimations indicate a constant reduction in O&M expenditures per inhabitant from 1995 to 2001, followed by a general increasing trend until 2009 and a U-shaped pattern over the last seven years.

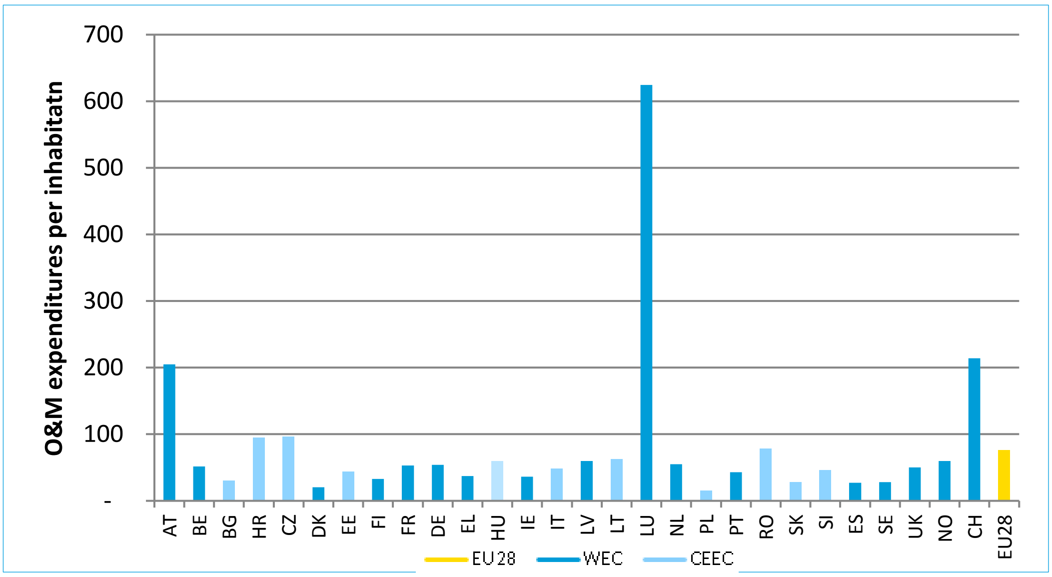
Figure 64 - Development of O&M expenditure per inhabitant over time (€ per inhabitant, PPS adjusted)



Note: For the US and Canadian states/provinces as well as for Japan, only data for 2016 were available.

Figure 65 shows the average O&M expenditures per inhabitant over the period 1995-2016 at country level. As discussed in Section 4.4.2, the highest value occurs in Luxembourg having a relatively high O&M expenditure levels and very low population. Annual O&M expenditures per inhabitant are high in Austria and Switzerland, because of the high cost due to network complexity and localisation in the Alpine region. At more aggregate level, the estimations for EU28, WEC and CEEC groups indicate O&M expenditures per inhabitant equal to 72, 87 and 51 euro, respectively.

Figure 65 - O&M expenditures per inhabitant (average for 1995-2016) per country (€ per inhabitant, PPS adjusted)



Notes:

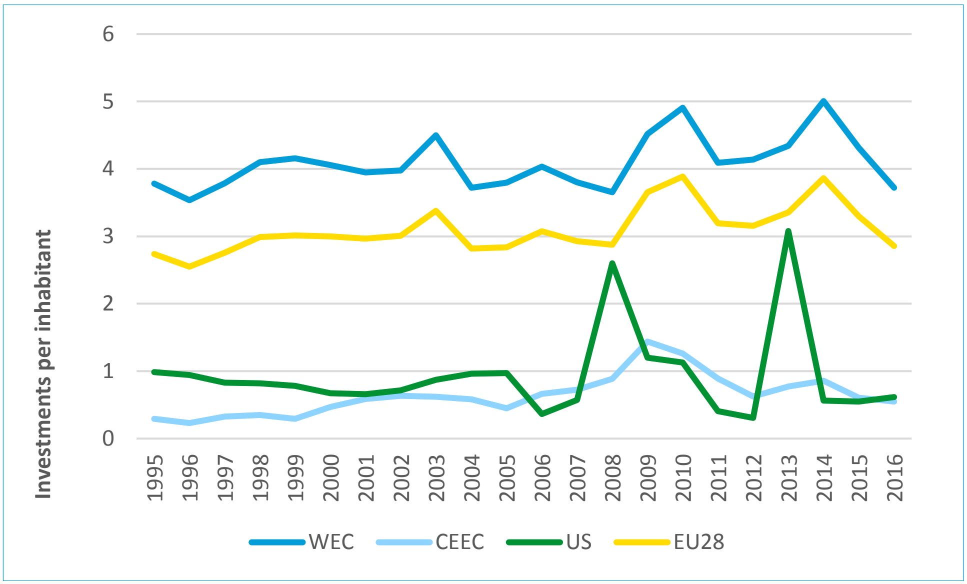
- for the US and Canadian states/provinces as well as for Japan, only data for 2016 were available;
- there are no railways in Cyprus and Malta.

D.4 Inland navigation

D.4.1 Investments

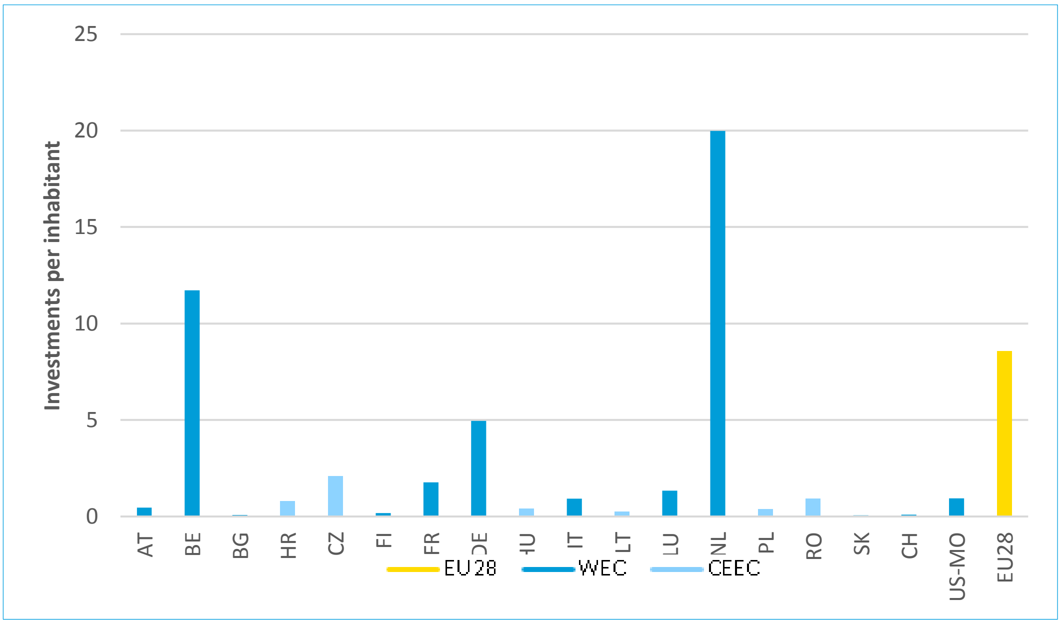
Figure 66 shows the development of IWT infrastructure investments per inhabitant over time.
The investment in inland waterways per inhabitant is quite stable in the EU28 and the WEC. The same holds for the investments per inhabitant of the CEEC. The variance in the investments per inhabitant in the US is higher, which is caused by the fact that for the US only one state is considered (in contrast, the EU28, WEC and CEEC figures cover multiple countries, smoothing any annual peaks identified for an individual country).

Figure 66 - Development of investments per inhabitant over time (€ per inhabitant, PPS adjusted)



The long-term average IWT infrastructure investments per inhabitant are shown for the various countries in Figure 67. These figures show that in the 'leading inland waterway countries' (Belgium, the Netherlands, Germany) investments per inhabitant are the highest. The higher investments per inhabitant and the Netherlands and Belgium compared to the Germany can be explained by the larger relative size of the IWT sector compared to population size in these two countries.

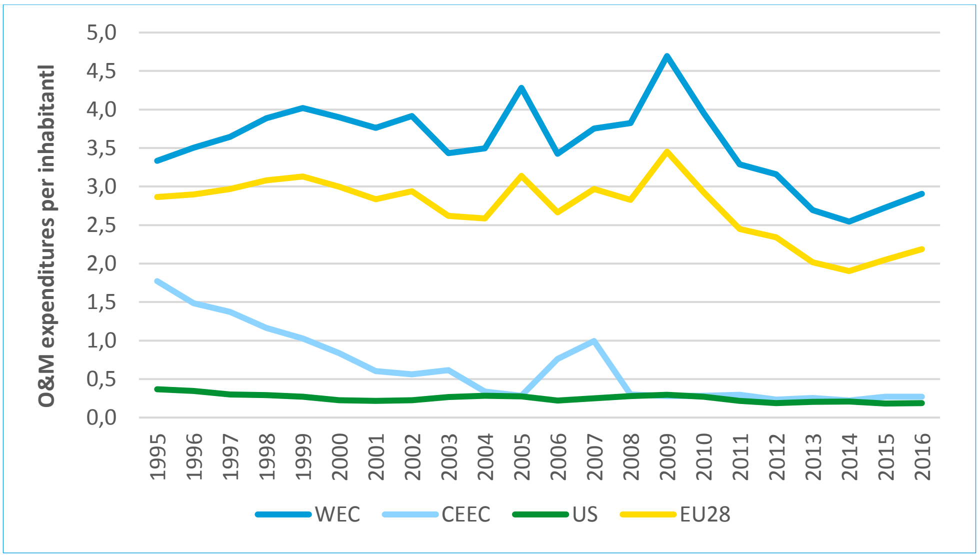
Figure 67 - Investments per inhabitant (average 1995 - 2016) per country (€ per inhabitant, PPS adjusted)



D.4.2 Operational and maintenance expenditures

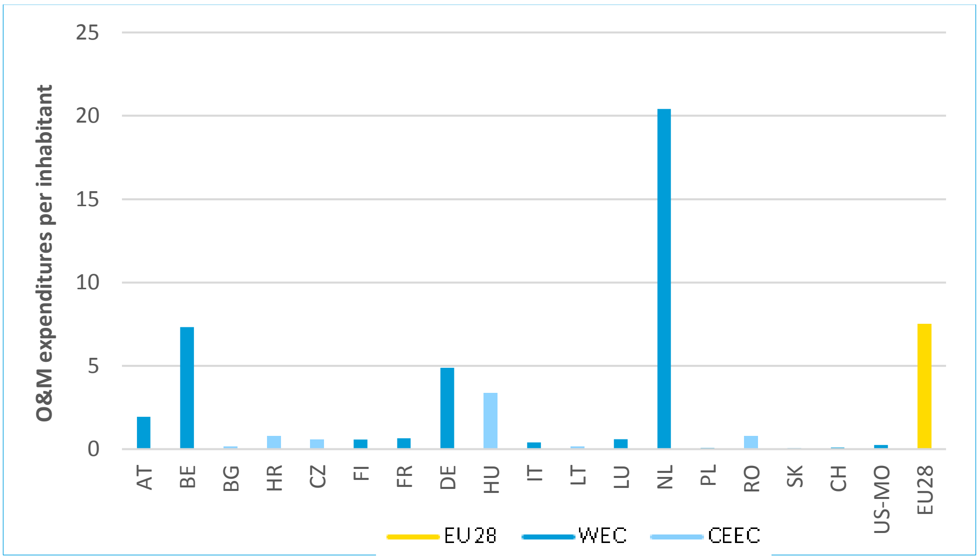
The development of O&M expenditures per inhabitant over time is shown in Figure 68. In the EU28 and the WEC, these are quite stable, although a decline is found since 2009 (economic crisis). In the CEEC there have been a declining trend from 1995 to 2005, but then the expenditures per inhabitant have been quite stable as well.

Figure 68 - Development of O&M expenditure per inhabitant over time (€ per inhabitant, PPS adjusted)



Finally, the O&M expenditures per inhabitant per country are shown in Figure 69.

Figure 69 - O&M expenditures per inhabitant (average for 1995-2016) per country (€ per inhabitant, PPS adjusted)



The graph of the O&M expenditures per inhabitant looks quite similar to the investments per inhabitant. It seems plausible that countries which invest most in IWT infrastructure per inhabitant spends most per inhabitant on operation and maintenance of this infrastructure as well.

E Allocation of infrastructure costs

E.1 Introduction

To estimate the infrastructure costs per vehicle category, the total infrastructure costs were allocated to the various vehicle categories with help of the equivalency factor method. Based on relevant cost drivers (proportionality factors) the various cost categories were allocated to the various vehicle categories. For all modes, we have carried out a literature review to choose the most relevant cost drivers for this exercise. The main results of this assessments were presented in the mode-specific chapters (Chapters 3 to 7). In this Annex we present some more detailed results from the literature review carried out for road and rail transport.

E.2 Road transport

To determine the cost drivers for road transport, eight studies have been reviewed. These include six national studies estimating the infrastructure costs of road transport for a specific country (i.e. Switzerland, The Netherlands, Denmark, Great Britain, Germany and Australia) and two studies providing a (qualitative) meta-analysis on this issue (i.e. (Fraunhofer-ISI & CE Delft, 2008) and (HLG, 1999). The main results of the review of these studies are summarised in Table 37.

Based on this literature review we conclude the following:

- Almost all studies distinguish between capacity and weight related enhancement costs. In general, about 90% of the enhancement costs are considered capacity related and 10% weight related (an exception is NTC (2005) which assumes that just 45% of the enhancement costs in Australia are weight related). In this study we use the same shares of capacity and weight related enhancement costs. As CE Delft (2008) and ITS (2001) we allocate the capacity related enhancement costs based on Passenger Car Equivalent (PCE) kilometres and the weight related enhancement costs based on 4th power axle load kilometres.
- Different approaches are used to allocate the renewal costs of road infrastructure. However, all studies distinguish between capacity related and weight related renewal costs. Based on the results from the various studies and detailed data for the Netherlands (not shown in Table 37, but presented in CE Delft (2008)) we assume that ca. 60% of the renewal costs are weight related and ca. 40% are capacity related. As for enhancement costs, the capacity related costs are allocated based on PCE-kilometres and the weight related costs on 4th power axle load kilometres.
- With respect to the allocation of maintenance costs, most studies distinguish between fixed and variable costs. Since the variable maintenance costs are — at least partly — weight dependent (the only exception is COWI (2004)), we allocate these costs based on 4th power axle load kilometres. With respect to the fixed maintenance costs almost all studies agree that these costs depend both on weight and capacity factors. However, different kind of approaches are used. In this study we apply the German approach (which was also used by CE Delft (2008) for the Netherlands), implying that 50% of the costs are allocated based on PCE-km, 35% based on vehicle kilometres and 15% are allocated to heavy goods vehicles.
- Both vehicle kilometres and PCE-kilometres (or a combination of both) are used as cost drivers to allocate the operational costs of road transport. In this study we apply the German approach (30% of the operational costs are allocated based on vehicle-kilometres, 70% based on PCE-kilometres).

Table 37 - Main results of literature review on allocation approaches applied in road infrastructure cost studies

Source	Country	Enhancement costs	Renewal costs	Maintenance costs	Operational costs
BSF (2003)	Switzerland	- 95% capacity related: 80% allocated based on PCE-km, 20% allocated based on vkm. - 5% weight related: fully allocated to HDVs (> 3.5 t) based on standard axle load kilometres.	- 55% capacity related: 80% allocated based on PCE-km, 20% allocated based on vkm. - 45% weight related: fully allocated to HDVs (>3.5 t) based on axle load vehicle kilometres.	- 100% allocated based on vkm.	- 100% allocated based on vkm.
CE Delft (2008)	The Netherlands	- 89% capacity related: allocated based on PCE-km. - 11% weight related: allocated based on standard axle load kilometres.	- Fixed costs: 35% allocated based on vkm, 50% on PCE-km and 15% are fully allocated to HGVs (>12 t). - Variable costs: mainly allocated based on standard axle load km.	- Fixed costs: 35% allocated based on vkm, 50% on PCE-km and 15% are fully allocated to HGVs (>12 t). - Variable costs: mainly allocated based on standard axle load km.	- Ca. 44% are allocated based on vkm, 14% based on standard axle load km and 41% based on PCE-km.
COWI (2004)	Denmark	- 85% (95% for regional roads) capacity related: 45% allocated based on vkm, 40 based on PCE-km (80% and 15% for regional roads, respectively). - 15% (5% for regional roads) weight related: allocated based on standard axle load.	- Fixed costs: allocated based on vkm - Variable costs: allocated based on PCE-kilometres (20 to 35%) and standard axle load (65 to 80%).	- Fixed costs: allocated based on vkm - Variable costs: allocated based on vkm (about 60%) and PCE-kilometres (about 40%).	- 100% allocated based on vkm.
ITS (2001)	Great Britain	- 85% capacity related: allocated based on PCE-km. - 15% weight related: allocated based on standard axle load km.	- Detailed approach. - Renewal costs are mainly allocated based on standard axle load kilometres.	- Detailed approach. - Variable costs are mainly allocated based on standard axle km. - Fixed costs are mainly allocated based on PCE-km and/or average gross vehicle weight km.	- Operational costs are mainly allocated based on PCE-km (a minor part is allocated based on average gross tonne km).
ProgTrans (2007)	Germany	- Very detailed approach. - Main part of cost elements is allocated based on PCE-km. - Smaller part of costs is allocated fully to specific vehicle categories (mainly HGVs).	- Very detailed approach. - According to IMPACT D2 about 50% are allocated based on PCE-km, 22% on vkm and 28% on standard axle load km.	- Fixed costs: 35% allocated based on vkm, 50% on PCE-km and 15% are fully allocated to HGVs (>12 t). - Variable costs: allocated based on PCE-km, axle load km and vkm. A part of the costs is allocated to specific vehicle categories.	- 30% allocated based on vkm. - 70% allocated based on PCE-km.

Source	Country	Enhancement costs	Renewal costs	Maintenance costs	Operational costs
NTC (2005)	Australia	- 45% weight related: allocated based on standard axle load. - 55% not attributable: allocated based on vkm.	- 45% weight related: allocated based on standard axle load. - 55% not attributable: allocated based on vkm.	- Detailed approach. - Allocated based on axle load km, PCE-km and vkm.	- 100% allocated based on vkm.
Fraunhofer-ISI and CE Delft (2008)	EU	- 100% allocated based on PCE-km.	- 80% allocated based on PCE-km. - 10% allocated based on vkm. - 10% allocated based on standard axle load km.	- 100% based on standard axle load km.	- 100% allocated based on vkm.
High level group (1999)	EU		- Costs should be allocated based on axle weight, gross vehicle weight and/or PCE-km.	- Cost should be allocated based on axle weights.	- Cost should be allocated based on vkm or PCE-km.

E.3 Rail transport

In order to determine the equivalency factors for rail transport, four studies have been reviewed (see Table 38). These are all studies assessing the rail infrastructure costs in specific European countries, i.e. Denmark, Germany, The Netherlands, Poland and Great Britain.

Based on the results of the literature review the following selection of equivalency factors have been made:
- Cost related to high speed lines are fully allocated to high speed trains.
- Enhancement costs are assumed to be 100% capacity related and allocated fully to passenger and freight trains based on train kilometres. This is in line with the approach followed by Calvo et al. (2011). CE Delft and ITS (2015) and CE Delft and VU (2014) also assume that enhancement costs are fully capacity related. In these studies, these costs are allocated fully to passenger trains (assuming that freight trains do not/barely run during rush hours). Although this allocation rule may be relevant for the specific countries considered in these two studies, an allocation to both passenger and freight trains seems more appropriate for all countries considered in this study. Compared to the other three studies, COWI (2004) and ITS (2001) do provide a more detailed and country-specific approach. However, due to a lack of data these could not be applied in this study.
- Renewal costs are partly allocated based on tonne-kilometres (variable part) and partly on train kilometres (fixed part). This approach is in line with CE Delft and ITS (2015) and largely comparable with CE Delft and VU (2014). Again, COWI (2004) and ITS (2001) do apply country-specific allocation factors which cannot be easily transferred to other European countries.
- As the renewal costs, maintenance costs are partly allocated based on train kilometres and partly based on tonne-kilometres. In line with CE Delft and ITS (2015), CE Delft and VU (2014) and COWI (2004), fixed maintenance costs are allocated based on train kilometres. As for the variable maintenance costs, it was chosen to allocate them for 50% based on train kilometres and for 50% based on tonne-kilometres (in line with CE Delft and ITS, 2015). This allocation reflects the fact that part of the variable maintenance costs are fully dependent on train movements, while another part also depends on the mass of the train (ProRail, 2012; CE Delft & ITS, 2012).
- In line with COWI (2004) and CE Delft and ITS (2012), the operational costs are fully allocated based on train-kilometres.

Table 38 - Main results of literature review on allocation approaches applied in rail infrastructure cost studies

Source	Country	Enhancement costs	Renewal costs	Maintenance costs	Operational costs
CE Delft and ITS (2015)	Germany, Netherlands, Poland and Great Britain	- 100% capacity related: fully allocated to passenger trains (assumption: freight trains do not run during rush-hours). - Costs related to HSL or dedicated passenger/freight infrastructure are fully allocated to HSL and passenger/freight trains, respectively.	- Variable costs are allocated based on tonne-kilometres. - Fixed costs are allocated based on train kilometres.	- Variable costs are partly (50%) allocated based on train kilometres and partly (50%) based on tonne-kilometres. - Fixed costs are fully allocated based on train kilometres.	- Fully allocated based on train kilometres.
CE Delft and VU (2014)	Netherlands	- 100% capacity related: fully allocated based on share in peak-time traffic demand - Costs related to HSL or dedicated freight infrastructure are fully allocated to HSL and freight trains, respectively.	- Variable costs are partly (79%) allocated based on tonne-kilometres, and partly (21%) based on a specific key developed by the Dutch rail infrastructure manager. This specific key implicitly assumes that the costs per km are three times higher for passenger trains as for freight trains. - Fixed costs are fully allocated based on train kilometres. - Costs related to HSL or dedicated freight infrastructure are fully allocated to HSL and freight trains, respectively.	- Variable costs are allocated based on specific key (same as for variable renewal costs) developed by the Dutch rail infrastructure manager. - Fixed costs are fully allocated based on train kilometres. - Costs related to HSL or dedicated freight infrastructure are fully allocated to HSL and freight trains, respectively.	- See maintenance costs.
Calvo et al. (2011)	Not country specific	- Considered as investment costs to add new functionalities to existing infrastructure (e.g., enhancement of capacity). Allocated based on train-km.	- Allocated based on tonne-kilometre.	- Allocated based on tonne-kilometre.	- Not available.
COWI (2004)	Denmark	- Allocated based on specific key developed by the Danish rail infrastructure manager.	- Allocated based on specific key developed by the Danish rail infrastructure manager.	- Fully allocated based on train kilometres.	- Fully allocated based on train kilometres.
ITS (2001)	Great Britain	- Fully allocated based on the apportionment of track access charges.	- See enhancement costs.	- See enhancement costs.	- See enhancement costs

F Funding of transport infrastructure

F.1 Introduction

Transport infrastructure may be funded from public or private funds or by Public Private Partnerships (PPPs). In this Annex we assess the evidence that is available on the institutional character of transport infrastructure expenditures. First, we discuss the data availability on funding sources of these expenditures. Second, some general findings on private funding of transport infrastructure are presented.

F.2 Data availability on funding of transport infrastructure

Data on the funding of transport infrastructure is not available from aggregate EU or global databases (like the OECD database) or studies. Therefore, we have assessed this issue based on national studies and accounts in this study. However, this assessment made clear that consistent and complete data on the funding of transport infrastructure is not available for most countries. In most countries, only data on total transport infrastructure expenditures/costs are presented, containing both public and private expenditures/costs. For countries/modes for which a distinction between different funding sources is available, data is often available for part of the infrastructure (e.g. in the Netherlands the share of PPPs in state road investments is available, but not the share in investments in urban and other roads) or for a few (recent) years only. Even for transport infrastructure managed by private operators, the share of private funding is often not clear. These operators usually receive public grants for investments in or maintenance of the infrastructure, but the size of these grants are often not available from public accounts or annual reports of the private transport operators.

For the reasons mentioned above, it was not possible to provide an overview of the shares of private, public and PPP funding of transport infrastructure in the countries considered in this study.

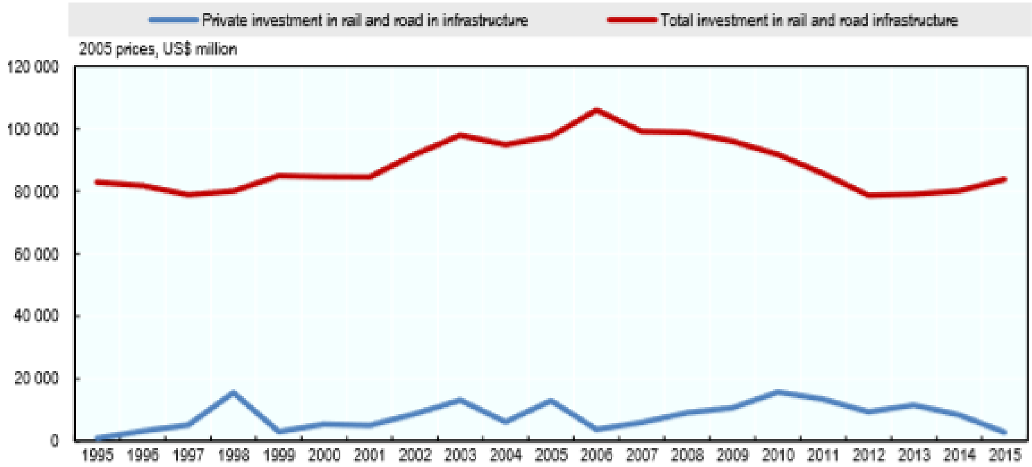
F.3 Some general findings on private funding of transport infrastructure

As we were not able to estimate the shares of different sources in the funding of transport infrastructure ourselves, we have reviewed literature in order to see what is known on the share of private funding of transport infrastructure. Empirical evidence on this issue in literature is very scarce. We only found a recent study by the ITF, presenting the results of an empirical assessment of private investments in transport infrastructure (ITF, 2018)[52]. Because of lack data unavailability, private investments in this assessment were limited to Public Private Partnerships (PPP). It is argued by Makovšek (forthcoming), however, that PPP are representative of the majority of private investment in the main transport infrastructure (rail, road, ports and airports). On the other hand, ITF (2018) mentions that PPps in general can be subject to significant public financial support and hence true private investment volume can be significantly less that the total volume of PPPs.

[52] At time of writing this study, the empirical data used by the ITF was not public (yet). Therefore, we were not able to use these data for our own empirical assessments.

In order to assess the share of private investments in total investments in transport infrastructure, ITF (2018) compared their data on private investments in 7 OECD countries with relatively high volumes of PPPs (UK, Spain, Portugal, France, Turkey, Italy and Germany) with total investments in these countries (data taken from the OECD database on transport investments). This assessment was limited to investments in road and rail infrastructure. As is shown in Figure 70, the private investment reached at best of times 10-15% of the total investments. As mentioned above, the true private investments are probably even lower as PPPs do generally contain significant shares of public investments as well. Furthermore, as these findings are relevant for countries with relatively high volumes of PPSs, private investment shares in other countries are probably (well) below 10%.

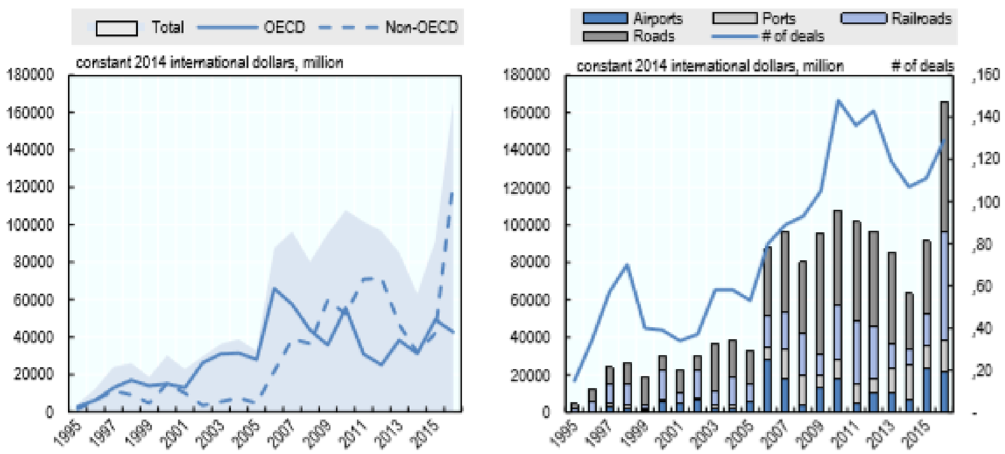
Figure 70 - Private and total investment in road and rail infrastructure in seven OECD countries, 1995-2014



Source: ITF (2018).

Although the share of private investment in total transport infrastructure investments is still relatively limited, its volume has been increased significantly over the last twenty years. This is shown by Figure 71, which presents the total volume and number of PPPs with respect to transport infrastructure in 111 countries. Particularly due to the economic crisis and the increasing fiscal constraints governments were subject to after 2010, private investments went up for these countries.

Figure 71 - Private investment in transport infrastructure



Source: ITF (2018).

G Motorway infrastructure costs

G.1 Introduction

In addition to the infrastructure costs for the entire road network (see Section 3.5), we have also estimated the infrastructure for motorways in the various countries. The results of this assessment are presented in this Annex. First, we discuss some methodological issues that differs between the assessments made for motorways and the entire road network (see Annex G.2). Next, the results with respect to total, average and marginal motorway infrastructure costs are presented in Annexes G.3 to G.5.

G.2 Some methodological issues

To estimate the motorway infrastructure cost, generally the same methodology as applied to estimate the infrastructure costs for the entire road network have been used (see Sections 2.4 and 3.3). There are, however, two differences between both approaches:

- *Different default parameters for breakdown investments to enhancement and renewal costs.* As discussed in Section 3.3, it is estimated that 75% of the investments on the entire road network are related to enhancement of the network and 25% to renewal. Based on empirical evidence it was found that the share of enhancement costs in total investments on motorways is on average a bit higher (80%). This implies that 20% of the motorway investments are related to renewal activities.
- *Different default parameters for breakdown total O&M costs to operational and maintenance costs*. In Section 3.3, the default shares of operational and maintenance costs in total O&M costs were estimated at 40 and 60% respectively for Western European countries, while for Central and Eastern European countries these shares were estimated at 30 and 70% respectively. Based on empirical data for eleven countries, we find that these shares are on average 45 and 55% on motorways (no differentiation between WEC and CEEC).

G.3 Total motorway infrastructure costs

The total costs of motorways in the various countries are presented in Table 39. In 2016, these costs were equal to about € 51 billion in the EU28. It should be noted that the infrastructure cost figures for motorways are less robust than the same figures for the entire road network, as the data availability on motorway infrastructure expenditures is poorer compared to the entire road network. For some countries (i.e. Cyprus, Estonia, Ireland, Norway, and the Canadian provinces) no data at all was available on motorway infrastructure expenditures, while for some other countries (Finland, Greece, Romania) only data on motorway investments was available. For these countries, motorway infrastructure expenditures have been estimated by unit costs (in €/km motorway) that have been derived from neighbouring countries or specific European regions (e.g. Southern Europe). Furthermore, for some countries data on motorway infrastructure expenditures is available, but only for a few years (e.g. for Belgium), which complicates the reliable estimation of particularly investment costs. Because of these large uncertainties, the motorway infrastructure costs as estimated in this study should be considered as rough indications of the actual costs.

Table 39 - Total road infrastructure costs in 2016 (billion €, PPP adjusted)

Member State	Investments costs	O&M costs	Total infrastructure costs		
			Fixed	Variable	Total
EU28	41.61	9.69	44.25	7.05	51.30
Austria	1.61	0.60	1.95	0.26	2.21
Belgium	0.41	0.40	0.67	0.14	0.81
Bulgaria	0.40	0.17	0.48	0.09	0.57
Croatia	1.01	0.19	1.11	0.09	1.20
Cyprus [b]	0.16	0.02	0.16	0.02	0.18
Czech Republic	1.45	0.75	1.96	0.24	2.20
Denmark	0.25	0.04	0.25	0.04	0.29
Estonia [b]	0.16	0.02	0.12	0.05	0.17
Finland [c]	0.22	0.23	0.38	0.08	0.45
France	3.33	1.41	4.02	0.71	4.73
Germany	4.85	0.55	4.64	0.76	5.40
Greece [c]	2.71	0.02	2.40	0.33	2.73
Hungary	1.05	0.05	0.97	0.14	1.10
Ireland [b]	0.51	0.07	0.50	0.08	0.58
Italy	4.52	0.87	4.66	0.73	5.39
Latvia [a]	-	-	-	-	-
Lithuania	0.05	0.03	0.06	0.01	0.07
Luxembourg	0.15	0.02	0.15	0.02	0.17
Malta [a]	-	-	-	-	-
Netherlands	2.84	0.26	2.64	0.46	3.10
Poland	1.23	0.11	1.16	0.18	1.34
Portugal	1.75	0.28	1.76	0.27	2.03
Romania [c]	0.47	0.19	0.56	0.10	0.66
Slovakia	0.67	0.10	0.67	0.10	0.77
Slovenia	0.66	0.03	0.60	0.09	0.69
Spain	6.28	1.79	6.92	1.15	8.07
Sweden	0.18	0.10	0.22	0.06	0.28
United Kingdom	4.72	1.40	5.26	0.86	6.12
Norway [b]	0.03	0.02	0.04	0.01	0.05
Switzerland	1.87	0.31	1.87	0.30	2.18
Canada – British Columbia [b]	2.70	1.10	2.99	0.81	3.80
Canada – Alberta [b]	4.28	1.74	4.73	1.28	6.02
US – California	5.19	2.19	6.28	1.10	7.38
US - Missouri	1.48	0.55	1.71	0.32	2.03
Japan	63.53	12.47	65.63	10.37	76.00

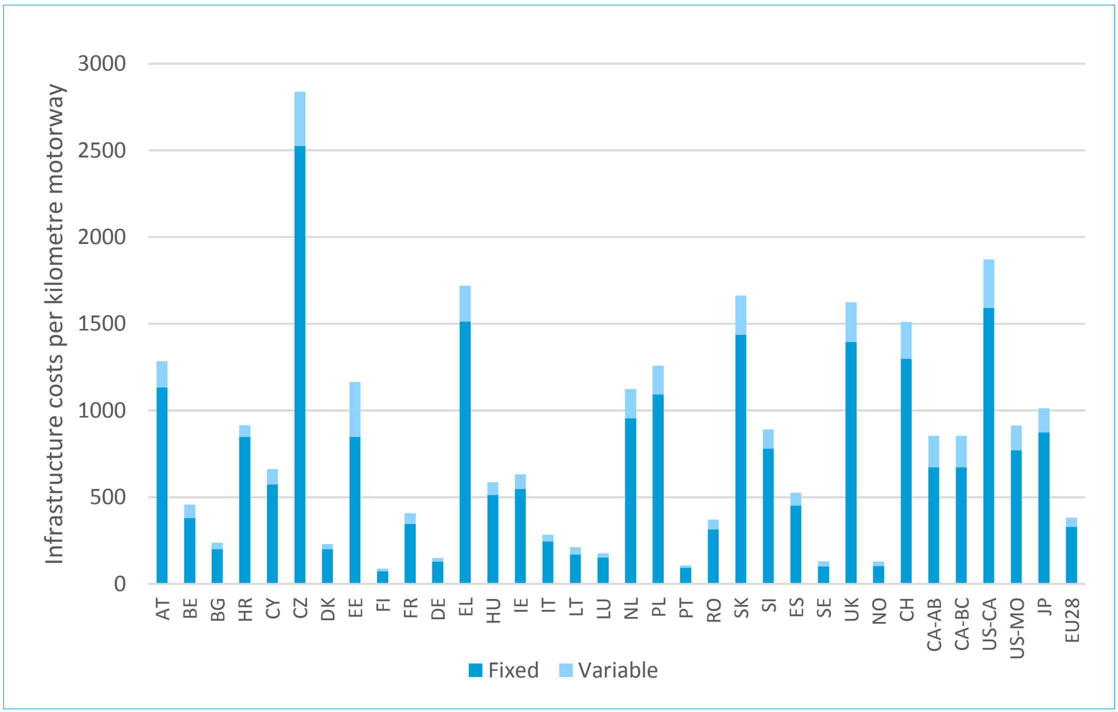
a There are no motorways in Latvia and Malta.

b For these countries the infrastructure costs (both investments and O&M costs) are estimated based on unit costs (€/km motorway) from neighbouring countries or European regions (e.g. Southern Europe). See Annex A.2 for more information.

c For these countries the O&M costs are estimated based on unit costs (€/km motorway) from neighbouring countries or European regions (e.g. Southern Europe). See Annex A.2 for more information.

Figure 72 provides an overview of the infrastructure cots per kilometre motorway. For most countries, these costs are between € 500,000 and € 1,000,000 per kilometre road. Particularly in Czech Republic, these costs are considerably higher, while also in Greece, Slovakia, Austria, UK, Switzerland and California the costs are relatively high. For Austria and Switzerland this may be explained by the high network complexity (many bridges and tunnels). For the other countries, large investment projects for motorways over the last twenty years (partly financed by European subsidy programmes) are an important explanation for the relatively high costs.

Figure 72 - Infrastructure costs per kilometre motorway (x 1,000 €/km, PPS adjusted)



Notes:
- no motorways in Latvia and Malta;
- discussions on the robustness of the figures per country can be found in the notes accompanying Table 39.

The total road infrastructure costs per vehicle category are presented in Table 40. Figures for buses are only presented for a limited number of countries, as in some countries buses are not used on motorways (according to Eurostat).

Table 40 - Total motorway infrastructure costs in 2016 per vehicle category (billion €, PPP adjusted)

Member State	Passenger car	Motorcycle	Bus	Coach	Van	HGV
EU28	26.53	0.77	0.32	4.20	5.38	14.10
Austria	1.24	0.02	0.05	0.18	0.35	0.39
Belgium	0.47	0.004	0.03	0.03	0.07	0.20
Bulgaria	0.26	0.001	-	0.07	0.04	0.20
Croatia	0.67	0.02	0.02	0.07	0.18	0.24
Cyprus	0.06	0.00	-	0.03	0.06	0.02
Czech Republic	1.13	0.05	-	0.18	0.26	0.58
Denmark	0.16	0.002	0.01	0.01	0.04	0.06
Estonia	0.07	0.0002	0.01	0.01	0.01	0.07
Finland	0.28	0.002	0.03	0.02	0.04	0.09
France	2.52	0.06	-	0.43	0.75	0.97
Germany	3.40	0.01	0.04	0.24	0.23	1.48

Member State	Passenger car	Motorcycle	Bus	Coach	Van	HGV
Greece	1.20	0.11	-	0.49	0.51	0.43
Hungary	0.46	0.01	0.01	0.17	0.12	0.34
Ireland	0.25	0.002	-	0.06	0.13	0.15
Italy	3.20	0.05	-	0.92	0.54	0.68
Latvia [a]	-	-	-	-	-	-
Lithuania	0.03	0.0005	0.002	0.0003	0.004	0.04
Luxembourg	0.05	0.001	0.003	0.003	0.05	0.07
Malta [a]	-	-	-	-	-	-
Netherlands	1.65	0.01	0.03	0.04	0.26	1.10
Poland	0.55	0.01	-	0.03	0.07	0.68
Portugal	0.90	0.02	-	0.12	0.30	0.69
Romania	0.24	0.001	-	0.08	0.10	0.24
Slovakia	0.35	0.003	-	0.03	0.08	0.31
Slovenia	0.35	0.002	0.01	0.04	0.07	0.22
Spain	3.46	0.37	-	0.76	0.38	3.10
Sweden	0.15	0.001	0.01	0.01	0.03	0.07
United Kingdom	3.46	0.02	0.06	0.16	0.72	1.70
Norway	0.03	0.0003	0.002	0.002	0.01	0.01
Switzerland	1.43	0.02	0.18	0.08	0.15	0.32
Canada – British Columbia	1.65	0.04	0.11	0.01	0.00	1.99
Canada – Alberta	3.62	0.04	0.47	0.03	0.00	1.86
US – California	5.05	0.02	0.56	0.18	0.22	1.35
US - Missouri	1.42	0.00	0.25	0.01	0.04	0.30
Japan	46.70	1.39	8.90	2.81	7.23	8.97

a There are no motorways in Latvia and Malta.

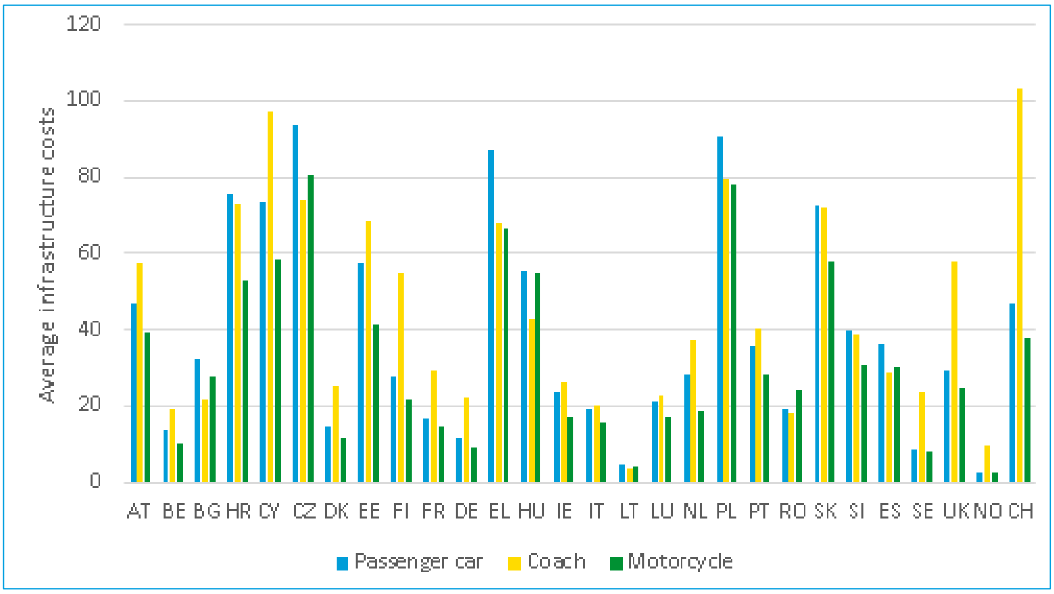
G.4 Average motorway infrastructure costs

In this section we present the average motorway infrastructure costs. To estimate these costs, transport performance data (passenger kilometres, tonne-kilometres, vehicle kilometres) and data on the motorway infrastructure (length of motorway network) are used. In general, the reliability and consistency (e.g. due to different definitions used for motorways in the various countries) of these data is poorer compared to the entire road network. Combined with the uncertainty in the infrastructure expenditure data (see Annex G.3), this results in a high level of uncertainty in the estimated cost figures at the country level.

Passenger transport

Figure 73 presents the average motorway infrastructure costs for road passenger transport modes in 2016 (in € per 1,000 passenger kilometre). No figures for buses are presented, as in many countries buses do not (significantly) use motorways. In contrast to the figures for the entire road network, the average costs per passenger kilometre for coaches are in the same range as the figures for passenger cars and motorcycles in most countries (for the entire road network the average costs for coaches were significantly higher than for cars and motorcycles). The main explanation for this finding is that the variable part of the motorway infrastructure costs is considerable lower than for the entire road network. As these variable costs are mainly weight dependent, the share of heavy vehicles (like coaches) in the total infrastructure costs is lower for motorways than for the entire road network.

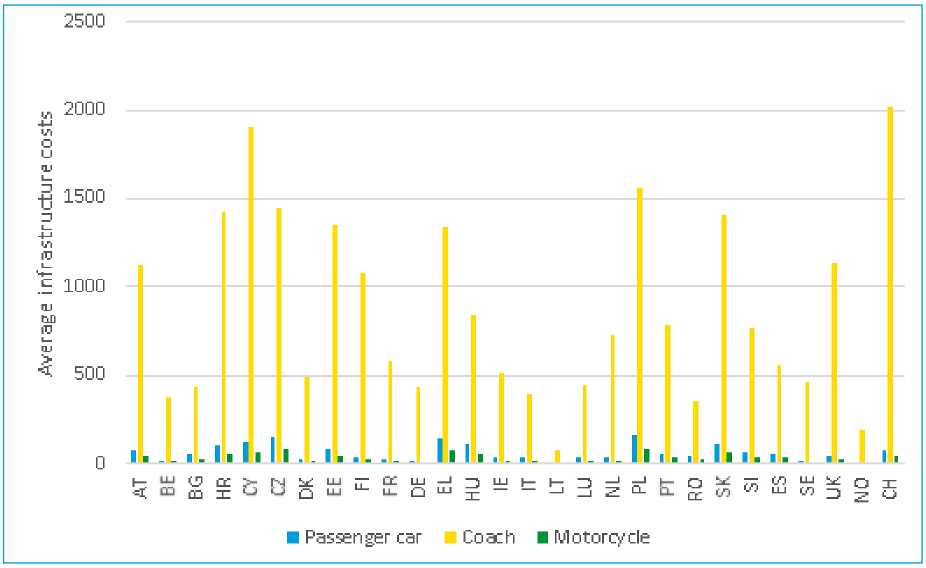
Figure 73 - Average motorway infrastructure costs for passenger modes in 2016 (€ per 1,000 pkm, PPS adjusted)



Relatively high average motorway infrastructure costs are found for countries like Poland, Czech Republic, Cyprus, Greece, Slovakia, and Croatia. These high cost levels can be explained by the large investment projects implemented over the last 15 years (partly financed by EU funding). The very low average infrastructure costs in Lithuania is explained by the very high utilisation rates of the Lithuanian motorways. According to the input data used for this study (see Annex C.2), it can be calculated that Lithuanian motorways are seven times more intensively used than the average EU28 motorway. This seems unrealistic and hence the results for Lithuania should be considered carefully.

Finally, the average infrastructure costs in € per 1,000 vehicle kilometre are presented for passenger transport modes in Figure 74.

Figure 74 - Average motorway infrastructure costs for passenger modes in 2016 (€ per 1,000 vkm, PPS adjusted)



Freight transport

The average motorway infrastructure costs for HGVs are presented in Figure 75 (in € per 1,000 tonne-kilometres) and Figure 76 (in € per 1,000 vehicle kilometres). Again, the average costs figures are high in countries like Cyprus, Czech Republic, Greece, Poland, and Slovakia, which are all countries that have invested significantly in motorway infrastructure over the last 15-20 years.

Figure 75 - Average motorway infrastructure costs for HGVs in 2016 (€ per 1,000 tkm, PPS adjusted)

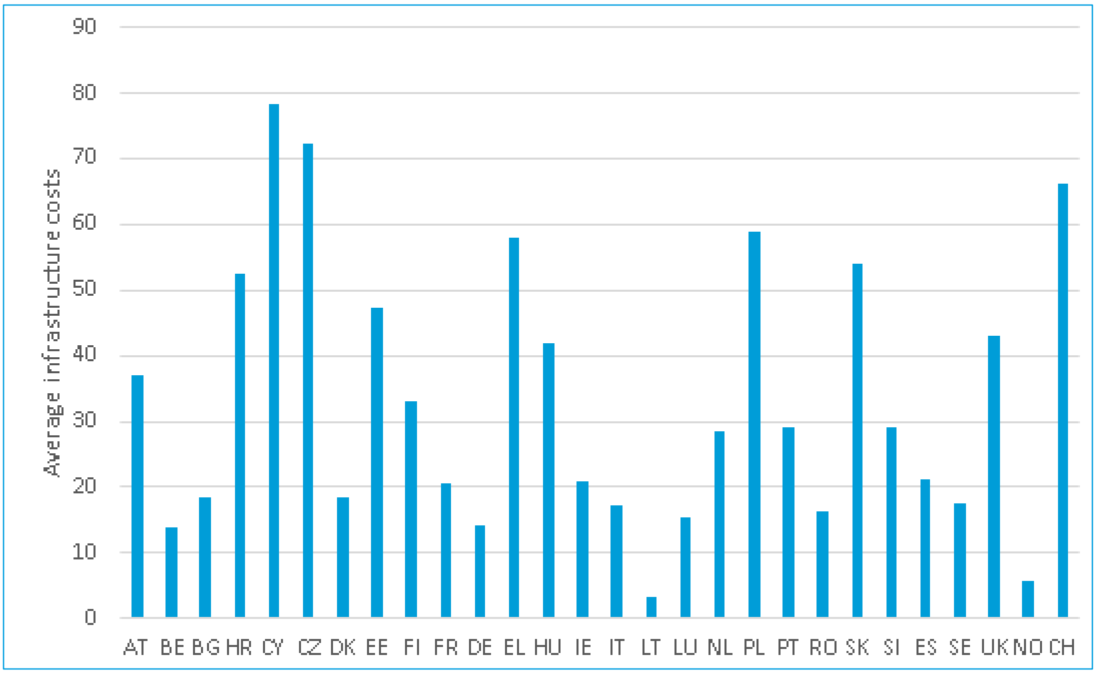
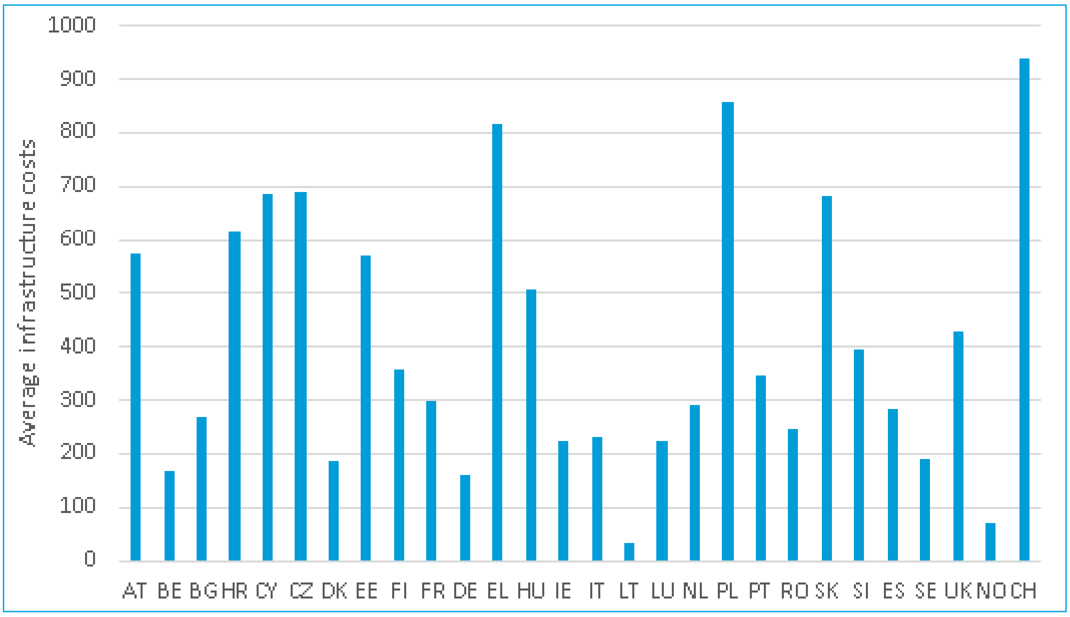


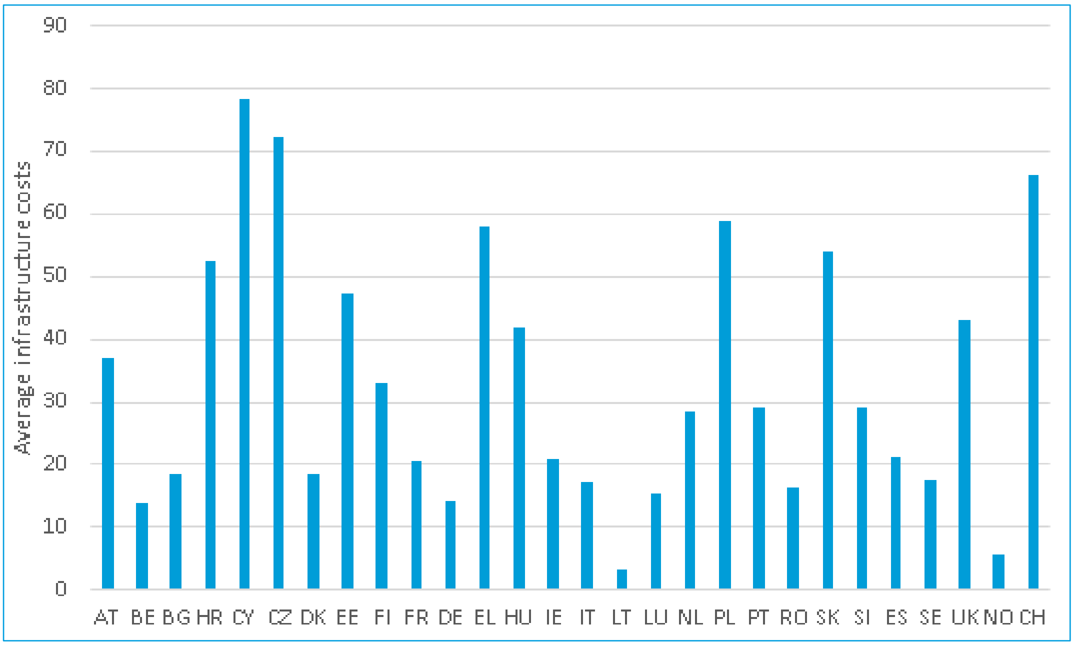
Figure 76 - Average motorway infrastructure costs for HGVs in 2016 (€ per 1,000 vkm, PPS adjusted)



Light commercial vehicles

Figure 77 shows the average motorway infrastructure costs for LCVs (in € per 1,000 vehicle kilometres). Again, the highest costs are mainly found for countries that have run large motorway investment programmes over the last 15-20 years (e.g. Cyprus, Czech Republic, Greece, Poland and Slovakia).

Figure 77 - Average motorway infrastructure costs for LCVs (€ per 1,000 vkm, PPS adjusted)



G.5 Marginal motorway infrastructure costs

In this section, the marginal motorway infrastructure cost figures are presented. As for the average cost figures, the uncertainty in these figures (at the country level) are relatively large.

Passenger transport

The marginal motorway infrastructure costs for road passenger modes are presented in Figure 78 (€ per 1,000 passenger kilometres) and Figure 79 (€ per 1,000 vehicle kilometres).

Figure 78 - Marginal motorway infrastructure costs for passenger modes in 2016 (€ per 1,000 pkm, PPS adjusted)

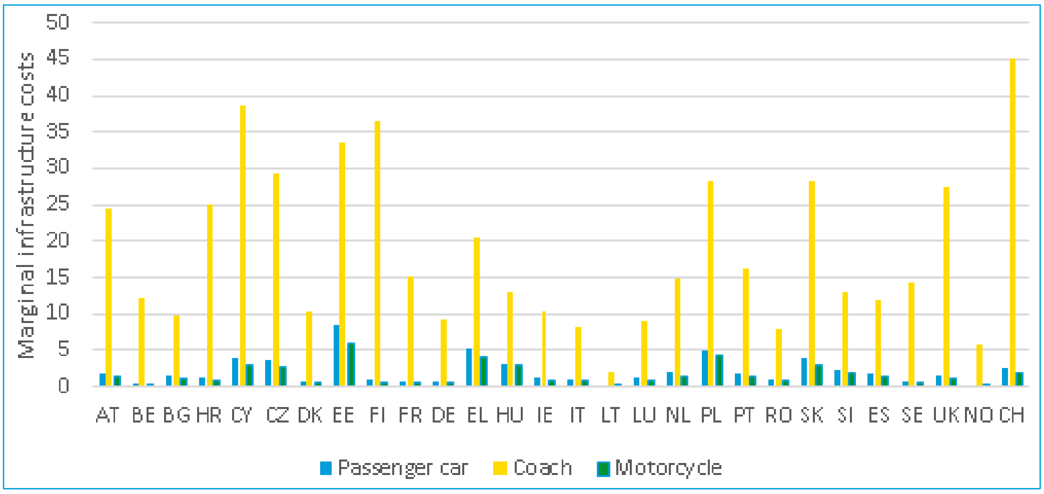
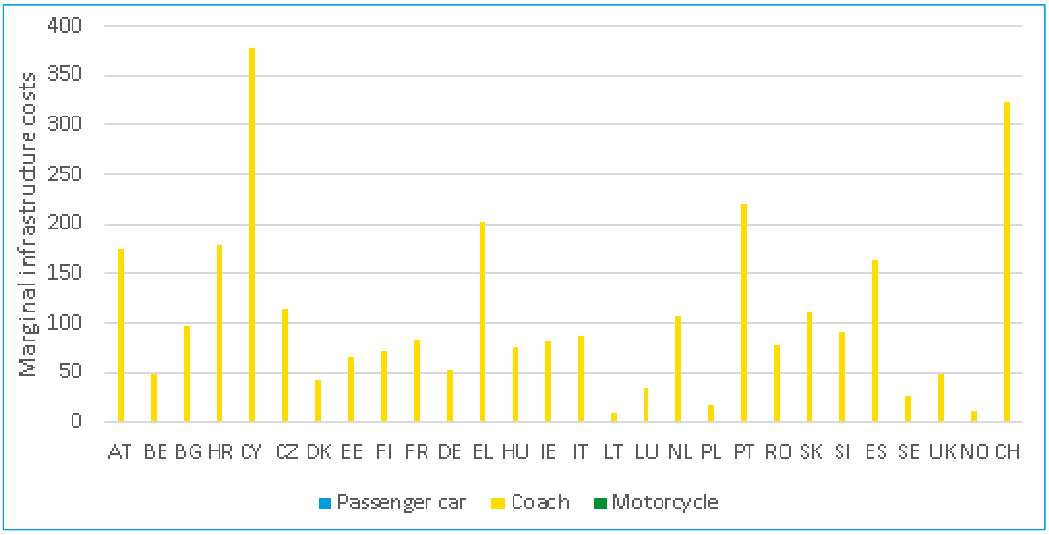


Figure 79 - Marginal motorway infrastructure costs for passenger modes in 2016 (€ per 1,000 vkm, PPS adjusted)



Freight transport

The marginal motorway infrastructure costs for HGVs are presented in Figure 80 (€ per 1,000 passenger kilometres) and Figure 81 (€ per 1,000 vehicle kilometres).

Figure 80 - Marginal motorway infrastructure costs for HGVs in 2016 (€ per 1,000 tkm, PPS adjusted)

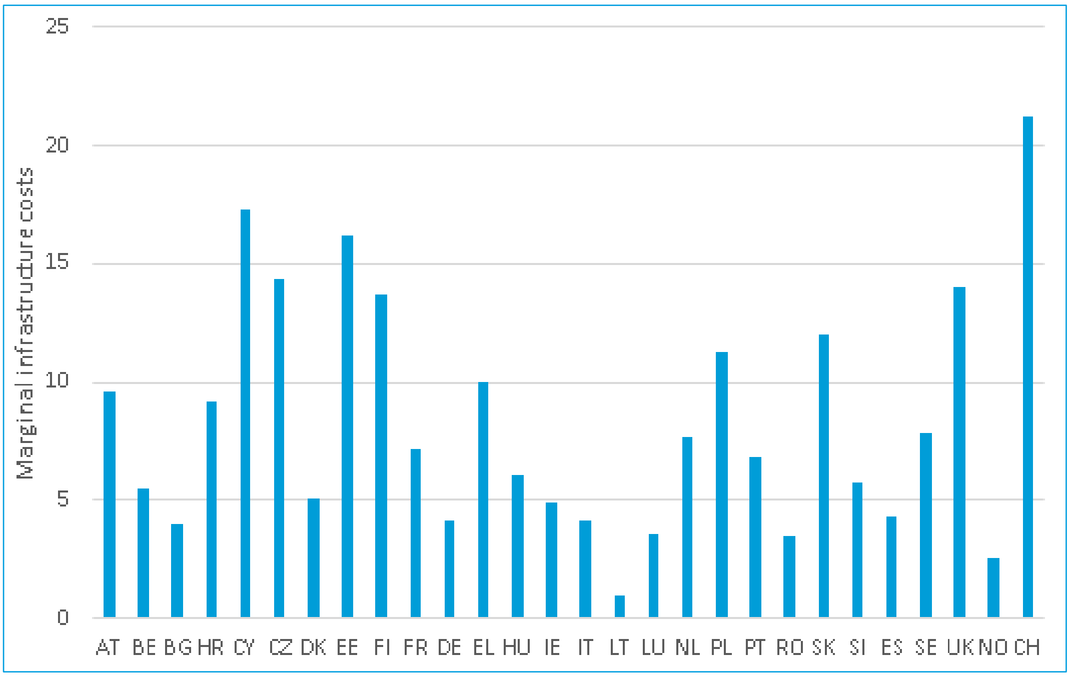
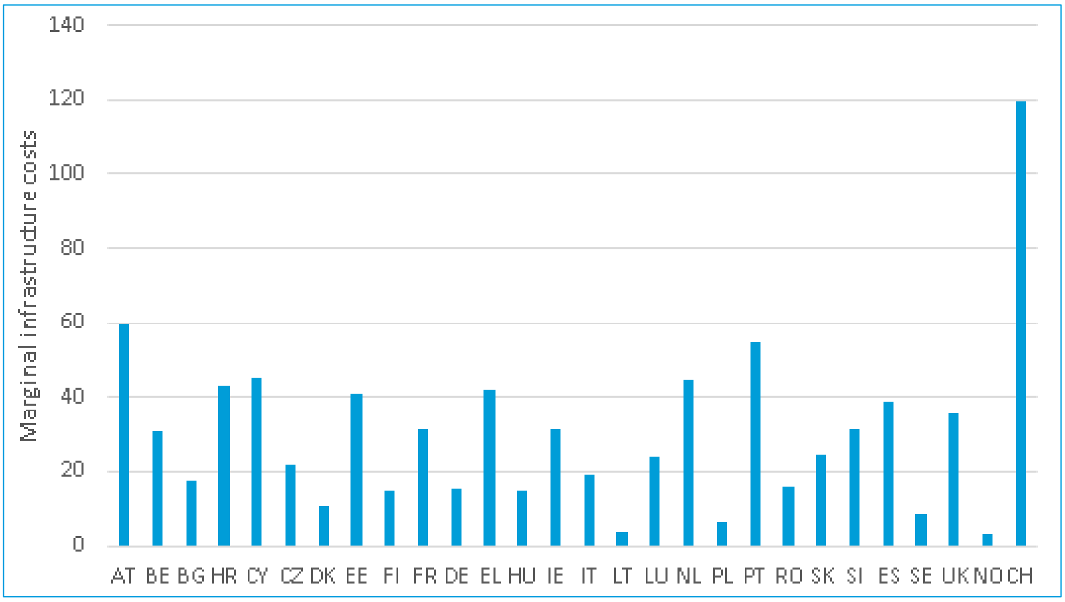


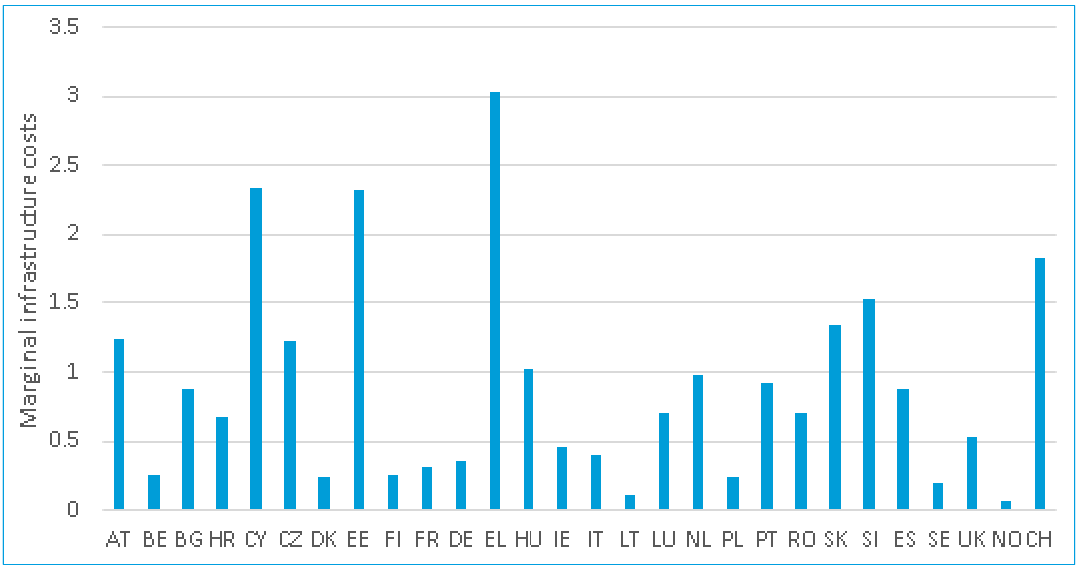
Figure 81 - Marginal motorway infrastructure costs for HGVs in 2016 (€ per 1,000 vkm, PPS adjusted)



Light commercial vehicles

The marginal motorway infrastructure costs for LCVs are presented in Figure 82 (€ per 1,000 vehicle kilometres).

Figure 82 - Marginal motorway infrastructure costs for LCVs in 2016 (€ per 1,000 vkm, PPS adjusted)



H Marginal costs reference vehicles

H.1 Introduction

In addition to the marginal infrastructure cost figures presented in Chapters 3 to 7, which mostly refer to some kind of average vehicles (e.g. an average conventional electric passenger train or an average inland navigation vessel), we have also estimated marginal infrastructure costs for some reference vehicles. The reference vehicles considered and the methodology to estimate marginal costs for these vehicles is explained in this Annex. The resulting figures can be found in the Excel Annex of this report.

H.2 Reference vehicles

An overview of the reference vehicles for which marginal infrastructure costs are estimated is given in Table 41. For road transport, no reference vehicles for the lighter vehicle categories (e.g. passenger cars, LCVs) are defined. As (marginal) road infrastructure costs heavily depend on the weight of the vehicle, the variance for these vehicle categories is relatively limited. Therefore, there is not much added value of presenting marginal infrastructure cost for various categories of passenger cars or LCVs.

Table 41 - Reference vehicles for which marginal infrastructure costs are estimated

Road transport	Rail transport	IWT	Maritime transport	Aviation
- HGV 3.5-7.5 tonnes - HGV 7.5-16 tonnes - HGV 16-32 tonnes - HGV 32+ tonnes	- Intercity passenger train electric - Intercity passenger train diesel - Regional passenger train electric - Regional passenger train diesel - Short container train electric - Short container train diesel - Long container train electric - Long container train diesel - Short bulk train electric - Short bulk train diesel - Long bulk train electric - Long bulk train diesel	- CEMT II (bulk) - CEMT II (container) - CEMT IV (bulk) - CEMT Va (bulk) - CEMT Va (container) - Pushed convoy 11,000 tonnes (bulk)	- Small container vessel (40,000 dwt) - Large container vessel (142,000 dwt) - Small bulk vessel (30,000 dwt) - Large bulk vessel (206,000 dwt)	- Bombardier CRJ900 - Embraer 170 - Airbus A320-232 - Boeing 737-700 - Airbus A340-300 - Boeing 777-300

H.3 Methodology to estimate the marginal infrastructure costs of reference vehicles

To estimate the marginal infrastructure costs for the various types of reference HGVs the same approach as for the other road vehicles is applied. This means that first total infrastructure costs for these vehicles have been estimated, broken down to the various cost categories (e.g. enhancement, fixed renewal, variable renewal, etc.). Based on these figures and using relevant transport performance data marginal infrastructure costs for these vehicles have been estimated (see Sections 2.4 and 3.3 for more information).

For the other reference vehicles, a less detailed approach have been applied, mainly because no transport performance data for these vehicles was available. Therefore, the marginal cost figures for the main vehicle categories (the ones mentioned in Table 2 in Section 1.3.1) are transferred/scaled based on relevant costs drivers. The cost drivers used were:

- rail transport: average load of the train (in tonnes);
- IWT: Average load of the vessel (in tonnes);
- maritime transport: average load of the vessel (in tonnes);
- aviation: 50% based on average number of passengers and 50% assumed to be equal to the average aircraft.

It may be clear that this approach is less robust than the approach used to estimate the marginal costs for the main vehicle categories. Therefore, the marginal infrastructure costs for the reference vehicles should be considered carefully.

I Overview content Excel annex

As part of this report, an Excel annex have been produced. In this annex, the following content can be found:

- Total infrastructure cost values per transport mode, including breakdowns to:
  - investment and O&M costs;
  - fixed and variable costs;
  - various vehicle categories (if relevant).
- Total infrastructure cost values per kilometre infrastructure network (for road, rail and inland navigation transport);
- Average and marginal infrastructure costs values in:
  - €/pkm, €/tkm and €/vkm for road, rail and IWT transport;
  - €/LTO, €/passenger and €/pkm for aviation;
  - €/tonne handled and €/passenger embarked or disembarked for maritime transport (average costs) and €/call (marginal costs).
- Marginal infrastructure cost values for the reference vehicles (see Annex H.2).

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