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A selected review on the negative externalities of the freight transportation: Modeling and pricing

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ABSTRACT

The planning of freight transportation activities creates benefits as well as costs. Among those costs, some of them, namely externalities, fall on other people/society that have no direct relevance to the operations of transportation. Such externalities are accrued expenses which should be addressed by actual pricing policies to enable an efficient and sustainable freight transportation system. This paper reviews externalities in quantitative terms, and then provides pricing studies of these costs per unit of freight transported along with the most recent estimations. The associated negative externalities are structured by transportation mode (road, rail, maritime, and air).

1. Introduction

Transportation deals with carrying goods and/or passengers using one or multiple modes of transport. A conventional focus on planning the associated activities, in particular for the former namely freight transportation, is to reduce expenses and, consequently, increase profitability by considering internal transportation costs, e.g., fuel costs, drivers' wages (see, e.g., Greene and Wegener, 1997; Forkenbrock, 1999, 2001). With an ever growing concern about the environment by governments, markets, and other private entities worldwide, organizations have started to realize the importance of the environmental and social impacts (e.g., air pollution, noise, and congestion) associated with transportation on other parties or the society as a whole. Such impact is termed as 'externalities', where 'other parties' are entities that did not choose to incur the impact. In 2008, the total external costs of transport in EU-27 (EU's 27 states plus Norway and Switzerland) amount to more than 5–6% of the total GDP (Van Essen et al., 2011). Kinnock (1995) provides a rough estimation of the external costs of transportation: proportional figures of 0.4%, 0.2%, 1.5% and 2% are applied to the total costs of air pollution, noise, accidents and congestion, respectively.

While it is acknowledged that passenger transportation plays a no-less significant role than freight transportation in externalities (Van Essen et al., 2011), the choice of transportation modes varies significantly in individual circumstances (e.g., travel distance, travel purpose, time and location constraints, local transportation infrastructure). The purpose of the paper is to promote awareness and understanding of transportation external costs from the perspective of business rather than individuals (e.g., passengers) as the latter to a greater extent involves the context and subjective decisions. Thus, the rest of the study mainly focuses on freight transportation. Where papers describing general transportation are included, the referred external

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costs are considered of direct relevance to freight transportation. Estimating the external costs of freight transportation can be used for several purposes: to guide for the design of more economically efficient pricing systems; to facilitate the allocation of research and development funds for mitigating the largest external costs; to support cost-benefit analysis of optimal investment in transportation modes and infrastructure[1]; and to aid historical or comparative analyses.

Externalities incur benefits as well as costs, termed as positive externalities and negative externalities. This paper addresses the latter. The most prominent negative externalities of relevance to transportation contain emissions (air pollution and greenhouse gases (GHGs)), noise, water pollution, congestion and accidents (see, e.g., Levinson et al., 1998; Spellerberg, 1998; Santos et al., 2010). Moreover, Land use (or infrastructure) is an increasing source of concern, due to the negative effects (e.g., visual intrusion) on the environment (Blum, 1998). Air pollution includes particulate matter (i.e., small particles of dust, soot, and organic matter suspended in the atmosphere), carbon monoxide (i.e., colorless, odorless, poisonous gas produced when carbon-containing fuel is not burned completely), ozone which is formed when emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) chemically react in the presence of sunlight, and hazardous air pollutants, also referred to as air toxics (i.e., chemicals emitted into the atmosphere that cause or are suspected to cause cancer or other severe health effects). The emissions of GHGs is probably the most well-known and studied externality of transportation due to its global effects. Transportation related noise can cause health problems, which is mostly considered to be nuisance for those that have to deal with it. Water pollution is resulting from spills, leakages and accidental or deliberate disposal of cargo material or other materials used in the transportation process. Congestion costs mainly arise due to the fact that the travel time of other transportation users increases. Accident costs refer to the emergency services attending the accidents, delay of traffic, and the costs to the victim's family in pain and suffering. Examples of land use effects include the visual intrusion of transportation on the landscape, and the destruction of habitats and species loss due to transport infrastructure.

To the best of our knowledge, the definitions of externalities in freight transportation have been limited to the abovementioned ones (i.e., emissions, noise, congestion, accidents, water pollution and land use) in the literature. However, there are other important externalities that require further attentions in academia as well as practice, such as the effects due to the production of vehicles and transport infrastructure (i.e., energy production, vehicle production, maintenance and disposal, infrastructure construction). In this paper, we have not covered the later group since the aim of the paper is to review the most widely discussed externalities in the literature and there is yet sufficient scientific evidence in the latter group. The maturity in this matter is still needed to fill the academic void left over by the researchers. A few initiatives (see, e.g., Maibach et al., 2008; Korzhenevych et al., 2014) have already emerged to provide a full assessment of externalities, but this was not enough to make a comparison like in other well discussed externalities.

Among prior studies investigating externalities of transportation (see, e.g., Miller and Moffet, 1993; Mauch and Rothengatter, 1995; IBI Group, 1995; Spellerberg, 1998; Ranaiefar and Regan, 2011), a predominate stream encloses initiatives to reduce emissions (e.g., carbon dioxide) from transportation by, for example, minimizing 'empty kilometers' (see, e.g., Demir et al., 2014b) or using 'greener' transportation modes (e.g., trains/barges compared with cars or trucks) (see, e.g., Forkenbrock, 2001; Black et al., 2003; Lawson, 2007; Zimmer and Schmied, 2008). While a few studies have paid attention to other externalities, the focus is limited on road transportation (see, e.g., Forkenbrock, 1999; Lindberg, 2002). This is not surprising as road is the dominant mode of inland transportation. However, transportation services involve various transportation modes – road, rail, maritime, air and pipeline, where externalities that arise are dramatically different (Maibach et al., 2008). Despite the increasing attention to transportation related externalities in the literature, actions to mitigate the externalities in practice do not seem as promising as expected due to the lack of alignment between the economic concern and environmental impact. Should the external costs of freight transportation be effectively internalized and paid, decisions and activities can be shifted from economic-led to the balance between economic and environmental concerns.

In the last decade, the body of knowledge on the reduction of externalities from freight transportation has grown notably, where most of the studies are case or context specific. This paper aims to provide a state-of-the-art review of the models and the pricing studies for externalities incurred by transportation and logistics covering different transportation modes. The scientific contribution of this study is threefold: (i) to review negative externalities that have been addressed in the freight transportation literature; (ii) to present and compare a proper mathematical modelling of each externalities, where possible; and (iii) to review the scientific literature on the internalization of the externalities. The remainder of this paper is organized as follows. Section 2 presents a review methodology for the literature study. Section 3 discusses the externalities of freight transportation followed by the modelling of externalities in Section 4. Section 5 investigates the pricing of the negative externalities. Conclusions and future research directions are stated in Section 6.

2. Review methodology

This review focuses on the freight transportation literature that addresses the negative externalities. The negative externalities are studied mainly based on the work of Maibach et al. (2008) and Brons and Christidis (2012) who examine

[1] In order to have a full assessment (Rodrigue et al., 2013) of transportation modes, a life-cycle of the transportation asset and infrastructure should be considered. However, it is not easy to consider the life-cycle of every input to the transportation system. These include: pre-production, construction, utilization, refurbishing, destruction, and disposal. Ignoring the life-cycle of all inputs may lead less reliable results.

externalities in two categories. These are environmental impacts and socio-economic impacts. The environmental impacts include air quality, climate change and noise whereas the socio-economic impacts include congestion and accidents. We have followed the same structure but mainly focused on the emissions (air quality and climate change), noise pollution, accidents and congestion. The following research questions are considered:

*RQ*1: What negative externalities have been addressed in the freight transportation literature?
*RQ*2: How are they of relevance to different transportation modes?
*RQ*3: How are externalities for each transportation mode measured in the literature?
*RQ*4: How should research on negative externalities in the field of freight transportation evolve?

Papers published in major journals in the domain of transportation (e.g., *Transportation Research Part A-E*, *European Journal of Operational Research*, *Journal of Transport and Supply Chain Management*, *Journal of Transport Economics and Policy*, *Journal of the Transportation Research Board, Research in Transportation Economics*, *Transportation Planning and Technology*, *Journal of Transport Geography*, *Energy Policy*, *European Journal of Transport and Infrastructure*, *Transport Policy*, *Journal of Transportation Economics*, and *Journal of Transportation and Statistics*) were initially the main source of selection. Those identified of relevance by title, key words, abstracts were carefully read to access the true relevance. References used in those relevant papers were investigated, where further relevant sources (e.g., overlooked papers, edited books, and technical reports) were identified. To our surprise, the topic especially the modeling and the pricing of negative externalities appear of more focus in technical reports granted by the European Union, the United States, and some private organizations. The final database, of which all items are used in this review, contains 39 journal papers, 64 technical reports and 16 the other types of studies (e.g., conference proceedings). As clustered on a yearly basis, one of the sources was published prior to 1980, 2 were in the 1981–1990 period, 24 were in the 1991–2000 period, and 92 were after year 2000.

3. The negative externalities of freight transportation

Research interest in externalities of freight transportation has continuously expanded in the last decade due to the increasing impacts on economy, environment, climate, and society. Dozens of negative externalities of relevance to freight transportation are described in the literature (see, e.g., OECD, 1997; EEA, 2010; McAuley, 2010; Ranaiefar and Regan, 2011; Brons and Christidis, 2012); this section categorizes the most important externalities of freight transportation in seven groups as shown in Fig. 1.

Fig. 1 presents an overview of the negative externalities of freight transportation. Each group of externalities is briefly discussed in the rest of the sections: whilst GHGs, water pollution, and land use mostly incur external costs to the environment and climate, others such as air pollution, noise, congestion, accidents impose harms to human life and generate unnecessary costs to economy.

Air pollution

Emissions can be categorized based on the impacts on local (<500 km in diameter), regional (>500 km in diameter) and

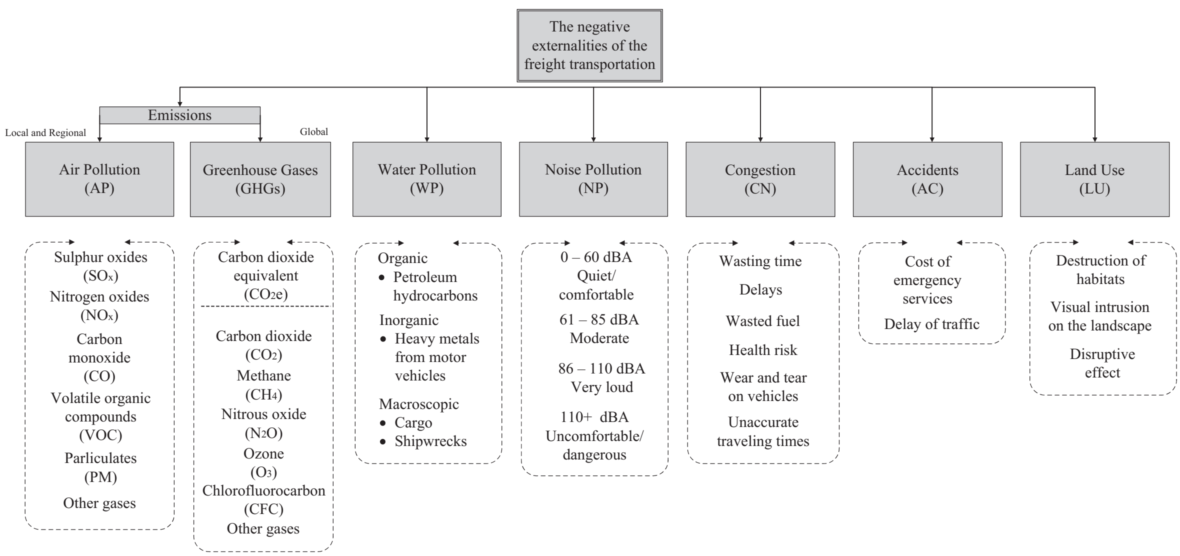

Fig. 1. The negative externalities of freight transportation.

global scales (terrestrial globe), and affect people, vegetation, global climate and materials. Local pollution harms human health, and causes material damage to buildings and vegetation (OECD, 1997). In particular, the local pollutants have been largely discussed, where it is emphasized that the source of the corresponding emissions includes a wide range of particulate matter (PM) in different sizes and compositions as well as gaseous air pollutants (McAuley, 2010). Fine particles may pose more severe health risks, due to the fact that they are easily inhaled and penetrate deeper into the lung (PSRC, 2010). Gaseous air pollutants are also associated with a number of health issues, such as asthma in children and other respiratory diseases, heart disease, cancer, and increased rates of premature death in adults (Ang-Olson and Ostria, 2005).

Pollutants are harmful in terms of their direct damage to environment and health (called conservative pollutants) as well as some of those being precursors to other detrimental pollutants (secondary pollutants) (McAuley, 2010). Carbon monoxide (CO) is considered to be a conservative pollutant when present in high concentrations (Lawson, 2007). These high concentrations may be found around congested roads or in cities. High concentrations are more likely to occur when there is little wind to disperse the emissions. CO reduces bloods oxygen-carrying capability; this can lead to acute effects (e.g., headaches) or chronic effects, such as, increasing the risk of heart disease (Lawson, 2007). VOCs and NO_x can potentially increase the risks of respiratory and heart disease and damage plants, waterways and ecosystems (PSRC, 2010). Besides the direct harms of CO, VOCs and NO_x as conservative pollutants, they are precursors to ozone (O_3) formation (the formation of smog in cities) (Placet et al., 2000) and indirect contributors to global warming. Sulphur oxides (SO_x) cause breathing problems and acid rain. Regional impacts derive from acidification and ground level ozone. GHGs emissions are well-known at a global level. They are classically excluded from air pollutants and discussed in a separate section because their direct harms to health are still debatable. Other pollutants emitted by transportation include toluene, benzene, polynuclear hydrocarbons, hydrogen sulphide, dioxin, etc. (OECD, 1997) of which the impacts are yet to be known.

Greenhouse gasses

GHGs are the most studied externality of freight transportation. They cause atmospheric changes and climate disruptions which are harmful to the natural and built environments, and pose health risks. GHGs are not classified as a pollutant in the classical sense. However, the United States Environmental Protection Agency (EPA) recognized that GHGs pose a danger to human health and welfare in 2009. GHGs absorb and emit radiations within the thermal infra-red range in the atmosphere, and significantly raise the Earth's temperature. The primary transportation-related man-made greenhouse gases in the Earth's atmosphere are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), etc. As CO_2 is the dominant man-made GHG, the impacts of other gases can also be calculated based on carbon dioxide equivalent (CO_2e). The impact of emissions on climate change is assessed by a comparison between the actual temperature changes in the last 100 years and those that are provided in the models with or without human influence. It is found that the actual temperature changes are very similar to those provided by the model in which the human influence is taken into account (IPCC, 2007). In particular, the Intergovernmental Panel on Climate Change has estimated that 13.1% of the GHGs emissions is caused by the transportation sector. As of December 2014, the level of GHGs is estimated to be equal to 398.78 (ppm), and is still increasing (ESRL, 2014).

Noise pollution

The transportation-related noise pollution is mostly considered to be a nuisance for people that have to deal with it frequently. When the noises are severe or the durations of the noises are long enough, health problems (e.g., stress, sleep disturbance, cardiovascular disease, and short or long-term hearing loss) occur (Andersson, 2005; Van Essen et al., 2011). Measuring the noise pollution is not straightforward. Noise can be measured in A-weighted decibels (dBA, dB(A) or dB(a)) in terms of their volumes. Besides the volume of the noise, other factors (e.g., pitch, frequency, duration and variability) should also be considered. Lower levels of noise (i.e., below 60 dBA) can be acceptable in a short-time duration, but harms to human health may occur as the duration increases. Noises in moderate levels (61–85 dBA) may increase the risks of cardiovascular diseases and result in nervous stress reactions. Noises above 85 dBA could cause severe hearing damages. Transportation noises can also affect sleep quality, particularly for those who live in high traffic areas (e.g., highways). Additionally, people who live near transportation hubs (e.g., rail stations and airports) could be disturbed constantly. The negative impacts of noise on human health could also generate various costs, such as medical costs, costs of productivity losses, and the costs of increased mortality.

Due to the non-linear characteristics of noise pollution, the monetary estimation is rather complex (Martini et al., 2013a). There are two main methods for estimating noise pollution costs, namely hedonic price methods and contingent valuation methods (Lu and Morrell, 2006). The former considers location, attributes of the neighbourhood and community, as well as environmental quality; it has been widely developed and applied by policy makers as unique price estimations for noise impacts can be obtained (Lu and Morrell, 2006; Martini et al., 2013b). The latter is based on surveying people's willingness to pay for specific improvements; while the estimation is more sensitive to changes, it is argued susceptible to biases (Navrud and Mungatana, 1994).

Water pollution

Freight transportation has both direct and indirect impacts on water quality (OECD, 1997). Shipping causes discharge of ballast water from marine vessels. If ballast is not segregated from cargo, it results in oil pollution to seas and coastal waters. Shipping is also a source of oil and chemical spills at ports and in coastal waters. Spills refer to leakages, accidental or deliberate disposal of cargo materials or other materials (lubricants, fuel, etc.) used in the transportation process (Lawson, 2007). The quality of water can also be affected by air pollution (e.g., acid rain). Whilst the problems of water pollution get more severe as shipping activities increase, they are not as easy to measure as air pollution where 'ton-kilometer' of freight is applied.

Congestion

Congestion happens in transportation networks when entities compete individually for a limited capacity. Congestion causes increased travel times, operating costs, and unreliability in travel activities (Banfi et al., 2000). The direct impact of congestion, as a freight transportation externality, refers to increased travel times to other entities in the transportation system. Congestion could also indirectly result in increased fuel costs, air pollution, noise pollution and stress levels.

Accidents

When talking about accidents, one generally thinks of damages to people, vehicles, freight, and infrastructure which directly incur in accidents. These damages are not the concern of this study given the scope of external impacts of freight transportation. Examples of externalities of accidents include the costs of emergency services attending the accidents, delay of traffic, and the costs to the victims family in pain and suffering (McAuley, 2010). Moreover, oil spills have obvious impacts on ecosystems and wildlife. Some of the truck accidents, train derailments, or gas pipeline accidents may release toxic or flammable chemicals which are harmful to human life and ecosystem.

Land use

Transportation planning decisions influence land use (or infrastructure) directly, by affecting the amount of land used for transport facilities, and indirectly, by affecting the locations and designs of infrastructure development (Litman, 2004). Examples of the corresponding external costs associated with freight transportation include replacing habitat with roads, rails, or other transportation infrastructure, the visual intrusion of transportation on the landscape, high traffic volumes that limit people to cross roads, and species loss caused by highways (OECD, 1997; Lawson, 2007).

4. Modeling of the negative externalities

This section is structured by transportation mode. For each mode, a brief overview of the transportation mode is provided and followed by the modeling of its negative impacts. The transportation modes covered in this section include road, rail, maritime, and air transportation. The relevance of externalities to each transportation mode have been studied by Mauch and Rothengatter (1995), IBI Group (1995), Van Essen and Maibach (2007), and EEA (2011). Table 1 presents a summary of these studies with evaluation of the impact levels of individual externalities on each transportation mode based on the monetary values provided in the studies.

Table 1 shows that most of the transportation modes are attached with air pollution and GHGs, although the amount of the pollution varies significantly. Road transportation generally has the biggest impact on environment except the sector of water pollution which actually has some indirect relevance to air pollution. Rail and maritime transportation have some similarities to road transportation but these modes can be categorized more environmentally friendly and less health threatening. The environmental risks posed by pipelines are accidents, air pollutant emissions, greenhouse gases, and land use that threats to the environment. Although pipeline is quite interesting, it is out of the scope of the paper due to limited studies reported in the literature. In the following subsections, an example of mathematical formulation that includes the fundamental (minimum requirements on the use of) explanatory variables for each type of externalities is provided. The focus of the simplicity in the examples is to encourage implementations, where more comprehensive models can be built upon as appropriate. Moreover, a tabulated comparison of the models is included at the end of each subsection. A good understanding of these models along with adequate use of operational research techniques facilitates more accurate counts of externalities in freight transportation planning (Demir et al., 2014a).

4.1. Road freight transportation

Freight transportation is the backbone of the economy, and road transportation has a strategic role in this framework. Road enables reliable and speedy freight transportation, where goods can be supplied to warehouses and retailers in a timely

Table 1
Relevance of the negative externalities per transportation mode.

Negative externalities	Road transportation	Rail transportation	Maritime transportation	Air transportation	Pipeline transportation
Air pollution	***	**	**	**	*
Greenhouse gases	***	**	**	**	*
Noise pollution	***	**	**	**	*
Water pollution	*	*	***	*	*
Congestion	***	*	*	*	*
Accidents	**	*	*	*	*
Land use	**	**	*	*	*

*: Low **: Medium ***: High.

fashion. In the last decade, a shift towards road transport has been recorded in European Union (EU). In 2011, road transportation made up over half of freight movements in most of the member states of EU (EC, 2013). Approximately 14,933 million tonnes of freight were transported by road in the EU-28 (EU's 28 states). A comparison between road and other modes of transportation shows that, in 2010, the quantities of freight transported by road in the EU-28 equaled approximately nine times of the amount transported by the other modes of transportation. Mathematical formulations for each externalities related to road transportation are discussed below.

4.1.1. Air pollution and greenhouse gases

Air pollution and GHGs have been extensively studied as road transportation externalities for two main reasons: (i) research on air pollution confirms that road transportation is by far the most polluting freight transportation mode for all pollutants (with the exception of PM) (see, e.g., EEA, 2011; EPA, 2013); (ii) the most of the emissions can be predicted fairly accurate provided that the amount of energy consumption is known (Demir et al., 2011, 2014a), which makes the modeling of such externalities quite straightforward. *Computer programme to calculate emissions from road transportation* (COPERT) is one of the most well-known emission model funded by the EU (Ntziachristos and Samaras, 2000; Gkatzoflias et al., 2012). The model estimates emissions for a range of vehicles by engine classification and vehicle type, which driven by a database of emissions covering vehicle class, engine technology and speed. Air pollution and GHGs produced by vehicles in different categories and weights are estimated by a number of regression functions. An example of emission function (in gram per kilometer) with different load and gradient factor is given by

$$E_{Ro}(v, D) = (e + (a\ \exp(-b\,v)) + (c\ \exp(-d\,v)))\cdot D, \tag{1}$$

where a to e are the coefficients depending on type of vehicle, type of fuel, payload and road gradient). Moreover, v is vehicle speed (km/h) and D is the traveling distance (km). Table 2 shows a set of output (gram per kilometer) for a 20–26 ton rigid truck running on Euro-5 diesel.

The COPERT also considers the payload and road gradient besides vehicle speed. The cost of air pollution and GHGs can be calculated as the multiplication of unit cost of externalities and the amount of emissions produced (per ton-kilometer).

4.1.2. Noise pollution

Noise pollution in road transportation is mainly caused by the sound of the vehicle engine and the sound of rolling. The impact of noise depends on the time of the day. For example, noise during the night obviously causes sleep disturbance which makes the damage of noise higher than that is in the day time. Information required for the calculation of noise pollution includes vehicle type, payload, speed, road gradient, road surface and impact duration. A historical review on traffic noise models can be found in Quartieri et al. (2009).

IMAGINE[2] provides a noise emissions model for road vehicles in terms of a sound power level (in dBA) which is an expression of the relative loudness of sounds in air as perceived by the human ear (Kephalopoulos et al., 2012). Both propulsion and rolling noises are estimated by the model. The sound level emitted by the sources as a function of the each octave band i (for practical reasons the audible frequency range can be separated into unequal segments called octaves) and the vehicle speed v can be calculated as

$$L_{Ro}(i, v) = 10\log(10^{L_r(i,v)/10} + 10^{L_p(i,v)/10}), \tag{2}$$

where $L_r(i, v)$ is the rolling noise and can be calculated as $L_r(i, v) = A_r(i) + B_r(i)\log(v/v_{ref}) + \Delta L_r(i, v),\ L_p(i, v)$ is the propulsion noise and can be calculated as $L_p(i, v) = A_p(i) + B_p(i)((v - v_{ref})/v_{ref}) + \Delta L_p(i, v)$. Moreover, $A_r,\ B_r,\ A_p$ and B_p are the coefficients and can be found in Table 3. Finally, v_{ref} is the reference speed (i.e., $v_{ref} = 70$ km/h).

A number of corrections may be needed to account for the effects of meteorology, driving, and road surface and tyres on the sound power level once a rough estimate (a flat (non-sloped) road, an air temperature of 20 °C, a dry road surface) has been produced. $\Delta L_r(i, v)$ is the sum of corrections to be applied to the rolling noise and $\Delta L_p(i, v)$ is the sum of corrections to be applied to the propulsion noise. Detailed explanation on these corrections can be found in Kephalopoulos et al. (2012).

Using the IMAGINE model, the noise emission of traffic flows can also be estimated. The directional sound power per meter per frequency band of the source and vehicle speed are calculated as

$$L'_{Ro}(i, v) = L_{Ro}(i, v) + 10\log(Q/(1000v)), \tag{3}$$

where Q is the steady traffic flow of vehicles.

4.1.3. Congestion

Congestion is a very serious phenomenon in road transportation and it can be measured as the sum of recurrent and non-recurrent delay in a traffic network (Skabardonis et al., 2003). The first category depends on the fluctuations in demand and the physical capacity of the road. The second category depends on the nature of the incident, such as breakdowns, and accidents. Congestion costs can be calculated with the free flow travel time which depends on the distance and the time spent in congestion period. Free flow time can be determined through the use of a travel time function. Its value depends on the

[2] IMAGINE: Improved Methods for the Assessment of the Generic Impact of Noise in the Environment (Peeters and Blokland, 2007).

Table 2
Emissions (gram per kilometer) obtained with COPERT.

Payload (%)	Gradient (%)	CO	NO_x	PM	CO_2e
0	0	0.095	1.847	0.0226	719
0	−2	0.069	0.761	0.017	319
0	+2	0.129	3.152	0.028	1164
50	0	0.105	2.250	0.024	866
50	−2	0.056	0.713	0.014	292
50	+2	0.160	4.14	0.03	1584
100	0	0.111	2.573	0.024	1014
100	−2	0.049	0.746	0.013	308
100	+2	0.165	4.791	0.032	2005

Table 3
Set of data and output of IMAGINE' noise model for two different speed levels.

Octave band (Hz)	A_r	B_r	A_p	B_p	$L_r(i,v)$ (dBA) ($v = 60$ km/h)	$L_p(i,v)$ (dBA)	$L_{Ro}(i,v)$ (dBA)	$L_r(i,v)$ (dBA) ($v = 80$ km/h)	$L_p(i,v)$ (dBA)	$L_{Ro}(i,v)$ (dBA)
63	87.0	30.0	104.4	0.0	85.0	104.4	104.4	91.0	104.4	104.6
125	91.7	33.5	100.6	3.0	89.5	101.0	101.3	95.3	101.3	102.3
250	94.1	31.3	101.7	4.6	92.0	102.4	102.7	97.9	102.7	104.0
500	100.7	25.4	101.0	5.0	99.0	101.7	103.6	104.9	103.6	107.3
1,000	100.8	31.8	100.1	5.0	98.7	100.8	102.9	104.5	102.9	106.8
2,000	94.3	37.1	95.9	5.0	91.8	96.6	97.9	97.4	97.9	100.7
4,000	87.1	38.6	91.3	5.0	84.5	92.0	92.7	89.9	92.7	94.5
8,000	82.5	40.6	85.3	5.0	79.8	86.0	86.9	84.8	86.9	89.0

distance, traffic volume, and roadway capacity. Numerous reasons can be responsible for delay on transportation infrastructure, such as, road works, accidents, driving behavior, and high flow/capacity ratios. Consequently, vehicles have to move slower than expected, and users need more time than they would have without the obstacles. From an economic point of view, time losses can be expressed in monetary terms. In addition, congestion presumably causes more air pollution, fuel consumption, and accidents.

We now present the formula introduced by Kirwan et al. (1995) and discussed in Proost and Dender (1999) to measure the congestion for a set of different vehicle types at peak and off-peak periods. The exponential congestion function (in minutes) can be written as

$$t_i = \frac{60}{v} = a + b\exp(cq_i), \tag{4}$$

where t_i the total time needed to drive one km by a truck in period i (peak and off-peak), q_i is the number of passenger cars per hour in period i. Moreover, $a,\ b$ and c are the model-specific congestion parameters. The marginal external cost of congestion of an additional vehicle kilometer can be calculated as

$$MECC_{q_i} = \frac{\partial_{t_i}}{q_i} \cdot x_i \cdot VOT_i, \tag{5}$$

where x_i is the total number of vehicles kilometer in period i and VOT is the value of the time (cost unit per hour) in period i. Other formulations of congestion can be found in (e.g., Lam and Small, 2001; Meng et al., 2012; Uchida, 2014).

4.1.4. Accidents

Accidents are those social costs of an unfortunate incident that occurs unexpectedly. The most important accident cost categories are material damages, administrative costs, medical costs, production losses, delay, and the so called risk value as a proxy to estimate pain, grief, and suffering caused by traffic accidents in monetary values. A model by Lindberg (2002) to estimate the number of accidents A is presented as below.

$$A = Qr, \tag{6}$$

where Q is the traffic volume and r is the accident risk for an freight user. The external costs of accidents can be also calculated as follows in (Márquez and Cantillo, 2013).

$$EC_{acc} = Qr((1 - S)(a + b) + c)), \tag{7}$$

where S is the share of total accident costs that fall on freight vehicle users, a is the risk based on an individuals willingness to pay (WTP), b is the WTP of the individuals relatives and friends, and c is the system external costs related to medical costs and the social security system. A different approach to estimate the accidents of freight transportation can be found in McAuley (2010).

4.1.5. A summary of models for road transportation

A overview of models for calculating the negative external costs is given in this section. Table 4 shows studies with modeling of the negative externalities for road transportation with their inclusion of the types of externalities. In addition, the modeling approach in each study is assessed by the complexity of data requirement, and the continuous improvement, where a three-point scale analysis is employed. The complexity of data requirement defines the number of explanatory variables required in the estimation of externalities. For example, a 'low' complexity level indicates the involvement of less than three explanatory variables, a 'medium' level covers four to six variables, and a model using more than six parameters is referred to a 'high' complexity in data requirement. The continuous improvement describes the frequency of revisions in time; the higher the score, the more reliable the model is assumed. A study with 2–3 iterations is considered a 'medium'level of continuous improvement, which differentiates the lower and upper levels.

The assessment of the modeling approaches is shown in the last two columns of Table 4. Air pollution and GHGs are largely focused in the literature. This is expected because the factors affecting these emissions are widely known. Noise pollution, congestion, and accidents are also well addressed in the literature but not as extensively as studies of emissions. There is no study found for water pollution as it is not directly related to the road transportation. Studies on modeling land use seem very limited.

4.2. Rail freight transportation

This section reviews models of externalities in rail freight transportation. A freight train is a combination of freight wagons hauled by one or more locomotives on a railway, transporting cargo between the origin and the destination as part of the transportation chain. A freight train can be categorized into electric or diesel locomotives: the former is powered by electricity from overhead lines; and the latter is a type of railway locomotive in which the prime mover is a diesel engine. Different locomotives could result in significantly different external costs.

Rail is a more efficient transportation mode than road in terms of ton-kilometers hauled per unit of energy consumed. However, a shipment by rail is not as flexible as road transportation, which results in a great proportion of freight being hauled by trucks in the world. In 2010, EU-28's freight transportation by rail amounted to 1589 million tons (EC, 2013).

Table 4
Studies with modeling of the negative externalities for road transportation.

Research	AP	GHGs	NP	CN	AC	The complexity of data requirement	The continuous improvement
DOT (1988)			√			***	*
Mun (1994)				√		**	*
Mayeres et al. (1996)			√	√	√	**	*
Greenwood and Bennett (1996)		√		√		**	*
Hickman et al. (1999)	√	√				**	*
Delucchi and Hsu (1998)			√			**	*
Wang (1999)	√	√				***	***
Joumard (1999)	√	√				**	*
Proost and Dender (1999)	√		√	√	√	*	*
Banfi et al. (2000)	√	√	√	√	√	*	*
Cappiello et al. (2002)	√	√				**	**
Samaras et al. (2002)	√	√	√			**	**
Nash et al. (2003)	√			√	√	**	**
Small and Chu (2003)				√		**	*
EPA (2003)	√	√				**	*
Delucchi (2003)	√	√				**	*
Black et al. (2003)	√	√	√	√	√	**	**
Barth et al. (2005)	√	√				***	**
Bickel et al. (2005)	√	√				**	*
Smit et al. (2007)	√	√				**	*
ISSRC (2008)	√	√				**	**
Hausberger et al. (2009)	√	√				***	***
Boulter and McCrae (2009)	√	√				**	**
EPA (2012)	√	√				**	***
NTM Road (2010)	√	√				**	**
Kouridis et al. (2010)	√	√				**	***
Breemersch et al. (2010)	√	√				**	**
Knörr et al. (2011)	√	√				**	**
CARB (2011)	√	√				**	*
Hausberger et al. (2012)		√				**	***
Gkatzoflias et al. (2012)	√	√				**	***
NAEI (2012)	√	√				**	***

*: Low **: Medium ***: High.

4.2.1. Air pollution and greenhouse gases

The procedure of calculating air pollution and GHGs depends on whether the train is diesel or electric powered. For trains with diesel power, the emissions can be estimated on the basis of the amount of diesel fuel consumed or the type of engine. For electric trains, there are no significant emissions from the train itself. The emissions arises from the source of electricity energy. Emissions can be calculated based on the energy that the train has consumed. Moreover, CO_2 and SO_2 are solely related to the amount of fuel consumed, while other pollutants depend on the engine condition, operating point and driving characteristics. The energy consumption of a train can be calculated by a function of gross train weight. However, there are also other factors that have an impact on energy consumption, such as train speed, aerodynamic characteristics of the locomotives, driving pattern, and the number of stops (Boulter and McCrae, 2009).

The primary energy consumption can be calculated as $E_{pri} = E_{tr}/\eta_{pri}$ where E_{tr} is the energy consumption rate for moving a train and η_{pri} is the efficiency rate (Boulter and McCrae, 2009). The energy consumption rate (E_{tr}) represents the energy delivered at the wheels. E_{tr} is generally counted as a function (i.e., $E_{tr} = (F_a + F_g + F_r + F_{acc})v$) of four driving resistances, including aerodynamic resistance, gradient resistance, rolling resistance, and acceleration resistance. An aerodynamic resistance is dependent on the frontal area of the train and locomotives, its shape, and its speed; it can be calculated as $F_a = 1/2C_aA_fpv^2$, where C_a is the air resistance coefficient, A_f is the frontal area (m^2), p is the air density (km/m^3) and v is the speed (m/s). The gradient resistance is determined by the weight of the train, and the size of the gradient to which the train is exposed; it can be calculated as $F_g = mg\sin\alpha$, where α is the gradient. The rolling resistance is a function of the total mass of the train, and the rolling resistance coefficient can be calculated as $F_r = f_rmg$, where f_r is the rolling resistance coefficient, m is the total mass of the train (kg), and g is the gravitational constant. The acceleration resistance is calculated as $F_{acc} = ma$, where a is the acceleration. The rolling and aerodynamic resistances are related to equipment design, varying from train to train. The gradient and acceleration resistances are only dependent on the total mass of the train.

Knowing the speed and acceleration figures, it is possible to calculate the energy consumption for a given driving condition. Energy consumption and emissions for any driving cycle can be computed by dividing the operation into a matrix of speeds and accelerations and summing up the energy consumptions for the individual conditions, weighted by the frequency.

$$E_{tot} = \sum_{i=1}^{N_{mode}} E_i(t)f_i(t), \quad (8)$$

where N_{mode} is the total number of driving levels and $f_i(t)$ is the frequency for each level. Using the data from Samaras et al. (2002), of the Netherlands, Table 5 provides emissions factor (in kilogram/gigajoule) for diesel and electrical engine trains. We note that the means of generating the electricity used to power electric train depends on burning fossil fuels or coal, both of which produce a large amount of emissions.

4.2.2. Noise

Rail transport causes noise mainly due to traction noise and rolling noise (EC, 2003). There is also a difference between daytime and night with regard to the impact. The required information for the calculation of noise costs includes type of train, speed, length of train, kind of brakes, quality of track, kind of sleepers, and duration.

A noise model by Kephalopoulos et al. (2012) to measure railway traffic noise in terms of a sound power level (in dBA) is presented below. The rail noise includes rolling, impact, squeal, traction, aerodynamic, source and other effects. The sound level emitted by one source can be calculated as

$$L_{Ra}(\psi, \varphi) = L_0 + \Delta L_{ver} + \Delta L_{hor}, \quad (9)$$

where ΔL_{ver} is the vertical directivity correction function of ψ, and ΔL_{ver} is the horizontal directivity correction function of φ. L_0 is the directional sound power level of the specific noise of a single vehicle in the directions ψ and φ. The noise emission of traffic flow can also be calculated. The directional sound power per meter per frequency band of the source is calculated as

$$L_{Ra'}(\psi, \varphi) = L_{Ra}(\psi, \varphi) + 10\log(Q/(1000v)), \quad (10)$$

where Q is the average number of vehicles per hour, and v is the train speed.

Table 5
Set of sample data for rail emissions.

Emissions	Diesel-powered engine	Electric-powered engine
CO_2e	0.032	0.024
CO	0.25	0.027
NO_x	1.32	0.631
HC	0.06	0.02
SO_2	0.075	1.44
PM	0.075	0.069

4.2.3. A summary of models for rail transportation

A summary of models for rail externalities are given in this section. Table 6 presents the relevant studies and their coverage of the externalities. For each study, the proposed model is assessed for the complexity of data requirement, and the continuous improvement.

As can be seen from the table, there is relatively limited work on the negative externalities for rail transportation compared with road transportation. To our knowledge, congestion and accidents in rail transportation are yet effectively modelled in the literature.

4.3. Maritime freight transportation

Maritime transportation can be over any distance by ship or barge through oceans, lakes, canals or rivers; it is commonly described as shipping. Freight can be moved in boxes, cases, pallets, and barrels. For the maritime mode, researchers have made clear distinctions between types of vessels, where different weight categories are used for different types. Vessels are classified differently in the literature, but common examples include the tanker and the bulk carrier. Some articles also define the types of cargo (e.g., liquid or dry).

4.3.1. Air pollution and greenhouse gases

Maritime transportation is the most emission-efficient mode as it can carry enormous amounts of goods per ship. The CO_2e emissions from ships mainly originate from the use of fuel. Unlike rail and road vehicles, there is no/little traffic involved in shipping, which means that there will be (practically) no losses of fuel due to speed fluctuations. The external cost for air pollution is also very low due to the fact that maritime transportation occurs off-shore, far away from populated areas. The seaborne transportation only accounts for global air pollution. However, there is also freight transportation using inland waterways, where the costs incurred due to health problems on local and regional scales should be considered.

The international maritime organization proposed a model to calculate maritime transportation pollutants based on engine power of both the main engine and auxiliary engines (Knörr et al., 2011). The auxiliary engines provide power to electrical instruments as well as loading and discharging gears (Knörr et al., 2011). For the mail engine, the total energy of the required engine power in kW h/tkm (P_{tkm}) is calculated as

$$P_{tkm} = \frac{ME_{MCR} \cdot ME_{load}}{Vi \cdot c \cdot u}, \tag{11}$$

where ME_{MCR} is the main engine maximum continuous rating, ME_{load} is the main engine load factor, V_i is the speed of the vessel at load i, c is the vessel's nominal capacity, and u is the utilization factor (Knörr et al., 2011). To compute the pollutants, it is essential to have the vessel specific fuel consumption (Vfc) per tonne-km which is calculated as

$$Vfc = P_{tkm} \cdot sfc, \tag{12}$$

where sfc stands for the specific fuel consumption factors which can be obtained from the manufacturers of the engines.

A simpler means of estimating pollutants is to use emission factors based on fuel consumption. This results in quantities of pollutants which can then be converted to money by using cost factors for each pollutant. As discussed in Knörr et al. (2011), a set of emissions data (in gram/ton-kilometer) is given in Table 7.

Table 6
Studies with modeling of the negative externalities for rail transportation.

Research	AP	GHGs	NP	The complexity of data requirement	The continuous improvement
Cato (1976)			√	**	*
Jørgensen and Sorenson (1997)	√	√		***	**
Hickman et al. (1999)	√	√		*	*
Joumard (1999)	√	√		**	*
Samaras et al. (2002)	√	√	√	**	**
Parajuli et al. (2003)		√		*	**
Black et al. (2003)	√	√	√	*	*
Delucchi (2003)	√	√		**	**
NTM Rail (2008)	√	√		**	**
Boulter and McCrae (2009)	√	√		*	**
Kim and Van Wee (2009)		√		**	**
Kim (2010)		√		***	**
Papson et al. (2011)		√		**	*
Knörr et al. (2011)	√	√		***	**
Persson and Zanganeh (2012)		√		**	**

*: Low **: Medium ***: High.

Table 7
Set of sample data for maritime emissions.

Emissions	Container vessel (6 t per TEU)	Container vessel (14.5 t per TEU)
CO_2	28.24	11.68
NO_x	0.72	0.30
HC	0.0288	0.0119
SO_x	0.17	0.17
PM	0.0639	0.0265

4.3.2. A summary for models for maritime transportation

A summary of studies that model maritime freight transportation externalities is presented in Table 8. Apart from emissions, the external costs of noise pollution is another sector that has been investigated but with little focus. As we know, ships are at open sea most of the time that no one can hear them. Even in the harbors, the sounds of the ships are not of particular significance. Waterborne transportation generally has little impact on congestion which occasionally occurs when bridges have to be raised to let vehicles pass.

4.4. Air freight transportation

External costs for air transport can hardly be generalized as they largely depend on the type of the airplane and the airfield. Studies tend to give different results as they are based on different airports.

4.4.1. Air pollution and greenhouse gases

While air transportation is literally the fastest way to move freight from A to B, it comes at the price of relatively high fuel consumptions; it is therefore the least fuel-efficient mode. The external costs for the emission of greenhouse gasses appear substantial compared with the limited cargo capacity. Although most of the emissions are at high altitude mainly contributing to global effects, air pollution also has a local effect around airports due to the large amount of air traffic coming to and going from the airports.

Emissions of aircraft originate from the fuel burnt in the main aircraft engines as well as the engines powering the auxiliary power units. CO_2, NO_x, and CO are emitted in the greatest quantities per tonne of fuel consumed, while other emissions include methane CH_4, by-product gases, and trace amounts of metals. The fuel use and emissions also depends on the fuel type, aircraft type, engine type, engine load and flying altitude. Operations of aircraft are usually divided into the landing and take off cycle (LTO), and the cruise phase. The former includes all aircraft activities such as taxi-in and out, take-off, climb-out, and approach and landing, and the latter contains all activities that take place at altitudes above 3000 feet. Watterson et al. (2004) provide a model to estimate the emissions of pollutant p from a particular Landing/Take-off (LTO) cycle m of operation:

$$E_{Air}(m,p) = N \cdot T(m) \cdot F(t_m) \cdot I_{a,p}(t_m), \tag{13}$$

where N is the number of engines, $T(m)$ is the time in mode m (sec), $F(t_m)$ is the weighted average fuel flow for an engine, and $I_p(t_m)$ is the weighted average emission factor of pollutant p. For the cruise mode, the emission for the flight distance d and pollution p can be calculated as $E_{Air}(d,p) = m_{g,p} \cdot d + c_{g,p}$, where $m_{g,p}$ is the slope of regression and $c_{g,p}$ is the intercept of regression. A set of emissions data provided by Winther et al. (2010) is given in Table 9.

4.4.2. Noise

Air transportation noises are mainly generated from the sounds produced by the engines of aircrafts. While road and rail noises have impacts throughout the whole country, noises caused by air transportation are centralized around the airports. ECAC (1997) developed a noise model for an individual aeroplane movement in terms of a sound power level (in dBA). For a selected point (x,y), the sound level emitted by one source can be calculated as

$$L(x,y) = L(\xi,d) + \wedge(\beta,l) + \Delta_L + \Delta_v + \Delta_t, \tag{14}$$

where $L(\xi,d)$ is the noise data based on the distance d, the thrust ξ, $\wedge(\beta,l)$ is the correction factor of attenuation of sound, Δ_L is the correction factor to consider the take-off noise. Δ_v and Δ_t are the correction factors for the speed changes and direction changes of an aeroplane, respectively.

4.4.3. A summary for air transportation

The studies that model the external costs of air transportation are summarized in Table 10 with the coverage of externalities and the competence of the modelling approach. As shown in the table, emissions have been typically the focus of study.

We present Table 13 in Appendix A to provide a better understanding of the models in terms of emission quantities.

Table 8
Studies with modeling of the negative externalities for maritime transportation.

Research	AP	GHGs	NP	The complexity of data requirement	The continuous improvement
Hickman et al. (1999)	√	√		*	*
Joumard (1999)	√	√		**	*
Samaras et al. (2002)	√	√	√	**	**
Georgakaki et al. (2002)	√	√		**	*
Black et al. (2003)	√	√	√	*	**
Endresen et al. (2003)	√	√		**	*
NTM Sea (2008)	√	√		**	**
Corbett et al. (2009)		√		**	*
Boulter and McCrae (2009)	√	√		*	*
Comer et al. (2010)	√	√		***	*
Fitzgerald et al. (2011)	√	√		*	*
Lindstad et al. (2011)		√		***	*
Knörr et al. (2011)	√	√		***	**

*: Low **: Medium ***: High.

Table 9
Set of sample data for maritime emissions.

Emissions	Domestic		International	
	LTO (kg/LTO)	Cruise (kg/ton)	LTO (kg/LTO)	Cruise (kg/ton)
CO_2	2680	3150	7900	3150
NO_x	10.2	11	41	17
CO	8.1	7	50	5
SO_2	0.8	1	2.5	1
NMVOCs	2.6	0.7	15	2.7

Table 10
Studies with modeling of the negative externalities for air transportation.

Research	AP	GHGs	NP	The complexity of data requirement	The continuous improvement
Hickman et al. (1999)	√	√		**	*
Joumard (1999)	√	√		**	*
Samaras et al. (2002)	√	√	√	*	**
Black et al. (2003)	√	√	√	**	**
NTM Air (2008)	√	√		*	**
Gualandi and Mantecchini (2008)			√	*	*
Boulter and McCrae (2009)	√	√		**	**
Knörr et al. (2011)	√	√		*	**
Howitt et al. (2011)		√		**	**

*: Low **: Medium ***: High.

5. Pricing of the negative externalities

As discussed in the previous sections, many environmental, social and health problems result from negative externalities. If the movement of freight has a negative externality to human life or to the environment, then the cost to society is greater than the cost that is paid, for example, by consumer. The costs of negative externalities should be internalized in a way so that they can be measured and controlled. Internalization means including the company's social costs in the company's private costs (Piecyk et al., 2010). In other words, externalities should be paid by companies that generate them; this may be realized by government, market or private organizations. The rest of this section reviews studies that address internalization of negative externalities in the field of freight transportation.

We also note that there are several studies looking at individual air pollutants such as NO_x and SO_x, and provide monetary values for these pollutants (see, e.g., Dings et al., 2002; Schipper, 2004; Lu and Morrell, 2006; Givoni and Rietveld, 2010). However, we aim to give an overall view of monetary values for each externalities.

5.1. Studies on the pricing of externalities

Internalizing the external costs of transportation is complex and requires a large amount of data, which explains the fact that no single study is comprehensive enough to incorporate all the models, estimates, externalities, and transportation modes. Some studies seek for a generic set of cost factors that can be used for the same types of externalities while others focus on more specific and detailed cost estimates varying in vehicle/engine types, countries, etc. Whilst specific cost factors may enable more accurate estimations than a generic set does, it has a much higher requirement on data availability and involves more complex calculations. The rest of the section presents a number of key studies addressing the pricing of the negative externalities in freight transportation. Table 11 summarizes the externalities and transportation modes covered in each of the studies.

- ECORYS (2004) estimates various externality costs associated with different transportation modes for the Marco Polo II project which is initiated by the European Commission with an aim to reduce road congestion and pollution. The idea is to encourage companies to use greener modes of transportation than road for freight movement if possible. A Marco Polo calculator, which prices the environmental/social impacts (e.g., air pollution, global warming, noise, accidents, congestion, and infrastructure) of four transforation modes road, rail, inland water ways, and short sea shipping, is provided for companies to assess alternative solutions. The cost indices (in €/tkm) used in the calculator are based on marginal cost estimates resulting from earlier research (e.g., UNITE,[3] RECORDIT[4]). One can find that inland waterway and short sea transport (together counted as maritime) have the smallest overall index value (e.g., 0.01 €/tkm and 0.009 €/tkm respectively) which is the sum of the individual environmental/social index values of relevance.
- Maibach et al. (2008) investigates the existing scientific and practitioner's knowledge on externalities in the *Internalisation Measures and Policies for All external Cost of Transport (IMPACT)* project commissioned by the European Commission. A handbook on estimation of external costs in the transport sector is produced by combining a variety of studies done by acknowledged firms/institutes; this enables a comprehensive and reliable set of external cost figures. Examples of the studies include UNITE, HEATCO,[5] and GRACE[6] which are part of European research programs intending to determine unified costs for transportation. The handbook provides as detailed information as, for example, externality cost indices for different types of vehicles and fuels in road transportation, congestion costs depending on VOT, emissions of air transportation varying in flight distance categories. In addition, case studies are provided in the handbook for details of using such information.
- McAuley (2010) analyzes the external costs of inter-capital freight transportation in Australia. Given the focus of inter-capital freight, it is not surprising that only road and rail transportation modes are discussed in the study. Costs of externalities (e.g., accidents, GHGs, noise, and congestion) associated with each of transportation modes are presented in ranges (e.g., the maximum and minimum unit costs). A number of examples estimating the costs of inter-capital fright shipping externalities between major cities (e.g., Sydney, Brisbane, Melbourne, and Perth) in Australia are presented. The paper concludes that inter-capital road freight has much lower externality costs than the average level of road freight due to the better conditions of the inter-capital roads.
- Delucchi and McCubbin (2010) study the external costs for the United States. All modes of transportation are included, and the corresponding externalities are priced for both freight and passenger transportation. However, estimates are not available for all the cost categories (e.g., freight transportation in air and maritime modes). It is argued that there are fewer estimates for freight transportation than for passenger transportation due to the lack of information and concerns. The presented estimates are largely based on the cost figures available in scientific articles. Occasionally, the authors provide their own estimates.
- Swarts et al. (2012) discuss the calculation of externality costs for South Africa. The article covers the external costs for accidents, air pollution, congestion, noise, and land use for road and rail transportation. The top-down and bottom-up approaches provided by Maibach et al. (2008) have been largely applied in the study, and the estimate of the individual externality cost are presented in details. However, only limited vehicle types and two transportation modes are discussed due to the specific context of the country and the availability of data.
- VTPI (2013) has recently reviewed prior studies on general transportation costs, including those focusing on freight costs. Among 18 cost categories discussed in the study, several (e.g., accidents, congestion, air pollution, climate change) are relevant to the identified main externalities. A total of 37 articles are reviewed ranging from 1975 to 2012. The most 'quantified' externality is accidents covered by 30 articles, whereas land use is the least 'quantified' cost category with only six articles. Given the wide scope of the review, a major focus is on road and rail modes.
- Korzhenevych et al. (2014) made an updated version of the handbook by Maibach et al. (2008) with an aim to incorporate more recent scientific studies and best practices. Key areas of the update include: new databases on noise, accidents, and emission factors; new and updated internalization models; improved estimates of input values of the models; recent research outputs on the environmental/social impacts; the account of existing taxes and charges; and more case studies. The additional literature between 2008 and 2014 did not reveal many new sources that could be recommended as best practice for estimating external congestion costs for rail, air, or maritime transportation. Hence, a more focus is on the road transportation sector which is in line with the fact the road mode occurs the majority of the external costs. The updated handbook also provides the costs estimates of other environmental impact based on the up- and downstream processes. This includes the external costs (e.g., pollution) of energy production, vehicle production/maintenance/disposal, and infrastructure construction/maintenance/disposal. Additionally, marginal infrastructure costs are provided in the handbook.

[3] UNIfication of accounts and marginal costs for Transport Efficiency (Nash et al., 2003).
[4] Real Cost Reduction of Door-to-door Intermodal Transport (Black et al., 2003).
[5] Developing Harmonised European Approaches for Transport Costing and Project Assessment (Bickel et al., 2005).
[6] Generalization of Research on Accounts and Cost Estimation (Nash et al., 2008).

Table 11
Externality costs in the literature.

Reference	AP	GHGs	NP	WP	CN	AC	LU	Road	Rail	Maritime	Air
ECORYS (2004)	√	√	√		√	√	√	√	√	√	
Maibach et al. (2008)	√	√	√	√	√	√	√	√	√	√	√
McAuley (2010)	√	√	√		√	√		√	√		
Delucchi and McCubbin (2010)	√	√	√	√	√	√		√	√	√	√
Swarts et al. (2012)	√	√	√		√	√	√	√	√		
VTPI (2013)	√	√	√	√	√	√	√	√	√	√	√
Korzhenevych et al. (2014)	√	√	√		√	√	√	√	√	√	√

5.1.1. Discussion of the selected prior studies in pricing

One can find an extensive range of articles for external costs in various fields. Studies included in the above review are those considered relatively new and of high relevance to the pricing of externalities in freight transportation. Korzhenevych et al. (2014), Maibach et al. (2008), Swarts et al. (2012), McAuley (2010), and Delucchi and McCubbin (2010) are similar studies in term of the setup. Each provides external costs figures in different categories which are quite handy to look up and apply to similar circumstances. A typical factor for one to consider while looking into the literature is the relevance of geographical locations. Examples of regions that are commonly addressed in the literature include Europe, South Africa, Australia, and the United States. Referring to the articles in the same geographical context has the following benefits: (i) the cost figures are already in the right currency, (ii) the pricing plans are aligned with the wealth of the region, and (iii) the cost estimates are set in consideration of the specific characteristics of the region.

There are also other reasons to choose a specific publication. For example, VTPI (2013) is useful for seeking additional sources for externalities. Delucchi and McCubbin (2010) follows a very clear structure, and is, therefore, easy to read. While costs are given in a range format, a typical difficulty is to align the right value to the specific case. McAuley (2010) includes some insights of using the cost ranges. Swarts et al. (2012) and ECORYS (2004) provide single cost figures for road, rail, and maritime which could be applied straightaway to similar cases. Korzhenevych et al. (2014) and Maibach et al. (2008) contain most comprehensive information of external costs in various categories (e.g., region, fuel type, vehicle type, traffic, environment, and human behavior).

5.2. Discussion of the cost figures

Table 12 provides an overview of the cost figures presented in the aforementioned studies. The original figures which are given in different currencies have been adapted to a unified format (i.e., Euro) for the ease of comparison. A range of values is applied in most of the cases as prices vary in further classification (e.g., type of engine and fuel) under each category (e.g., air pollution for road transportation). It is noticed that format of the cost figures may also differ in the unit of measurement (e.g., €ct/vkm, €ct/tkm, €/km, €/LTO).

It is found that the upper bound values for air pollution and GHGs in the road category provided by Korzhenevych et al. (2014) are extremely high (e.g., six times higher than those in other studies). This suggests one should look into the original cost figures, compare the detailed categories, and reflect the case to an appropriate cost level when pricing. Simply using an average of the minimum and maximum values may cause large variations to the actual case. The accident costs for road transportation provided by Korzhenevych et al. (2014) and Maibach et al. (2008) appear in wider ranges due to the coverage of various road types and different countries. The external costs for noise and congestion are relatively low in McAuley (2010) and Swarts et al. (2012) because the geographical samples used in the studies are located in relatively low-density transportation networks.

Air pollution and greenhouse gasses for rail transport are apparently priced higher in Maibach et al. (2008). The main reason for this is the inclusion of the indirect emissions (e.g., emissions due to electricity production). While the direct emissions are generally negligible in all of the studies, the indirect emissions appear significant. The costs of accidents and noise pollution cause by rail transportation are found to be lower in the article of Swarts et al. (2012) than in others, which is most likely due to the differences in income levels between South Africa and other regions. Interestingly, the congestion costs of rail and air transportation provided by Maibach et al. (2008) include negative values. The authors believe that congestion can be generally a positive externality in rail and air modes which could potentially keep trucks of the road.

Compared with the road and rail modes, maritime and air transportation have received much less attention on the topic of externalities. Only air pollution and GHGs are priced in maritime transportation in Korzhenevych et al. (2014), Maibach et al. (2008) and Delucchi and McCubbin (2010) which are the only studies among others addressing the mode. The external cost figures for air transportation hardly fall in a common range due to the lack of studies. The values given in the air category are all based on case studies, which results in high variations.

We also note that the external costs in urban areas are much higher than in non-urban areas (Van Essen et al., 2011). For example, in urban areas, accident costs are about half of the external costs, while in non-urban areas and particularly on motorways the costs of emissions are dominant.

Table 12
An overview of external cost figures.

		AP	GHGs	NP	WP	CN	AC
Road							
1	€ct/tkm	0.89	0.26	0.28	–	2.26	0.43
2	€ct/vkm	1.4–38.3	1–2.9	0.13–12.7	1.05	2–3.5*	0.09–27.54
3	€ct/tkm	0–0.38	0.04–0.07	0–0.02	–	0–9.21	−0.01–1.27
4	€ct/tkm	0.05 –8.36	0.0–0.21	0.0–2.37	0.0–0.02	0.24	0.05–0.89
5	€ct/tkm	0.31*	–	0.13	–	0.13	0.32
6	€ct/tkm	0.0–2.39	0.07	0.02	–	0.01–0.29	0.07–0.26
7	€ct/vkm	0.3–56.6	2.3–13.2	0.7–35.8	–	0.0–404	0.1–46.2
Rail							
1	€ct/tkm	0.46	0.46	0.09	–	–	0.14
2	€/km	0.14–7.19	0.31–0.35	0.05–1.71	0.01	−1–0.2	0.08–0.30
3	€ct/tkm	0.0–0.13	0.02	0.0–0.01	–	0.0–1.30	0.03
4	€ct/tkm	0.0–0.07	0.0–0.09	–	–	0.01	0.05
5	€ct/tkm	0.05	–	0.0	–	–	0.03
6	€ct/tkm	0.02–1.13	–	0.01	–	–	0.01–0.03
7	€ct/tkm	0.08–0.9	0.26	0.02–0.90*	–	0.2	0.02
Maritime							
1	€ct/tkm	0.56	–	–	–	–	–
2	€/km	0.89–12.60	0.08–1.14	–	–	–	–
4	€ct/tkm	0.04–0.76	0.0–0.10	–	–	–	–
6	€ct/tkm	0.43	–	–	–	–	–
7	€ct/tkm	0.87–6.40	0.5–0.41	–	–	–	–
Air							
2	€/LTO	45–300	130–3710	90–1200	–	−16–10*	12–309
4	€ct/tkm	0.0–0.85	0.20	–	–	–	–
7	€/LTO	75–416	465–13,308	0.0–702	–	0.9–1.0**	–

1: ECORYS (2004); 2: Maibach et al. (2008); 3: McAuley (2010); 4: Delucchi and McCubbin (2010); 5: Swarts et al. (2012); 6: VTPI (2013); 7: Korzhenevych et al. (2014); **€/minute; tkm:tonne-kilometer ; vkm:vehicle-kilometer; LTO: Landing/take-off cycle.
* €/kilometer.

5.3. Case studies in internalization

Given the exploratory nature of pricing the externalities in freight transportation, case studies appear a dominant research method. One could argue that such studies lack generality while the context specific and *know-how* details available in those studies are of high practical value. It has been found from previous discussion that the *geographical difference* is a major factor that affects the pricing of freight transportation externalities. Hence, a selective set of case studies regarding different geographical areas are reviewed in this section.

- *United States of America*: Forkenbrock (1999) investigates four types of external costs of intercity freight trucking. These negative externalities include emissions, accidents, noise and unrecovered costs associated with the provision, operation, and maintenance of public facilities. Results show that negative external costs are equal to 13.2% of private carrier costs and user fees would need to be increased about threefold to internalize these external costs. In a similar study of Forkenbrock (2001), the author investigates the negative external costs for several types of freight trains and compares them with the private costs experienced by railroad companies. The negative externalities include emissions, accidents and noise. Results show that external costs related to rail transportation are approximately 0.25 cent (US) per ton-mile, less than the 1.11 cent for freight trucking; however, external costs for rail constitute a larger amount relative to private costs, 9.3–22.6%.
- *Norway*: Eriksen (2000) discusses the external costs (e.g., air pollution, GHGs, noise, accidents, land use and congestion) of transportation considering the concept of the willingness-to-pay (WTP) method. The estimated marginal external cost of each of the transportation modes is compared to what is actually paid at the margin for the mode in taxes and charges that are of relevance to transportation volumes. The findings indicate: small vans generally internalize their external costs in the form of traffic charges; only a small proportion of the external costs caused by cargo vessels are by the traffic related charges; and airplanes pay a lot more than their estimated external costs because they cover the total costs of the central aviation administration.
- *Czech Republic*: Andersson (2005) focuses on means of reducing the environmental impacts of freight transportation in road and rail networks. The relationship between increasing road freight transportation and its effects on air pollution is particulary investigated. Results suggest that the current practice is not environmentally sustainable, and there is a significant need for improvements in certain externalities (e.g., air pollution). Further recommendation includes improving the rail transportation system to ease environmental pollution as the current low prices for motorway charging result in extremely heavy usage of road transportation which has the most substantial environmental/social impacts among other transportation modes.

- *North Sea Region*: Sandvik (2005) studied the region to investigate the two new short sea cargo routes. In particular, the alternatives are assessed in different scenarios involving multi-modal transportation and various technologies/speeds. The environmental impacts are measured based on energy consumption, where emissions considered include CO_2, CO, SO_2, NO_x, and PM. It is found that the conventional fast ferry services (e.g., RoRo ships) generally create higher emissions that do multi-modal transportation chains. Moreover, it is stated that regulation forces to control NO_x emissions and Sulphur-content are needed for short sea shipping to compete with rail and road transportation.
- *United Kingdom*: Piecyk and McKinnon (2007) investigate the degree to which the external costs (e.g., emissions, noise, congestion, accidents and infrastructure) of road freight transportation are currently being internalized by taxation. The authors look at two scenarios: the first case uses emissions data for lorries from the government's NAEI model; and the second one is based on the assumption that all trucks produce the maximum amount of pollutants permitted by EU regulations. Scenario analysis shows that taxes on lorries would have to rise by around 50% to fully internalize negative externalities. Moreover, the authors state that the UK is already much closer to full internalization of the external costs in road freight transportation than most other EU countries.
- *Australia*: A decision support tool which estimates the monetary, market, and socio-economic costs of alternative road-based on rail-based logistics chains is developed in Access Economics (2007). Externalities including infrastructure wear, congestions, accidents and environmental coasts can also be examined in the tool. The application of the tool is demonstrated in two case studies: one is a typical road-based logistics chain for meat exports; the other is for grain exports, representing a rail-based logistics chain. The road case reports only infrastructure wear costs are somehow compensated by user changes (e.g., vehicle registration charges) while other external costs remain under recovery. For the case of the rail-based chain, the costs of all the externalities are covered by the user changes (e.g., rail access fees). In both cases, the access to infrastructure and the availability of services are the main factors influencing the choice of transportation modes. The tool facilitates comparisons of external costs of using different transportation modes, vehicles and routes, and displays the split of external costs into different categories.
- *Colombia*: Márquez and Cantillo (2013) model Colombian multi-modal freight transport network incorporating transport external costs. Externalities considered include congestion, accidents, air pollution and GHGs for road, rail, and inland waterways. Marginal costs are calculated using two approaches which are applied in seven selected routes: one assumes that an additional unit of demand does not affect the equilibrium of the transport network, and then the marginal cost is estimated as the sum of marginal costs on the shortest path links; the other assumes that an additional unit of demand changes the network equilibrium and, consequently, the marginal costs are estimated by calculating the difference between the two equilibrium scenarios. An average rate of external costs is estimated as 37%, 12%, 1% of the value of domestic costs for road, rail, and inland waterway respectively.

6. Conclusions and future research directions

Freight transportation activities have been conventionally planned with a focus of cost reduction or profit maximization, where only internal transportation costs are taken into account. With an ever growing concern for the environment, negative external costs of transportation and the means to controlling them have brought governments' and logistics companies' attention. As a result, there have been emerging solutions provided by scientific researchers as well as practitioners to minimizing negative externalities in the design of the transportation systems. To enable effective internalization of the external costs – the right models are applied to the right scenarios, this paper has contributed by providing a comprehensive and timely review of the negative freight transportation externalities addressed in the literature and by providing implications on how the field should evolve in the future. In particular, an overall picture of pertinent transportation externalities in quantitative terms along with pricing studies regarding the associated costs is presented for different transportation modes. Five important conclusions are revealed as follow:

- One can see that, for both modeling and pricing of the negative externalities, the majority of the studies are done in the domain of road transportation. This does not come as a surprise. According to EC (2010), 76.4% of the inland transportation in EU is carried out by the road which explains the appeal of the research focus.
- Among the externalities, air pollution and GHGs are the most discussed negative externalities (Demir et al., 2014a). One reason might be that other types of negative externalities are not easy to follow and measure. For example, noise pollution can be measured but it is not easy to extract from other sources of noises. Water pollution is legally forbidden, but it is not easy to follow with visual tracking. The complexity of modeling congestion and accidents lies in the high varieties of their impacts. Land use is quite often closely related to political reasons.
- The definitions of externalities tend to be limited in emissions, noise, congestion, accidents, water pollution and land use. However, there are other externalities such as the effects due to the production of vehicles and transport infrastructure. These include: energy production, vehicle production, maintenance and disposal, infrastructure construction.
- A top-down approach seems more common than bottom-up estimations in the practice of internalizing negative externalities; this is due to the complexity of measuring individual entities in the transportation networks. For example, the impact of ton-kilometers rather than other related parameters (e.g., type of vehicle and road) is typically measured in the pricing literature.

- The challenges for studying freight externalities and their imparts as well as comparisons of them across different transportation modes include availability of reliable and consistent data (e.g., lack of real-time data), differences in units of measurement (e.g., km/h vs mph), global versus regional nature of some mode of transportation (e.g., aviation and shipping), and limited responses to the technological advances (e.g, electric vehicles).

Summarizing current studies on the negative externalities of freight transportation, the following five areas are identified as further research directions.

- It is important to know how much traffic could be transferred from road transportation to rail and ship transportation (see, e.g., Zimmer and Schmied, 2008; Boer et al., 2011). For example, Zimmer and Schmied (2008) states that only 1.2%, road tone-kilometers, of the freight transportation can be shifted to more environmental friendly modes. This ratio could be increased by relaxing those factors that confine the modal shift, such as, making the mode economically viable and increasing their reliability and infrastructure capacity.
- There exist several ways to increase the awareness of the negative externalities, such as, *willingness to pay* (WTP) and *value of a statistical life* (VOL). These methods look at the maximum amount that an individual is willing to sacrifice in money terms to avoid something undesirable. Hence, it is more important to consider how much customers are willing to pay rather than how much they should be charged when externalities are priced.
- There is a need for enhancing the accuracy and reliability of modeling the external costs, where standard results should be obtained for each of the individual externalities. This can be achieved by comparing and assessing existing models in different practical settings.
- The life-cycle of the transportation mode (e.g., the period from the preproduction to scrapping the asset) and the infrastructure should be considered in the modeling and pricing of the negative externalities.
- Reducing negative externalities creates benefits to not only environment but also transportation companies. For example, a lower level of GHGs means less fuel consumption; the health of drivers will be less threatened if noise pollution is effectively controlled. Although a few studies have highlighted these benefits, further attention to strategies for and solutions to promoting the benefits is required.

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Table 13
Several average emission amounts given in the literature.

Reference	Emissions	Road	Rail	Maritime	Air
		g/km; Euro I diesel, 70 km/h	g/km	kg/ton of fuel	g/km
Hickman et al. (1999)	CO	1.076	5–40	3.8–9	–
	NO_x	2.0247	30–70	59–88.5	–
	PM	0.1932	1–6	0–7.6	–
	SO_x	–	1–10	21–57.3	0.32–1
	CO_2	429.51	–	3110–3250	3100–3220
		g/km; Euro IV diesel	g/tonkm	g/kW h	g/km
Boulter and McCrae (2009)	CO	0.001–0.342	–	0.51–1.31	30.5–62.3
	NO_x	0.339–1.115	0.15–0.35	11.94–18.14	0.8–2.2
	PM	0.014–0.249	–	0.19–0.50	–
	CO_2	106–269	–	167–193.43	–
		g/L; motorway	g/km	kg/km	kg/km; 100% loaded
NTM Road (2010)	CO	0.05	–	0.37	8.61
NTM Rail (2008)	NO_x	15	55.4	4.35	77.3
NTM Sea (2008)	PM	0.08	2	0.16	–
NTM Air (2008)	SO_x	–	0.08	3.37	–
	CO_2	2614	3181	221.35	9003
		g/km; Euro-V diesel	g/kg	g/KWh	g/kg fuel
Knörr et al. (2011)	CO	–	–	1.5–2.5	–
	NO_x	2.30–3.08	48.3	10–12.9	0.1
	PM	19.1–30.6	1.3	0.3	0.2
	SO_x	–	–	0.6–4	1
	CO_2e	718–1384	3268	–	3150

g/km: gram/kilometer; kg/km: kilogram/kilometer; g/kW h: gram/kilowatt-hour; g/L: gram/Liter.

Appendix A

We summarize several emissions quantities discussed in the literature in Table 13.

References

Access Economics, 2007. The Costs of Road and Rail Freight. Technical Report. RIRDC Publication, Barton, Australia. <https://rirdc.infoservices.com.au/downloads/07-185> (10.10.14).

Andersson, J., 2005. Reducing Environmental Impacts of Freight Transport Sector: The Case of the Czech Republic. Master's Thesis. Department of Technology and Society, Lund University, Sweden.

Ang-Olson, J., Ostria, S., 2005. Assessing the Effects of Freight Movement on Air Quality at the National and Regional Level. Technical Report. U.S. Federal Highway Administration, Washington. <http://www.oregon.gov/odot/td/tp/docs/reports/fhwafrtairqualrep1.pdf> (10.10.14).

Banfi, S., Doll, C., Maibach, M., Rothengatter, W., Schenkel, P., Sieber, N., Zuber, J., 2000. External Costs of Transport: Accident, Environmental and Congestion Costs in Western Europe. Technical Report. INFRAS/IWW, Zurich, Switzerland.

Barth, M., Younglove, T., Scora, G., 2005. Development of a Heavy-duty Diesel Modal Emissions and Fuel Consumption Model. Technical Report. UC Berkeley: California Partners for Advanced Transit and Highways. California, USA. <https://merritt.cdlib.org/d/ark%3A%2F13030%2Fm5cj8fkb/1/producer%2FPRR-2005-01.pdf> (10.10.14).

Bickel, P., Burgess, A., Hunt, A., Jong, G.D., Laird, J., Lieb, C., Lindberg, G., Mackie, P., 2005. HEATCO–Developing Harmonised European Approaches for Transport Costing and Project Assessment. Technical Report. University Stuttgart, Germany. <http://heatco.ier.uni-stuttgart.de/HEATCO_D5.pdf> (10.10.14).

Black, I., Seaton, R., Ricci, A., Enei, R., 2003. Final Report: Actions to Promote Intermodal transport. Technical Report. Commission of the European Communities. <http://www.transport-research.info/Upload/Documents/200607/20060727_155159_96220_RECORDIT_Final_Report.pdf> (10.10.14).

Blum, U., 1998. Positive externalities and the public provision of transportation infrastructure: an evolutionary perspective. J. Transport. Stat. 1, 81–88.

Den Boer, E., van Essen, H., Brouwer, F., Pastori, E., Moizo, A., 2011. Potential of Modal Shift to Rail Transport – Study on the Projected Effects on GHG Emissions and Transport Volumes. Technical Report. CE Delft, The Netherlands.

Boulter, P., McCrae, I., 2009. ARTEMIS: Assessment and Reliability of Transport Emission Models and Inventory Systems: Final report. Technical Report. Berkshire, United Kingdom. <http://www.inrets.fr/ur/lte/publi-autresactions/fichesresultats/ficheartemis/artemis.html> (10.10.14).

Breemersch, T., De Ceuster, G., Chiffi, C., Fiorello, D., Ntziachristos, L., Kouridis, C., Knörr, W., 2010. Update and Further Development of Transport Model TREMOVE. Technical Report. European Commission. <http://ec.europa.eu/clima/policies/transport/vehicles/docs/2010_tremove_en.pdf> (10.10.14).

Brons, M., Christidis, P., 2012. External Cost Calculator for Marco Polo Freight Transport Project Proposals. Technical Report. Institute for Prospective and Technological Studies, Joint Research Centre. <http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=4759> (10.10.14).

Cappiello, A., Chabini, I., Nam, E., Lue, A., Zeid, M.A., 2002. A statistical model of vehicle emissions and fuel consumption. In: Proceedings. The IEEE 5th International Conference Intelligent Transportation Systems, 2002, Singapore. pp. 801–809.

CARB, 2011. EMFAC2011 Technical Documentation. Technical Report. California, USA. <http://www.arb.ca.gov/msei/emfac2011-documentation-final.pdf> (10.10.14).

Cato, D.H., 1976. Prediction of environmental noise from fast electric trains. J. Sound Vib. 46, 483–500.

Comer, B., Corbett, J.J., Hawker, J.S., Korfmacher, K., Lee, E.E., Prokop, C., Winebrake, J.J., 2010. Marine vessels as substitutes for heavy-duty trucks in Great Lakes freight transportation. J. Air Waste Manage. Assoc. 60, 884–890.

Corbett, J.J., Wang, H., Winebrake, J.J., 2009. The effectiveness and costs of speed reductions on emissions from international shipping. Transport. Res. Part D: Transp. Environ. 14, 593–598.

Delucchi, M.A., 2003. A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity use, Heating and Cooking Fuels, and Materials. Technical Report. California, USA. <http://www.escholarship.org/uc/item/9vr8s1bb> (10.10.14).

Delucchi, M.A., Hsu, S.L., 1998. The external damage cost of noise emitted from motor vehicles. J. Transport. Stat. 1, 1–24.

Delucchi, M.A., McCubbin, D.R., 2010. External Costs of Transport in the US. Technical Report. Institute of Transportation Studies (UCD), USA. <http://escholarship.org/uc/item/13n8v8gq> (10.10.14).

Demir, E., Bektaş, T., Laporte, G., 2011. A comparative analysis of several vehicle emission models for road freight transportation. Transport. Res. Part D: Transp. Environ. 6, 347–357.

Demir, E., Bektaş, T., Laporte, G., 2014a. A review of recent research on green road freight transportation. Eur. J. Oper. Res. 237, 775–793.

Demir, E., Van Woensel, T., de Kok, T., 2014b. Multidepot distribution planning at logistics service provide Nabuurs B.V. Interfaces 44, 591–604.

Dings, J.W.N., Wit, R.C.M., Leurs, B.A., Davidson, M.D., Fransen, W., 2002. External Costs of Aviation. Technical Report. CE, Delft, The Netherlands. <http://www.ce.nl/art/uploads/file/02_7700_04.pdf> (10.10.14).

DOT, 1988. Calculation of Road Traffic Noise. Technical Report. Department of Transport, United Kingdom. <http://www.persona.uk.com/ashton/Core_docs/New/D49.pdf> (10.10.14).

EC, 2003. Position Paper on the European Strategies and Priorities for Railway Noise Abatement. Technical Report. European Commision, Luxembourg. <http://ec.europa.eu/environment/noise/pdf/railway_noise_en.pdf> (10.10.14).

EC, 2010. Freight Transport Statistics. Technical Report. European Commision, Luxembourg. <http://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2010_en.htm> (10.10.14).

EC, 2013. Energy, Transport and Environment Indicators. Technical Report. Luxemburg: European Commission. <http://ec.europa.eu/eurostat/web/products-pocketbooks/-/KS-DK-13-001> (10.10.14).

ECAC, 1997. Report on Standard Method of Computing Noise Contours Around Civil Airports. Technical Report. European Civil Aviation Conference, France. <http://www.boeing.com/commercial/noise/ECACDOC29e.pdf> (10.10.14).

ECORYS, 2004. Ex Ante Evaluation, Marco Polo II, 2007-2013. Technical Report. European Commission. <http://ec.europa.eu/transport/facts-fundings/evaluations/doc/2004_marco_polo.pdf> (10.10.14).

EEA, 2010. External Costs and Charges Per Vehicle Type (TERM 025) – Assessment. Technical Report. European Union. <http://www.eea.europa.eu/data-and-maps/indicators/external-costs-and-charges-per/external-costs-and-charges-per> (10.10.14).

EEA, 2011. Specific Air Pollutant Emissions (TERM 028) – Assessment. Technical Report. European Union. <http://www.eea.europa.eu/data-and-maps/indicators/specific-air-pollutant-emissions/specific-air-pollutant-emissions-assessment-3> (10.10.14).

Endresen, Ø., Sørgård, E., Sundet, J.K., Dalsøren, S.B., Isaksen, I.S.A., Berglen, T.F., Gravir, G., 2003. Emission from international sea transportation and environmental impact. J. Geophys. Res.: Atmos., 108

EPA, 2003. User's Guide to MOBILE6.1 and MOBILE6.2: Mobile Source Emission Factor Model. Technical Report. United States Environmental Protection Agency, USA. <http://www.epa.gov/oms/models/mobile6/420r03010.pdf> (10.10.14).

EPA, 2012. Motor Vehicle Emission Simulator (MOVES): User's Guide for MOVES2010b. Technical Report. United States Environmental Protection Agency, USA. <http://www.epa.gov/oms/models/moves/documents/420b12001b.pdf> (10.10.14).

EPA, 2013. Fast Facts U.S. Transportation Sector Greenhouse Gas Emissions Office of Transportation and Air Quality 1990-2011. Technical Report. Office of Transportation and Air Quality. <http://www.epa.gov/otaq/climate/documents/420f13033a.pdf> (10.10.14).

Eriksen, K.S., 2000. Calculating external costs of transportation in Norway. In: NECTAR Conference, Delft, The Netherlands. pp. 9–25.

ESRL, 2014. NOAA In Situ Carbon Dioxide (CO_2) Measurements. Technical Report. National Oceanic and Atmospheric Administration. <http://www.esrl.noaa.gov/gmd/obop/mlo/programs/esrl/co2/co2.html> (10.10.14).

Fitzgerald, W.B., Howitt, O.J.A., Smith, I.J., 2011. Greenhouse gas emissions from the international maritime transport of New Zealand's imports and exports. Energy Policy 39, 1521–1531.
Forkenbrock, D.J., 1999. External costs of intercity truck freight transportation. Transport. Res. Part A: Policy Pract. 33, 505–526.
Forkenbrock, D.J., 2001. Comparison of external costs of rail and truck freight transportation. Transport. Res. Part A: Policy Pract. 35, 321–337.
Georgakaki, A., Coffey, R., Sorenson, S.C., 2002. Development of a Database System for the Calculation of Indicators of Environmental Pressure Caused by Maritime Transport. Technical Report. Department of Mechanical Engineering, Technical University of Denmark.
Givoni, M., Rietveld, P., 2010. The environmental implications of airlines' choice of aircraft size. J. Air Transp. Manage. 16, 159–167.
Gkatzoflias, D., Kouridis, C., Ntziachristos, L., Samaras, Z., 2012. COPERT 4 Computer Programm to Calculate Emissions from Road Transport – Users Manual. Technical Report. The European Topic Centre on Air and Climate Change. <http://emisia.com/sites/default/files/COPERT4v9_manual.pdf> (10.10.14).
Greene, D.L., Wegener, M., 1997. Sustainable transport. J. Transp. Geogr. 5, 177–190.
Greenwood, I.D., Bennett, C.R., 1996. The effects of traffic congestion on fuel consumption. Road Transp. Res. 5, 18–35.
Gualandi, N., Mantecchini, L., 2008. Aircraft noise pollution: a model of interaction between airports and local communities. Int. J. Mech. Syst. Sci. Eng. 2, 484–488.
Hausberger, S., Rexeis, M., Zallinger, M., Luz, R., 2009. Emission Factors from the Model PHEM for the HBEFA: Version 3. Technical Report. TU Graz, Austria. <http://www.hbefa.net/d/documents/HBEFA_31_Docu_hot_emissionfactors_PC_LCV_HDV.pdf> (10.10.14).
Hausberger, S., Kies, A., Laine, P., Rexeis, M., Sandstrom-Dahl, Z.S.C., Schulte, L.E., Silberholz, G., Steven, H., Verbeek, R., 2012. Reduction and Testing of Greenhouse Gas Emissions from Heavy Duty Vehicles – LOT 2. Technical Report. University of Technology Graz, Austria. <http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/hdv_2011_01_09_en.pdf> (10.10.14).
Hickman, J., Hassel, D., Joumard, R., Samaras, Z., Sorenson, S., 1999. MEET-Methodology for Calculating Transport Emissions and Energy Consumption. Technical Report. European Commission. <http://www.transport-research.info/Upload/Documents/200310/meet.pdf> (10.10.14).
Howitt, O.J.A., Carruthers, M.A., Smith, I.J., Rodger, C.J., 2011. Carbon dioxide emissions from international air freight. Atmos. Environ. 45, 7036–7045.
IBI Group, 1995. Full Cost Transportation Pricing Study: Final Report to Transportation and Climate Change Collaborative. Technical Report. Toronto, Canada.
IPCC, 2007. Climate Change 2007. Synthesis Report. Technical Report. Intergovernmental Panel on Climate Change, Geneva, Switzerland. <https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf> (10.10.14).
ISSRC, 2008. IVE Model users Manual Version 2.0. Technical Report. International Sustainable Systems Research Center. <http://www.issrc.org/ive/downloads/manuals/UsersManual.pdf> (10.10.14).
Jørgensen, M.W., Sorenson, S.C., 1997. Estimating Emissions from Railway Traffic. Technical Report. Technical University of Denmark, Denmark.
Joumard, R., 1999. Methods of Estimation of Atmospheric Emissions from Transport: European Scientist Network and Scientific State-of-the-art Action COST 319 Final Report. Technical Report. INRETS, France. <http://www.inrets.fr/ur/lte/cost319/C319finalreport.pdf> (10.10.14).
Kephalopoulos, S., Paviotti, M., Anfosso Ledee, F., 2012. Common Noise Assessment Methods in Europe. Technical Report. Publications Office of the European Union, Luxembourg.
Kim, N.S., 2010. Intermodal Freight Transport on the Right Track? Environmental and Economic Performances. Master's thesis. Delft University of Technology, The Netherlands.
Kim, N.S., Van Wee, B., 2009. Assessment of CO_2 emissions for truck-only and rail-based intermodal freight systems in Europe. Transport. Plann. Technol. 32, 313–333.
Kinnock, N., 1995. Towards Fair and Efficient Pricing in Transport. Technical Report. European Commission. <http://europa.eu/documents/comm/green_papers/pdf/com95_691_en.pdf> (10.10.14).
Kirwan, K., O'Mahony, M., O'Sullivan, D., 1995. Speed-flow Relationships for use in an Urban Transport Policy Assessment Model. Technical Report. Trinity College Dublin, Dublin, Ireland.
Knörr, W., Seum, S., Schmied, M., Kutzner, F., Anthes, R., 2011. Ecological Transport Information Tool for Worldwide Transports. Technical Report. Berlin, Germany. <http://www.infras.ch/downloadpdf.php?filename=Methodikbericht.pdf> (10.10.14).
Korzhenevych, A., Dehnen, N., Brocker, J., Holtkamp, M., Meier, H., Gibson, G., Varma, A., Cox, V., 2014. Update of the Handbook on External Costs of Transport. Technical Report. European Commission. <http://ec.europa.eu/transport/themes/sustainable/studies/doc/2014-handbook-external-costs-transport.pdf> (10.10.14).
Kouridis, C., Gkatzoflias, D., Kioutsioukis, I., Ntziachristos, L., Pastorello, C., Dilara, P., 2010. Uncertainty Estimates and Guidance for Road Transport Emission Calculations. Technical Report. European Commission Joint Research Centre Institute for Environment and Sustainability. <http://publications.jrc.ec.europa.eu/repository/handle/111111111/14202> (10.10.14).
Lam, T.C., Small, K.A., 2001. The value of time and reliability: measurement from a value pricing experiment. Transport. Res. Part E: Logist. Transport. Rev. 37, 231–251.
Lawson, J., 2007. The Environmental Footprint of Surface Freight Transportation. Technical Report. Transportation Research Board, Canada. <http://onlinepubs.trb.org/onlinepubs/sr/sr291_lawson.pdf> (10.10.14).
Levinson, D.M., Gillen, D., Kanafani, A., 1998. The social costs of intercity transportation: a review and comparison of air and highway. Transp. Rev. 18, 215–240.
Lindberg, G., 2002. Deliverable 9: Accident Cost Case Studies: External Accident Cost of Heavy Goods Vehicles. Technical Report. Luxemburg: European Commission.
Lindstad, H., Asbjørnslett, B.E., Strømman, A.H., 2011. Reductions in greenhouse gas emissions and cost by shipping at lower speeds. Energy Policy 39, 3456–3464.
Litman, T.A., 2004. Land use impact costs of transportation. World Transp. Policy Pract. 1, 9–16.
Lu, C., Morrell, P., 2006. Determination and applications of environmental costs at different sized airports–aircraft noise and engine emissions. Transportation 33, 45–61.
Maibach, M., Schreyer, C., Sutter, D., Van Essen, H.P., Boon, B.H., Smokers, R., Schroten, A., Doll, C., Pawlowska, B., Bak, M., 2008. Handbook on Estimation of External Costs in the Transport Sector. Technical Report. CE Delft and INFRAS, Delft, The Netherlands. <http://ec.europa.eu/transport/themes/sustainable/doc/2008_costs_handbook.pdf> (10.10.14).
Márquez, L., Cantillo, V., 2013. Evaluating strategic freight transport corridors including external costs. Transport. Plann. Technol. 36, 529–546.
Martini, G., Manello, A., Scotti, D., 2013a. The influence of fleet mix, ownership and LCCs on airports' technical/environmental efficiency. Transport. Res. Part E: Logist. Transport. Rev. 50, 37–52.
Martini, G., Scotti, D., Volta, N., 2013b. Including local air pollution in airport efficiency assessment: a hyperbolic-stochastic approach. Transport. Res. Part D: Transp. Environ. 24, 27–36.
Mauch, S.P., Rothengatter, W., 1995. External Effects of Transport. Technical Report. International Union of Railways, Paris, France.
Mayeres, I., Ochelen, S., Proost, S., 1996. The marginal external costs of urban transport. Transport. Res. Part D: Transp. Environ. 1, 111–130.
McAuley, J., 2010. External costs of inter-capital freight in Australia. In: Australasian Transport Research Final Report: Actions to Promote Intermodal transport (ATRF).
Meng, Q., Liu, Z., Wang, S., 2012. Optimal distance tolls under congestion pricing and continuously distributed value of time. Transport. Res. Part E: Logist. Transport. Rev. 48, 937–957.
Miller, P., Moffet, J., 1993. The Price of Mobility: Uncovering the Hidden Costs of Transportation. Technical Report. Natural Resources Defence Council, New York, USA.
Mun, S.I., 1994. Traffic jams and the congestion toll. Transport. Res. Part B: Methodol. 28, 365–375.

NAEI, 2012. Emission Factors. Technical Report. National Atmospheric Emissions Inventory, United Kingdom. <http://naei.defra.gov.uk/data/emission-factors> (10.10.14).
Nash, C. et al., 2003. UNIfication of Accounts and Marginal Costs for Transport Efficiency (UNITE). Technical Report. European Commission. <http://www.its.leeds.ac.uk/projects/unite/downloads/Unite%20Final%20Report.pdf> (10.10.14).
Nash, C.A., Matthews, B., Link, H., Bonsall, P.W., Lindberg, G., van de Voorde, E., Ricci, A., Enei, R., Proost, S., 2008. GRACE – Generalisation of Research on Accounts and Cost Estimation. Technical Report. ITS, University of Leeds, Leeds. <http://www.ifr.uni-kiel.de/de/forschung/grace-final-report.pdf> (10.10.14).
Navrud, S., Mungatana, E.D., 1994. Environmental valuation in developing countries: the recreational value of wildlife viewing. Ecol. Econ. 11, 135–151.
NTM Air, 2008. Environmental Data for International Cargo Transport. Technical Report. NTM, Sweden.
NTM Rail, 2008. Environmental Data for International Cargo Transport. Technical Report. NTM, Sweden.
NTM Road, 2010. Environmental Data for International Cargo Transport. Technical Report. NTM, Sweden.
NTM Sea, 2008. Environmental Data for International Cargo Transport. Technical Report. NTM, Sweden.
Ntziachristos, L., Samaras, Z., 2000. COPERT III Computer Programme to Calculate Emissions from Road Transport: Methodology and Emission Factors (Version 2.1). Technical Report. EEA, Denmark. <http://edz.bib.uni-mannheim.de/daten/edz-bn/eua/00/tech49.pdf> (10.10.14).
OECD, 1997. The Environmental Effects of Freight. Technical Report. Organisation for Economic Co-operation and Development. <http://www.oecd.org/trade/envtrade/2386636.pdf> (10.10.14).
Papson, A., Ang-Olson, J., Schmeltz, J., Bing, A., 2011. Fuel economy comparison of four west coast rail corridors using a streamlined analysis methodology, in: Transportation Research Board 90th Annual Meeting.
Parajuli, A., Ferreira, L., Bunker, J.M., 2003. Freight Modal Energy Efficiency: A Comparison Model. Technical Report. Queensland University of Technology, Australia. <http://eprints.qut.edu.au/307/> (10.10.14).
Peeters, B., van Blokland, G.J., 2007. The Noise Emission Model for European Road Traffic. Technical Report. IMAGINE. <http://www.mp.nl/sites/all/files/publicaties/IMA55TR-060821-MP10%20-%20IMAGINE%20Deliverable%20D11.pdf> (10.10.14).
Persson, M., Zanganeh, M., 2012. A Model for Mapping Carbon Dioxide Emissions During Freight Transports at Höganas AB, Sweden. Master's Thesis. Packaging Logistics, Lund University, Sweden.
Piecyk, M., McKinnon, A.C., 2007. Internalising the External Costs of Road Freight Transport in the UK. Technical Report. Logistics Research Centre: Heriot-Watt University, Edinburgh. <http://www.greenlogistics.org.uk/SiteResources/1fbb59ff-3e5a-4011-a41e-18deb8c07fcd_Internalisation%20report%20(final).pdf> (10.10.14).
Piecyk, M., McKinnon, A., Allen, J., 2010. Evaluating and internalizing the environmental costs of logistics. In: Green Logistics: Improving the environmental sustainability of logistics. The Chartered Institute of Logistics and Transport, London, The United Kingdom.
Placet, M., Mann, C.O., Gilbert, R.O., Niefer, M.J., 2000. Emissions of ozone precursors from stationary sources: a critical review. Atmos. Environ. 34, 2183–2204.
Proost, S., Van Dender, K., 1999. TRENEN II STRAN Final Report for Publication, Models for Transport, Environment and Energy. Technical Report. Project Coordinator Centre for Economic Studies, Katholieke Universiteit, Leuven, Belgium. <http://www.transport-research.info/Upload/Documents/200310/trenen.pdf> (10.10.14).
PSRC, 2010. Vision 2040: Final Environmental Impact Statement. Technical Report. Puget Sound Regional Council, Washington, USA. <http://www.psrc.org/growth/vision2040/background/vision2040-feis/> (10.10.14).
Quartieri, J., Mastorakis, N.E., Iannone, G., Guarnaccia, C., Dambrosio, S., Troisi, A., Lenza, T.L.L., 2009. A review of traffic noise predictive models. In: Applied and Theoretical Mechanics, 5th WSEAS International Conference Puerto De La Cruz, Canary Islands, Spain. pp. 72–80.
Ranaiefar, F., Regan, A., 2011. Freight-transportation externalities. In: Logistics Operations and Management: Concepts and Models. USA.
Rodrigue, J.P., Comtois, C., Slack, B., 2013. The Geography of Transport Systems. Routledge, New York, USA.
Samaras, Z., Giannouli, M., Kouridis, C., Tourlou, E., Zachariadis, T., Babatzimopoulos, T., 2002. Development of a Database System for the Calculation of Indicators of Environmental Pressure Caused by Transport: Transport and Environment Database System. Technical Report. Thessalonki, Greece.
Sandvik, E.T., 2005. Environmental Impacts of Intermodal Freight Transport. Technical Report. Møreforsking Molde AS, Molde, Norway.
Santos, G., Behrendt, H., Maconi, L., Shirvani, T., Teytelboym, A., 2010. Part I: externalities and economic policies in road transport. Res. Transport. Econ. 28, 2–45.
Schipper, Y., 2004. Environmental costs in European aviation. Transp. policy 11, 141–154.
Skabardonis, A., Varaiya, P., Petty, K.F., 2003. Measuring recurrent and nonrecurrent traffic congestion. Transport. Res. Rec.: J. Transport. Res. Board 1856, 118–124.
Small, K.A., Chu, X., 2003. Hypercongestion. J. Transp. Econ. Policy 37, 319–352.
Smit, R., Smokers, R., Rabé, E., 2007. A new modelling approach for road traffic emissions: VERSIT+. Transport. Res. Part D: Transp. Environ. 12, 414–422.
Spellerberg, I.F., 1998. Ecological effects of roads and traffic: a literature review. Glob. Ecol. Biogeogr. 7, 317–333.
Swarts, S., King, D., Simpson, Z., Havenga, J., Goedhals-Gerber, L., 2012. Calculation of freight externality costs for South Africa. J. Transp. Supply Chain Manage. 6, 207–222.
Uchida, K., 2014. Estimating the value of travel time and of travel time reliability in road networks. Transport. Res. Part B: Methodol. 66, 129–147.
Van Essen, H.P., Maibach, M., 2007. Methodologies for external cost estimates and internalisation scenarios. In: Workshop on Internalisation, CE Delft and INFRAS, Delft, The Netherlands.
Van Essen, H., Schroten, A., Otten, M., Sutter, D., Schreyer, C., Zandonella, R., Maibach, M., Doll, C., 2011. External Costs of Transport in Europe-update Study for 2008. Technical Report. UIC, Delft, The Netherlands.
VTPI, 2013. Transportation Cost and Benefit Analysis. Technical Report. Victoria Transport Policy Institute, USA. <http://vtpi.org/tca/> (10.10.14).
Wang, M.Q., 1999. GREET 1.5-transportation Fuel-cycle Model: Methodology, Development, Use, and Results. Technical Report, vol. 1. Argonne National Laboratory, Illinois, USA. <https://greet.es.anl.gov/publication-20z8ihl0> (10.10.14).
Watterson, J., Walker, C., Eggleston, S., 2004. Revision to the Method of Estimating Emissions from Aircraft in the UK Greenhouse Gas Inventory. Technical Report. Report to the Global Atmosphere Division, DEFRA, London, The United Kingdom.
Winther, M., Rypdal, K., Sørensen, L., Kalivoda, M., Bukovnik, M., 2010. Civil and Military Aviation. Technical Report. EMEP/EEA Emission Inventory Guidebook. <http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009> (10.10.14).
Zimmer, W., Schmied, M., 2008. Potentials for a Modal Shift from Road to Rail and Ship – A Methodological appRoach. Technical Report. The European Topic Centre on Air and Climate Change, The Netherlands. <http://acm.eionet.europa.eu/docs/ETCACC_TP_2008_18_transport_modal_shift_pots.pdf> (10.10.14).