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Review

External Costs in Inland Waterway Transport: An Analysis of External Cost Categories and Calculation Methods

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Abstract: Sustainable transport, such as using inland waterway transport (IWT), represents a major pillar of the European Green Deal to reduce global warming. To evaluate the different inland transport modes (road, rail, IWT), it is crucial to know the external costs of these modes. The goal of this paper is a critical review of external cost categories (e.g., accidents, noise, emissions) and external cost calculation methods of IWT to provide ideas for future research. We identified 13 relevant papers in a literature review dealing with external costs of IWT. In a meta-analysis, the papers were assigned to the seven external cost categories: accident, noise, congestion, habitat damage, air pollution, climate change and well-to-tank emissions. The most investigated external cost categories are climate change, air pollution and accidents. Two studies were identified as the major external cost calculation methods for IWT in the abstract. Our paper shows that the data basis of IWT is significantly lower than for road/rail. The measurement of energy consumption and related emissions of IWT needs to be qualitatively and quantitatively improved and brought up to the level of road traffic, to ensure an accurate comparison with other modes of transport.

Keywords: inland waterway transport; external costs; transport emissions; sustainability; sustainable freight transport; external cost calculation methods

1. Introduction

Sustainability is a major goal of the European Climate Policy, with the aim of limiting the effects of global warming and climate change. In December 2019, the "Green Deal" was announced by the European Commission, aiming at a 90% reduction of emissions by 2050 in the transport sector [1]. Developing the vision of sustainable transport systems from abstract ideas to actual implementation constitutes a major challenge for many logistics, supply chain management and transport stakeholders. A modal shift towards sustainable transport modes, such as railway or inland waterway (IWT), is a major part of the Green Deal [1] and has the potential to reduce the negative side effects caused by road transport, including external costs from emissions, noise and congestion [2]. Railway and IWT are the inland transport modes with the lowest emissions and external costs compared to road and air transport [3,4].

The energy consumption of inland shipping is around 75% lower compared to road transport, which means that inland vessels can transport one tonne of cargo almost four times as far as a truck with the same energy consumption. Moreover, IWT has hardly any noise emissions and a high potential of available capacities for cargo shipping, in particular on the Danube [5]. Thirteen European Union countries offer an interconnected waterway system that allows for the transport of goods throughout Europe. The dominant European waterway is the Rhine-Main-Danube corridor, which connects the Black Sea with the North Sea (i.e., the port of Rotterdam). The vast majority of European inland navigation (around 80%) is concentrated in the north of Europe—in the Rhine countries, such as Germany and the Netherlands, as well as in Belgium [6]. This is also reflected by the modal split: whereas in the Netherlands around 43% of all goods are transported by IWT, in Austria it makes up around 6% of the total freight volume [7]. IWT is used for bulk goods such as ores, sands, building materials (25%), petroleum products and coal (25%), agricultural products and food (15%), containers (11%) and metal and metal waste (9%). It is highly important to emphasize the regional differences between transported goods. For example, in Northern European countries, the share of container transport is much higher than in Eastern European countries. Even if IWT offers various advantages and possibilities, the total share of goods transported has been constant [6]. To keep the advantages of IWT and meet the targets of the European Green Deal, innovation is crucial for a higher competitiveness and further reduction of (external) costs. In addition, highly competitive seaports support the development of sustainable IWT with current initiatives to increase the share of inland shipping [8] also for hinterland transport. An essential measure to support the competitiveness of IWT is an understanding of the external costs, to allow for the evaluation and comparison with other transport modes.

Table 1 shows the number of studies found in the SCOPUS and EBSCO databases dealing with external costs for the following transport modes: rail, road, inland waterways and maritime. The results show that there is already a considerable number of papers dealing with the external costs of road (556) and rail (242). For IWT (20) and maritime transport (30), the number of studies focused on external costs is rather low. This result reflects the need for more studies on the external costs of IWT and maritime transport and illustrates the urgency to increase the data density for these transport modes.

Table 1. Results for papers dealing with external costs per transport mode.

Database	IWT	Rail	Road	Maritime
SCOPUS	19	235	533	29
EBSCO	8	34	90	2
Sum *	20	242	556	30

* Duplicate sources were not considered.

In this paper, we follow the definition of external costs by Schroten et al. [3]: "External costs, also known as externalities, arise when the social or economic activities of one (group of) person(s) have an impact on another (group of) person(s) and when that impact is not fully accounted, or compensated for, by the first (group of) person(s). In other words, external costs of transport are generally not borne by the transport user and hence not taken into account when they make a transport decision." Schroten et al. [3] divide external costs into seven categories: accident, noise, congestion, habitat damage, air pollution, climate change and well-to-tank emissions. Table 2 explains the seven external cost categories which are used in this paper.

Following the approach of PROPOLIS [9], external costs can be allied with the three dimensions of sustainability. PROPOLIS is a project funded by the European Commission under the Fifth Framework Programme with the aim of researching, developing and testing integrated land use and transport policies, tools and comprehensive assessment methods to define sustainable long-term urban strategies and demonstrate their impact in European cities. For this purpose, selected indicators have been assigned to the three dimensions of sustainability [9].

The environmental dimension deals with the conservation of natural resources, the reduction of harmful emissions and the resilience and adaptability of biological and physical systems; the economic dimension is mainly concerned with increasing the prosperity of society; and the social dimension deals with intra- and intergenerational equity, the elimination of poverty and the rights of future generations [9].

Table 2. Explanation of external cost categories.

Accident costs	Material damage or immaterial damage resulting from accidents that are not covered by insurance payments (e.g., human costs, medical costs, administrative costs, loss of production)
Noise costs	Costs from unwanted noise of varying duration, intensity or other quality that causes physical or psychological harm to humans
Congestion costs	Congestion costs are the delay costs and welfare loss associated with the congestion.
Costs of habitat damage	Costs resulting from negative impacts of transport on nature and landscape: loss of habitats (ecosystems), fragmentation of habitat, habitat degradation through emissions
Air pollution costs	External costs from the following four types of impacts caused by the emission of transport-related air pollutants: health effects, crop failures, material and construction damage, loss of biodiversity
Climate change costs	The costs of climate change are defined as the costs associated with all the effects of global warming: sea level rise, crop failures, health costs, damage to buildings and materials (weather damage), loss of biodiversity and problems with water supply.
Cost of well-to-tank emissions	The cost of well-to-tank emissions (=cost of energy production) includes the production of all types of energy sources, which leads to emissions and other externalities. This includes the extraction of energy sources, processing (e.g., refining or electricity generation), transport and transmission, construction of energy plants and other infrastructure

Adapted from Schroten et al. [3].

As these dimensions are interlinked and sometimes competing [10], we want to emphasize that the seven external cost categories generally refer to more than the economic dimension of sustainability, as, for example, greenhouse gases produce environmental costs as well as social costs regarding health and economic costs such as reduced sales for negative environmental image costs. It is important to mention that some parts of these costs lead to actual paid costs, which then refers to the concept of internal costs instead of external costs [11]. Table 3 shows a selection of indicators aligned with the three dimensions of sustainability [9].

Table 3. Selection of indicators used in the PROPOLIS project.

Dimension	Indicator
Environmental dimension	Greenhouse gases from transport Acidifying gases from transport Volatile organic compounds from transport Land coverage Fragmentation of open space
Social dimension	Exposure to particulate matter from transport in the living environment Exposure to nitrogen dioxide from transport in the living environment Exposure to traffic noise Total time spent in traffic Traffic deaths Traffic injuries
Economical dimension	Investment costs Transport user benefits Transport operator benefits

In our paper, we will answer three research questions. The three-fold goal of this paper is a critical review and state-of-the art analysis of

- external cost categories (answering RQ1: "Which external cost categories are currently covered for IWT?") and
- calculation methods for IWT (answering RQ2: "Which calculation methods for external costs are used for IWT?").
- Moreover, we will provide research ideas for future studies (answering RQ3: "How should the topic of IWT and external costs be extended in the future?").

Our study focuses on inland transport and, in particular, on the examination of external cost calculation methods for IWT. According to European Union studies, the main modes of inland transport are road, rail and inland waterways [7,12]. Internal costs which "consist of the operational-private costs borne by the transport and intermodal terminal operators, and the time costs of goods tied in transit" [11] (p. 33), for example costs for shipping, ownership, insurance, maintenance, labor, energy, taxes or fees paid, are not part of this study.

This paper is structured as follows. In Section 2, we describe how we proceeded with the literature review to identify papers on IWT about external costs using inclusion/exclusion criteria and categories for analyzing the literature. Based on the literature review, we identified 13 studies for further analysis. Then, in Section 3, we analyzed how and which of those 13 studies cover the seven external cost categories (e.g., accidents, climate change costs). Afterwards, we determined which external cost calculation methods are used by these 13 papers, resulting in two major methods. These two methods are described and compared. Moreover, the factors are discussed using the three dimensions of sustainability and the corresponding indicators of the PROPOLIS study of the European Commission [9]. In Section 4, the future need for research into external costs for IWT is presented, followed by Section 5, with the conclusion and limitations of our study.

2. Method

In this paper, we used a literature review to identify the most commonly used external cost calculation methods for IWT. Afterwards, the identified methods were analyzed. To investigate the current academic status of external costs and sustainable transport, we conducted a literature review focusing on IWT. The review was carried out in 02/2020 using the databases SCOPUS and EBSCO Business Source Elite. The literature review was based on the systematic literature review from Datta [13]. The search was limited to metadata, which included the title, abstract and keywords. The search terms used can be found in Table 4. The first result shows 20 papers dealing with external costs and IWT. We included rail, road and maritime transport, in order to compare the number of results between the transport modes.

Table 4. Keywords and search terms used in the literature review.

External Costs	AND	Transport	AND	Inland Waterway
External AND cost*		Transport*		inland AND (navigation OR waterway OR vessel)
Database	Search string (example)			
SCOPUS	TITLE-ABS-KEY (external AND cost* AND transport* AND (inland AND (navigation OR waterway OR vessel)))			
EBSCO	(TI external cost* OR SU external cost* OR AB external cost*) AND (TI transport* OR SU transport* OR AB transport*) AND ((TI inland OR SU inland OR AB inland) AND ((TI navigation OR SU navigation OR AB navigation) OR (TI waterway OR SU waterway OR AB waterway) OR (TI vessel OR SU vessel OR AB vessel)))			

A first review of the studies, which was based on the relevance of the title and abstract for the objective of our study, showed that 20 studies on IWT were suitable for further in-depth review. The 20 full papers were then further examined based on explicit inclusion and exclusion criteria (Table 5), to ensure that their content was relevant to our research goal and the methods chosen.

As a result, seven papers were rejected, leaving 13 studies that were coded and analyzed regarding the categories of external costs. The categories used in extracting and analyzing data are presented in Table 6.

Table 5. Inclusion and exclusion criteria for papers in the literature review.

Inclusion Criteria	Rationale
Publication in peer reviewed journals	Practitioner documents reflect real world practices for calculation of external IWT costs.
Papers have to show or discuss practices of external cost study of IWT	The focus of our research is to identify the most commonly used studies on external costs and critically review the calculation methods for IWT. This requires the inclusion of studies that use external cost studies for calculation of external costs from IWT.
Exclusion criteria	
Full paper not available	To ensure the relevance of each study for our topic, only full papers were accepted.
Studies where the derivation of the calculation of external costs of the IWT is completely missing	Studies that neither explain the calculation method of external costs nor provide sources of external costs are not useful for our research.

Table 6. Categories used in extracting and analyzing data in the systematic review.

Area	Category		Information Obtained
Descriptive	Publication date Journal Authors Title		Year of publication Journal name Names Full title of the paper
Thematic	External cost categories	Accident costs Noise costs Congestion costs Costs of habitat damage Air pollution costs Climate change costs Cost of well-to-tank emissions	Information on the status quo and calculation for inland navigation

The external cost calculation categories and methods of these 13 relevant studies are analyzed in the next section. In a meta-analysis, the external cost categories used and the most commonly used external cost calculation methods are identified. Subsequently, the most frequently used calculation methods of the external cost categories are compared. In addition to a general description of the calculation factors, an assessment of the relationship between these calculation factors with regard to the three dimensions of sustainability is also provided. For this purpose the calculation factors are compared with the three dimensions of sustainability and the corresponding indicators of the PROPOLIS study of the European Commission [9]. Finally, the calculation methods for inland navigation are critically reviewed.

3. Results and Discussion

In this section, the 13 identified papers about IWT and external costs are evaluated regarding the external cost categories used. Afterwards, we analyzed the external cost calculation methods and identified the most used ones. The two most important external cost calculation methods were PLANCO [14] and Schroten et al. [3]. Then, we investigated how the external costs of these studies were calculated and compared the calculation methods.

3.1. Analysis of the External Cost Categories

Thirteen papers dealing with IWT and external costs were identified as relevant for in-depth analysis (Table 7). As a first step, we investigated which of the seven external cost categories (e.g., costs for accidents or climate change) were used. Table 8 lists the seven external cost categories and shows which papers deal with each category. Multiple assignments to external cost categories are possible.

Table 7. Identified studies for in-depth analysis.

#	Authors	Year of Publication	Journal	University/Company	Country
[15]	Merchan et al.	2019	Transportation Research Part D	University of Liège	Belgium
[16]	Meers et al.	2018	Transportation Research Part D	University of Brussels	Belgium
[17]	Bojic et al.	2018	Journal of Cleaner Production	University of Novi Sad	Serbia
[18]	Al Enezy et al.	2017	Research in Transportation Business & Management	University of Antwerp	Belgium
[19]	Mostert et al.	2017	Research in Transportation Business & Management	University of Liège; Hasselt University	Belgium
[20]	Kos et al.	2017	Promet-Traffic & Transportation	University of Rijeka; University of Split	Croatia
[21]	Sihn et al.	2015	Procedia CIRP	Fraunhofer Austria Research GmbH; Vienna University of Technology; Polytechnic of Bari	Austria, Italy
[22]	Lu and Yan	2015	Maritime Economics & Logistics	Shanghai Jiatong University	China
[23]	Caris et al.	2014	Journal of Transport Geography	Hasselt University; University of Liège; Research Foundation Flanders; University of Brussels	Belgium
[24]	Horváth	2014	ICIL 2014 Conference Proceedings	Széchenyi István University	Hungary
[25]	Van Lier and Macharis	2014	Research in Transportation Business & Management	University of Brussels	Belgium
[26]	Márquez and Cantillo	2013	Transportation Planning and Technology	Universidad Pedagógica y Tecnológica de Colombia; Universida del Norte	Colombia
[27]	Macharis et al.	2010	Transportation Research Part A	University of Brussels	Belgium

Table 8. Assignment of the studies to external cost categories.

External Cost Categories	1	2	3	4	5	6	7	8	9	10	11	12	13	Sum
Accident costs		x	x	x		x	x	x	x	x		x	x	10
Noise costs		x	x	x		x	x	x	x	x			x	9
Congestion costs		x		x		x	x	x	x			x	x	8
Costs of habitat damage														0
Air pollution costs	x	x	x	x	x	x	x		x	x	x	x	x	12
Climate change costs	x	x	x	x		x	x	x	x	x	x	x	x	12
Cost of well-to-tank emissions	x			x					x		x			4

References: 1. Merchan et al. [15], 2. Meers et al. [16], 3. Bojic et al. [17], 4. Al Enezy et al. [18], 5. Mostert et al. [19], 6. Kos et al. [20], 7. Sihn et al. [21], 8. Lu and Yan [22], 9. Caris et al. [23], 10. Horváth [24], 11. van Lier and Macharis [25], 12. Márquez and Cantillo [26], 13. Macharis et al. [27].

The results of Table 8 show that the most investigated categories are climate change costs (12 of 13 studies), air pollution costs (12 of 13 studies) and accident costs (10 of 13 studies). Noise costs (9 out of

13 studies) and congestion costs (8 out of 13 studies) were also addressed by the majority of the studies. The results show that the costs of well-to-tank emissions (4 out of 13 studies) are rarely investigated. External costs of habitat damage for IWT are not addressed in any of the papers.

3.2. Identification of External Cost Calculation Methods Used

As a second step, the 13 papers were examined regarding the external cost calculation methods used. The papers and the external cost calculations methods are listed in Table 9. Whereas for some papers it was clear which external cost calculation methods they refer to, for others we had to do further research to identify the original source of the external cost calculation method.

Table 9. Papers and external cost calculation methods.

	Papers	Used External Cost Calculation Method
1	Merchan et al. [15]	Korzhenevych et al. [28]
2	Meers et al. [16]	Korzhenevych et al. [28] van Lier and Macharis [25] → refers to Maibach et al. [29] de Vlieger et al. [30] → refers to Friedrich and Bickel [31] Maibach et al. [29]
3	Bojic et al. [17]	PLANCO [14]
4	Al Enezy et al. [18]	Korzhenevych et al. [28] Maibach et al. [29] PLANCO [14]
5	Mostert et al. [19]	Korzhenevych et al. [28]
6	Kos et al. [20]	Korzhenevych et al. [28] van Essen et al. [32] → refers to Maibach et al. [29] NEA et al. [33] → refers to Maibach et al. [29] PLANCO [14]
7	Sihn et al. [21]	Brons and Christidis [34] → refers to Maibach et al. [29]
8	Lu and Yan [22]	Eriksen [35] → no exact prices for IWT
9	Caris et al. [23]	Korzhenevych et al. [28] Maibach et al. [29] Brons and Christidis [34] → refers to Maibach et al. [29] PLANCO [14] NEA et al. [33] → refers to Maibach et al. [29]
10	Horváth [24]	Dolinsek et al. [36] → refers to PLANCO [14]
11	Van Lier and Macharis [25]	Maibach et al. [29]
12	Márquez and Cantillo [26]	Byatt et al. [37] → only provides CO2 prizes
13	Macharis et al. [27]	De Vlieger et al. [30] → refers to Friedrich and Bickel [31] Maibach et al. [29]

Two major external cost calculation methods were identified: (1) the "Handbook on External Costs of Transport" [28,29], in different versions (2008, 2014), and (2) the method by PLANCO [14]. We found that nine of the 13 papers relied on different versions of the "Handbook on External Costs of Transport", which is issued by the European Commission [28,29]. Five of the 13 papers used the external cost calculation method by PLANCO [14].

The study from van Essen et al. [32] is an update of the UIC study by Schreyer et al. [38] and refers to numerous external cost categories by Maibach et al. [29]. NEA et al. [33] and Brons and Christidis [34] refer to the IMPACT study of 2008 [39], which is the basis of Maibach et al. [29]. In addition, van Lier and Macharis [25] use the external costs from Maibach et al. [29]. Dolinsek et al. [36] uses the calculation method by PLANCO [14].

There were three other external cost calculation methods, which are not based on PLANCO [14] or "Handbook on External Costs of Transport" [28,29]. De Vlieger [30] takes the external costs from Friedrich and Bickel [31] and deals with Dutch data on IWT from 1995. Eriksen [35] calculates external costs using shadow prices for emissions without separate costs for IWT. Byatt et al. [37] only include prices for CO2 tonnes and does not explicitly deal with the calculation of external costs.

We found a new version of the "Handbook on External Costs of Transport" which was published in 2019 on behalf of the European Commission [3]. The new version extends and updates the external cost calculation methods with current data. For a more detailed analysis, we used the external cost calculation methods by PLANCO [14] and Schroten et al. [3]. Decisive criteria for this were the numerous citations, the comprehensive description of the method for calculating the external costs, the possibility of comparing the external costs with those of road and rail transport and the relevance of the data with regard to IWT. The two external cost calculation methods are discussed in more detail in the next section.

3.3. Discussion of Schroten et al. [3] and PLANCO [14]

As a third step, we analyzed and discussed the two most frequently used external cost calculation methods, Schroten et al. [3] & PLANCO [14], in more detail. After a discussion of the average costs of freight transport for each method, the calculation methods for each external cost categories were compared and critically discussed.

Table 10 lists the external cost factors of PLANCO [14] for the transport modes road, rail and inland waterways. The study provides the average external cost factors per tonne-kilometer for the cost categories accidents, noise, air pollution and climate change for Germany for the year 2005. The external cost factors per mode of transport are differentiated between bulk and container transport.

Table 10. Average external costs of freight transport (Germany, 2005) per transport mode.

External Cost Categories	Road		Rail		Inland Waterway	
	€-cent/tkm		€-cent/tkm		€-cent/tkm	
	Bulk	Container	Bulk	Container	Bulk	Container
Accident costs	0.43	0.43	0.06	0.06	0.03	0.03
Noise costs	0.79	0.79	0.84	0.84	0.00	0.00
Air pollution costs	0.32	0.17	0.05	0.04	0.12	0.12
Climate change costs	0.47	0.26	0.18	0.16	0.12	0.11
Total	2.01	1.65	1.13	1.1	0.27	0.26

Adapted from PLANCO [14].

Table 11 shows the external cost categories of the "Handbook on External Costs of Transport" [3] for the transport modes road, rail and IWT. The study provides the external cost categories accidents, noise, congestion, habitat damage, air pollution, climate change and well-to-tank emissions for the EU-28 area for the year 2016. Moreover, costs for light commercial vehicles, heavy goods vehicles and electric and diesel trains are included.

In addition to the average external cost factors and total external costs, Schroten et al. [3] provide a list of marginal external cost factors per tonne-kilometer for four different vessel types (Table 12). External costs of climate change and well-to-tank emissions (WTT) are differentiated according to the type of cargo. For external air pollution costs, the emission class of the engine is considered according to the emission standards from the Central Commission for Navigation on the Rhine (CCNR).

A comparison of the tables shows that the studies differ in the degree of breakdown into subcategories of external costs. PLANCO [14] offers a differentiation of the average external costs according to the type of cargo (bulk and container). Schroten et al. [3] also offer this differentiation, but only when listing marginal external costs. This differentiation is of great relevance, since the values can differ significantly depending on the type of cargo. Other categories such as car transport should be considered for future external cost calculations, as emission calculation studies such as the Global Emissions Council Framework [40] show that the difference in emissions due to the different weight and aerodynamics can be significant.

Table 11. Total and average external costs of freight transport (EU-28, 2016) per transport mode.

External Cost Categories	Road		Rail		Inland Waterway	
	Total Costs (Billion €)	€-cent/tkm	Total Costs (Billion €)	€-cent/tkm	Total Costs (Billion €)	€-cent/tkm
Accident costs	42.8	6.0 (LCV) 1.3 (HGV)	0.3	0.1	0.1	0.1
Noise costs	14.5	1.6 (LCV) 0.5 (HGV)	2.5	0.6 (electric) 0.4 (diesel)	n.a.	n.a.
Congestion costs	70.1	16.8 (LCV) 0.8 (HGV)	n.a.	n.a.	n.a.	n.a.
Costs of habitat damage	8.0	1.35 (LCV) 0.2 (HGV)	1	0.2 (electric) 0.2 (diesel)	0.3	0.2
Air pollution costs	29.4	4.7 (LCV) 0.8 (HGV)	0.71	0.0 (electric) 0.7 (diesel)	1.9	1.3
Climate change costs	22.8	4.0 (LCV) 0.5 (HGV)	0.2	0.0 (electric) 0.2 (diesel)	0.4	0.3
Costs of well-to-tank emissions	7.5	1.15 (LCV) 0.2 (HGV)	0.6	0.2 (electric) 0.1 (diesel)	0.2	0.1
Total	195.1	35.6 (LCV) 4.2 (HGV)	5.4	1.1 (electric) 1.8 (diesel)	2.9	1.9

Adapted from Schroten et al. [3].

Table 12. Marginal external costs of inland waterway transport (IWT) (EU28, 2016, in €-cent/tkm).

Vessel Type	Type of Cargo	Emission Class	Accident	Air Pollution	Climate Change	Noise	Congestion	WTT	Habitat
CEMT II (350t)	Bulk	CCNR 0	0.1	3.36	0.34	n/a	n/a	0.15	0.0
		CCNR 1		2.82					
		CCNR 2		1.82					
		Average		3.25					
	Container	CCNR 0		2.14	0.21			0.09	
		CCNR 1		1.79					
		CCNR 2		1.15					
		Average		2.07					
CEMT IV (600t)	Bulk	CCNR 0		2.00	0.20			0.09	
		CCNR 1		1.67					
		CCNR 2		1.08					
		Average		1.84					
CEMT Va (1500t)	Bulk	CCNR 0		1.82	0.18			0.08	
		CCNR 1		1.53					
		CCNR 2		0.99					
		Average		1.53					
	Container	CCNR 0		2.06	0.21			0.09	
		CCNR 1		1.73					
		CCNR 2		1.12					
		Average		1.74					
Pushed convoy (11,000 t)	Bulk	CCNR 0		1.48	0.15			0.06	
		CCNR 1		1.24					
		CCNR 2		0.80					
		Average		0.89					
	Container	CCNR 0		1.10	0.11			0.05	
		CCNR 1		0.92					
		CCNR 2		0.60					
		Average		0.67					

Adapted from Schroten et al. [3].

An essential distinction that is missing in both studies is the distinction between fuel types. Schroten et al. [3] offer a distinction between electricity and diesel for rail, and the significant differences in external costs underline the importance of this distinction. However, this distinction is missing for the other modes of transport. Alternative fuels are also essential in view of the European Green Deal [1] and therefore need to be considered for future calculations. Future studies on the specific emission values of alternative fuels, such as those of the Smart Freight Centre and Global Logistics Emissions Council Framework [41], should provide the basis for differentiated calculations with regard to external costs.

In the following sections, the calculation methods of the external cost categories are compared. The focus of the following sections is on the general description of the calculation factors and their examination regarding the three dimensions of sustainability, as well as on a critical view of the calculation methods for IWT.

3.3.1. Accident Costs

In the PLANCO study [14], the external accident costs result from the calculation of human costs and material damage in accidents in which a freight vehicle was involved. For the calculation of human costs, the number of casualties per mode of transport is divided into different levels of injury and multiplied by the corresponding cost factor. The cost factors for human costs and material damage were taken from calculations by the German Federal Highway Research Institute [42]. For rail transport and IWT, separate cost factors for material damage were calculated based on the damage estimates of evaluated accident reports. The resulting total external accident costs were related to the transport performance in tonne-kilometers by the respective mode of transport.

Schroten et al. [3] deal with significantly more subcategories of external accident costs and distinguish between human costs, loss of production, medical costs, administrative costs and property damage in the case of external accident costs. Due to insurance payments, only a certain percentage of these cost categories are considered external costs. For example, it is assumed that 100% of material damage is covered by insurance and therefore does not have to be taken into account in the calculation of external accident costs. In addition, the study uses correction factors for the number of accidents to compensate for the problem of unreported accidents [43–45]. This concerns mainly road transport, as it is very unlikely that accidents in rail transport and IWT go unnoticed. In the case of accidents involving different modes of transport, the accident costs are allocated to the mode of transport that caused the accident. Within a mode of transport, the accident costs are assigned according to the damage potential of the vehicles involved [32,46].

A comparison with the PROPOLIS study [9] shows that both studies consider the social dimension and economic dimension of sustainability when calculating external accident costs. In terms of social dimension, both studies refer to human costs caused by traffic deaths and traffic injuries. In terms of economic dimension, PLANCO [14] refers to material damage and economic damage caused by traffic deaths and traffic injuries, and Schroten et al. [3] refer to loss of production, administrative costs, medical costs and property damage. The environmental dimension of sustainability, such as additional emissions due to congestion caused by accidents, is covered in the related external cost categories of climate change and air pollution [3] (see Section 3.3.5).

The calculation of external accident costs for IWT must be critically analyzed in both studies regarding the used cost factors and accident data. Schroten et al. [3] use the accident rate per 1000 vehicle-kilometers for IWT based on data from the Dutch Ministry of Waterways and Public Works. However, this is an approximate value for the risk of IWT, that does not correspond to the actual accidents that occurred. PLANCO [14] takes a more accurate approach, based on the evaluation of accident reports from the water police and other data of the German Federal Ministry of Transport, Building and Housing. Such data should also be collected from other EU countries to improve the accuracy of the cost factors for the EU area. The general lack of information on external accident costs of IWT was already mentioned in previous versions of the "Handbook on External

Costs of Transport" [28,29] but was not considered relevant due to the low accident rate [18,20,23]. However, this justification should be critically questioned, as IWT has a clear advantage over other modes of transport due to its low accident figures, which should be substantiated and promoted with sufficient scientific data.

3.3.2. Noise Costs

Noise costs are calculated using the same methodology in both studies. The number of people and the extent of noise pollution is determined by interviewing the affected population. The cost factors for noise result from the willingness of the affected people to pay for the reduction of environmental noise levels. In addition, treatment costs for cardiovascular diseases resulting from increased noise pollution are taken into account [47,48]. With regard to the dimensions of sustainability, the focus is on the social dimension and calculation of the health effects of traffic noise pollution [9].

Schroten et al. [3] consider noise costs of IWT as negligible or non-existent, since it is assumed that transport takes place mainly in sparsely populated areas and IWT barely produces any noise. PLANCO [14] considers the noise exposure from IWT to be irrelevant. IWT is significantly quieter than rail and road transport, both in terms of loading and route routing. As a result, IWT has so far been able to comply with noise emission limits without the need for noise protection measures [14].

Even if the noise costs of IWT are negligible compared to road and rail transport [18,22,23,28,29], measurements—in particular for ships at anchoring places—should be conducted for future research to validate the data. Anchored ships generate noise because their diesel engines generate the necessary electricity. The connection to shore-side electricity is not yet possible everywhere or is not considered economically viable due to the costs involved [49–51].

3.3.3. Congestion Costs

Congestion costs are not addressed in the PLANCO study [14], since they can be neglected for IWT. The calculations of congestion costs by Schroten et al. [3] focus on road freight transport, as they are highly relevant for this sector. Congestion costs result from the calculation of delay costs and welfare loss. The calculation of these costs depends on numerous factors, such as speed-flow functions, demand curves [52,53], value of time [45,54,55] as well as the social costs in terms of welfare loss. The costs are calculated using simulation tools for the European area [56]. A comparison with the three dimensions of sustainability and the related indicators of the PROPOLIS study [9] shows that this calculation focuses mainly on the social dimension and the indicators of accessibility and traffic. The costs of additional emissions caused by congestion are not considered, as they are included in the external costs of air pollution and climate change (see Section 3.3.5). For rail transport, congestion costs are generally not relevant due to the fixed train schedules. However, in the case of highly used networks, train delays can cause congestion even for scheduled services. Schroten et al. [3] also consider the future calculation of scarcity costs in the event that the means of transport of regular services strongly compete with each other in terms of time slots. However, such a calculation requires a great deal of information and is highly context-specific [3]. For IWT, congestion costs are considered similar to those of rail transport and therefore not relevant. An idea for further critical evaluation is the analysis of congestion situations in ports or at bottlenecks such as locks, which might be relevant for inland navigation and may cause considerable congestion costs [18,28].

3.3.4. Costs of Habitat Damage

PLANCO [14] refers to the cost rates of a study by INFRAS [57] which are intended to show the costs of the renaturation of sealed surfaces along transport routes. However, due to the uncertainties in the delimitation of impaired areas, the study refrains from using these cost rates and from monetizing habitat damage. Schroten et al. [3] calculate the costs of habitat damage based on the length (or area) of the infrastructure network of the transport modes and the derived annual cost factors for habitat loss and habitat fragmentation per kilometer based on a study by INFRAS/Ecoplan [58]. A comparison with the PROPOLIS study [9] shows that this calculation clearly refers to the ecological dimension of sustainability and takes the environmental indicators of land coverage and fragmentation of open space into account.

External costs due to habitat damage cause by IWT are significantly lower than for road transport due to the small infrastructural changes and the absence of fragmentation effects. The crediting of infrastructural areas of IWT is difficult to define and requires critical examination. It should be examined whether the waterway should be assessed differently to road and rail networks due to its multifunctionality as a mode of transport, recreational area and natural habitat. Positive measures to protect biodiversity, such as fish ladders, as well as measures to preserve the course of the river and the ecosystem, could be taken into account in existing calculations [58]. The fact that none of the 13 reviewed studies deals with the external costs of habitat damage makes it clear that the calculation method needs to be further reviewed in order to gain relevance and establish itself in the external cost calculation.

3.3.5. Costs of Air Pollution, Climate Change and Well-to-Tank Emissions

For the calculation of air pollution, climate change and well-to-tank emissions, the input values are vehicle performance data [59], emission factors per vehicle type and cost factors of air pollutants. Multiplying these values results in the external costs of air pollution, climate change and well-to-tank emissions. The cost factors for air pollutants refer to the health effects, crop losses, material and building damage and biodiversity loss caused by air pollutants. The cost factor for CO_2 equivalents corresponds to the avoidance costs of one tonne of CO2e. Schroten et al. [3] use the cost factors of air pollutants from the Environmental Prices Handbook 2017 [60] and a CO2e price of 100€/t based on the average of the values found in the literature. PLANCO [14] refers to the cost rates from the method convention of the German Federal Environment Agency from 2007 [61] and uses a value of 70€/t as CO2e price. A comparison with the PROPOLIS sustainability indicators [9] shows that the calculation of the external costs of air pollution and climate change takes into account the environmental dimension of sustainability, by addressing global climate change and air pollution from transport emissions, and the social dimension of sustainability, by addressing the health effects from air pollution.

The emission factors used for IWT originate from the same studies. Schroten et al. [3] refer to an IFEU study from 2017 [62], which in turn refers to values from an IFEU/INFRAS study from 2013 [63]. This study calculates the emission factors of inland navigation and refers to engine performance from the studies of the WTZ Roßlau [64] and the Central Ship Investigation Commission ZSUK [65] and for older engines from Energie-Umwelt-Beratung E.V. and Germanischer Lloyd [66] and the Research Institute for Inland Navigation VBD [67]. PLANCO [14] obtains the emission factors from the studies of Energie-Umwelt-Beratung E.V. and Germanischer Lloyd [66] and VBD [67]. The data basis for the derivation of emission factors are test bench measurements, which are part of type approval procedures for compliance with emission limits [63]. The emission factors used are therefore based on laboratory values and do not correspond to actual values in practice.

The recent PROMINENT study [68] shows that the engine load factors which are generally used are very high and do not correspond to the values in practice. Another problem is the age structure of the ship engines of the IWT fleet [63]. The age structure of ship engines can be easily traced from 2003 onwards due to registration requirements, but estimates have to be made for older ships, as no data sets are available. Furthermore, the calculations are based on values of the German and Dutch fleet. The age structure of the ship fleet in other countries will therefore deviate from these values. This problem will diminish with the increasing motorization of ships, but is currently still a possible distortion factor of the actual emissions of IWT.

4. Further Research

We identified a high potential for future research of external cost calculation methods of IWT. The evaluation of the external cost calculation for air pollution, climate change and well-to-tank emissions has shown that the measurement of energy consumption and related emissions of IWT needs to be improved to obtain more accurate consumption data and thus ensure an accurate comparison with other modes of transport in terms of sustainability. For IWT, the measurement of real data to define the specific energy consumption per tonne-kilometer by ship class, ship size and river type and the measurement of the respective transport performance in tonne-kilometers is required [63]. This data was already collected for different ship types in previous studies [4,68,69]. For future external cost calculations, this data should be taken into account in order to obtain more realistic values for IWT. The differentiation of external costs according to different ship models should also be further developed to bring the specific calculation of inland navigation closer to the level of road transport. The study by Schroten et al. [3] has a pioneering role here, as it offers external marginal cost factors for four types of ship and further differentiates according to the type of cargo and emission class (see Table 12). However, a clearer differentiation for further ship types would be desirable to obtain more specific values regarding emissions and the related external costs of IWT, and thus ensure a more accurate assessment of its sustainability in comparison to other transport modes.

The calculation of external accident costs, congestion costs and noise costs for IWT should be further pursued despite the currently low estimated relevance, in order to ensure an accurate comparison with road transport in these cost categories. Table 13 summarizes the major results of our study. It shows the evaluation of IWT compared to road and rail for the external cost categories. Moreover, the future research column summarizes the major gaps in the existing literature concerning the calculation of each external cost category.

Table 13. External cost categories and future research for IWT.

External Cost Category	Evaluation of IWT	Future Research
Accident costs	very low accident costs	Evaluation of accidents and related costs in all relevant EU countries
Noise costs	very low noise costs	Evaluation of the noise of ships at anchor
Congestion costs	very low congestion costs	Evaluation of congestion situations in ports or at bottlenecks such as locks
Costs of habitat damage	very low cost of habitat damage	Evaluation of the multifunctionality (i.e., multi-use as recreational area, touristic area) of waterways
Costs of air pollution, climate change and well-to-tank	lower than road, similar to rail	Identification of ships older than 2003 Evaluation of used theoretical vs. practical values for energy consumption and its parameters (e.g., engine load factors)

We are aware that besides the external costs, numerous internal costs such as shipping costs, operating costs, up-front costs, time costs, special unit costs, bulk costs and fixed costs need to be considered in order to assess the impact of a modal shift of freight transport to inland navigation. Internal costs should also be further researched on a modal-specific basis in order to accurately present the potential advantages and disadvantages. In the case of inland waterway transport, for example, it should be discussed to what extent inland waterway transport contributes to the reduction of storage costs due to its combination of low speed and high loading capacity, as the goods remain in transit for a longer time. Furthermore, in case of a modal shift from road transport to rail and waterway, the costs of pre- and post-transportation have to be considered accordingly and charged to the respective means of transport.

Due to the omnipresent topic of climate change, we are firmly convinced that the internalization of external costs will play a major role in the future when calculating and comparing transport scenarios.

Briefly summarized, the major recommendations for further research are:

- Measurement of energy consumption and related emissions of IWT needs to be qualitatively and quantitatively improved and brought up to the level of road transport, to ensure an accurate comparison of the related external costs with other modes of transport.
- Other external cost categories such as noise costs, congestion costs and costs of habitat damage should also be further researched, as these categories have the potential to demonstrate some advantages of sustainable transport modes such as rail and IWT, which could play a role in the future internalization of external costs.

5. Conclusions and Limitations

The goal of this paper is a critical review and state-of-the art analysis of external cost categories and calculation methods for IWT. In addition, we provided research ideas for future studies. We conducted a meta-analysis and found 13 relevant papers. We analyzed those 13 papers regarding the seven external cost categories of Schroten et al. [3] (i.e., accident costs, noise costs, congestion costs, costs of habitat damage, air pollution costs, climate change costs and costs of well-to-tank emissions) and the external cost calculation methods used. We found that the most investigated external cost categories for IWT are air pollution costs, climate change costs and accident costs. While noise costs and congestion costs have also been analyzed by several studies, well-to-tank emissions are rarely considered and the costs of habitat damage were not addressed at all. Generally, the number of studies on the external costs of IWT is significantly lower than for rail and road transport, implying that the database of IWT is not as detailed as the database for rail and road transport.

The examination of the external cost calculation methods used resulted in two major external cost calculation methods: the "Handbook on External Costs of Transport" [3] and PLANCO [14]. The analysis of these two studies showed that the calculation methods of IWT are partly based on estimated and averaged performance values instead of values in practice, due to the lack of data, which leads to unstable values for IWT. This is mainly due to the fact that external cost categories, such as accident costs, noise costs and congestion costs are not considered relevant enough for IWT. However, it is precisely the advantage of low external costs compared to road transport that should be highlighted with adequate data and calculations. As far as the external costs of climate change are concerned, there are already clear advantages for IWT, as the average external costs of greenhouse gas emissions from IWT are about 40% lower than those of road transport with heavy goods vehicles (Table 11). Furthermore, IWT could demonstrate its additional value regarding the external costs of habitat damage through the multifunctionality of inland waterways and its related services for habitat protection. The future research needs for IWT presented in Table 13 show that there are still numerous research areas that need to be sufficiently covered in order to correctly assess IWT as a sustainable mode of transport both on a political level and in practice. An adequate data base would help shippers as well as society to become more aware of the sustainability of IWT.

The examination of the calculation factors of both studies with regard to the three dimensions of sustainability showed that the external cost calculations are already very much concerned with addressing the external costs of all three dimensions and thus follow a holistic approach. This is also important for the future, to uncover hidden external costs and to integrate them accordingly in future calculations.

This study has potential limitations. Our literature review is limited to the databases EBSCO and SCOPUS. There might be further results that are not covered in our literature review in other databases. Another limitation of this paper is that we focused on the external cost calculation studies by Schroten et al. [3] and PLANCO [14] and did not analyze other calculation methods. Moreover, only studies explicitly concerned with the external costs of IWT were included. Thus, the paper is limited in that it does not report research conducted on other subjects conceptually or theoretically close to external costs.

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