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A shift-share based tool for assessing the contribution of a modal shift to the decarbonisation of inland freight transport

Olaf Jonkeren*, Jan Francke and Johan Visser

Abstract

Resulting from the 21st UN Climate Change Conference (COP21) in Paris in 2015, the European Union's (EU) current climate and energy objective is to reduce greenhouse gas (GHG) emissions by 40% below 1990 levels by 2030, and transportation must play a vital role in achieving this target. Decarbonization is therefore one of the main challenges for the freight transport sector in Europe. Several measures are suggested to contribute to this goal, including clean vehicle technologies, optimising networks and modal shift. This paper focuses on the latter measure; specifically, we reveal the value of shift-share analysis as a method for assessing a freight modal shift's contribution to carbon dioxide (CO_2) emission reduction. The shift-share method is in fact a decomposition analysis that originated in the field of regional economics. However, it can also be applied in other fields, including transport economics. We have exploited this method's broad applicability to develop a tool that can evaluate how rail and inland waterway transport perform in terms of their contributions to CO_2 emission reduction due to a modal shift. In demonstrating the tool, we analyse the market for freight transport that has the Netherlands as an origin, destination or both, thereby distinguishing between five distance markets. The goal of this paper is to present and show the value of the tool. The tool can provide policy makers with background information about the changes in CO_2 emissions of a freight transport modal shift that occurred in the past, which in turn can be helpful in devising future transport policies. A particular strength of the tool is that it can be used on any spatial scale - countries, regions, corridors, etc. In addition, the data requirements and computing complexity of the shift-share method is low.

Keywords: Modal shift, Inland freight transport, Shift-share analysis, CO_2 emission reduction, Assessment tool

JEL codes: R40, R48

1 Introduction

Transport in the EU[1] continues to grow, and on this spatial scale transport's share of total CO_2 emissions increased from 18.8% in 1990 to 25.3% in 2012 [13]. The EU's current climate and energy objective is to reduce GHG emissions by 40% below 1990 levels by 2030, and transportation must play a vital role in achieving this target [39]. For the freight transport sector, a range of decarbonisation measures exist, including clean vehicle technologies and optimisation of transport networks. Another, regularly cited measure is the shifting of freight from road to more efficient transport modes, such as rail and inland waterways. The European Commission has been promoting shifts from road freight transport to more sustainable modes for many years. Unfortunately, these alternative modes currently claim but a modest share in most European regions [27]. The Eurostat figures in Table 1 reveal that, as measured in ton kilometers, inland freight transport's modal split in the EU28, hardly changed between 2005 and 2016 [11]. Road's share is lower on the global scale than on the European scale. Excluding inland waterways, Kaack et al. [19] found the current global road and rail modal split to be around 60:40. However, they also noted that many countries are experiencing growth in road freight transport and in shifts from rail to road. The road share in the Netherlands was 52% in both 1990 and 2015 [18]. Since

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Table 1 Modal split (% based on ton-kilometres) in EU28, adjusted for territoriality

Mode	2005	2016
Road	75.7%	76.4%
Rail	17.9%	17.4%
Inland waterways	6.4%	6.2%

Source: Eurostat [11]

CO_2 emissions per ton-km by truck are still higher than CO_2 emissions per ton-km by rail and inland waterways [20], climate gains can still be achieved by means of a shift. Consequently, this remains an important field of research.

One reason why the more sustainable modes have yet to realise a larger share could be due to the fact that it is often difficult for policy makers to assess how rail and inland waterways can attract cargo. What are the critical success factors? As based on freight transport data, it is often possible to calculate a modal shift that occurred in the past. However, such information does not tell us anything about the background details of the shift. In which cargo markets did rail and inland waterways gain market share? And is the shift likely to last in future? Such information can be valuable for policy makers in the field of freight transport. The objective of this paper is to present a tool that can compile such information. More specifically, the tool assesses how transport modes perform in freight transport markets in terms of CO_2 emission reductions resulting from a modal shift. Such a tool does not yet exist. Our newly developed assessment tool is based on the shift-share method and can contribute to developing future freight transport policies.

The remainder of this paper is structured as follows: section 2 presents a literature overview of research methods in the field of modal shift as they pertain to CO_2 emissions. In addition, the shift-share method is explained. Section 3 forms the core of this paper, presenting a tool that can assess how a modal shift contributes to CO_2 emission reduction. This tool is applied to a case study in the Netherlands. Section 4 discusses the usability of the tool for freight transport policy. Lastly, section 5 presents a conclusion.

2 Methodology

2.1 Literature overview of methods

In 2004, Macharis and Bontekoning [23] and Bontekoning et al. [4] stated that intermodal freight transportation research was emerging as a new transportation research application field, arguing that it could and should be a research field in its own right. Bontekoning et al. [4] therefore proposed several research needs, including research into policy formulation and evaluation, and research into methods and techniques for addressing the problems in intermodal freight transport. This paper meets these two research needs by proposing a tool that can help policy makers in the field of freight transport to assess the background of a modal shift.

Since 2004, research of intermodal freight transport has matured. Given the scope of this study, a complete review of the intermodal freight transport literature is not appropriate. Instead, in our discussion of the literature we have only included studies that analyse both modal shift and the resulting change in CO_2 emissions. We have studied the relevant literature from a methodological perspective; that is, for each study we identified and categorized the method used to analyse a mode shift in freight transport. This facilitates a comparison of existing methods with the method on which our tool is based.

We conducted a literature search in Google Scholar and Scopus, using combinations of the key words 'modal shift', 'climate change', 'CO_2 emission', 'models', 'tools', 'European Union', and 'inland freight transport'. Having found some relevant studies, we then used forward and backward snowballing to find more relevant work. We do not claim to have included all relevant studies in the literature overview. However, we are fairly certain that we have covered all existing methods for the analysis of a modal shift in freight transport.

One way to classify studies on mode shift is the distinction between macro and micro, as explained by Ruesch [38]. The distinction is based on the spatial level of the data and information used. A macro-approach for analyzing modal shift is based on analyses of aggregated freight flows on regional, national or international levels, using freight flows matrices and characteristics of the transport network. A micro-approach analyses freight flows and logistics/transport chains on the company level, using information on these chains, the behavior of individual companies, and the key factors for the decision making process such as cost, reliability and transport time. Another way for classifying methodologies on mode shift takes the various types of models as a starting point. We have used this latter way as the primary way to structure the discussion, as it better reveals the uniqueness of the methodology behind our tool. Table 2 presents the different methods. In general, four methods can be distinguished: choice modelling, Life Cycle Analysis (LCA), strategic freight transport network models, and decomposition analysis. Studies which cannot be classified in one of those four groups are listed in the category 'Other methods'. Not all the studies in Table 2 are discussed below. Only those studies which are needed to illustrate a methodology are referred to.

We have included two examples of freight mode choice modelling in our overview. One is based on

Table 2 Methods for analyzing modal shift in freight transport and its CO_2 gains

Method and approach	Study	Transport modes	Model name and/ or characteristics	Application modal shift analysis	Remarks
Choice modelling[a] (micro)	Regmi and Hanaoka [37]	Road and rail (diesel only)	Binary mode choice model based on SP survey	Corridor between Loas and Thailand, 43 freight forwarders.	A 30.5% reduction in CO_2 emissions due to a shift from 100% road to 56.8% road.
	Buhler and Jochem [5]	Road and rail	Binary mode choice model based on RP survey	498 freight forwarders in Germany	A drop of 1% (if a road user charge applies) to 4% (due to increased rail speed) in CO_2 emissions.
(Semi-) LCA (macro)	Kim and van Wee [21]	Road, rail (diesel and electricity), Short Sea Shipping (SSS)	Explicitly includes emissions from electricity production	Corridor between Western and Eastern Europe	Comparison of CO_2 emissions for 7 unimodal/intermodal scenarios.
	Kim and van Wee [22]	Road and rail (diesel and electricity)	Explicitly includes emissions from electricity production	No specific area	Comparison of CO_2 emissions for 5 unimodal/intermodal scenarios.
	Nocera and Cavallaro [32]	Road and rail	Well-to-wheel principle	Transalpine corridors	Comparison of CO_2 emissions in 2030 for 3 scenarios compared to baseline 2030.
Strategic freight transport network models (macro)	Nelldal and Andersson [30]	Road and rail	TRANSTOOLS[b], strategic transport network model	European Union	Reduction of 20% of EU transport GHG emissions over land by 2050 compared to baseline.
	Jonkeren et al. [17]	Road, rail, Inland Waterways (IWW)	NODUS, GIS-based transport network model based on virtual network concept	The Rhine freight corridor	Increase of 1.1% of annual CO_2 emissions due to modal shift from IWW to road.
	Mostert et al. [28].	Road, rail, IWW	Intermodal allocation model	Freight flows within, from and to Belgium (NUTS 3 level)	Study focuses on effect of modal shift on pollution rather than CO_2.
	Asuncion et al. [2]	Road, rail, SSS	GIS-based optimization model: New Zealand Intermodal Freight Network	Auckland-Wellington Auckland – Christchurch	Significant CO_2 emission savings due to a modal shift
	de Bok et al. [3]	Road, rail, IWW	BASGOED, strategic transport network model	Netherlands	Analyses effect of implementing CO_2 pricing on modal split.
	Macharis et al. [24]	Road, rail, IWW	LAMBIT model, GIS-based model for location analysis of Belgian intermodal terminals	Belgium	Analyses effect of internalization of external costs, among which CO_2 on market area of intermodal transport.
	Tavasszy and Meieren [40]	Road, rail, IWW	TRANSTOOLS, strategic transport network model	EU	Modal shift can cover 8% of the total reduction potential for CO_2.
	Tsamboulas et al. [42]	Road, rail, IWW, SSS	Macro-scan tool	Lerida – Karlsruhe Halkida – Ingolstadt	One of the applications is internalization of CO_2 costs.
	Zhang and Pel [43]	Road, rail, IWW (intermodal and synchromodal)	SynchroMO model	Rotterdam hinterland (Rhine river corridor until Duisburg.	Only container flows and for short-term analysis (24 h)
Decomposition analysis (macro)	Notteboom and Coeck [33]	Road, rail, IWW	Shift-share analysis	Belgian freight transport market	No effect on CO_2 calculated in this report. Method used for analysis of change in intermodal competition.
Other methods (mixed micro, macro)	Islam and Zunder [15]	Road, rail	Case studies based on interviews, questionnaires, company data and strategic transport network models.	1) Dourges – Mataro 2) Mechelen – Zeebrugge 3) Amiens – Mechelen – Euskirchen 4) Rotterdam – Busto Arsizio	2500 t CO_2 saved per year in Corridors 1 and 2 jointly in 2008/2009.

[a] We refer to Arencibia et al. [1] for important considerations in choice modelling for freight transport
[b] Islam et al. [14] provide a detailed description of the TRANSTOOLS modelling tool

Stated Preference (SP) data, and the other on Revealed Preference (RP) data obtained in a survey among shippers. Because the data is gathered at the company level, this is clearly a micro-approach. The models include variables such as costs, transport time and transport reliability. The mode shares are generated by using the parameter values in combination with average values for the mentioned variables. Applying these shares to the total amount of ton-kilometers and CO_2 emission factors results in total CO_2 emissions per transport mode. In this way several modal splits, with corresponding CO_2 emissions, can be generated for different policy scenarios. Regmi and Hanaoka [37] explain these steps in detail. A disadvantage of this method is the need for substantial amounts of disaggregated data [44]; consequently, application at the European level is difficult to achieve. Marcucci and Gatta [25] recently proposed an innovative procedure for acquiring stakeholder specific data for discrete choice modeling that can reduce data acquisition time and costs. Although they applied this procedure in an urban freight transport context, it could be transferable to a larger spatial scale, thus rendering discrete choice modeling on the EU level more feasible.

Kim and van Wee [21, 22] proffered Semi-LCA modelling as a means of estimating CO_2 emissions from transport; they consider their LCA assessment as 'Semi' because they include emissions from exhaust and production of fuel, but exclude emissions from the construction of infrastructure and vehicle maintenance.[2] In short, as based on the input data for demand, distance, speed, load factor, weight, vessel type, engine type, and fuel type, the emissions for rail and inland waterways intermodal systems are estimated according to the drayage, long-hauling and terminal operation processes, and for long-hauling only when it involves an all-road solution. Nocera and Cavallaro [32] also use the LCA methodology, and, based on the 'Well-to-Wheel' principle, they estimated the future CO_2 emissions of transalpine corridors for several modal shift scenarios. They then used meta-regression to economically evaluate the CO_2 reduction. Given the nature of the inputs, LCA can be deemed a macro-approach.

Models moreover that fall into the category of strategic freight transport network models use a macro-approach. The main characteristic of these models is that they contain several or all steps of the four-step model, which comprises trip generation, trip distribution, mode choice and route assignment (see for example [34]). The first two steps are often supported by an economic model. The TRANSTOOLS model for example contains a spatial Computable General Equilibrium (CGE) model, while the modal split module is aggregate logit [16]. NODUS, which only performs the modal split and route assignment steps, needs OD-matrices, cost functions, and transport networks as inputs. BASGOED, a conventional four-step transport model, has a limited number of zones and commodity types; moreover, its distribution and model choice model coefficients are estimated on aggregate data, and it uses inputs (generation and attraction) from the economy model of another transport model called SMILE+. For more details, we refer to de Jong et al. [16]; they provide a complete overview and description of national and international transport models in Europe. Finally, LAMBIT (Location Analysis for Belgian Intermodal Terminals), a GIS-based location analysis model that allows for ex-ante and ex-post analyses of policy measures in favor of intermodal transport, is built on three main inputs: transportation networks, transport prices, and container flows from the municipalities to and from the port of Antwerp.

In the scientific literature, decomposition analyses was used only once to analyse a modal shift in freight transport (see [33]). The purpose of that study was to analyse changing patterns of intermodal competition. Decomposition analysis was never used to analyse how a modal shift impacts CO_2 emissions. This paper will be the first to use a decomposition analysis for that purpose. Given the use of aggregated data on the sector level, this is clearly a macro-approach.

Lastly, in the category 'Other methods', Islam and Zunder [15] apply a mix of methods for analysing modal shift and the resulting drop in CO_2 emissions in several case studies. The case studies focus on several companies and corridors in Europe, and a mix of macro- and micro-approaches are used.

A key observation from the literature overview in Table 2 is that strategic freight transport network models are most frequently used to analyse the CO_2 emission reduction resulting from a modal shift. The advantage of such models is that users usually need not start from scratch. OD matrices, Geographical Information System (GIS)-layers, cost- and choice information are often already available from previous applications. Once used for analysing a certain freight transport problem, the adaptability of such models to analyse other problems is thus high. In order to perform a systematic comparison we have assessed the different methods on several criteria. Table 3 shows this comparison on the basis of the criteria 'adaptability', 'data requirements', 'computation complexity', and 'accuracy'.

While the adaptability of strategic freight transport network models is high, it can be considered low for the rest of the methods. For example, for decomposition analysis, for every research question the user has to start from scratch gathering and tuning the data inputs. On the other hand, the data requirements for decomposition analysis are also low. Freight transport data on quantities transported by several transport modes by cargo type for two different moments in time is already enough. Data requirements for the other methods are higher. For choice modelling the effort for gathering sufficient

Table 3 Method comparison

Criteria	Method			
	Choice modelling	LCA	Strategic freight transport network models	Decomposition analysis
Adaptability	Low	Low	High	Low
Data requirements	High	Moderate	Moderate	Low
Computation complexity	Moderate	Moderate	High	Low
Accuracy	High	Moderate/Low	Moderate/Low	Moderate/Low

and good quality data is relatively large. The same applies to LCA and strategic freight transport network models because different types of data is needed: data on quantities transported, cost data, data on economic development, data on energy production (in case of LCA), etc. The third criterion, computation complexity, is positively correlated with the level of data requirements. Consequently, the computation complexity of decomposition analysis is lower than the other methods. Because choice models produce point estimates and confidence intervals this method is considered most accurate. Regarding the remaining three methods it is more difficult to judge on the accuracy. Often the data inputs as well as the model outputs are of an aggregate nature. We have therefore judged the accuracy of these methods 'Moderate to Low', depending on the level of detail of the model used. Overseeing Table 3, the advantage of decomposition analysis lies in its low data requirements and low computation complexity.

A last, but important remark which must be made is that except for decomposition analysis, the methods in Table 2 most often analyse what-if scenario's based on policy interventions; this concerns the analysis of a *potential* modal shift for which the cause is known, and not the background details of a change in CO_2 emissions due to a *realized* modal shift. Nevertheless, this is important knowledge for policy makers in the field of freight transport, as they may want to know if the realized shift is stable, i.e. if the shift is likely to last over the long-term. It makes a difference if the shift is established due to the competitiveness of the less emitting modes or because these modes are - possibly coincidentally - present in the strongly growing freight markets and taking advantage of that fact. Our tool can reveal this background information of a realized modal shift, thereby also contributing to the existing literature on methods for analysing a mode shift in inland freight transport. The tool and its use are illustrated in section 3. The method behind the tool is a type of decomposition analysis, shift-share analysis and is explained in section 2.3. Because this method is used to explain a modal shift, we first describe this shift in the next section.

2.2 Descriptive analysis of modal shift

The modal shift analysis focuses on the Netherlands, using freight transport data in tons, as provided by Statistics Netherlands. More specifically, we use a customized freight transport Origin-Destination (OD)-matrix whose origins and destinations comprise the 12 Dutch provinces, Germany, Belgium, Italy and 'other'. Because our study is from the Dutch perspective, only those freight transport flows relating to the Netherlands (as an origin, destination or both) are included in the OD matrix. Further, the dataset contains information about distances, cargo types, ports of loading and unloading, and the number of tons transported by road, rail and inland waterways. At this level of detail, the data is available for two years: 2005 and 2014.

The dataset distinguishes between five distance classes, 0–50 km, 50–100 km, 100–300 km, 300–500 km, and more than 500 km. Figure 1 provides a visualization of the modal shift based on tons in those distance classes, presenting the modal splits for the two designated years.

Figure 1 shows that rail and inland waterways increased their shares of the modal split in the longer distance classes (transport over 100 km) between 2005 and 2014. Concurrently, these modes lost freight in the less than 100 km transport market. Considering all distances, the shift was − 3.0 for road, + 0.2 for rail, and + 2.8 for inland waterways, with the figures representing the percentage points change between 2005 and 2014.[3] The most striking changes occurred in the 300–500 km distance market. In this segment road lost 28.6 percentage points of its 2005 share, while inland waterways gained 30.9 percentage points. It must be noted that this is relatively small segment, at around 8%, as shown in Table 4. A closer look at the data for this distance market reveals that the gain in modal split for inland waterways can be traced back to the growth of cargo markets 2 and 7, and the gain of market share in cargo markets 0, 2 and 10.[4] See Appendix 1 for the used classification of numerical cargo markets.

The shift from road to inland waterways is likely related to developments in the energy industry. CCNR [6] reveals an increase in coal transports on the Rhine between 2009 and 2013, which was

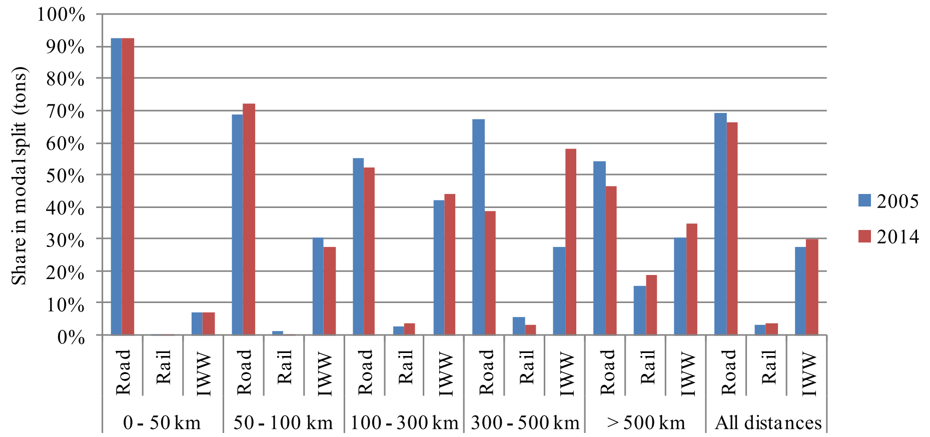

Fig. 1 Modal split in 2005 and 2014 measured in tons transported to, from and within the Netherlands. The tons transported in containers are included. Source: Statistics Netherlands, calculations by KiM. Note: IWW = Inland waterways

expected to continue in 2014, owing to the low price of coal. Moreover, several power plants in Germany are located along waterways within a 300–500 km radius of the Port of Rotterdam [12]. The combination of these two findings could be one explanation for the large increase in the share for inland waterways between 2005 and 2014. The share for rail is highest in the transport market of over 500 km, which indicates that rail is cheapest over the longest distances. Moreover, the fact that freight trains can cross natural barriers, like the Alps, and inland waterways cannot, likely contributes rail's higher share in this distance market compared to the other distance markets.

It appears that at the disaggregate level, changes in modal split can significantly differ from those at the aggregate level. Distinguishing between market segments sheds some light on possible causes for a modal shift. Section 2.3 addresses this point in greater detail by presenting a methodology that decomposes the growth of the transported quantity for each transport mode.

Table 4 Size of the distance markets in tons (including those in containers)

Distance class	Absolute (tons × 1.000.000)		Relative	
	2005	2014	2005	2014
0–50 km	315	317	30.8%	30.2%
50–100 km	131	182	12.9%	17.3%
100–300 km	377	360	37.0%	34.3%
300–500 km	80	82	7.8%	7.8%
> 500 km	118	109	11.5%	10.4%
All	1021	1050	100.0%	100.0%

Source: Statistics Netherlands and calculations by KiM

2.3 Explanatory analysis of modal shift: the shift-share method

The basis of the modal shift presented in the previous section is a change in the quantities transported by each individual transport mode. Table 5 shows the direction and the size of these changes.

The observed change is negative for road and positive for rail and inland waterways. Of interest is discovering what the possible causes are for these changes. To this end we apply a shift-share analysis to decompose the changes into several components.

The shift-share method [9] derives from the field of regional economics, where it is often used to decompose the regional growth of jobs or productivity (see Nazara and Hewings [29], for example). In our study the variable of interest is the growth in the number of tons transported, and the three transport modes - road, rail and inland waterways - are the objects to which the method is applied. Notteboom and Coeck [33] have taken a similar approach in examining intermodal competition in Belgian inland transportation. Freight transport data from 1980 to 1991 and a shift-share analysis were used to position the main inland transport modes - road, rail, and inland waterways - and assess and partially explain the changing patterns in intermodal competition.

Table 5 Change in transported number of tons per transport mode

Transport mode	Tons (× 1,000,000) 2005	Tons (× 1,000,000) 2014	Change 2005–2014
Road	708	696	−1.7%
Rail	34	38	10.4%
Inland waterways	279	316	13.3%
Total	1021	1050	2.8%

Source: Statistics Netherlands and calculations by KiM

The shift-share analysis decomposes absolute growth in freight transport between two years into a transport market effect, a cargo market effect, and a competition effect for each transport mode. The transport market effect is equal to the expected growth of each transport mode, as if it had developed like the total transport sector. The cargo market effect results from the specialization of a transport mode in growing and shrinking cargo markets. Finally, the competition effect is the result of an increase or decrease of a transport mode's market share in the cargo markets where it is active. The competition effect is an indicator for transport mode's competitiveness. The decomposition of each transport mode's total growth can now be presented in eq. 1. We refer to Table 6 for a description of the symbols.

$$Q_i^{t+l} - Q_i^t = TM_i + CM_i + C_i \tag{1}$$

$Q_i^{t+l} - Q_i^t$ is total growth in tons during the period under analysis. The three components are calculated as follows:

$$TM_i = Q_i^t(G) \tag{2}$$

$$CM_i = Q_i^t(G_i - G) \tag{3}$$

$$C_i = Q_i^t(g_i - G_i) \tag{4}$$

Table 6 Explanation of the symbols in the equations (1)–(6)[a]

Symbol	Description
Q	quantity, number of tons transported
TM	transport market effect, tons
CM	cargo market effect, tons
C	competition effect, tons
t	year
l	length of period under analysis, in years
i	cargo type
G	growth percentage of the total transport market
Gi	general growth percentage of cargo type *i*
gi	mode specific growth percentage of cargo type *i*
Δ*CO2*	change in CO2 emission
Ad	average distance
Ef	emission factor
d	distance market
m	mode before shift
n	mode after shift

[a] Equation (6) can be found in Section 3

In order to conduct a shift-share analysis for each mode, a summation over *i* is needed, as shown in eq. 5.

$$\sum\nolimits_i \left(Q_i^{t+l} - Q_i^t\right) = \sum\nolimits_i TM_i + \sum\nolimits_i CM_i + \sum\nolimits_i C_i \tag{5}$$

In our application of eq. 5, $t = 2005$ and $t + l = 2014$. The results of the shift-share analysis is presented in Fig. 2. The horizontal axis shows the various components' contributions to the total growth.

The transport market effect is, logically, equal for all three modes. This effect is represented by the blue bars in Fig. 2. The decomposition reveals that the overall positive growth for inland waterways was the result of a positive transport market effect, negative cargo market effect and strong positive competition effect. The negative cargo market effect resulted from a specialization in shrinking commodity markets 3 and 8 in the Standard Goods Classification for Transport Statistics 2007 (NST2007). Table 7 shows that these commodity markets experienced the largest absolute decrease. The positive competition effect was mainly due to gains in market share in cargo markets 3, 7, and 8. In total, the inland waterways' competition effect was positive in eight of the eleven cargo markets, which implies that inland waterways possess unobserved factors that render this mode more competitive. These unobserved factors can be highly diverse. CCNR [6] notes that "the waterways still have spare capacity", and this was apparent in 2012 when the inland waterways were able to compensate for the lost production of two oil refineries. Inland waterways may therefore be better suited than other modes to handle increases in demand for liquid bulk transport and consequently capturing a larger part of the pie. Another possible cause could be improvements to waterway infrastructure. In 2013 a new lock was opened in the Mittelweser waterway in Germany [41]. Desk research focusing on specific transport markets can thus identify likely causes for the competition effect. Rail's positive transport market effect was accompanied by a strong positive cargo market effect. In examining the data it appears that rail is specialized in growing cargo markets 2, and a 'residual' group '0' consisting of cargo markets 5 and 13–20.[5] Further, rail benefitted from a small positive competition-effect, which was mainly the result of its strong gain in cargo market 2. Road's negative overall growth was caused by a negative competition-effect, which was larger than the sum of the positive transport market effect and cargo market effect. Road especially lost freight in cargo markets 3, 7, and 8.[6]

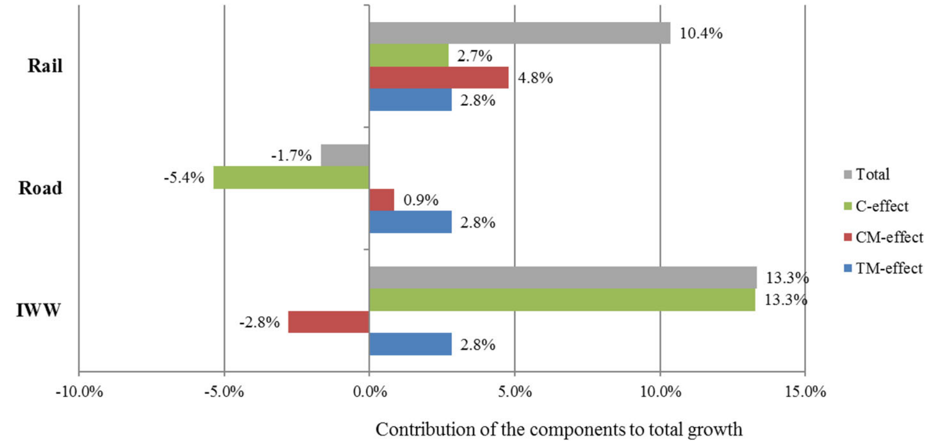

Fig. 2 Result shift-share analysis on growth tons transported between 2005 and 2014 to, from and within the Netherlands. Source: Statistics Netherlands, calculations by KiM. Note: IWW = Inland waterways

3 CO$_2$ emission analysis tool

In addition to the total transport market, shift-share analysis can also be applied to the individual distance markets, as considered in Section 2.2. This offers the opportunity to identify differences in cargo market effects and competition effects between the various distance markets. We have seen in Section 2.3 that the competition effect of inland waterways and the cargo type effect for rail are positive in the total transport market. However, it is likely that the size of the effect varies among the distance markets. We have therefore repeated the shift-share analysis for all five distance markets. In examining the results in Appendix 2, we observe much more pronounced changes in transported quantities between 2005 and 2014, as compared to the results for the total market in Fig. 2. The amounts transported doubled (IWW, 300–500 km) or more than halved (rail, 50–100 km) for several combinations of distance market and transport mode. Consequently, the three components resulting from the shift-share analysis also garner more extreme values.

The shift-share components offer useful material for a tool that is capable of assessing a modal shift's contribution to CO$_2$ emission reduction. This tool is presented as a framework in Fig. 3. The framework's horizontal axis represents the value of the competition effect and the vertical axis the value of the cargo market effect.[7] Next, balls are used in the framework to denote all

Table 7 Development of cargo markets between 2005 and 2014

NST2007 commodity group	Tons (× 1000) 2005	Tons (× 1000) 2014	Absolute growth in tons (× 1000)	Growth percentage
0 (5 and 13–20)	211,931	231,963	20,032	9.5%
1	75,949	81,210	5260	6.9%
2	30,117	47,016	16,899	56.1%
3	237,710	196,635	− 41,075	−17.3%
4	122,055	142,265	20,210	16.6%
6	19,738	34,247	14,508	73.5%
7	76,363	79,119	2755	3.6%
8	110,591	92,326	−18,265	−16.5%
9	57,987	68,251	10,263	17.7%
10	45,216	42,167	− 3048	−6.7%
11	19,992	25,135	5142	25.7%
12	14,035	10,315	− 3720	−26.5%
Total	1021,690	1050,653	28,962	2.8%

Source: Statistics Netherlands and calculations by KiM

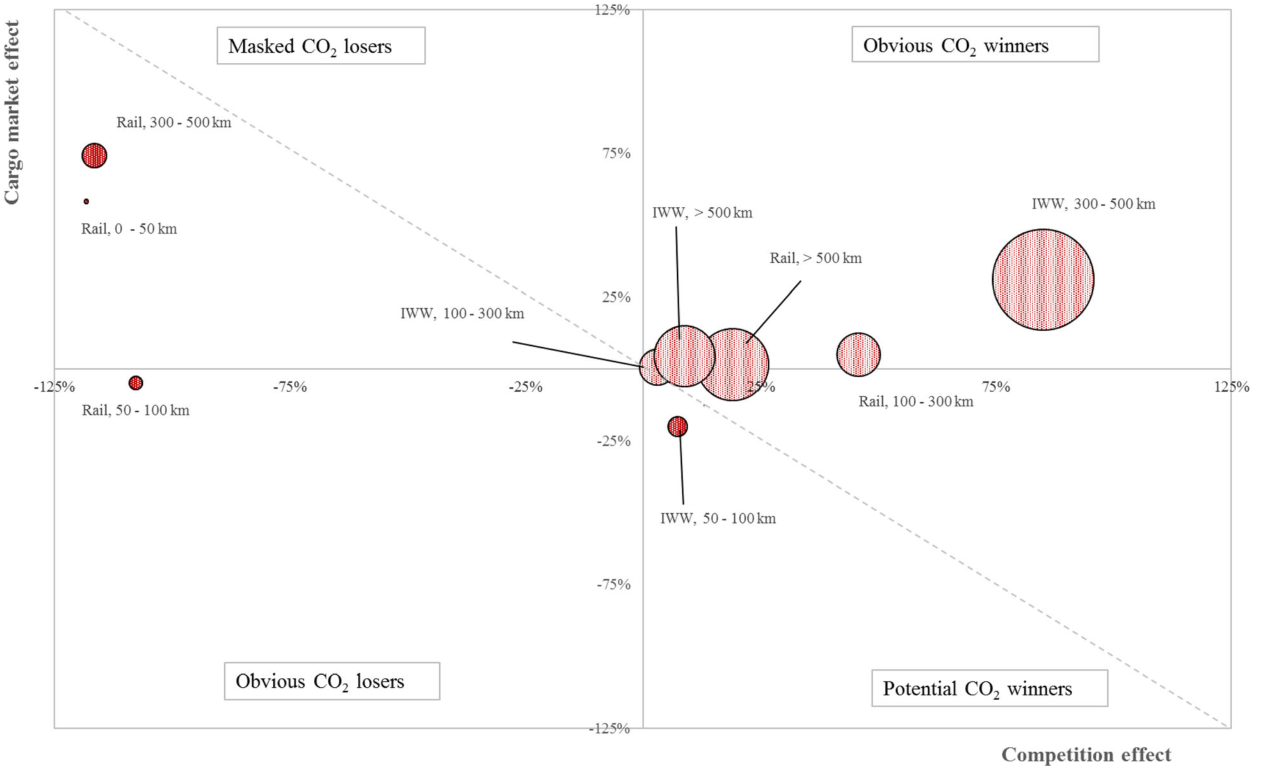

Fig. 3 Positioning of rail and inland waterways based on the shift-share components and according to their contribution to CO$_2$ reduction. This framework was inspired by PBL [35]. Note: the ball for IWW 0–50 km is very small and located behind the ball for 'Rail > 500 km'.

combinations of transport mode, except for road, and distance market.[8] The color of a ball indicates whether a transport mode is responsible for a decrease (pink) or increase (red) in CO$_2$ emissions due to a modal shift. The size of the balls depends on the distance market, the size of the modal shift due to the CM-effect and C-effect in tons, and the emission factors of the transport modes. Consequently, the size of a ball is an indication of the size of the CO$_2$ impact resulting from a shift from one transport mode to another in a particular distance market.

In order to estimate the color and size of the balls, the shift in the number of tons transported from one mode to another in each distance market must be translated into ton-kilometers. Because ton-kilometers are missing in our dataset, we have assumed that actual distances for road transport are uniformly distributed around the mean distance in each distance market. For rail and inland waterways we assume a detour factor of 1.2 compared to road, because the rail and inland waterway networks have a lower density than the road network. See Table 8 for the average distances. We acknowledge that the above-mentioned assumption is quite strong; however, because our paper's stated aim is to illustrate the use of the tool, we consider this simplification acceptable at this time. We do acknowledge however that it would be better to work with ton-kilometre data.

Table 8 Assumed average distances in the distance markets

Distance market	Average distance road	Average distance rail and IWW
0–50	25	30
50–100	75	90
100–300	200	240
300–500	400	480
> 500	700	840

In a next step the shift in CO_2 emission is calculated for each distance market as follows: the number of tons shifted due to the joint CM- and C-effect is multiplied by the distance and emission factor of the transport modes before and after the shift. Finally, the mode's emissions after the shift are subtracted from the mode's emissions prior to the shift. See Eq. 6 for the mathematical formulation. The emission factors for 2014 are shown in Table 9. These factors are specifically applicable to the Dutch freight transport situation in 2014.

$$\Delta CO2_{d,m,n} = \left(Q_{d,m} * Ad_{d,m} * Ef_{m}\right) - \left(Q_{d,n} * Ad_{d,n} * Ef_{n}\right) \quad (6)$$

In Equation 6 $\Delta CO2_{d,\ m,\ n}$ is the change in CO_2 emission in distance market d due to a shift from mode m to mode n. For an explanation of all symbols we refer to Table 6. By means of Equation 6 the size and color of every ball in Fig. 3 is determined. Thus, the red ball denoting rail in the 300–500 km distance market results from the fact that in this market rail has lost tons to inland waterways. Because inland waterways' CO_2 emission factor is higher than for rail, this shift results in increases in CO_2 emissions and hence a red ball. Despite the fact that 300–500 km is quite far, the ball's size is relatively small; this is due to the fact that the number of tons shifted from rail to inland waterways is limited. Although we performed several sensitivity analyses by varying the average distances, this does not alter the picture in Fig. 3 very much, as the size of the balls changes only slightly.

We now turn to the interpretation of the quadrants in the framework. The quadrants are based on the values of the CM-component and the C-component of the shift-share analysis. The balls located in the upper right quadrant are called 'Obvious CO_2 winners'; they deserve this name because these balls depict transport modes that have increased their market share and are specialized in cargo markets that have above-average growth rates. This is an ideal situation from a CO_2 reduction perspective for two reasons: these modes are active in the 'right' cargo markets, and they are competitive, offering a good starting position for attracting more cargo in future. The balls in the lower right quadrant are called 'Potential CO_2 winners', as these modes are competitive but specialized in the 'wrong' cargo markets, i.e. those with below-average growth. Consequently, although these modes already possess factors that make them competitive, it would be desirable for these cargo markets to be reorientated, so that they become more involved in the above-average growth markets. Should they succeed, these balls will shift upwards and become 'Obvious CO_2 winners'. The balls in the lower left quadrant are called 'Obvious CO_2 losers', as they have lost tons due to a negative competition effect and their specialization in the wrong markets. The 'Masked CO_2 losers', situated in the upper left quadrant, find themselves in a dangerous position; their lack of competitiveness is masked by the fact that they have experienced (modest) growth in the number of tons transported because they are active in above-average growing cargo markets. However, they run the risk of ending up in the lower left 'Obvious CO_2 losers' quadrant should these cargo markets experience a decline in future.

Table 9 CO_2 emission factors for 2014

Transport mode	Grams per ton-km
Road	90.3
Rail	11.3[a]
Inland waterways	38.6

Source: KiM [20], CE Delft [7]

[a] It is assumed that 20% of rail freight transport is performed by diesel trains and 80% by electric trains (CE [7])

A first observation from Fig. 3 is that inland waterways has experienced a positive competition effect between 2005 and 2014 in all the distance markets. This was not the case for rail, but given the size of rail's balls on the right side of the y-axis, rail was responsible for considerable CO_2 reductions in both the longest distance market of more than 500 km and the medium distance market of 100–300 km. The balls in the 'Obvious CO_2 winners' quadrant imply that in five out of ten distance markets rail and inland waterways are performing well in terms of competitiveness and specializing in the 'right' markets. Moreover, these five balls are also relatively large, implying that in terms of ton-kilometers the shift to rail and inland waterways was accomplished in the more important markets and that the tons were acquired from a mode with a higher CO_2 emission coefficient. The five remaining balls are located in the other quadrants, which means that rail and inland waterways are doing less well in those five markets. However, because these markets are smaller in size (in terms of ton-kilometers), the increase in CO_2 emissions due to a modal shift is relatively small.[9]

A point of concern from a CO_2 perspective is rail's performance in the 300–500 km distance market. Rail is active in growing cargo markets within this distance market yet simultaneously has lost market share. A closer look at the data reveals that it is the fast-growing NST2007 cargo market 2 that is virtually solely responsible for rail's position in the 300–500 km distance market. From the perspective of the transition in the energy sector and transition towards a circular economy, it is dangerous for rail to depend to a large extent on this cargo market. Should this cargo market shrink, rail will lose more tons than inland waterways and road (modes with higher CO_2 emission factors), because rail specializes in this cargo market and will thus run the risk of moving to the 'Obvious CO_2 losers' quadrant.

Another interesting ball is that for inland waterways in 300–500 km distance market, where it appears that NST2007 cargo markets 2 and 7 are the drivers of growth in the number of tons transported. Like cargo market 2, cargo market 7 is a bulk market that is likely to be affected by the mentioned transitions. Nevertheless, inland waterways can rely on its competitiveness in cargo market 7. Inland waterways gained market share in all cargo markets within the 300–500 km distance market, but especially in NST2007 cargo markets 0, which is the 'residual' group consisting of commodity groups 5 and 13–20, 2, and 10. This means that inland waterways is strong in both the bulk and containers markets, which is a good starting point for future CO_2 emission reductions in this distance market.

4 Discussion

The presented framework visualizes in a glance how freight transport modes perform from a CO_2 emissions perspective in a modal shift context. The combination of the size and the color of the balls immediately expresses whether, and to what extent, the modal shifts have resulted in reduced CO_2 emissions. Additionally, the position of the balls in the framework's quadrants express whether a transport mode is likely to contribute to the decarbonization of freight transport in future. A shift based on improvements to a transport mode's competitiveness is more likely to last in future than a shift based on that transport mode's overrepresentation in above-average growing markets. In the latter case, the transport mode's position in the framework is highly subject to the volatility of cargo markets. A transport mode's position is more stable if it is mainly based on its competitiveness, because such competiveness will mute any possible impact from future declines of the cargo markets in which it is overrepresented..

On the basis of the framework, policy makers in the freight transport field are better able to steer their modal shift policies: they can see in which markets inland waterways and rail perform well in terms of CO_2 emission reductions due to a modal shift, and then strive to determine what the factors for success were. Conversely, they can also see where inland waterways and rail have underperformed. The question to then be answered is how good positions for rail and inland waterways can be guaranteed in future and how less advantageous positions improved. Studying the data that feed the framework in greater detail can reveal which are the most important cargo markets in terms of size, if these markets are growing or shrinking, and how competitive a transport mode is in these markets. Combining this information with expected developments, such as the circular economy, ongoing energy transitions and innovations in the transport sector, can help shape successful policies aimed at the decarbonization of freight transport. Unfortunately, the tool does not elucidate the factors that lie behind the competition effect. Possible factors could be identified by means of desk-and field research of the specific transport markets though.

Because the tool does not reveal the reasons for being competitive ex-post, we do not know which policy interventions worked and did not work. Research methods, including those cited in Table 2, cannot reveal this either, but they can be used for ex-ante analysis and thus valuable for shaping future policies. As proposed by Marcucci et al. [26] and le Pira et al. [36], integrated discrete choice and agent-based modeling could be useful additional assets. The starting point for their modeling approach is that a good policy is one that provides a package of measures integrating the interests of the diverse stakeholders, which, for inland freight transport, are shippers, carriers, receivers, governments, et al.. The integrated modeling approach takes into account stakeholders' heterogeneous preferences and simulates their interactive behavior in a consensus building process, providing useful suggestions for policy makers about the potential acceptability of a set of policies to be eventually discussed with stakeholders. Although these studies apply to an urban context, their approach might also be feasible on the larger spatial scale of a country or the EU.

The tool can be applied to various spatial scales. Instead of distance markets or EU countries, one could also distinguish between the domestic, border crossing and cabotage markets of a given country for example. Another idea is to apply the tool to the various Alpine corridors, where for years the authorities have been striving to establish a (further) mode shift from road to rail. An additional advantage of the tool is that shift-share - the supporting methodology behind the tool – has low data requirements and also computing complexity is low.

The main drawback of how the tool is applied in this paper is that data on tons was combined with assumed average distances. Hence, a key improvement would be to directly use ton-kilometers data instead of ‘derived’ ton-kilometers data. If for example such data were available on the EU Member State level, comparisons between countries would be possible.[10] However, because the stated aim of this paper is to illustrate and explain the tool and its usability, the use of derived ton-kilometre data is deemed to be but a minor drawback.

5 Conclusion

We conclude that for freight transport with an origin, destination or both in the Netherlands, a modal shift from road (– 3,0 percentage points), to rail (+ 0,2 percentage points), and to inland waterways (+ 2,8 percentage points) occurred in the period 2005–2014. No transported freight was shifted in the less than 100 km distance market. This implies that the shift for the total market wholly occurred in the more than 100 km distance market. A shift-share analysis, decomposing growth in the number of tons transported by each mode, for the total transport market reveals that the modal shift mainly results from rail being specialized in the above-average growing cargo markets and from inland waterways becoming more competitive between 2005 and 2014.

The core of this research paper is however the presentation of a tool that can be used to assess how a freight modal shift contributes to CO_2 emission reductions. This meets the need for research into methods to address problems in the area of intermodal transport. One of these problems is that in freight transport the shift to more sustainable modes has been very modest in the past 10 to 15 years. This problem can be addressed by our tool. The assessment tool is based on the shift-share method, which is well known in the field of regional economics. The tool shows how rail and inland waterways have performed in terms of CO_2 emissions reduction, while taking into account the transport modes’ competitiveness and the development of the cargo markets in which they are active. The tool thus provides policy makers with valuable information about the background to changes in CO_2 emission due to freight modal shifts in past years. This information can be used as a starting point for devising future freight transport policies aimed at attracting more cargo by rail and inland waterways.

6 Endnotes

[1] To increase reading convenience, we would like to mention that a list of abbreviations used in this paper can be found between the conclusions and the references.

[2] In Nocera and Cavallaro [31], CO_2 emissions from construction are taken into account.

[3] The mode shares in 2005 were 69.3% for road, 3.4% for rail, and 27.3% for inland waterways.

[4] The cargo type classification we use is based on the 2007 standard goods classification for transport statistics, in short the NST2007 commodity classification of the European Commission [10]. The classification, with a description of the numerical cargo markets, can be found in Appendix 1.

[5] For analytical reasons the commodity groups 5 and 13–20 had to be aggregated into one so-called ‘residual group’. This is group number 0.

[6] Note that these are exactly the markets where inland waterways gained market share, which makes sense, as not all transport modes can gain market share at the same time in one cargo market. Where one mode gains market share, one or two other modes will lose.

[7] To describe this as an analogy with a pie: a positive value on the vertical axis implies that the pies (cargo markets) in which a transport mode has a relatively large share have grown between 2005 and 2014. A high positive value on the horizontal axis means that a transport mode has captured a larger part of the pies between 2005 and 2014.

[8] Balls for road are not shown because the aim of the framework is to visualise shifts to and from the least emitting transport modes - rail and inland waterways.

[9] Considering that rail has the lowest CO_2 emission factor, as shown in Table 9, note that it would be ideal from a CO_2 perspective to have all the rail balls located in the upper right quadrant, and the IWW balls positioned to the left and below the rail balls.

[10] Ton-kilometer data per NST2007 commodity group on the EU-country level is available for road, rail and inland waterways at Eurostat. However, because ton-kilometers for rail and inland waterways are reported according to the territoriality principle, and those for road according to the nationality principle, a correct analysis of the CO_2 effect of a modal shift in EU Member States is not possible. From this, the need for collecting ton-kilometer data on the basis of the territoriality principle for road *per NST2007 commodity group* becomes immediately clear. At the aggregate level (all commodity groups together) such data is available for road. See Cloodt [8] for a detailed explanation of the nationality and territoriality principles.

Appendix 1

Table 10 NST2007 cargo type classification

Division	Description
01	Products of agriculture, hunting, and forestry; fish and other fishing products
02	Coal and lignite; crude petroleum and natural gas
03	Metal ores and other mining and quarrying products; peat; uranium and thorium
04	Food products, beverages and tobacco
05	Textiles and textile products; leather and leather products
06	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials; pulp, paper and paper products; printed matter and recorded media
07	Coke and refined petroleum products
08	Chemicals, chemical products, and man-made fibres; rubber and plastic products; nuclear fuel
09	Other non-metallic mineral products
10	Basic metals; fabricated metal products, except machinery and equipment
11	Machinery and equipment n.e.c.; office machinery and computers; electrical machinery and apparatus n.e.c.; radio, television and communication equipment and apparatus; medical, precision and optical instruments; watches and clocks
12	Transport equipment
13	Furniture; other manufactured goods n.e.c.
14	Secondary raw materials; municipal wastes and other wastes
15	Mail, parcels
16	Equipment and material utilised in the transport of goods
17	Goods moved in the course of household and office removals; baggage transported separately from passengers; motor vehicles being moved for repair; other non-market goods n.e.c.
18	Grouped goods: a mixture of types of goods which are transported together
19	Unidentifiable goods: goods which for any reason cannot be identified and therefore cannot be assigned to groups 01–16.
20	Other goods n.e.c.

Source: European Commission [10]

Appendix 2

Table 11 Shift-share results for the five distance markets

	Tons 2005	Tons 2014	% change	TM-effect	CM-effect	C-effect
Distance market 0–50 km						
Road	291,240,398	293,509,387	0.8%	0.6%	0.8%	−0.6%
Rail	1,042,875	424,153	−59.3%	0.6%	58.3%	−118.2%
IWW	22,666,423	22,876,538	0.9%	0.6%	−12.7%	13.0%
Distance market 50–100 km						
Road	90,441,652	131,711,026	45.6%	38.3%	8.8%	−1.4%
Rail	1,226,300	315,033	−74.3%	38.3%	−4.9%	− 107.7%
IWW	39,764,105	49,919,460	25.5%	38.3%	−20.2%	7.4%
Distance market 100–300 km						
Road	208,860,765	188,594,615	−9.7%	−4.5%	−0.7%	− 4.5%
Rail	9,531,849	13,940,457	46.3%	−4.5%	4.9%	45.9%
IWW	159,125,896	157,924,527	−0.8%	−4.5%	0.7%	3.1%
Distance market 300–500 km						
Road	53,690,766	31,651,994	−41.0%	2.6%	−18.5%	−25.1%
Rail	4,287,383	2,585,584	−39.7%	2.6%	74.2%	−116.5%
IWW	21,734,196	47,518,322	118.6%	2.6%	31.0%	85.1%
Distance market > 500 km						
Road	63,798,975	50,765,389	−20.4%	−7.1%	−2.9%	−10.4%
Rail	18,163,737	20,628,259	13.6%	−7.1%	1.6%	19.1%
IWW	35,899,828	38,124,519	6.2%	−7.1%	4.4%	8.9%

Abbreviations

CCNR: Central Commission for Navigation on the Rhine; CGE model: Computable General Equilibrium model; CO_2: Carbon dioxide; COP21: 21st Conference Of Parties; EU: European Union; EU28: The current 28 members of the European Union; GHG: Green House Gas; GIS: Geographical Information System; IWW: Inland Waterways; LCA: Life Cycle Analysis; NST2007: Standard goods classification for transport statistics 2007; NUTS: Nomenclature of Territorial Units for Statistics; OD matrix: Origin-Destination matrix; RP: Revealed Preference; SP: Stated Preference; SSS: Short-Sea Shipping

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Availability of data and materials

The data that support the findings of this study are available from Statistics Netherlands but restrictions apply to the availability of these data, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Statistics Netherlands.

Authors' contributions

OJ performed the shift-share analyses, invented the framework and did most of the writing. JF did the acquisition of the data from Statistics Netherlands, made an intellectual contribution to the analyses and assisted in writing the article. JV made an intellectual contribution to the analyses and assisted in writing the article. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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