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The significance of the urban context for the sustainability performance of intermodal road-rail transport

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Abstract

The purpose of this paper is to analyse the implications of the urban context for the sustainability performance of intermodal road-rail transport (IRRT). By calculating the external costs of a road transport and an intermodal alternative of consolidated cargo between a freight forwarder's consolidation terminals, the paper shows that the environmental benefits of a modal shift depend on the relative location of the intermodal terminal and shipper and receiver in the spatial structure. A careful integration of the intermodal terminal in the urban spatial structure is therefore a necessity if IRRT is to contribute to the sustainable development of the freight sector.

Keywords: intermodal transport, sustainability, urban transport, pre- and post haulage, case-study, modal shift.

1. Introduction

Transport demand is closely linked to economic development and for several decades there has been a close correlation between the growth of freight transport and economic growth showing that freight transport is a vital component for the generation of welfare. On the other hand, freight transport also imposes significant negative impacts on the environment (e.g., atmospheric emissions, use of non-renewable fuels, waste and loss of ecosystems), on society (e.g. public health, accidents, noise and reduction of quality of life) and on the economy (e.g. waste of resources and congestion resulting in decreasing journey reliability and city accessibility) [1]. The increase in inland freight transport demand is mainly met by road freight while the share of rail and inland waterways has declined. The growth of road freight is a continuing environmental burden because the growing

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road freight transport volumes have over-compensated the improved emission level per kilometre driven which were achieved by the introduction of alternative fuels and innovative vehicle technology [2]. Technological innovation is unlikely to be the sole answer for reducing energy consumption and emissions of the freight sector [3]. A key policy objective for the freight sector's sustainable development is therefore to reduce the imbalance in the development of the different transport modes and to transfer freight to less environmentally damaging modes like rail.

Although a modal shift from road to intermodal road-rail transport (IRRT) is desirable, there are also studies, which are more pessimistic about its potential contribution to energy usage reduction and environmental improvement [4]. The relative environmental advantages of rail over road are reduced when the less energy efficient trucks still required for pre- and post haulage (PPH) to and from rail terminals are factored into the analysis [5]. Furthermore, while the regional and global impacts are lowered due to the use of energy efficient rail transport, PPH and terminal operations can add to local traffic impacts [6]. The significance of the trade-off between local traffic impacts and energy use and emissions benefits depends largely on the amount of PPH traffic in urban areas, which is highly determined by the local spatial pattern. The sustainability potential of IRRT therefore has a significant urban dimension. The purpose of this paper is to analyse the implications of the urban context for the general potential of IRRT to contribute to sustainable development of the freight transport sector.

This paper takes a case study approach. By calculating the external costs of a single-mode road and intermodal transport of consolidated cargo between a freight forwarder's consolidation terminals, the trade-off between additional local environmental impacts and global environmental gains when shifting freight from single-mode road transport to IRRT is analysed. The paper is structured as follows. Section 2 provides the theoretical background of this paper. It introduces the unsustainable impacts of freight transport and defines the concept of intermodal road-rail transport. Section 3 presents the selected cases and the data and method for the external cost calculations. In section 4 the case study results are presented and analysed. Section 5 discusses the results and section 6 contains the conclusions.

2. Frame of reference

2.1. Unsustainable impacts of freight transport

The unsustainable impacts of freight transport are numerous and multifaceted and can be categorised according to different dimensions. The impacts mentioned in the literature usually are accidents, noise, air pollution (health, material damage and biosphere), climate change risks, disturbance to the landscape and separation in urban areas; additional effects from upstream/downstream processes and congestion [7]. These impacts differ in time as well as in geographical scale. Table 1 provides a summary of the unsustainable impacts of freight transport and categorises them according to their geographical scale, i.e., whether the impacts are only palpable on a local level where the traffic takes place or whether they have regional or global effects. The unsustainable impacts are also multidimensional regarding their mitigation measures as they derive from different aspects of transport. Impacts from traffic and infrastructure, which are mainly local problems, require a reduction of traffic volumes. Impacts caused by emissions to air are a problem on the local and regional scale and can be mitigated on the vehicle level by clean technology. Finally, impacts from the use of fossil energy resources are a global problem and require a change in the energy supply. This categorisation follows a hierarchy as a reduction of traffic volumes will also lead to a reduction of emissions and energy use while on the other hand, alternative fuels and clean engines will not lead to a reduction of traffic or infrastructure impacts.

2.2. Intermodal road-rail transport

Intermodal transport is the combination of two or more transport modes in one transport chain. The fundamental idea behind intermodal transport is that the service and cost advantages of each transport mode are joined together in order to improve the overall efficiency of the transport system [8]. The by far biggest distance is performed by large-scale transport modes like rail, inland waterways, short sea shipping or ocean shipping where the units are consolidated with other shipments and economies of scale are being achieved. Road transport is assigned to the short-haul, or collection and distribution of freight. Intermodal transport thus increases the reach of the larger modes of sea and rail and enhances the efficiency of the transport system [9].

Table 1: Categorisation of unsustainable impacts of freight transport

Impact category	Local	Regional	Global
Emissions to air	Public health Soiling of surfaces	Buildings and material damage Biodiversity loss Ecosystem loss Agriculture crop/ forestry losses	
Fossil energy use			Climate change Energy dependency
Traffic/Infrastructure	Noise Accidents Congestion Separation effects Loss of space Habitat fragmentation/ (quality) loss Visual intrusion		
Up- and downstream effects	Production of energy, vehicles and infrastructure adds to energy use and emissions to air impacts, and has external effects on markets other than the transport market, i.e., the energy market		

Rail operations are generally considered environmentally friendly since electric traction provides access to various forms of renewable energy. Introducing renewable energy into rail in order to achieve zero-emission-transport and to avoid the negative consequence of being locked-in an oil-based energy supply is therefore easier than to road transport. However, electrical trains using renewable energy are not completely emission-free either since they emit particles mainly originating from wear of rails, brakes, wheels, and carbon contact strips [10]. According to CE Delft [11] the biggest unsustainable impact of rail is noise in urban areas. On existing railway networks freight traffic is the main source of noise, which threatens political and public support for increasing the share of rail traffic [12]. The infrastructure also causes separation effects in urban areas as well as impacts on nature and landscape, i.e., loss and fragmentation of habitats.

PPH by diesel trucks is the major source of air pollution in the intermodal transport chain and it also accounts for a significant share of the IRRT chain's energy demand. Furthermore, PPH usually takes place in urban areas where it shares the infrastructure with passenger traffic and their congestion, noise, accidents and air pollution impacts are much higher than for intercity traffic [11]. Moreover, because of the low capacity utilization due to empty driving, which is inherent in pick-up and delivery traffic, the distance travelled in urban areas is generally higher than for all-modal road transport [13].

From a city's perspective, a modal shift can therefore imply higher traffic and air pollution impacts while the total impacts over the whole transport chain are decreased. The significance of the trade-off between local traffic impacts and energy use and emissions benefits depends largely on the amount of PPH traffic in urban areas, which is highly determined by the local spatial pattern. Often, the intermodal terminals are located close to the city centre while the shippers and receivers of intermodal freight are located at the urban fringe areas with good connection to the surrounding highway-ring [13]. As a consequence, the PPH and rail distance travelled in urban areas is higher than the urban driving distance of the single-mode road transport. In the next section, the implications of the urban context for the potential of intermodal transport to contribute to sustainable development is assessed in a case study.

3. Case study on external costs of a modal shift

The goal of this case study is to analyse the trade-off between additional local environmental impacts and global environmental gains when shifting freight from single-modal road transport to IRRT. This is achieved by calculating the external costs of a single-modal road transport of consolidated cargo between a freight forwarder's consolidation terminals. The results are compared with a potential intermodal alternative for this transport. This section describes the selected cases as well as the data collection and calculation method.

3.1. Description of the cases

The transport flow analysed is the long-distance operations in a freight forwarders less-than-truckload network. These transports are generally suitable for IRRT, since the transport volumes are big enough to fill intermodal loading units and the time and frequency requirements (overnight transport once a day) of consolidated cargo are in line with the production system of IRRT, which is usually operated as night jumps. The underlying proposition of this case study is that the local spatial pattern determines the scale of the trade-off between additional local environmental impacts and global environmental gains. To study the impact of this trade-off on the improvement potential of a modal shift, two cases with sharply contrasting characteristics are studied. In order to analyse the significance of the PPH traffic in urban areas for the additional local environmental impact of a modal shift, one scenario is constructed. It analyses the effect of an alternative terminal location, which reduces the PPH distance in sensitive urban areas.

The first case is a transport in Sweden between Gothenburg and Stockholm with a relatively long transport distance (ca. 480 km). Furthermore, rail in Sweden uses emission-free electricity (within the boundaries of this case study). Therefore, this case represents good circumstances for achieving substantial reductions in CO_2 emissions through a modal shift. The intermodal terminals in Stockholm and Gothenburg are located close to the urban core while the freight forwarders distribution terminals are located in urban fringe areas (see Appendix A, Figure 4 and Figure 5). This urban spatial structure results in relatively long PPH distances in urban traffic conditions (see Appendix B, Table 2). The all-road alternative, however, also creates traffic in urban areas since the distribution terminals are located north of the city centres while the motorway enters both Gothenburg and Stockholm from the south. The alternative terminal location chosen for Stockholm is a terminal to be built north of Stockholm close to the airport (See Appendix B, Figure 5b). This location increases the total PPH distance but the PPH trip takes place in less sensitive urban areas.

The second case represents less favourable preconditions as it involves a relatively short transport distance in Germany (between Hanover and Bremen, ca. 130 km), where the rail-electricity mix is to a great extent based on fossil energy sources. In Bremen, the intermodal terminal and the freight forwarder's terminal are located in the same logistics area, which is located in the north-western part of Bremen (see Appendix A, Figure 6). Due to the close proximity of intermodal terminal and freight forwarder's distribution terminal, PPH distances are very short. The all-road alternative, on the other hand, generates significant urban traffic, since the trucks have to cross a sensitive urban area to reach the motorway in the south of Bremen. In Hanover, on the other hand, a modal shift leads to a significant increase in urban road traffic since the intermodal terminal in Hanover is located close to the urban core while the logistics areas are located along the motorway A2 north of the city and along the A7 in the east (see Appendix A, Figure 7a). The alternative location analysed in this scenario is an intermodal terminal east of Hanover close to the motorways A2 and A7, hence allowing easy access from the logistics areas (Figure 7b). There have been plans to establish a hub for a national intermodal hub-and-scope network at this site for many years [14].

3.2. Method and data

To calculate the external costs data on the following items is required:

- Data on the shipment (origin and destination, shipment size, pick-up and delivery time) and vehicle data (truck size, Euro class, train size, load factors, etc.) were collected by telephone and email communication with freight forwarders and transport operators in Sweden and Germany. In Germany the shipment size is 2 swap bodies with a total payload of 16 tons. The vehicle used is a truck with trailer with a total length of 18,75m. In the Swedish case, the shipment size is 3 swap bodies with a total payload of 24 tons on a truck with trailer with a total length of 24m. In both cases the trucks fulfil Euro class 4. These combinations are used in both the all-road and the intermodal alternative.
- Truck operations: The PPH trips include both an empty positioning trip and a laden trip between the intermodal and the freight forwarder's terminal. In the all-road alternative, the vehicles operate directly between the freight forwarders' terminals. Since the freight volumes are balanced, no empty positioning is needed.
- Vehicle emission data: Emissions for road transport were calculated using the calculation method and environmental data developed by The Network for Transport and Environment, NTM [17].
- Data on locations: The locations of origin and destination and locations of intermodal terminals within the cities as well as the distances of typical routes between origin and destinations were retrieved from online route planning tools: GoogleMaps for locations within the cities and road routes and distances [15], and Ecological Transport Information Tool (EcoTransIT) for rail routes and distances [16].
- Traffic conditions (free flow, saturated or congested traffic): The traffic conditions in the origin and destination cities are estimated based on interviews with the freight forwarders. In the all-road alternative they are assumed to be 100% free-flow since these trips take place during night. In the intermodal alternative, the shipments are picked up at the freight forwarders' terminals in the origin cities (Gothenburg and Hannover) between 5PM and 7PM and hence the pick-up trips coincide with the afternoon rush hour. The latest delivery time in the destination cities (Stockholm and Bremen) is in the evening rush hour between 5AM and 7AM. The traffic conditions assumed for the calculation of emissions and congestion costs of the PPH trips in Hannover, Stockholm and Gothenburg are 20% of the driven distance as free-flow traffic, 60% as saturated traffic and 20% as stop&go traffic. In Bremen, PPH traffic does not mix with passenger transport, hence 100% of the PPH traffic takes place in free flow traffic conditions.
- Data on intermodal trains in Germany was collected by telephone interviews with intermodal operators. The intermodal train has a capacity of 80 TEU and a load factor of 80%. The data for the intermodal train in Sweden was retrieved from WSP [18]. It has a capacity of 72 TEU and a load factor of 78%. The emission data was calculated using EcoTransIT [16].
- Data on intermodal terminals were collected by telephone interviews with terminal operators. In the terminal in Hannover and Bremen the load units are transhipped with gantry cranes, consuming 4,5 kWh per load unit. In Gothenburg and Stockholm, the transhipments are performed with diesel-driven reach-stackers. The emission data was retrieved from WSP [18].
- External cost data: To estimate the external costs of the calculated emissions and traffic, the values presented by CE Delft [11] are used.

4. Results and analysis

The results of the case studies are shown in Figure 1. In the Swedish base case (emission-free electricity and a long transport distance) the externalities decrease by 44%, while a modal shift in the base case in Germany (fossil-fuel based electricity and short transport distance) increases the externalities by 19%. Hence, the calculations are in line with the general hypothesis that a modal shift only leads to significant reductions of externalities in case of favourable preconditions. However, they also indicate that the improvement potential of a modal shift depends on the urban spatial structure. In case of the alternative terminal location in Hanover the external costs are below the all-road alternative (-5%). The alternative terminal location in Stockholm, however, does not lead to an improvement of the environmental performance (+2% compared to the base case). These differences indicate that a careful analysis is necessary.

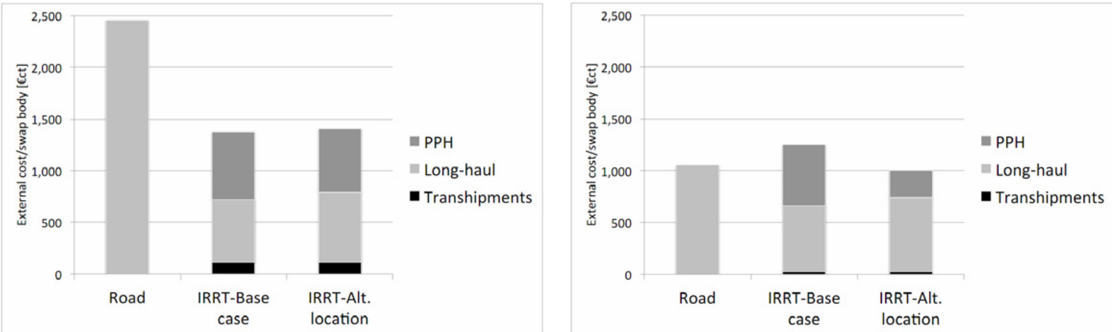

Figure 1. The environmental consequences of a modal shift (a) Sweden (b) Germany

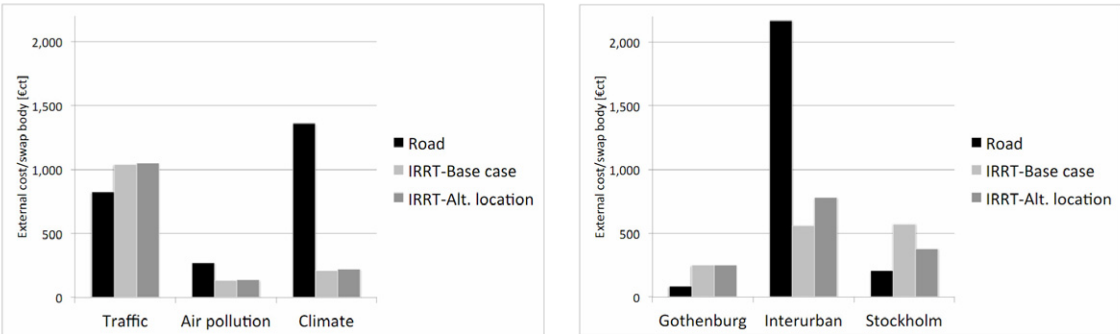

Figure 2. The environmental consequences of a modal shift in Sweden (a) by impact category (b) by region

4.1. The consequences of a modal shift in the Swedish case

In this section, the results for the Swedish case are analysed based on the sustainable transport categories defined in Table 1. “Fossil energy use” is denoted as climate, “Emissions to air” is denoted as *air pollution* and “Infrastructure/traffic” as *traffic*. Figure 2 (a) shows that the significant reductions are mainly achieved in terms of climate impact (-85% compared to all-road) and in air pollution impacts (-51%). These significant reductions are achieved at the cost of increasing traffic impacts (+26%), due to the necessary PPH operations in the origin and destination region, which are longer and less efficient compared to the all-road alternative. Since in the alternative-terminal-scenario the post-haulage distance is longer, the increase in traffic impacts and climate impacts is slightly bigger than in the base case.

Figure 2 (b) shows the results based on the different regions where the transports take place. The big savings of a modal shift occur on the long-haul transport between Gothenburg and Stockholm (-74%). In the cities, on the other hand, a modal shift almost triples the externalities (i.e. +196% in Gothenburg and 179% in Stockholm). The results thus confirm the significance of the less efficient PPH operations, which furthermore partly take place in more sensitive urban areas compared to single-mode road transport. An interesting observation is that the alternative terminal location in Stockholm only slightly changes the total externalities; while there is a significant change in the way these externalities are distributed geographically. The alternative terminal location has a positive effect for Stockholm where the externalities decrease by 34% compared to the intermodal base case. These benefits are achieved at the cost of higher externalities in the inter-urban region (+40%). Despite these reductions in Stockholm, however, the impacts in the urban area remain above the levels of the single-mode road alternative.

4.2. The consequences of a modal shift in the German Case

Although in the German case a modal shift from single-mode road transport to IRRT does not lead to significant changes in total external costs, there are significant changes in the different impact categories (Figure 3a). On the one hand, a modal shift leads to significant reduction of air pollution impacts (-40%). On the other hand, traffic impacts (+44%) and climate change costs increase substantially (+34%). The alternative terminal location significantly reduces the traffic impacts to the same level as the all-road alternative and further decreases the air pollution impacts and slightly reduces the increase in climate impacts.

There are also significant changes in the geographical distribution of the external costs (Figure 3b). In the Hannover region the single-mode road transport alternative does not generate any urban traffic, hence external costs are very low. As a consequence, a modal shift, which generates significant additional road and rail traffic in the urban area, drastically increases the externalities (+ 3155%). The alternative terminal location significantly reduces the PPH traffic in Hannover and hence the externalities (-41% compared to the intermodal base case), however, they are still significantly above the level of the single-mode road alternative. This is due to the rail haul, which crosses the whole city. In Bremen, on the other hand, the externalities decrease by 15%, since the intermodal terminal and receiver are located in the same industrial area and hence PPH distances are short. The biggest changes occur in inter-urban areas where the externalities decrease by 45%.

5. Discussion – the environmental improvement potential of IRRT

The multiple case-study analysed the trade-off between additional local environmental impacts and global environmental gains of a modal shift of two transport chains with sharply contrasting characteristics in terms of relative environmental advantage of rail over road. It also analysed the relevance of the terminals' location in the urban spatial structure. It was not the aim to draw general conclusions on the usefulness of a modal shift from these two cases. Instead, two polar types of cases were chosen in order to highlight the significance of the local spatial structure on the sustainability performance of intermodal transport.

The analysis of the results confirms that a modal shift can result in reduced climate and air pollution impacts as a result of the general environmental benefits of rail in terms of energy use and emissions. However, these benefits are achieved at the expense of higher traffic impacts in more sensitive areas. The activities that are most critical to the local environmental impacts are PPH and rail traffic in urban areas. Urban PPH traffic is especially important because PPH often takes place during rush hour and hence contributes to urban congestion while the single-mode road transport often takes place during night with no congestion effects. The externalities of PPH compared to single-mode road freight are therefore significantly higher. In order to compensate for these additional traffic impacts from PPH in urban areas a certain distance need to be covered to achieve enough savings in CO_2 emissions on the long-haul. The break-even distance for achieving a relative environmental benefit depends on the relative advantage of rail over road in terms of climate impact and the relative disadvantage of PPH over single-mode road in terms of traffic impacts. Assuming a further introduction of alternative fuels in the road freight sector, which potentially decreases the environmental benefits of rail on the one hand, and increasing congestion problems in cities, which increases the traffic impacts of PPH on the other hand, the break-even distance for a modal shift is likely to increase in the future. This challenges the possibilities to reduce the CO_2 emissions in the freight sector by a modal shift.

Taking a geographical perspective on the environmental improvement potential of IRRT reveals that a modal shift is mainly beneficial for intercity-regions, while the externalities in the origin and destination cities can increase significantly. It is the transport facilities' locations that suffer from their extensive land use and traffic externalities. Despite the fact that a modal shift might be beneficial at large, for cities aiming for a high quality of

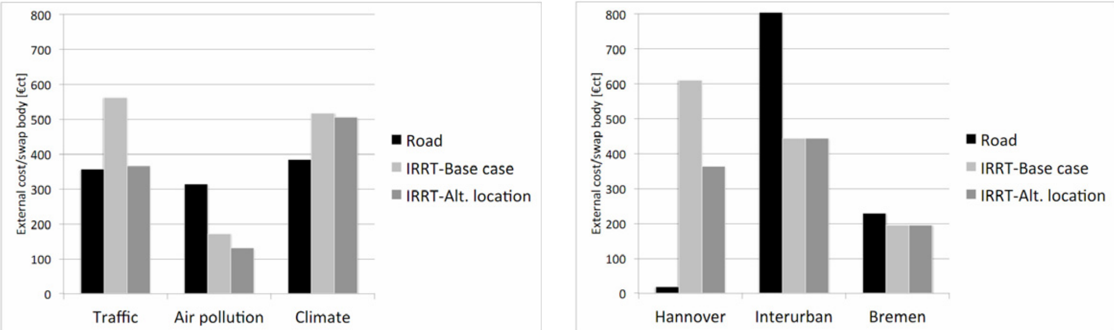

Figure 3. The environmental consequences of a modal shift in Germany (a) by impact category (b) by region

live, IRRT is a disturbing factor, since a modal shift increases the impacts on congestion and air quality. This can have negative implications for modal shift strategies, since investments in intermodal terminals, which are a prerequisite for future growth of rail freight, are likely to be opposed by local authorities if a modal shift increases the externalities in urban areas.

The scale of the geographical trade-off is largely determined by the relative location of the intermodal terminal and shipper and receiver in the spatial structure. This structure can vary significantly. In the current spatial structure of many cities where the intermodal terminals are often located close to the city centre while the shippers and receivers of intermodal freight are often located at the urban fringe areas with good connections to the surrounding highway-ring, the PPH and rail distance travelled in urban areas is higher than the urban driving distance of the single-mode road transport. An alternative terminal location closer to the shippers and receivers can significantly decrease the distance of PPH trips in urban areas and hence decrease its traffic impacts. These savings can be substantial and can even result in lower externalities than for all-road, if the terminal and the shipper are located in close proximity to each other. The significantly smaller traffic impacts in urban areas can encourage local authorities, rather than forcing them, to help integrating IRRT in the urban spatial structure. This study indicates that a "rail-suitable" location of terminal and shipper/receiver within the urban area can reduce the structural disadvantages of IRRT over road with the result that also a modal shift for relatively short distance transports can result in total environmental benefits. Such a rail adapted land-use planning resulting in more environmentally friendly PPH operations will also be beneficial for the competitiveness of IRRT, for which PPH time and costs are crucial factors.

6. Conclusions

The purpose of this paper was to analyse the implications of the urban context for the general potential of IRRT to contribute to sustainable development of the freight transport sector. Research in the field of sustainable freight transport often assumes that a modal shift is a suitable measure for reducing the environmental impacts of the freight sector, which are often limited to CO_2 emissions and climate impact. A few papers discuss the traffic and air pollution impacts of IRRT and highlight the importance of the contextual conditions but without providing any quantitative evaluation. This paper provides actual external cost values of a modal shift for these impacts and puts them into relation to the CO_2 savings. Although external cost valuation is a complex issue and quantifying the impacts is far from easy and straight forward, this paper concludes that the sustainability performance of intermodal transport has a significant urban dimension. The sustainability performance of IRRT depends on the relative location of the intermodal terminal and shipper and receiver in the urban spatial structure. In case of unfavourable geographical conditions of terminal and shipper and receiver in the urban setting, a modal shift can reduce the climate and air pollution impacts, which are, however, achieved on the costs of higher traffic impacts. A modal shift is then mainly beneficial for intercity-regions, while the externalities in the origin and destination cities can increase significantly.

A careful integration of the intermodal terminal in the urban spatial structure is therefore a necessity if IRRT is to contribute to the sustainable development of the freight sector. If PPH distances in urban areas are kept short, a modal shift can also be beneficial for short distance transports. Consequently, this article shows that research on the sustainability potential of IRRT needs to include the integration of the intermodal terminal and the shippers' and receivers' location in the urban spatial structure. Local authorities, which are responsible for land-use and transport planning, therefore have an important role to play if a sustainable modal shift is to be achieved.

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Appendix A.

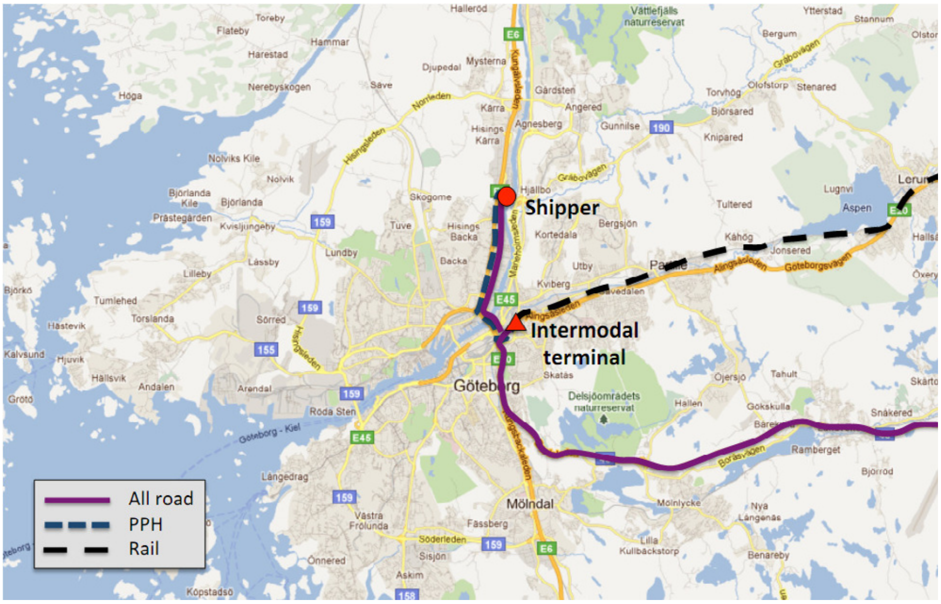

Figure 4. Location of shipper and terminal in Gothenburg

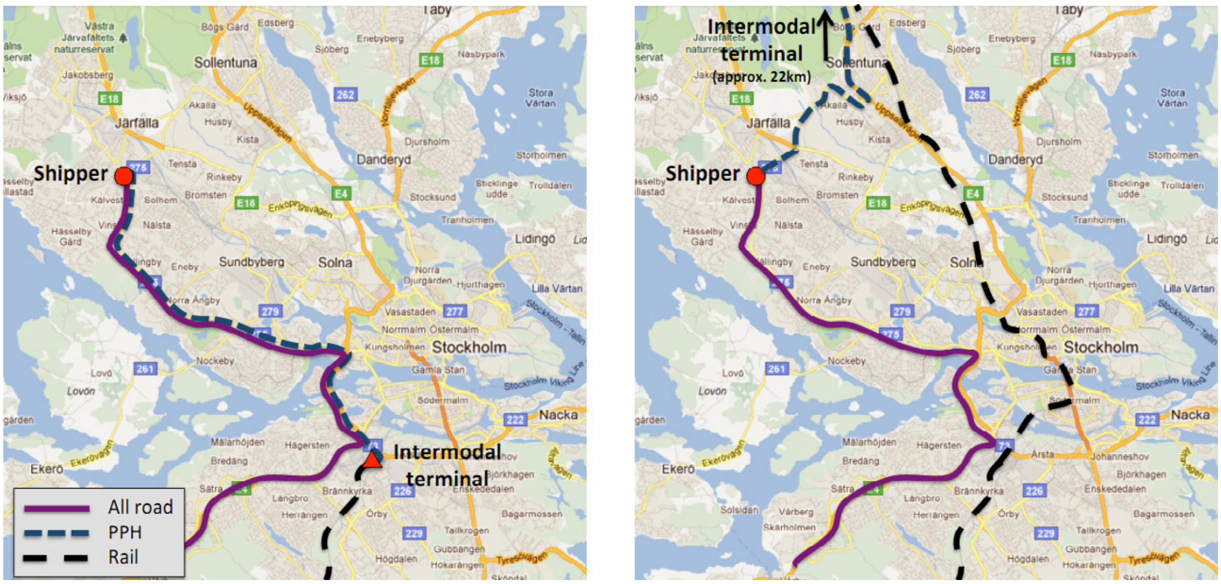

Figure 5. Location of shipper and terminal in Stockholm (a) current terminal location (b) alternative terminal location

Figure 6. Location of shipper and terminal in Bremen

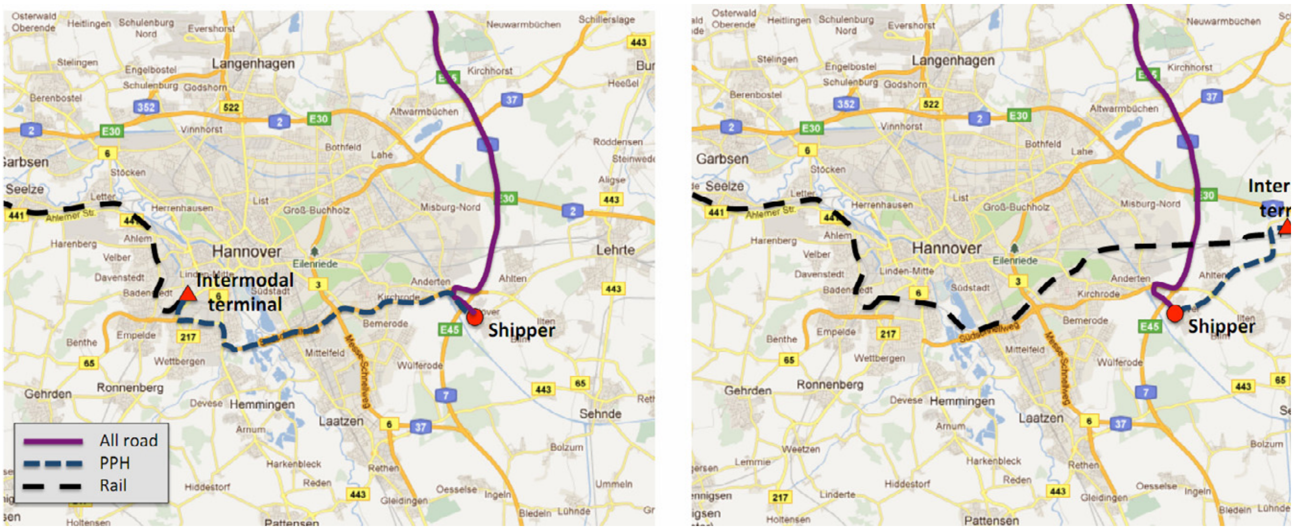

Figure 7. Location of shipper and terminal in Hanover (a) current terminal location (b) alternative terminal location

Appendix B.

Table 2. Urban and rural distances of road and intermodal transport chains in the German and Swedish case

		Total		Origin		Interurban		Destination	
		Urban	rural	Urban	rural	Urban	rural	Urban	rural
Sweden	Road	83	402	9	7	43	395	32	0
	Intermodal-base case	125	355	16	2	81	353	29	0
	- PPH	*25*	*2*	*6*	*2*	*0*	*0*	*19*	*0*
	- Rail	*100*	*353*	*10*	*0*	*81*	*353*	*10*	*0*
	Intermodal-Alt. terminal location	145	384	16	2	91	373	40	9
	- PPH	*21*	*20*	*6*	*2*	*7*	*12*	*9*	*6*
	- Rail	*124*	*364*	*10*	*0*	*84*	*361*	*31*	*3*
Germany	Road	13	120	0	2	0	107	13	11
	Intermodal-base case	87	63	24	8	41	55	22	0
	- PPH	*13*	*6*	*11*	*6*	*0*	*0*	*2*	*0*
	- Rail	*74*	*57*	*13*	*2*	*41*	*55*	*20*	*0*
	Intermodal-Alt. terminal location	86	71	7	16	41	55	22	0
	- PPH	*3*	*6*	*1*	*6*	*0*	*0*	*2*	*0*
	- Rail	*83*	*65*	*6*	*10*	*41*	*55*	*20*	*0*