Evaluation of Green Transport Modes for Containerized Cargo

Martin Hrusovsky

Abstract The increasing volumes of greenhouse gas (GHG) emissions from transport and the negative effects of congestion, noise and accidents lead to the search for new transport alternatives in Europe. These alternatives take into account the negative impacts of transport on environment and society in addition to minimization of the transport costs. If these additional aspects are considered, it is in many cases advantageous to use intermodal transport instead of choosing a direct transport by truck. However, this is still not the case in practice since the road transport is the most preferred transport mode in the EU. The purpose of this paper is to create an evaluation framework including various criteria for comparing different transport alternatives. The criteria combine economic factors including transport costs, inventory costs and time with external effects expressed in costs of GHG emissions, air pollution, accidents, noise and congestion. The framework is used for evaluation of transport alternatives between Vienna and Istanbul including road transport, rail transport, inland waterway transport (IWT) and short sea shipping (SSS).

1 Introduction

Transport describes any activity related to the movement of goods, persons or information which is demanded due to a spatial separation of different economic activities, such as production and consumption of goods. Transport therefore significantly facilitates the trade between the countries and supports the economic growth. However, the increasing demand for products leads to increasing transport volumes resulting in negative external effects of transport (Cole 2005).

M. Hrusovsky (✉)
Institute for Production Management, WU Vienna University of Economics and Business, Welthandelsplatz 1, 1020 Vienna, Austria
e-mail: martin.hrusovsky@wu.ac.at

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The external effects of transport negatively influence the environment and society in several ways. Firstly, transport sector belongs to the biggest producers of CO_2 and other GHG emissions responsible for global warming and climate changes. Secondly, transport negatively impacts the local population via the emissions of air pollutants and noise causing various health damages. Thirdly, the socio-economic impacts arising from accidents and congestions are important. All these negative effects can be expressed in external costs representing the costs for the society that are not paid by the responsible transport users. This leads to incorrect incentives and distortions in market equilibrium. Therefore the external costs of transport should be internalized by state interventions in form of laws, taxes or emission certificates (Maibach et al. 2008).

Since the external costs of transport are not paid by the users, they were not included in transport mode decisions in the past. Therefore companies mostly chose road transport for its relatively low costs and high flexibility which results in a very high share of the road transport on the modal split in Europe. However, if the external costs are considered, road transport might not be always the optimal alternative. Especially for containerized goods it might be convenient to use intermodal transport chains in which the goods are transported in the same transport unit by different transport modes. As a result, the concept of green transport supporting sustainable forms of transport has been introduced.

Despite the importance of external costs of transport for the society, they should not be the only factor but should rather be combined with other factors. This is also the purpose of this paper which creates a framework for evaluation of transport alternatives combining economic criteria (e.g. costs, time) with external effects of transport on environment and society (e.g. GHG emissions, accidents, congestion). The introduction is followed by a short literature review concerning green transport and calculation of external costs in Sect. 2. Section 3 presents the framework for evaluation of transport alternatives. This framework is used in Sect. 4 which compares four transport alternatives for transport of containers between Vienna and Istanbul including road transport, rail transport, IWT and SSS. Section 5 summarizes the results and concludes the paper.

2 Literature Review

Although the topic of green transport is extensively discussed in the available literature, there is no unique definition for green transport. However, most definitions are related to the minimization of negative external effects of transport. The research on external factors started in 1970s in Great Britain and was motivated by the increasing lorry traffic. At that time the studies were oriented on the reduction of emissions but did not help to reduce the traffic volume. The results highlighted the need for inclusion of additional factors for evaluation of transport (McKinnon 2010). Despite this fact, many authors include only environmental factors into the definition of green transport as found out by Carter and Rogers (2008) in their analysis about sustainable supply chain management. This is the case of Srivastava (2007) who claims that environmental aspects should be included into supply chain management for increasing the operational efficiency. However, Feitelson et al. (2001) conclude that concentration on environmental aspects does not lead to minimized external impacts of transport and more complex policies including several aspects should be introduced.

The combination of different factors is also the essential part of the concept of sustainability. In his triple bottom line concept Elkington (1999) claims that instead of concentration on economic costs companies should rather search for a balance between economic, ecological and social factors. For transport the ecological and social factors can be expressed in form of external costs including GHG and air pollution emissions, accidents, noise and congestion. In the EU these costs were estimated in various studies, such as INFRAS/IWW (2004), IMPACT (Maibach et al. 2008) or PLANCO (2007). The results of these studies are the basis for the evaluation framework presented in the next section.

3 Evaluation Framework

The evaluation framework presented in this section combines the economic factors and external factors in order to find the most sustainable way of transport. The economic factors are represented by the total logistics costs (TLC) including the transport costs and inventory costs. The inventory costs for transport and inventory holding at the final destination are influenced by the second economic factor which is the transport time. The external factors combine the impacts on environment and society and can be expressed in costs for air pollution, GHG emissions, accidents, noise and congestion. All presented cost categories are summarized in order to obtain the total sustainability costs (TSC) which can be defined as

$$\begin{aligned} TSC = {} & TLC + air\,pollution\,costs + GHG\,emission\,costs + accident\,costs \\ & + noise\,costs + congestion\,costs \end{aligned} \tag{1}$$

The economic and external factors required for the calculation of TSC are shortly described in the following sections.

3.1 Economic Factors

3.1.1 Total Logistics Costs

From the supply chain management point of view, the economic costs of transport include in addition to the direct transport costs also costs related to transport time and inventory. These costs are part of the total logistics costs concept (TLC) presented among others by Blauwens et al. (2006). TLC can be computed as

$$TLC = transport\,costs + cycle\,inventory\,costs + inventory\,in\,transit\,costs + safety\,stock\,inventory\,costs \tag{2}$$

The transport costs paid for transport of goods can be calculated based on the costs of each vehicle or transport prices offered by transport companies. For the cycle stock costs the order volume, the value of the goods and the holding costs are required. The inventory in transit costs depend on the speed and transport time of each transport mode. The safety stock inventory has to be held by the customer due to uncertainty of demand and lead time.

3.1.2 Transport Time

Transport time denotes the total transport time needed for transport of goods between origin and destination. In addition to the pure driving time of the vehicle, transport time includes also loading and unloading times and time needed for transhipment and waiting in terminals. The calculation of transport time for trains and short sea vessels is based on publicly available schedules which can be used as planned driving times. For the road transport several routing tools estimating the driving time according to the infrastructural limitations (e.g. speed limits, driving bans), legal restrictions (e.g. resting periods) and current traffic situation can be used (PTV 2013). In case of IWT a calculation scheme implemented by via donau (2007) including the times needed for sailing, notification, loading and unloading can be used for the transports on the Danube.

3.2 External Factors

The calculation of costs for external factors is difficult since the exact estimation of negative effects from transport is not possible. The impact of transport depends on various variables, such as geographical scope, time duration, affected population, monetary valuation and many others that are changing constantly. Therefore the results might differ significantly dependent on the methodology used.

In general, external costs of transport can be computed either as average or as marginal costs. Average costs are estimated in a top-down approach using aggregated values from national statistics. In order to obtain the costs per km, the cost function has to be simplified. For the marginal costs the bottom-up approach is applied. This approach estimates the costs based on case studies considering specific traffic conditions. However, the estimated values are difficult to aggregate in order to be comparable between the modes or countries. In most cases the results of both approaches are very similar except for noise and congestion costs. In noisy areas marginal noise costs are lower than average costs. In congested sections the marginal congestion costs exceed the average costs. Usually a combination of both approaches is used in practice (Maibach et al. 2008).

The values for external costs used in this paper are marginal costs based on the IMPACT project (Maibach et al. 2008) which were updated by Brons and Christidis (2011) to the price level of 2011. The coefficients are estimated using the impact pathway approach developed in ExternE project. This approach at first defines the relevant emissions in order to estimate their dispersion and concentration in the monitored area. Thereafter the impact of the increased concentration on the population and nature is calculated. In the last step, the impact is expressed in monetary values using the willingness to pay (WTP) and value of statistical life (VOSL) concepts (Maibach et al. 2008). The coefficients for each cost category are calculated separately for each EU country. In this paper they are used for calculation of air pollution, accident, noise and congestion costs. For the calculation of GHG emission costs a methodology based on Kranke et al. (2011) is used.

Air pollution emissions are released by vehicles with combustion engines and include gases such as particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x) or sulphur dioxide (SO_2). Their amount depends on the vehicle and engine type, fuel, speed, geographical location, load factor and driving behaviour (Maibach et al. 2008). In order to obtain the air pollution costs for a certain transport, the number of vehicle kilometres (vkm) has to be multiplied by the unit cost of pollutant. Brons and Christidis (2011) estimated the costs of air pollution between 0 and 24.4 EUR/1,000 tkm depending on the transport mode and country.

The marginal accident costs describe the additional risk of accident from a new actor entering the traffic flow. They represent only the external costs that are not covered by insurance premiums which results in rather low values. They are mainly relevant for road transport and rail transport. In IWT and SSS the number and impact of accidents is very low and therefore the accident costs are negligible (Maibach et al. 2008). Brons and Christidis (2011) recommend values between 0.0 and 1.7 EUR/1,000 vkm.

Noise costs represent the negative impact of noise on human health. The impact can be expressed either in annoyance costs for disturbances and discomfort or health costs for health problems such as hearing problems, cardiovascular diseases or sleep disruptions. Marginal noise costs depend on the existing noise level, the time of the day and the affected population. They are only relevant for road and rail because IWT and SSS operations are conducted away from densely populated areas (Maibach et al. 2008). The recommended values by Brons and Christidis (2011) are between 0.6 and 5.6 EUR/1,000 tkm.

Congestion costs arise due to the insufficient capacity of the infrastructure which leads to congestion. They represent the time losses due to delays and the impact of congestion on air pollution, GHG emissions and accidents. Congestion costs are mainly relevant for the road transport and rail transport. For SSS the costs cannot be estimated due to missing detailed data about delays in ports. For IWT delays are caused mainly by waiting in front of locks but the congestion costs are negligible

(Maibach et al. 2008). In their calculations Brons and Christidis (2011) propose values between 0.1 and 5.5 EUR/1,000 vkm.

GHG are gases preventing the heat escaping from the Earth. Therefore a certain concentration of GHG in the atmosphere is necessary for life on the planet. However, since the beginning of the industrial revolution their concentrations are increasing and today GHG significantly contribute to global warming and climate changes. The most important GHG are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (Maibach et al. 2008).

The amount of GHG emissions is calculated according to the methodology described by Kranke et al. (2011) based on the proposal of the CEN standard prEN 16258:2011. The calculation considers all six GHG and the scope of emissions is well-to-wheel including emissions from fuel consumption and emissions from fuel production and distribution. In order to obtain the amount of CO_2 emissions, the fuel consumption has to be calculated which is directly proportional to the amount of emissions. The emissions of other GHG are on average 1.05 % of the CO_2 emissions according to the calculation of the Institut für Energie- und Umweltforschung Heidelberg.

In road transport, the fuel consumption depends on the vehicle type and its engine, air and rolling resistance, road gradient, traffic situation, speed, driving behaviour and utilization. Fuel consumption factors are divided into classes according to the emission class of the vehicle and its utilization. The emission factors are 2.95 kg/l of diesel for CO_2 emissions and 3.01 kg/l for all GHG emissions.

Emission factors in rail transport differ for the electric and diesel traction. They are dependent on the gross weight of the train, type of cargo, utilization and topography. The specific energy consumption factors can be calculated as

$$EF_{Etrain} = 1.20\,\mathrm{kWh/trainkm} \times \mathrm{m}_{gross}^{0.38} \tag{3}$$

for the electric train and

$$EF_{Dtrain} = 0.326\,\mathrm{l/trainkm} \times \mathrm{m}_{gross}^{0.38} \tag{4}$$

for the diesel train with m_{gross} representing the gross weight of the train.

The factors important for the fuel consumption in IWT are the vessel type, utilization, speed of the river, speed of the vessel and the sailing direction (upstream or downstream). The calculations of fuel consumption for the Danube are based on the methodology used by via donau.

In SSS the amount of GHG emissions depends on the size and gross weight of the vessel and the type of the fuel. Vessels usually use different fuels for the main and auxiliary engines and therefore the share of each fuel on the total fuel consumption has to be known. Since the exact information is difficult to obtain, Kranke et al. (2011) propose average emission factors for different shipping lines which are also used in this paper.

The GHG emissions calculated for each transport mode have to be converted into costs by multiplying them with a price per ton. The value used in this paper is 70 EUR/t recommended by PLANCO (2007).

4 Case Study: Transport of Containers Between Vienna and Istanbul

In this section the evaluation framework presented in Sect. 3 is used for comparing the TSC of transport alternatives for containerized goods between Vienna and Istanbul. The transport includes multiple containers per week but the costs are calculated for one 40-foot container loaded with 23 t of plastics. The first alternative describes the route via Trieste which is a port in Italy often used for export of goods from Austria. Alternative 2 takes into consideration the direct transport by truck. In Alternative 3 direct transport by train between the container terminals in Vienna and in Istanbul is described. Alternative 4 combines IWT on the Danube with truck transport. The alternatives are depicted in Fig. 1. After the description of the alternatives their TSC are compared in Sect. 4.5.

At the beginning of each alternative the route and used transport modes are described. The route always starts at a container terminal in Vienna from which an empty container is taken and ends in the container terminal in Istanbul where the empty container is brought back after the delivery of goods to the customer. After that the transport time is calculated. It is assumed that containers leave the factory in

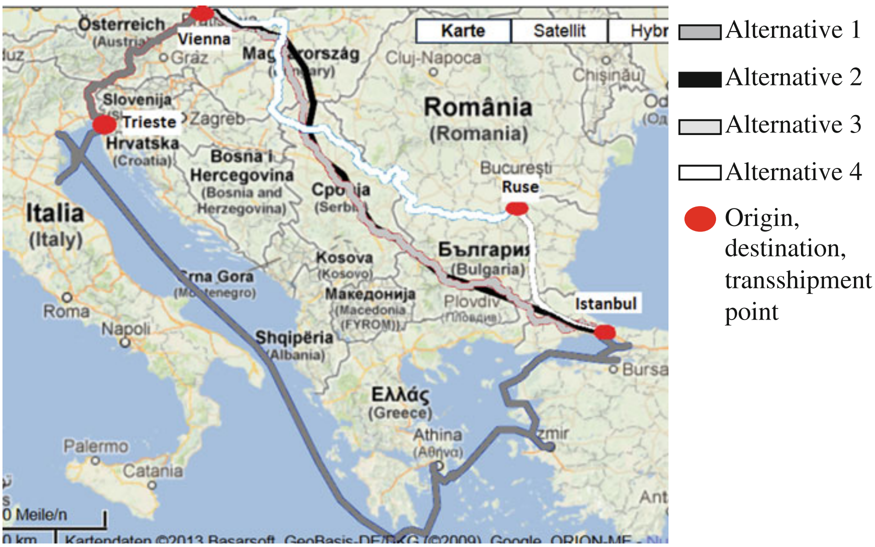

Fig. 1 Transport alternatives

regular intervals and are immediately transported to the closest terminal where they have to wait for the departure of the following vehicle. In the next step, TLC are calculated. Transport costs are either computed as costs for each vehicle and terminal or approximate transport prices are used where no detailed information about costs is available. For the road the transport costs are estimated using a standard EURO IV class truck taken from PLANCO (2007). The values for purchasing price, labour costs, insurance and fleet management are set lower due to the use of older trucks and lower wages in the Eastern Europe. Rail costs are estimated using data from PLANCO (2007) and information about infrastructure charges in each country. Although detailed data about the cost structure is missing, the results should correspond to the prices offered by transport companies. For IWT the data from via donau (2007) is used. Instead of estimating the SSS costs the approximate prices valid in October 2012 are taken. For inventory costs the holding costs rate is assumed to be 20 % of the goods value which is set to 1,450 EUR/t. It is assumed that the demand of one customer is one container per week and the goods are delivered once per week, therefore the customer has to hold 3.5 days of cycle inventory. Due to missing information about uncertainty of demand and lead time the safety stock inventory in days is assumed to be 25 % of the transport time needed in each alternative. The inventory costs include also the costs for container leasing with 2.60 EUR/day. At the end of the description of each alternative the costs for external factors are computed. More information about the calculations can be found in Hrusovsky (2013), although some values and alternatives have been updated for this paper.

4.1 Alternative 1: Intermodal Transport Vienna-Trieste-Istanbul

In the first alternative, the transport starts in container terminal in Vienna from where an empty container is transported by truck to a factory located close to the terminal. Here the container is loaded and brought back to the terminal. After that it is loaded on a train which leaves to Trieste five times per week and covers a distance of 564 km (RCA 2013). In the port of Trieste the container is transhipped to a short sea vessel which sails to Istanbul. The vessel is operated as a liner service calling at different Italian, Slovenian, Greek and Turkish ports which increases the distance to 2,944 km (Seagoline 2013). Finally, the container is brought by truck from the Ambarli port in Istanbul to a customer located 40 km away from the port and the empty container is brought back to the port after unloading.

The transport time consists of the transport time for each leg and waiting times in terminals. The truck in Vienna needs 1 h for loading the container, 0.27 h for transport to the terminal (PTV 2013) and 0.5 h for unloading the container in the terminal. Since the containers come in regular intervals and the trains leave five times a week, one container has to wait on average 0.7 days until the departure of the train. The train transport takes 3.2 days (RCA 2013) and the average waiting time in Trieste is 3.5 days since the vessel leaves once per week. The sea voyage takes 15 days (Seagoline 2013). For the last leg in Istanbul the truck needs 0.15 days which leads to average total transport time of 22 days.

The calculation of TSC starts with the transport costs of the truck in Vienna which is dedicated to the transports between factory and terminal. For the transhipment in the terminal the fees for loading, unloading and storage have to be paid. After estimation of rail costs the terminal charges for Trieste and Istanbul together with SSS costs have to be added. For the road transport in Istanbul again a dedicated truck is assumed. In addition, the inventory costs have to be added which are relatively high due to the long transport time. During the transport 1,554 kg of GHG emissions are released including also emissions from transhipment in terminals (Kranke et al. 2011). TSC are calculated in Table 1.

4.2 Alternative 2: Truck Transport Vienna-Istanbul

In Alternative 2 the container is transported by truck directly from the factory in Vienna to the customer in Istanbul. The empty container is taken from the container terminal in Vienna to the factory where it is loaded. After that it is transported via Hungary, Serbia and Bulgaria to Istanbul covering a distance of 1,561 km. After the delivery of the goods to the customer the empty container is brought back to the container terminal in Istanbul. The transport time needed for this delivery is 3.5 days including also buffer times for border waiting times and other unexpected delays (PTV 2013). The transport costs include only the costs of the truck and the relatively short transport time leads to low inventory costs. The amount of GHG emissions is 1,844 kg and TSC are displayed in Table 1.

4.3 Alternative 3: Rail Transport Vienna-Istanbul

The third alternative considers the transport by train between terminals in Vienna and Istanbul. The transport starts again with the pick-up of empty container, loading at the factory and transport of the loaded container to the terminal. From here the trains leave four times a week travelling 1,620 km to Turkey (IFB 2013). In Istanbul the last mile of the transport is conducted by truck. The transport time of the train is 4.5 days and the average waiting time in terminal in Vienna is 0.9 days. The total transport time together with the truck transports is 5.6 days. Transport costs calculation for rail is based on PLANCO (2007) and infrastructure charges in each country. Since the main part of the transport is executed by electric train, the amount of GHG emissions is 591 kg which is low in comparison to other alternatives. TSC for Alternative 3 are computed in Table 1.

4.4 Alternative 4: IWT Vienna-Ruse-Istanbul

In the fourth alternative the IWT on the Danube to Bulgaria is considered where the containers are transhipped to truck. Although currently no regular container liner services between Austria and Romania exist on the Danube, there are various companies operating vessels on the Danube capable of transporting containers (via donau 2007). In this alternative a motorized cargo vessel with a capacity of 2,000 t and 66 TEU is used which departs once per week from the port of Vienna. The transport on the Danube is possible until the port of Constanta where the container can be loaded on vessels of different sea shipping lines. However, the transport by SSS from Constanta to Istanbul is relatively expensive as shown in Hrusovsky (2013). Therefore in this alternative the IWT to Ruse in Bulgaria combined with truck transport between Ruse and Istanbul is considered.

Before the IWT the container is again delivered by truck to the port of Vienna where it has to wait on average 3.5 days until the departure of the vessel. For the 1,428 km long trip to Ruse the vessel needs 4.5 days including the time for loading, unloading and notification at the ports (via donau 2007). After unloading in Ruse the container is taken by a truck to the customer. For the distance of 573 km 1.2 days are needed including also waiting times at the border between Bulgaria and Turkey (PTV 2013) which results in total transport time of 9.3 days. The truck used between Ruse and Istanbul is again a standard EURO IV truck used in Alternative 2 resulting in costs of 725 EUR. The costs for the vessel are based on via donau (2007) with a reduced fuel consumption of 6.9 kg/1,000 tkm calculated especially for this route. The IWT costs are with 469 EUR relatively cheap. Due to the longer distance the amount of GHG emissions is relatively high with 1,712 kg. Table 1 summarizes TSC for Alternative 4.

4.5 Comparison of Results

The calculation of TSC for each of the four alternatives is displayed in Table 1 which shows the costs for each defined cost category. As the results show, Alternative 1 with transport via Trieste has the longest distance and needs the longest transport time due to several transshipments. As a result, it leads to the highest TSC, although the sum of external costs is lower than in case of the truck transport in Alternative 2. Besides the highest external costs, Alternative 2 has also the second highest transport costs, but offers the possibility of fast transport which leads to lower inventory costs. The cheapest alternatives from the point of view of the transport costs are Alternative 3 using rail and Alternative 4 combining IWT and truck transport. Although the IWT is much cheaper, the longer distance and use of truck increase the external costs. Moreover, inventory costs are also higher in comparison to Alternative 3 because of the longer transport time. As a result, Alternative 3 is the cheapest alternative from the point of view of TSC. The main advantage of this alternative is the use of electric train on the majority of the route which leads to relatively low air pollution and GHG emission costs. The train drives

Table 1 Total sustainability costs for each transport alternative

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Distance (km)	**3,613**	**1,607**	**1,714**	**2,055**
Pure transport time (days)	18.0	3.5	4.7	5.8
Waiting time (days)	4.2	0.0	0.9	3.5
Total transport time (days)	**22.2**	**3.5**	**5.6**	**9.3**
Transport costs (EUR)	2,139	1,747	1,420	1,400
Inventory costs (EUR)	630	154	208	302
Total logistics costs (EUR)	**2,769**	**1,901**	**1,628**	**1,703**
GHG emission costs (EUR)	109	129	50	120
Air pollution costs (EUR)	341	359	194	476
Accident costs (EUR)	7	18	10	6
Noise costs (EUR)	32	62	56	24
Congestion costs (EUR)	6	126	9	46
Total sustainability costs (EUR)	**3,263**	**2,596**	**1,947**	**2,374**

directly between Vienna and Istanbul with transhipments only at the beginning and end of the route which leads to the second lowest transport time.

The comparison of external costs shows high differences between the alternatives with high importance of air pollution costs. However, it should be noted that the values are strongly dependent on the methodology and therefore the results can differ significantly for different methodologies. In order to prove the results, the external costs were also calculated with values from PLANCO (2007) and Essen et al. (2011) which came to the same order of the alternatives. However, the difference in TSC between Alternative 3 and 4 using PLANCO (2007) was only 50 EUR whereas for Essen et al. (2011) the difference was 466 EUR. Besides the external costs, the results are also dependent on the holding costs rate. In the calculation presented in Table 1, TSC of Alternative 2 become lower than TSC of Alternative 4 if the holding costs rate is higher than 53 %.

5 Conclusions

Transport activities facilitate the trade between countries which positively influences the economic growth. However, transport also causes several negative external effects which are currently not considered in the decisions about the transport mode choice. Therefore an evaluation framework combining economic and external factors of transport and computing the TSC was presented in this paper. As the results showed, whereas the transport costs of one alternative might be lower, the consideration of TSC might lead to different decisions because of lower external costs of another alternative. However, it should be taken into consideration that the results for external costs are dependent on the methodology and therefore they can vary significantly dependent on the chosen methodology.

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