Green Supply Chain Design Considering Warehousing and Transportation

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Abstract. Green supply chain design considers besides costs and service level as well the environmental impact. There is a trade-off in terms of costs and environmental impact between the size of warehouses and the transport mode and transport frequency. High frequent deliveries with trucks result in high emission during transport, but low emission during the storage process. Less frequent delivery with trains or ships have a lower emission during transport, but the items must be stored for a longer time and so need more space in a warehouse. The consequences are illustrated with a case study. The total CO_2 emission and the eco-efficiency are calculated.

Keywords: CO_2-emission · Warehousing · Transportation · Eco-efficiency · Trade-off

1 Introduction

Supply chain design is in most cases done under costs and service level considerations. If the environmental impact is as well considered then the term green supply chain design is used. The common measurement of the environmental impact is the CO_2 emission. Beside CO_2 different gases have a much higher impact on the global warming then CO_2. Considering the global warming potential of CO_2 as 1, other gases like Methane CH_4 or Nitrous oxide N_2O have a much higher factor than CO_2. The global warming potential of Sulphur hexafluoride SF_6 is 23,900 times higher than that one of CO_2. Therefore the emission is often converted to CO_2-equivalents CO_2e. The different gases of a combustion process are transferred to the CO_2 emission, having the same impact. Besides the atmospheric pollution of different gases, the noise pollution, vibration, accidents and waste are other external impacts of freight transport.

In a transport chain the highest emission takes often place during the transport. Energy savings methods like the use of EURO-6 trucks or alternative fuels have a positive impact on the environment but a negative impact on the costs of a transport chain. This correlation is shown in Fig. 1. If a company wants to be the cost-leader it will probably not consider the environmental impact. Companies which want to green their supply chain have to invest money to reduce the emissions.

The strategic design of logistics networks focusses primarily of the infrastructure and the transportation mode. The infrastructure is described by the facility location problem. There the number of facilities, the location and the capacity of a network node are calculated. This location analysis is well known in operations research.

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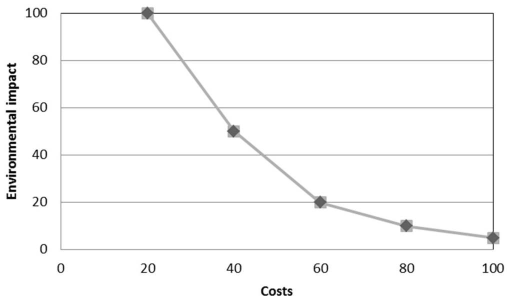

Fig. 1. Trade-off between total costs and environmental impact.

Transporting goods with trains instead of an aircrafts could result in a reduction of the CO_2 emission by the factor of 40. But transportation duration increases and the flexibility of the supply chain decreases.

Different companies have a Green House Gas reduction program. These companies want to lower the CO_2 or CO_2e emission of their supply chain. Therefore a carbon footprinting process has been started at these companies. The carbon footprint can be done in several ways (Fig. 2).

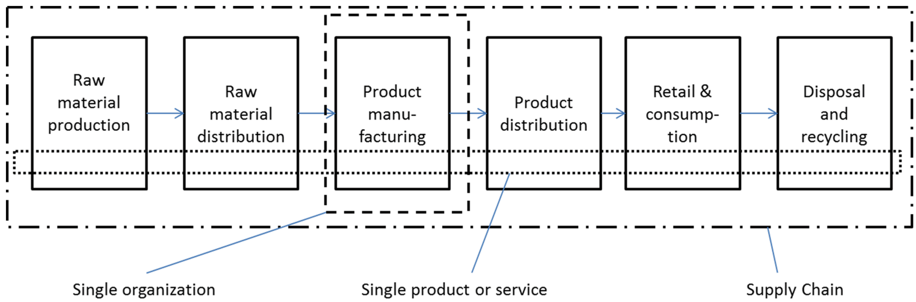

Fig. 2. Carbon Footprinting [9].

Some companies are doing the carbon footprint process for their company or their organization. This is in some cases the easiest way because the needed data for the analysis can be measured within the company having access to the different data. For a single item like jeans the total CO_2 emission can be measured along the supply chain. This starts with the raw material production and distribution and the manufacturing and product distribution. In order to achieve a total life cycle assessment the consumption and the disposal or recycling are also included in the accounting process. The highest level is the carbon footprint of the complete supply chain. Considering various players in different regions of the world, this process is very complex to handle. Various guidelines exist for the carbon footprint measuring and reporting:

- ISO 14067: Greenhouses Gases –Carbon Footprint of Products. Requirements and Guidelines for Quantification and Communication (ISO 14067, 2013)
- The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard. Revised Edition (World Business Council for Sustainable Development, World Resources Institute, 2013)
- PAS 2050: Specification for the Assessment of the Life Cycle Greenhouse Gas Emission of Gods and Services (British Standards Institution, 2011)

Worldwide exist more guidelines. Larger companies or industry branches even may use their own methodology to measure the emission.

2 Literature Review

The optimization of the logistic infrastructure is investigated by an increasing number of researchers, Harris et al. [1] investigate the impact of CO_2-emissions of the number of depots in a transport chain and the fill rate of trucks, varying from 60 % to 90 % as well as the total costs. They used the center of gravity approach for the facility location problem. This approach accords well with the originally generated experimental data from a network of the automotive sector. To minimize the costs 2 depots are used, for minimizing the environmental impact 2–3 depots are used.

In another study Harris et al. [2] solved the capacitated facility location problem for costs and the CO_2 emission from transportation and running facilities. The study is based on realistic data of transport and distribution network. For up to ten depots in a supply chain, a special algorithm is used for solving the problem. The total costs and CO_2 emission are given in Fig. 3. The different possibilities of having open or closed depots are given in Fig. 3 by 0: depot closed or 1: depot open. The results correspond to the trade-off given in Fig. 1.

Mallidis et al. [3] investigate the green supply chain design of regions in South-East Europe. They found that the optimization of the supply chain based on CO_2 emissions does not increase substantially the supply chain network costs. Other findings are the sharing of warehouses. The results are lower CO_2 emissions and just a slight increase in the costs compared to dedicated warehouses.

Dekker et al. [4] give a substantial overview about the possibilities of operations research and its application in green supply chain design. Design, planning and control of supply chains are explained under the consideration of transportation, inventory of products and facility decisions. They indicate several areas where environmental aspects could be included in operations research models for logistics.

Aronsson and Brodin [5] discuss the possibility of changing the logistics infrastructure without performance losses in terms of costs and delivery service. Changes of three companies are explained as well as the effects and results. Changes of the transport mode, standardization of load carriers, consolidation of flows are aspects all three companies have in common for cost reduction and reduced emission. The benefit for the companies was that both cost and the environmental impact reduction were possible at the same time.

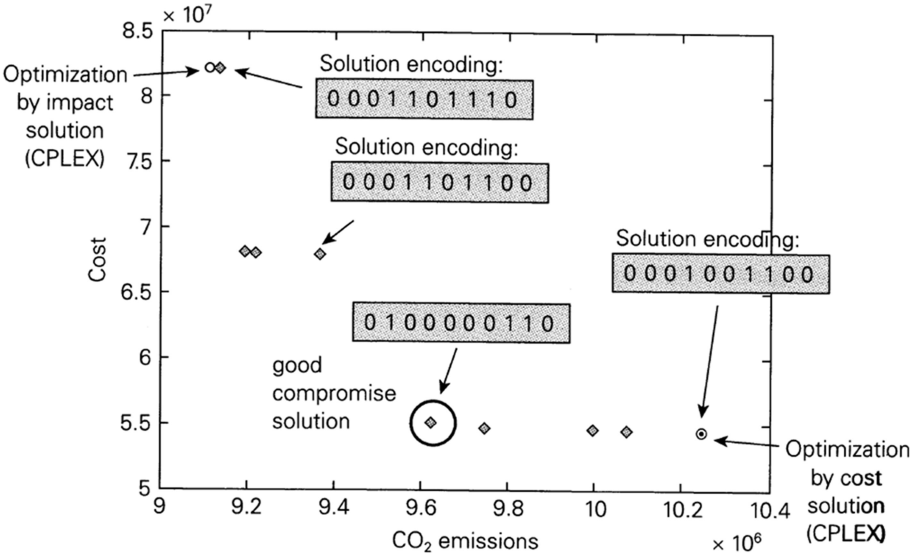

Fig. 3. Environmental impact and total costs for a facility location problem [2].

Elhedhli and Merrick [6] use Lagrangian relaxation to determine the network design under different emission costs. The application is focused on regions that have a carbon tax or cap-and-trade system. For the design network it is suggested that more distribution centers should be integrated in the network to reduce the vehicle travel distances.

Rizet et al. [7] calculate the CO_2 emission from New Zealand to different locations in Europe and compare the results with the emission of the competitive supply chain within Europe. The findings are the dominant influence of the maritime transport from New Zealand to the European location. This transport mode is responsible for over 80 % of the CO_2 emissions of the transport chain considering transportation by ship, truck and storages. For the internal European supply chain in the UK the CO_2 emission of the storage facilities are responsible for up to 60 % and more.

A complete lifecycle assessment is done by Köhler and Steinhilper [8]. For an automotive supplier all necessary data from transport chains, material specification, supplier locations and production technology are generated. The CO_2 balance is generated with the life cycle software SimaPro PHD-version 7.1.8. For three different metal products the main CO_2e emission takes place during the raw material of steel. For these parts only 11 % of the total CO_2e emission comes from logistics whereas the external transport has the highest impact. The internal logistics generates only 1 % of the CO_2e emissions. In Fig. 4 these emission data are shown.

Depending on the supply chain, the balancing method and the mathematical algorithm as well as the system boundaries different results and impacts on the environment are generated and discussed in the literature.

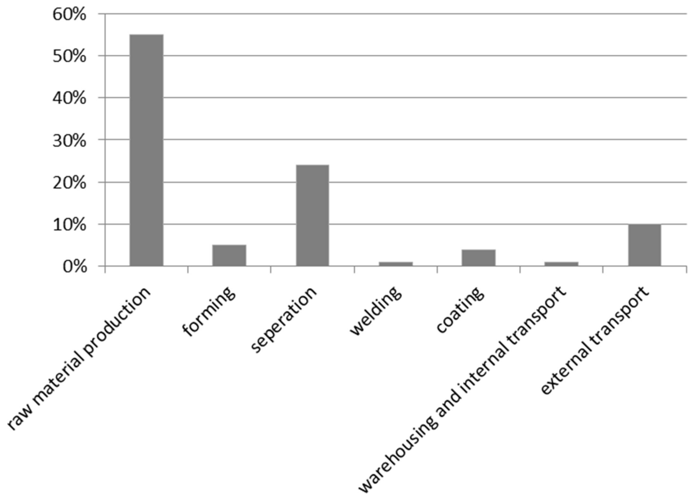

Fig. 4. CO2e emission of an automotive supply chain on a product base [8].

3 Method

The calculation of the impact of the transport volume on the storage size and their impact is done by process of the World Business Council for Sustainable Development. In Fig. 5 the typical approach is given.

Step 1: The objectives of the case study are to identify the influence of the transport mode and frequency on the warehouse capacity and size and on the total environmental impact. The warehouse can consist of a non-cooling and a cooling area. Processes are the transportation by truck, train or ship from a warehouse to another distribution center. The frequency and the capacity of the different transport modes vary and so does the required space in the distribution center.

Step 2: McKinnon and Piecyk [9] suggest different systems boundaries around transport operations for carbon measurement. This is shown in Fig. 6.

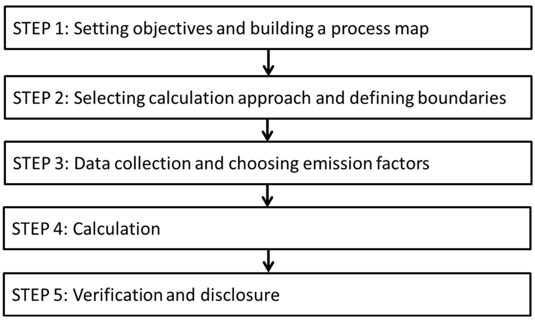

Fig. 5. Steps to calculating the carbon footprint [12].

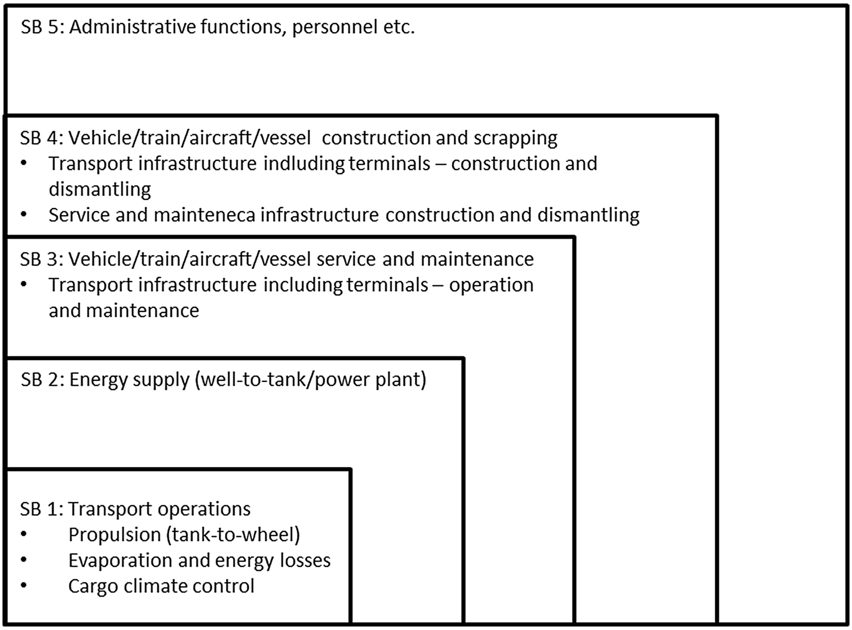

Fig. 6. System boundaries around transport operations for carbon measurement [9].

Emission data from different transportation modes are available. The energy consumption of warehouses is also reported in different publications. So system boundary SB 3 is chosen for the calculation. The SB 1 and SB 2 are related to the transportation solely, SB3 the warehouse operations but not construction and dismantling are integrated (Fig. 7).

In the distribution centre different items are also stored for a specific time. Between the warehouse and the distribution center trucks, trains or ships transport the items. A one-way transportation is considered.

Step 3: The transportation emissions are calculated with the EcotransIT-software from IFEU [10] as well as with average values given in Table 1. EF are the specific emission factors of a transport mode.

For the emission of the distribution center data from Süssenguth [11] are taken. In their investigation 9 different warehouses with and without cooling section are investigated. The average value of the energy consumption of the warehouses is 80 kWh per m^2 and year. The data vary from 40 to almost 140 kWh per m^2 and year. Corresponding to a conversion factor of 0.569 kg CO_2/kWh given by the German federal environmental agency for the year 2014 the emissions are between 21.56 kg CO_2/m^2 year and 75.46 kg CO_2/m^2 year. For the calculation real data from one specific warehouse are taken for the case study.

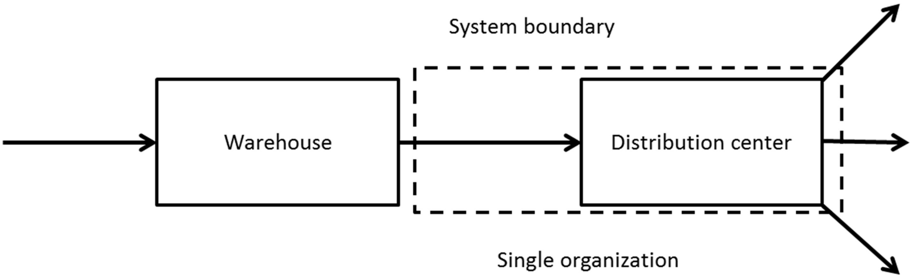

Fig. 7. System boundary of the case study.

Table 1. Average emission factors for the calculation.

Transport mode	EF [CO_2e g/t km]
Train	30
Truck	60
Ship	10

Table 2. CO_2 emission data for the distribution center [11] without cooling section.

Data	Value
Area	28,000 m^2
CO_2 emission per year	672.1 t
Emission factor CO_2 kg per m^2 and year	24.0

4 Results

Step 4: For calculating the CO_2 emissions an activity based approach is used. The emissions of the transportation are given by:

$$CO_2 \text{ emission}_{\text{transport}} = \text{ weight} \times \text{distance} \times \text{emission factor} \tag{1}$$

The emissions of warehousing activities in a distribution center are given by:

$$CO_2 \text{ emission}_{\text{distributioncenter}} = \text{ storage period} \times \text{emission factor} \tag{2}$$

It is also possible to calculate the CO_2 emission with the size of the warehouse/distribution center:

$$CO_2 \text{ emission}_{\text{distributioncenter}} = \text{ area} \times \text{emission factor} \tag{3}$$

For the arbitrary case study the transport between warehouse and distribution center takes place every day per truck, or every week per train or once a month per ship. The distance is 200 km. The lower the transport frequency the higher is the average stock in the distribution center.

Table 3. Data for the calculation.

Data	Train	Truck	Ship
Number of pallets received per year	345,000	345,000	345,000
Number of pallets locations	30,000	10,000	90,000
Utilization factor	80 %	80 %	80 %
Average stock	24,000	8,000	72,000
Weight per pallet [kg]	500	500	500
Value per pallet [€]	750	750	750
Interest rate	7 %	7 %	7 %

First the influence of the loading factor is considered. It is assumed that the truck costs 300.00 € for the transport. If the number of pallets transported by truck is increased from 27 to the maximum load of 33, a decrease in transportation costs of 2.02 € is achieved. Considering an increase in the storage period by 5 days and so additional tied up capital costs by 0.73 €, the total savings are 1.29 € per pallet. The total costs savings are then 445,000 € per year. The emission by transport is decreased as well. The increase of the CO_2 emission of the warehouse is calculated next. Distribution planning has a high impact on the costs and emissions. According to the high amount of transported goods of the case study it is considered in the next calculation that all trucks are fully loaded.

The total CO_2 emissions of the chosen system boundaries are given in Fig. 8 for the distance of 200 km.

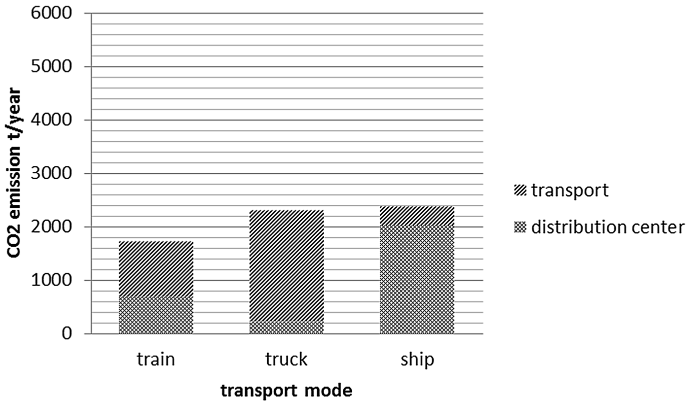

Fig. 8. CO_2 emission for the 200 km distance.

The train has the lowest total CO_2 emission of the transport chain. For truck transport the dominant CO_2 emission is the transport itself. For the slowest transport mode of the ship the size of the distribution center/warehouse matters. Increasing the distance between the two locations the transport the ship benefits due to its low

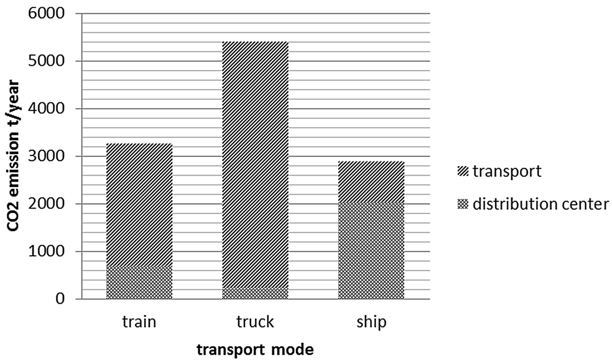

Fig. 9. CO_2 emission for the 500 km distance.

emission during transport. Keeping the size of the stock area the same the results are shown in Fig. 9.

The emission factor per m^2 is assumed to be 24 kg and year. This is compared to other values quite low. If the factor is increased to the upper end of 72 kg CO_2/m^2 year the CO_2 by the factor of three for the distance of 200 km are given in Fig. 10.

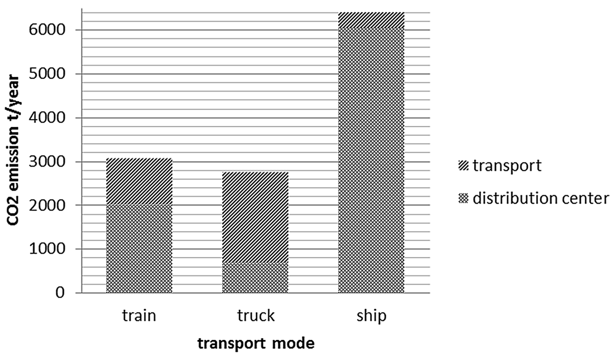

Fig. 10. CO_2 emission for the 200 km distance and an emission factor of 72 kg CO_2/m^2 year.

In this case the truck has the lowest total emission. The investigations are based on real data from warehouses in Germany and the CO_2 emission with the conversion factor of 0.569 kg CO_2/kWh. This conversion factor differs in Europe. Countries with a higher use of renewable energy or atomic energy have a smaller conversion factor. This value could be as low as 0.08 kg CO_2/kWh and so just 15 % of the value in Germany. France has because of their atomic energy plants these kinds of low values. Taking the simple approach from the case study, the green supply chain design would result in different solutions for the size of warehouses and the transport mode in the countries of France and Germany considering CO_2 as the major measure of environmental impact.

Another measure for the environmental impact is the eco-efficiency. This is given by:

$$\text{Eco-efficiency} = \text{value added}/\text{environmental impact added} \quad (4)$$

The value added is the increase in the value of a product within a process. In this case the added value is the transport from the warehouse to the distribution center and the storing activities before unloading the product on a further transport mode. Assume that the value is 10.00 € per pallet. With the values from Tables 2 and 3 the total CO_2 emission can be calculated per pallet and year. This is the environmental impact added in kg CO_2. By using Eq. 4 the eco-efficiency is given for this transportation and storing process by the values in Table 4.

Table 4. Eco-efficiency for the distance of 200 km.

Transport mode	Value [€/kg CO_2]
Train	2.02
Truck	1.50
Ship	1.46

5 Conclusions

Step 5: The environmental impact of a distribution network of a distribution center and different transport modes is investigated. Warehousing and transportation both must be considered in the carbon footprint accounting. The most important factors are the distance of transportation and the specific emission factor of the building. Taking average values for the CO_2 emission of warehouses can result to wrong recommendations in the supply chain design. The difference between average values and the real consumption can be quite high. Extending the system boundary in the case study to the other warehouse will guide to other solutions in terms of optimal low environmental impact supply structure. All boundaries and assumption have to be well documented.

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