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About the impact of rising oil price on logistics networks and transportation greenhouse gas emission

Wendelin F. Gross · Cristina Hayden ·
Christian Butz

Abstract Logistics networks need to handle globally growing transportation volumes in cost efficient and sustainable configurations. This research explores the impact of the oil price on the optimal degree of centralization of logistics networks through the fluctuation of transportation costs. The impact of the degree of centralization on greenhouse gas emissions of transportation is evaluated. Investigations are conducted by means of a model consisting of logistics network, logistics costs, carbon dioxide emissions and an empirically determined relationship of oil price, fuel price and transportation costs. First, the dependency of transportation costs in European road transports from oil prices is derived. Then, the optimal configuration of the logistics network is determined for a range of oil prices. Sensitivity analysis on the value of traded goods is performed. Results show an existing dependency of the European logistics network structure limited to oil prices above 150 USD/barrel. Dependency on the oil price increases for high-value goods compared to low-valued goods. Carbon dioxide emissions diminish with lower centralization degree, as an effect of lower total transport distance.

Keywords Greenhouse gas · Logistic network design · Oil price · Transportation costs · Mathematical optimization · Comparative statics

W. F. Gross (✉) · C. Hayden
4flow research, 4flow AG, Hallerstrasse 1,
10587 Berlin, Germany
e-mail: w.gross@4flow.de

C. Butz
Beuth University of Applied Science,
Luxemburger Strasse 10, 13353 Berlin, Germany

1 Introduction

Worldwide population and the internationalization of national economies are on the rise and boost energy consumption as well as trade. At the same time, customer's time sensitivity and heterogeneous demand lead to the disaggregation of B2B and B2C shipments. Companies apply new business concepts like e-commerce and virtual enterprise, in order to cope with these challenges. Customized goods are offered at any time and can be delivered to virtually any place worldwide within days. Integration and interaction of companies create complexity and dependency on efficient and reliable logistics. Consequently, transportation volumes increase and logistics gain in importance [1].

Between 2000 and 2008, freight transportation in the EU increased by 17%. Whereas freight transports grew by 2% annually, road transports increased by 2.7% annually in the same period. Domestic sea freight excluded, the share of road transports in total freight transportation reached 72.5% in 2008 accounting for 26.7% of total final energy consumption in the EU-27 [2].

Energy supply in Europe depends highly on imports. Between January and August 2010, Europe imported roughly 2,000,000 barrel (bbl) of crude oil worth around 154 billion USD [3]. Thus, fuel consumption in transportation is not only important for the logistics industry but also of interest for the entire national and international economic relationships.

The crude oil price is influenced by key factors related to politics, economy, technological development and the environment. These factors include the growth rate of economies, exchange rates, use of regenerative energies, exploration of new oil sources as well as risks like accidents, war and natural disasters [4]. Their interplay causes

uncertainty about the future development of the oil price, making its prediction a very hard task. As to demand and supply, both rising demand from emerging countries, and uncertainty about accessible resources at the sources play a key role on crude oil market development. According to the peak oil theory, availability of crude oil is limited and production will not keep pace with demand on the long run [5].

As crude oil and its derivatives become incrementally scarce, their market price shows a high volatility. In 2008, it reached more than 145 USD in July and dropped to less than 40 USD 5 months later. In 2011, its price rose by 25% within 4 weeks [6]. A reason might have been the uprising in Arabia. However, models based on supply and demand of crude oil provide neither explanation of historic oil prices nor estimation of the future oil prices [7, 8].

Another effect of increasing transportation volumes is the emission of greenhouse gas. Anthropogenic greenhouse gas emissions provoke global warming and climate change according to the prevailing scientific belief. Carbon dioxide (CO_2) is the most prominent greenhouse gas. Between 2000 and 2007, total annual CO_2 emissions in the EU-27 increased by 1.9%. In the transportation sector,[1] however, the emission of CO_2 increased by 7.2% [2].

Logistic activities use warehouses or transshipment facilities to constitute logistic networks, which enable the regional consolidation of transports for different customers and from different suppliers. Through freight consolidation, the utilization of the means of transportation can be increased, and therefore, overall transportation distance as well as CO_2 emissions can be reduced.

2 Research design and objectives

This paper studies the influence of the oil price on the structure of logistic networks through the impact of transport costs on overall logistic costs. Furthermore, it quantifies the indirect effect of the oil price on the network ecological footprint through the amount of CO_2 emissions. Therefore, a representative distribution network for a European retailer is modeled, and several network scenarios are studied.

Retail distribution networks can serve customers in a variety of configurations. The total number of transshipment facilities or warehouses and their regional distribution define the degree of centralization of a distribution network. Centralized networks with few warehouses enable lower overall stocks than decentralized ones, while decentralized networks can provide shorter lead-time to the customers [9].
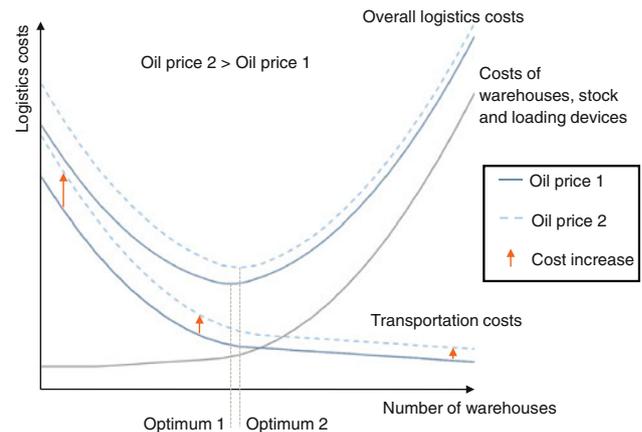

Fig. 1 Theoretical dependency of the optimal number of warehouses, logistics costs and oil price

The definition of the optimal network structure is one of the main tasks of the strategic planning in logistics.

Since decentralized distribution networks are less transport-intensive than centralized ones, the major hypothesis of our study is that decentralized distribution networks are more efficient regarding overall logistics costs and CO_2 emissions than centralized ones when oil prices rise and vice versa (see Fig. 1).

This study deals with strategic network planning and supports practitioners by performing a numerical analysis for several centralization scenarios for a retail distribution model in Europe. Results provide insights in the sensitivity of the network to variations of the crude oil price, in terms of optimal network structure and the associated ecological footprint. Furthermore, results including the effect of goods value through capital cost of stock are discussed.

In the following sections, a review of the relevant literature and the research methodology are provided. Then, results are discussed.

3 Literature review

Logistics emerged in the 1960s and 1970s as an independent field of study and practice. It consolidated fragmented but related activities that included purchasing, material management and physical distribution [10]. Purchasing refers to the process of supplier selection, price negotiation and terms of delivery. Material management deals with the handling of raw and semi-finished goods from the receipt of goods to the shipment. Physical distribution refers to the distribution of goods to the customer or point of sale. The understanding of logistics developed from the function of goods transformation in space and time to a holistic management view including planning and controlling activities

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[1] Persons and goods.

[11]. The goal of the management view of logistics is the streamlining of the entire business organization according to the flow of material and information [12].

Green Logistics attempt to minimize the impact of logistics processes on natural resources by means of strategic and technical measures [13]. It became a part of logistic planning and operations since the early 1990s as awareness of environmental problems grew in our society [14]. The major incentives for environmental policies are rather tactically than strategically important. Legal demands, the control of environmental costs, social expectations and customer demands as well as minimization of liability are important incentives for greening logistics [15].

In the last decade, research on the volatility of crude oil price and on its effect on transportation have received increasing attention. Hamilton examines the factors responsible for the fluctuation of crude oil prices [8]. As key features, he identifies low price elasticity of demand, the strong growth in demand from China, the Middle East and other newly industrialized economies, as well as the failure of global production to increase. In further research, he explores the effects of the run-up of oil prices between 2007 and 2008 and preliminary oil price shocks on the US economy [16]. Roeger [17] analyses the impact of the permanent oil price increase in the European Union considering output and inflation.

Diesel prices, as one key factor influencing transport costs within a logistic network, rise rapidly following an increase in the price of crude oil, but fall slowly after a decrease. The asymmetric response of petrol and diesel prices on the crude oil price has been the focus of numerous studies since 1990 [5, 18–21].

The subject of cost optimal configuration of logistic networks under the assumption of linear logistics costs is well researched [22–28]. Melkote and Daskin [28] combine the optimization of facility location and the underlying transportation network focusing on investment costs. Their results show that it is more cost-effective to invest in few facilities and many links at small investment levels. By increasing budget, they analyze that more facilities and fewer links are adequate. As a consequence, the transport costs decrease within the transportation network.

The number of papers that examine increasing fuel prices and their impact on a logistic network configuration is limited. Gosier et al. [29] examine the effect of rising prices of petroleum-based fuels on five supply chain functions: network strategy, sourcing and procurement, planning and forecasting, transportation, and distribution. Their research shows that increasing oil prices and therefore augmenting transportation costs influence the optimal location, number and size of distribution centers. Concerning the location of warehouses Cidell [30] shows that there is a tendency of spatial concentration and dispersion on the US market.

Simchi-Levi et al. [31] analyze supply chain changes due to risen crude oil prices. According to their research, companies try to reduce shipping times and costs by moving production closer to demand and by altering the optimal number of distribution centers in the supply chain structure.

Andreoli et al. [32] examine the relation between the rapid growth rate of the US warehousing establishments and the increasing fuel price, between 1998 and 2005. Rising oil prices and high volatility reduce the advantages (e.g., economies of scale) of mega distribution centers[2] and shift back advantages to regional distribution centers through the capitalization on differentials in fuel efficiency across transport modes.

The optimization of a logistics network by modifying the number, location and size of hubs has an impact on the network transport routes. On the other hand, transportation efforts within a logistic network have a strong correlation with its CO_2 emissions. Paksoy et al. [33] study a green supply chain network optimization problem by considering transportation costs and capacity allocation constraints in order to reduce the emission of CO_2. Wang et al. [34] developed a green supply chain network design model. They analyzed that improving the capacity of the network and increasing the supply of the facilities can decrease both CO_2 emissions of the whole network and total costs.

4 Research methodology

Research is conducted with a model-based approach. A realistic retail distribution network in Europe is modeled for a set of fifteen scenarios. On one edge of the set, a centralized network with only one warehouse that serves all customers is modeled. On the other edge, a decentralized structure with fifteen warehouses spread over Europe is considered. Basic network data, such as sourcing network, customer footprint and customer demand, are common for all scenarios. As a consequence of the different number of warehouses and associated economies of scale, they differ in the stock level and in the rate applied for the storage costs. For each scenario, which includes one warehouse more than the previous one, the network is generated separately by optimizing transport costs. Afterward, overall logistics costs, which include transport, handling, storage and capital costs, are assessed for each scenario (see Fig. 2).

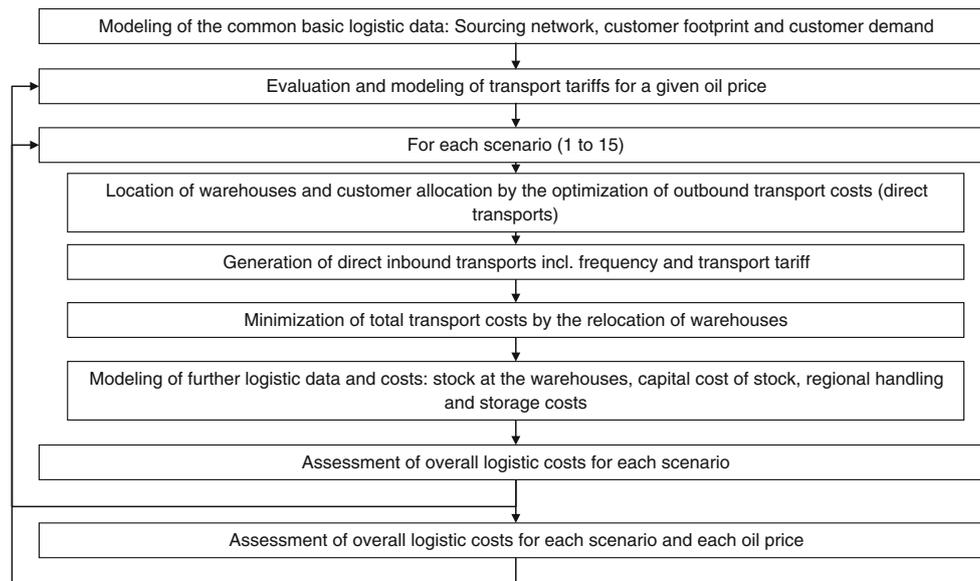[2] Employing more than 100 workers in facilities greater than 500,000 square feet.

Fig. 2 Workflow for the generation and assessment of the scenarios

The modeling process begins with the generation of the set of fifteen scenarios based on the common basic network data. Then, the warehouses are located, and customers are allocated for each scenario through the optimization of transport costs. The optimization of transport costs is a two-step process. First, the geographical location of the warehouses on a continuous solution space and the allocation of customers are solved by the minimization of outbound transport cost with a heuristics based on Stolletz and Stolletz [35]. Therefore, the total demand is divided geographically into as many regions as warehouses are modeled. Each warehouse is located at the center of gravity of its demand region, considering the throughput to each customer weighted with the variable outbound transport costs, which are calculated on the basis of a given delivery frequency and the oil price–dependent transport tariffs. Afterward, the warehouses are linked to the source network through direct transports, and both a delivery frequency and a transport tariff are defined for each of them. Therefore, a subsequent mathematical optimization minimizes the total transport costs of the network, including inbound and outbound transport costs, by the possible relocation of the warehouses. Thus, higher inbound transport costs lead to the relocation of the warehouses near to the source, while higher outbound costs to their relocation near the customers.

In the next step, the stock level is calculated for each warehouse. In the end, overall logistics costs for each scenario are calculated and analyzed for varying oil prices, which translate in different transport tariffs. The total costs at several oil prices are then compared, in order to identify the most competitive network regarding the number of warehouses. Oil prices ranging from the all-time low between 1974 and 2010 (15 USD/bbl) [6] up to a hypothetic stress price (200 USD/bbl) are applied.

The emissions of carbon dioxide (CO_2) caused by inbound and outbound road transportation are calculated for each scenario and oil price in order to evaluate the impact of network redesign on the ecological footprint [36].

The standard logistics planning software 4flow vista is applied for modeling, optimization, analysis and evaluation of the networks [37]. 4flow vista aims at the reduction of logistic costs, the improvement of performance and the establishing of sustainability through more accurate strategic design and tactical planning of complex logistic networks. 4flow vista supports decision making by the comparison of static scenarios, which reflect alternative approaches to achieve preliminary set objectives, for example, minimization of costs or greenhouse gas emissions. The approaches stem from best practices, numerical analysis and mathematical optimization of site location, goods allocation, transport concept, and transport frequency. Transport concepts comprise routing of transports, means of transportation and transport frequencies and allow the modeling of direct transports as well as pick-up and delivery tours [37].

5 Model

The input to both the structure of the distribution network and the cost model are provided in the following sections.

5.1 Scope of the distribution network

The distribution network model covers continental Europe and the British and Irish Isles including all countries of the EU-27 and the member candidate Croatia. Demand for homogeneous goods is modeled through roughly 1,000 customer locations, which represent NUTS 2 regions[3] of the European Commission (see Fig. 3). A total demand of 7.2 million pallets per year is distributed according to the gross domestic product in the respective region, thus simulating typical customer demand [38].

Each customer location is served exclusively by one warehouse through direct transports on a weekly basis. Homogeneous light trucks with a capacity of 2.7 tons and 30 pallets and a fuel consumption of 19.25 l per 100 km are used.

As to the sourcing side, intercontinental trade is assumed and the sourcing network is simplified to one source located at the seaport in Rotterdam, which receives the whole demand to be distributed. The source is linked to the optimized warehouses for each scenario through direct transports. These inbound transports serve the replenishment of the warehouses and have a weekly transport frequency. In this case, heavy trucks with a capacity of 24 tons and 60 pallets and a fuel consumption of 32.7 l per 100 km are used. By weekly transports between one source and one warehouse, the transport volumes are high enough to apply full-truck-load transport tariffs. For both inbound and outbound transports, the availability of trucks is not constrained.

The warehouses store and distribute the goods directly to pre-allocated customers. Their capacity is not constrained and, in accordance with a strategy of outsourcing warehouse operations, the facility size is assumed to be flexible according to needed capacity. Hence, the warehouse capacity depends on throughput and stock level.

5.2 Cost model

The cost model defines the parameters for the distribution network. Four types of costs are associated with the warehouses: capital costs for stock, storage costs, handling costs and costs for loading devices.

- Capital costs depend on the goods value in stock and are calculated with a yearly interest rate of 8%. The goods value is assumed to be 1,500 EUR/m³, which represents a medium value for goods in German retail. Thus, a total demand of 7.2 million pallets equal 10.8 billion EUR per year is served by the network. Both assumptions are based on empirical data.
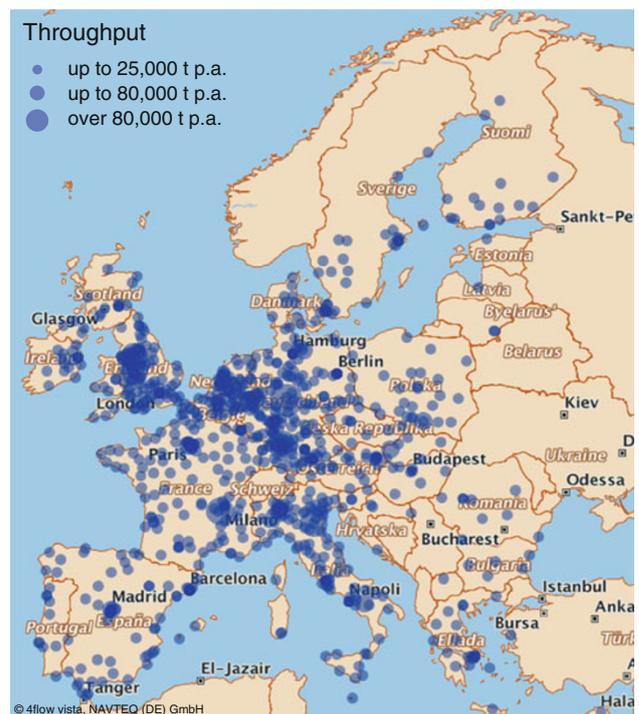

Fig. 3 Distribution of customer demand according to gross domestic product in European NUTS 2 regions

- Storage costs account for used floor space according to warehouse throughput and stock level. The rate for the storage costs is specified as a weighted average of the storage prices for the top 10 European countries in accordance with GDP and amount 70.64 EUR per m² p.a. (see Table 1).

Stock is modeled for every warehouse based on safety and basic stock. The safety stock is calculated as to serve demand over 15 days. The level of the basic stock depends on the number of warehouses in the network and the customer demand per warehouse. Economies of scale are considered for the basic stock. The weekly throughput of each warehouse is weighted with the square root of the total number of warehouses in the network for basic stock calculation [9].

- Handling costs account for handling processes at warehouses, and the rate is also weighted for the top 10 European countries in accordance with GDP. A mean time for warehousing processes per unit goods of 5.5 min is considered, which leads to following yearly handling costs per pallet in EUR (see Table 2).
- Costs for loading devices account for the number of pallets circulating in the network and result from overall demand. A European average price for the rent of equipment of yearly 7.5 EUR per pallet is considered.

Table 1 Storage costs in EUR per m^2 p.a. [source: Author]

	DE	FR	UK	I	ES	NL	P	B	SE	AT	Average GDP
Storage cost in EUR/m^2 p.a.	66.00	63.60	117.12	53.16	58.80	70.32	38.40	52.80	72.00	66.00	70.64
Weight GDP	0.23	0.18	0.17	0.15	0.10	0.05	0.03	0.03	0.03	0.03	1.00

Table 2 Handling costs in EUR per pallet p.a. [source: Author]
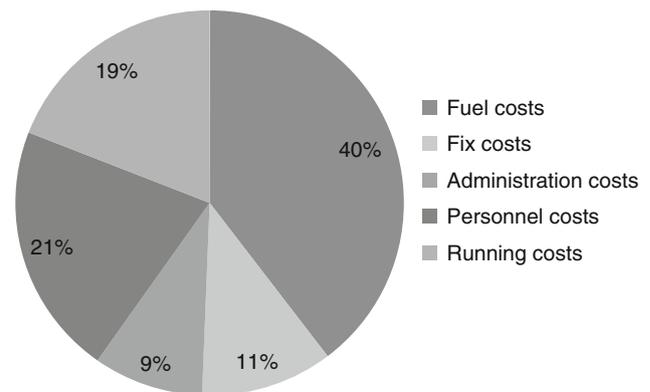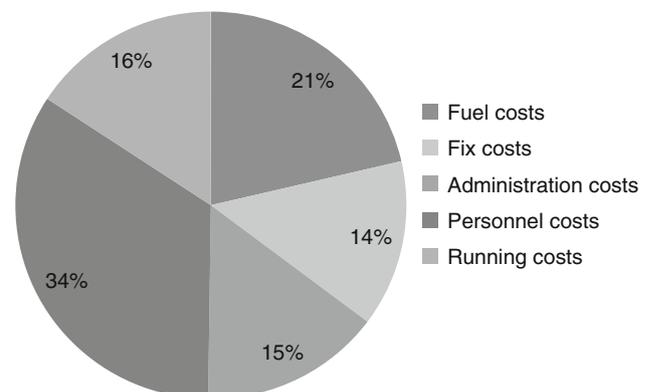
	DE	FR	UK	I	ES	NL	P	B	SE	AT	Average GDP
Handling cost in EUR/pallet p.a.	5.02	5.51	4.24	4.30	3.23	5.14	1.35	5.58	5.54	5.04	70.64
Weight GDP	0.23	0.18	0.17	0.15	0.10	0.05	0.03	0.03	0.03	0.03	1.00

Two types of costs are associated with transports: Transport costs including equipment, personnel, fuel and other consumables, and capital costs for goods in transport. Oil price fluctuations affect the transportation costs through the fuel costs. Time-dependent factors such as persistency and flanking dynamic aspects are not part of this study.

- Transport costs are modeled in the network through transport tariffs, which are a fixed rate per distance unit. This enables a differentiation of means of transportation and a distance-based cost regression for inbound and outbound transports. The values for these transport tariffs are obtained from a cost function, which considers not only the oil price through fuel costs, but also fix, administration, personnel and running costs per distance unit. Furthermore, average toll costs of 0.17 EUR per km are charged on top. The structure of this function is based on a typical cost composition for trucks in Germany [39]. Light and heavy trucks, which serve inbound and outbound transports, respectively, are modeled with different cost functions in respect to their utilization (see Figs. 4, 5). Following the logic of the top 10 European countries GDP, a weighted value for Europe is built up.

- Fuel costs are modeled through a linear regression between fuel prices and oil prices over the last 10 years in Europe. Therefore, different tax structures in European countries and the development of the exchange ratio between USD and EUR are taken into account (see Table 3).

Based on these cost structures, a given oil price is translated in a valid transport tariff for both inbound and outbound transports. The linear regression shows that an increment of the oil price by 100 USD/bbl causes an increment of 0.22 and 0.06 EUR/km for inbound and outbound transport costs, respectively (see Fig. 6).

The results for inbound transports are coherent with a previous study [31], which presents similar results for the US market. By the same increase in the oil price, an increment of 0.4 USD/mile is expected. By a rough unit

Fig. 4 Structure of the weighted function for inbound transport costs for Europe

Fig. 5 Structure of the weighted function for outbound transport costs for Europe

conversion, an equivalent of 0.2 EUR/km is obtained. Different modeling assumptions and particular market conditions lead to a slight difference between both results.

- Capital costs for goods at transport depend on transportation time and are calculated with the same interest rate as cost of capital for stock in the warehouses.

Table 3 Linear regression between fuel and oil price for the top 10 European countries

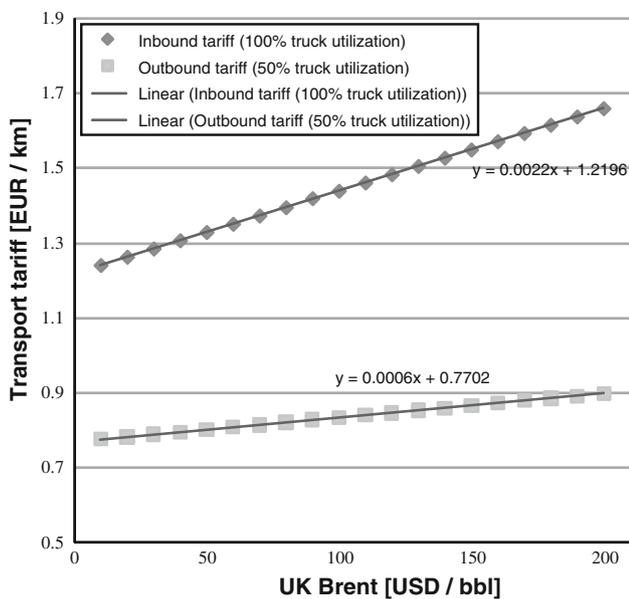| Country	m	n	R^2
Fuel price: $= m*$UK Brent price $+ n$ [EUR/lt]			
Fuel price Germany	1.65	0.60	0.96
Fuel price France	1.57	0.58	0.98
Fuel price UK	1.08	1.04	0.92
Fuel price Italy	1.50	0.68	0.98
Fuel price Spain	1.49	0.48	0.98
Fuel price Norway	1.63	0.56	0.98
Fuel price Portugal	1.76	0.42	0.97
Fuel price Belgium	1.38	0.59	0.94
Fuel price Sweden	1.60	0.63	0.94
Fuel price Austria	1.81	0.43	0.98
Fuel price EU	1.50	0.66	

Fig. 6 Oil price–dependent transport tariffs

Based on these cost parameters, transport costs are optimized, warehouses are located, and customers are allocated. Overall logistics costs are calculated for each scenario and serve as the main evaluation criterion for the network competitiveness.

5.3 Carbon emission model

The carbon emission model uses standard emission values for each truck type according to literature data (see Table 4).

The emissions are modeled as a function of traveled distance and truck utilization. Highly utilized transports thus cause fewer emissions per unit transported than transports with low utilization. Emissions caused by manufacturing processes, warehousing, premises and recycling are not taken into account. For each scenario, yearly CO_2 emissions are calculated. Due to the differences concerning average transport utilization, inbound and outbound transport processes are distinguished.

6 Results

The analyses of the model and the scenario runs provide three findings related to the influence of oil price on the structure of logistic networks. First, the optimal structure of the distribution network depends on the oil price. Second, traded goods value has considerable impact on the sensitivity of the network response to the oil price variation. Third, total CO_2 emissions are prone to the network structure, and thus, CO_2 savings by network restructuring are achievable.

6.1 Oil price dependency of the distribution network structure

The results show that the oil price dependency of the examined distribution network structure is given but limited to high oil prices. The most competitive degree of centralization reflected by the number of warehouses in the network remains constant within an oil price range from 15 to 150 USD/bbl. Thus, there is no necessity of a structural network adjustment considering oil prices that were effective between 1974 and 2009.

A distribution network with six warehouses in Europe is the most competitive at current oil prices (91 USD/bbl) within the regarded setting as total logistic costs remain minimal (see Fig. 7).

However, there is a trend toward decentralization, with more warehouses, when oil prices rise above roughly 150
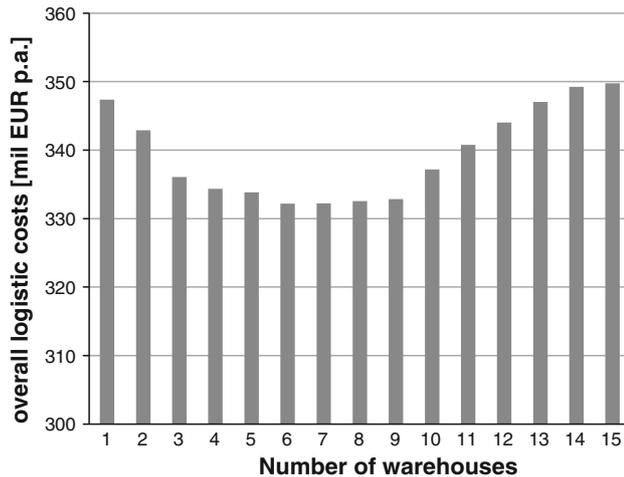
Table 4 Standard emission values [36]

Truck type			CO_2 emission [g/km]		
	Capacity (tons)	Emission classification	<25% utilization	25–75% utilization	>75% utilization
Light truck	2.6	EURO4	305	327	349
Heavy truck	24	EURO4	677	925	1,159

Fig. 7 Overall logistic costs of networks with various numbers of warehouses at 91 USD/bbl oil price

USD/bbl. The most competitive network structure then contains up to nine warehouses. A moderately centralized logistics network with nine warehouses represents a steady state in the applied model at oil prices between 180 and 200 USD/bbl.

6.2 Traded goods value dependency of the distribution network structure

Data analysis indicates that another parameter affects the significance of the oil price influence on distribution networks. The value of traded goods modulates the sensitivity of the network response to the oil price variation. Medium-value goods with 1,500 EUR/m^3 evoke the above-mentioned behavior. The impact of the oil price on logistic networks for low-value goods (1,000 EUR/m^3) is of even less significance. Then, the degree of centralization is constant for an oil price range of 15–200 USD/bbl, with the most competitive network containing nine warehouses. In case of high-value goods (2,000 EUR/m^3), the opposite holds true. The oil price becomes an important factor for the competitiveness of logistic networks within the examined range of 15 up to 200 USD/bbl. While low prices favor centralized networks with three warehouses, high prices tend to promote a moderately decentralized network with six warehouses (see Fig. 8). The mean oil price on 2008 (91 USD/bbl) is used as reference for a middle price in the chosen range.

6.3 Impact on CO_2 emissions

The most competitive distribution network structure at low and moderate oil prices and traded goods value of 1,500 EUR/m^3 comprises 6 warehouses. The transport-related CO_2 emissions associated with this network structure
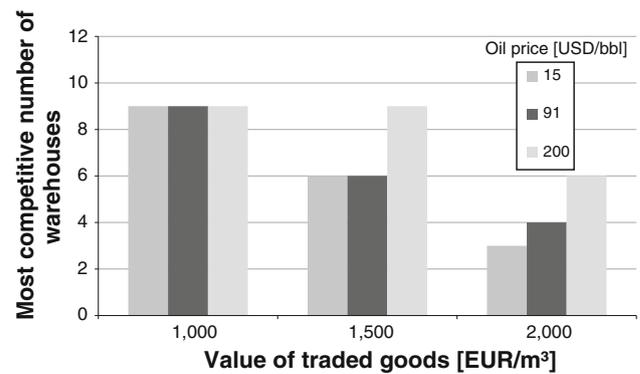

Fig. 8 Optimal number of warehouses depending on value of traded goods

Fig. 9 CO_2 emissions depending on number of warehouses

amount 91,632 tons yearly. The network structure that is most competitive at high and very high oil prices above 150 USD/bbl contains 8 and 9 warehouses, respectively. The CO_2 emissions in these more decentralized network structures amount 85,799 and 84,783 tons yearly, respectively (see Fig. 9). CO_2 emissions are calculated separately for inbound and outbound transports due to the considerably varying emission values depending on the means of transportation and utilization.

Distribution network restructuring toward decentralized structures thus offer potential savings of 5,833 tons or 6.4% and 6,849 tons or 7.5% CO_2, respectively. The CO_2 reduction is achieved mainly by the outbound transports, whereas emissions generated by inbound transports show a very slight difference between the network structures.

7 Discussion

The characteristic behavior of the model is that overall costs vary with the degree of centralization represented by the number of warehouses in the network and the value of traded goods. This is caused by two parameters with contrary dependency on the degree of centralization, transport costs and capital costs.

Centralized networks induce more transportation costs than decentralized ones since the routes are longer and truck utilization is usually worse on outbound than inbound transports. Thus, transportation costs decrease in the course of decentralization.

On the contrary, centralized networks with few warehouses require less stock in total than decentralized networks with many small-scale warehouses. This is because the latter can hardly benefit from economies of scale. Thus, capital costs and costs for storage space increase in decentralized networks as a result of increased stock level.

The value of traded goods directly affects the most competitive number of warehouses since capital costs for stock in warehouses arise from stock level and stock value. Total stock level in the network results from the number of warehouses. Thus, high-value goods favor networks with fewer warehouses, in order to avoid capital costs, without respect on the oil price level as capital costs are oil price–independent. The same effect can be assumed for a change of the interest rate on stock of currently 8% in the model. Any rise of interests would increase the capital costs and render a centralized distribution network more competitive compared to a decentralized. Vice versa, network decentralization becomes more cost efficient in times of low interests.

The degree of centralization is not steadily dependent on oil price within the model although correlation of transportation costs and oil price is modeled as linear. This model behavior stems from the customer footprint, which is not uniformly spread over the map but match the economic power of European regions.

The CO_2 emissions of transportation depend on the degree of centralization of the network. The more warehouses are spread in the demand area, the less CO_2 is emitted. This is because decentralization reduces total traveled distance in outbound transport while increasing traveled distance in inbound transport. As truck utilization in inbound transports is better than in outbound transports, the total CO_2 emissions are reduced. Thus, decentralization of networks can contribute to Green Logistics. An environmentally sustainable network structure can even pay off and lead to lower total logistic costs in the scenario of rising oil prices.

As the oil price influence on logistics structure is limited within the regarded range, the necessity of fundamental changes in logistics networks in the course of rising oil prices is questionable and depends on the current maturity of the network. Outcomes of high oil prices such as a general drop of demand seem to be of greater importance for the logistics structure than the rise in transportation costs. Therefore, the increase in transportation costs by 0.22 EUR per kilometer per oil price rise of 100 USD/bbl has to be analyzed considering the overall transportation volume. In the year 2008, road transport in Germany covered a distance of over 31.4 billion kilometers. An increment of the oil price of 10 USD would mean for Germany an increase of around 690 million EUR in transportation costs per year.

Considerations on network restructuring are bound to limitations. Although existing logistics networks are often not in an optimized state concerning the location of warehouses, both disclosure and closure of warehouses are long-term operations associated with considerable investment in material and personnel. Furthermore, the persistency of the oil price level is vague and subject to erratic fluctuation. Consequently, decisions on network restructuring have to be taken according to the specific settings within the network and future outlook of the entire development. Equally, other impacts of carbon fuel consumption like CO_2 emission might be a more pressing issue than transportation costs.

Further research should address alternative investments, in order to investigate the worthiness of network restructuring. The influence of diversified production programs with locally customized products and the relevance of the location of multiple sources in the network should be regarded. Different alternative measures for the reduction of CO_2 emissions in logistics should be evaluated and compared in terms of effectiveness, cost and realization potential. It might even prove that measures in areas not related to logistics are much more efficient in the reduction of CO_2 emissions. Also, dynamic simulation of logistics network's behavior at fluctuating oil prices would provide further insight into benefits of network restructuring at high oil prices. For this purpose, the static model provides valuable results about oil price levels that are of concern for restructuring considerations.

References

1. Gross W, Hayden C (2010) Oil price impact on logistics network structure—a model-based approach. In: Cunha G-G, Landau L, Bruzzone A, Saetta S (eds) The international workshop on applied modeling & simulation, May 5–7, Rio de Janeiro, 2010, pp 190–195
2. European Commission (EC) (2010) EU energy and transport in figures, statistical pocketbook
3. European Commission (EC) Directorate-General for Energy (2011) Registration of crude oil imports and deliveries in the European Union (EU27). http://ec.europa.eu/energy/observatory/oil/doc/import/coi/eu-coi-2010-01-08.pdf. Accessed 11 Apr 2011
4. Butz C, Gross W, Hayden C, Zesch F (2010) Der Einfluss des Ölpreises auf Distributionsnetzwerke von Industrie und Handel. Ein Mythos wird entzaubert, 4flow AG, Berlin

5. Kaufmann RK, Laskowski C (2005) Causes for an asymmetric relation between the price of crude oil and refined petroleum products. Energy Policy 33:1587–1596

6. US Energy Information Administration (USEIA) (2011) Monthly U.S. crude oil imported acquisition cost by refiners. http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=r1300___3&f=m. Accessed 10 Mar 2011

7. Gronwald M (2009) Zur empirischen Analyse des Ölpreises. Ein Überblick über aktuelle Forschungsergebnisse, ifo Schnelldienst 62(1):16–19

8. Hamilton JD (2009) Understanding crude oil prices. Energy J Int Assoc Energy Econ 30(2):179–206

9. Gudehus T (2005) Logistik. Springer, Berlin

10. Ballou RH (2007) The evolution and future of logistics and supply chain management. Eur Bus Rev 19(4):332–348

11. Goepfert I (2004) Einführung, Abgrenzung und Erweiterung des supply chain managements. In: Busch A (ed) Integriertes supply chain management: Theorie und Praxis effektiver unterneh-mensübergreifender Geschäftsprozesse, Gabler, Wiesbaden

12. Weber J (2008) Überlegungen zu einer theoretischen Fundierung der Logistik in der Betriebswirtschaftslehre. In: Nyhuis P (ed) Beiträge zu einer Theorie der Logistik. Springer, Berlin

13. van Hoek RI (1999) From reversed logistics to green supply chains. Supply Chain Manag An Int J 4(3):129–135

14. Rodrigue JP, Slack B, Comtois C (2001) Green logistics. In: Brewer AM, Button KJ, Hensher DA (eds) Handbook of logistics and supply-chain. Pergamon, London, 1st edn., repr., pp 339–350

15. Murphy PR, Poist RF (2003) Green perspectives and practices. Supply Chain Manag An Int J 8(2):122–131

16. Hamilton JD (2009) Causes and consequences of the oil shock of 2007–2008. Brookings Pap Econ Act 1:215–284

17. Roeger W (2005) International oil price changes: impact of oil prices on growth and inflation in the EU/OECD. Int Econ Econ Policy 2:15–32

18. Bachmeier L, Griffin J (2003) New evidence on asymmetric gasoline price responses. Rev Econ Stat 85:772–776

19. Bettendorf L, Van der Geest S, Varkevisser M (2003) Price asymmetry in the Dutch retail gasoline market. Energy Econ 25:175–190

20. Honarvar A (2009) Theoretical explanations for asymmetric relationships between gasoline and crude oil prices with focus on the US market. OPEC Energy Rev 33(3–4):205–224

21. Radchenko S (2005) Oil price volatility and the asymmetric response of gasoline prices to oil price increases and decreases. Energy Econ 27(5):708–730

22. Amiri A (2006) Designing a distribution network in a supply chain system: formulation and efficient solution procedure. Eur J Oper Res 171:567–576

23. Elhedhli S, Goffin J-L (2005) Efficient production-distribution system design. Manag Sci 51:1151–1164

24. Eskigun E, Uzsoy ER, Preckel PV, Beaujon G, Krishnan S, Tew JD (2005) Outbound supply chain network design with mode selection, lead times and capacitated vehicle distribution centers. Eur J Oper Res 165:182–206

25. Jayaraman V, Ross A (2003) A simulated annealing methodology to distribution network design and management. Eur J Oper Res 144:629–645

26. Klose A, Drexl A (2005) Facility location models for distribution system design. Eur J Oper Res 162:4–29

27. Meepetchdee Y, Shah N (2007) Logistical network design with robustness and complexity considerations. Int J Phys Distrib Logist Manag 37:202–222

28. Melkote S, Daskin MS (2001) An integrated model of facility location and transportation network design. Transp Res Part A Policy Pract 35(6):515–538

29. Gosier R, Simchi-Levi D, Wright J, Bentz BA (2008) Past the tipping point. Record oil prices require new supply chain strategies to enable future high performance. http://www.accenture.com. Accessed 11 Apr 2011

30. Cidell J (2010) Concentration and decentralization: the new geography of freight distribution in US metropolitan areas. J Transp Geogr 18(3):363–371

31. Simchi-Levi D, Nelson D, Mulani N (2008) Crude calculations: why high oil prices are upending the way companies should manage their supply chains. Wall Str J, Eastern edn, New York, NY, USA. September 22, 2008, p R.8

32. Andreoli D, Goodchild A, Vitasek K (2010) The rise of mega distribution centers and the impact on logistical uncertainty. Transp Lett Int J Transp Res 2:75–88

33. Paksoy T, Özceylan E, Weber G-W (2010) A multi objective model for optimization of a green supply chain network. In: Third global conference on power control and optimization, 2–4 February. Gold Coast, Australia

34. Wang F, Lai X, Shi N (2010) A multi-objective optimization for green supply chain network design. Decis Support Syst 51(2):262–269

35. Stolletz R, Stolletz L (2008) Linearisierungsverfahren für Standortplanungsprobleme mit nichtlinearen Transportkosten. Zeitschrift für Planung & Unternehmenssteuerung 19(3):261–280

36. HBEFA (2004) Handbuch Emissionsfaktoren des Stra-ßenverkehrs 2.1, INFRAS im Auftrag des Bundesamtes für Umwelt, Wald und Landschaft Bern, des Umweltbundesamtes Berlin, des österreichischen Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, des Bundesmin-isteriums für Verkehr, Innovation und Technologie und des Umweltbundesamts Wien

37. 4flow AG (2010) 4flow vista: white paper. Planning and design of logistics networks

38. Eurostat (2009) Regional gross domestic product (million EUR), by NUTS 2 regions. http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&language=en&pcode=tgs00003&plugin=1. Accessed 13 Mar 2010

39. Heintze A (2008) Der Diesel Schock. Logistik inside 7(9):50