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Costs and Benefits of Green Logistics

4flow Supply Chain Management Study 2013

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Preface

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Dear Reader,

Green logistics is a hot topic in supply chain management and currently part of many discussions about sustainability and innovation. Yet too often it remains nothing more than a fuzzy buzzword. Precise assessments of the costs and effects of concrete green logistics are scarce.

Can logistics contribute to a reduction of greenhouse gas emissions? How much would this cost the companies? These were the two questions that motivated the 4flow Supply Chain Management Study 2013.

We selected realistic cases that combine numerical models, statistical data and logistics expertise to calculate the costs and effects of 11 green logistics measures which would reduce emissions. The cases cover strategic, tactical and operational measures for supply chain planning and operations.

We think the results are quite interesting: Some green logistics measures even save costs. In contrast, other green logistics measures are accompanied by very high extra costs. Which measures save costs and how additional costs compare to the prices of emission certificates is what you will discover in the 4flow Supply Chain Management Study 2013.

This study would not have been possible without the support and passionate commitment of all colleagues involved. We would like to express our respect and appreciation to the entire team for the great result.

We hope you enjoy reading the 4flow Supply Chain Management Study 2013 as much as we have enjoyed preparing it for you.

May 2013
Berlin, Germany

Dr. Stefan Wolff

Wendelin Gross

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Management summary

The 4flow Supply Chain Management Study 2013 unveils how logistics can contribute to a sustainable economy. Using case studies, 11 measures have been evaluated that reduce carbon dioxide equivalent (CO_2e) emissions in strategic and tactical logistics planning. All measures are ecologically sound since they reduce emissions between 1% and 80% in the cases investigated. In seven case studies, the implementation of the measures leads to extra costs of €2,400 to €13,300 per year for each reduced ton of CO_2e. Interestingly, four of the measures can be considered ideal because implementing them saves costs and reduces emissions at the same time.

The four ideal green logistics measures

1. Merging two separately operated inbound networks consisting of several hubs or cross-docks bears potential for emission reduction and cost savings. Consolidated material flow and joint use of existing hubs cause these positive effects. Regarding organizational and compliance challenges, the support of an independent expert is highly recommended.

2. Longer combination vehicles (LCV) are practical on the main haul compared to standard trailers because the efficiency gained through greater payload outweighs the higher emission output of the trucks. A large shipping volume is assumed and external effects or risks such as traffic congestion are neglected.

3. Extending delivery windows at destinations such as retail stores by 30 minutes or more results in better utilization and reduced driving distance of the trucks. Thus, the effects on costs and emissions are positive. The delivery window extension requires the willingness of the supply chain partners to cooperate.

4. Delivering to retail destinations on fewer days per week helps to reduce emissions and save costs. Due to the consolidated shipping volume, delivery trips can thus be performed more efficiently. The availability of goods at the depot and the storage space at the stores are constraining factors.

The road to efficient and sustainable logistics

There is a significant amount of potential cost savings in almost any dynamic logistics network. Frequent or continuous optimization is therefore a necessity. Taking ecological sustainability into consideration when making efficiency decisions can lead to the achievement of both goals at once: more efficient logistics and fewer emissions. Furthermore logistics and supply chain managers are well able to reduce emissions within their domain at relatively high costs. A comprehensive approach must consider these costs in comparison to alternative emission reduction measures in areas such as manufacturing or electricity generation.

Zusammenfassung

Die 4flow Supply Chain Management Studie 2013 verdeutlicht, wie die Logistik zu einer nachhaltigen Wirtschaft beitragen kann. In Fallbeispielen werden elf Maßnahmen aus der strategischen und taktischen Logistikplanung zur Reduzierung von Treibhausgasemissionen (CO_2e) bewertet. Alle untersuchten Maßnahmen sind aus ökologischer Sicht sinnvoll. In den Fallbeispielen können die Emissionen um 1 bis 80 % gesenkt werden. In sieben der elf Maßnahmen führt die Umsetzung zu jährlichen Mehrkosten von 2.400 € bis 13.300 € je reduzierte Tonne CO_2e. Die weiteren vier Maßnahmen werden als ideal beurteilt, weil sie in den Fallbeispielen zu Kosteneinsparungen bei gleichzeitiger Minderung der Emissionen führen.

Die vier idealen grünen Logistikmaßnahmen

1. Die Integration zweier Inbound-Transportnetzwerke, die zuvor unabhängig geplant und betrieben wurden, birgt Potenziale zur Senkung von Kosten und Emissionen. Diese positiven Effekte entstehen durch die Konsolidierung von Materialflüssen und die gemeinsame Nutzung von Umschlagspunkten.

2. Der Einsatz von Gigalinern an Stelle von Standard-Trailern auf Hauptläufen ist in den untersuchten Fallbeispielen ökologisch und ökonomisch sinnvoll. Höhere Zuladung steigert die Effizienz im Transport und kompensiert höhere Kosten und Emissionswerte des größeren Transportmittels. In dem untersuchten Fall wurden hohe Transportmengen veranschlagt und externe Risiken wie Verkehrsstaus vernachlässigt.

3. Das Verlängern von Anlieferzeitfenstern für Abladestellen, beispielsweise an Handelsfilialen, um 30 Minuten oder mehr ermöglicht es, eine höhere Transportmittelauslastung zu erreichen und so die zurückzulegenden Transportstrecken zu reduzieren. Kosten und Emissionen können also reduziert werden, wenn die beteiligten Supply-Chain-Partner bei der Anpassung der Anlieferzeitfenster kooperieren.

4. Eine Reduzierung der wöchentlichen Anliefertage in der Distribution ermöglicht es ebenfalls, Kosten und Emissionen zu senken. Konsolidierungseffekte im Transport führen in diesem Fall zu effizienteren Transporten. Die Verfügbarkeit von Waren an den Depots sowie die Lagerfläche in den Handelsfilialen können den Effizienzgewinn begrenzen.

Der Weg zu einer effizienten und nachhaltigen Logistik

In nahezu jedem dynamischen Logistiknetzwerk gibt es signifikante Kostensenkungspotenziale. Regelmäßige und kontinuierliche Optimierung ist unerlässlich, um diese zu realisieren. Wird zusätzlich ökologische Nachhaltigkeit als Kriterium zur Bewertung von Planungsalternativen berücksichtigt, können beide Ziele erreicht werden: sowohl Kosteneffizienz als auch die Reduzierung von Treibhausgasemissionen.

Darüber hinaus gibt es zahlreiche logistische Maßnahmen zur Verringerung des Schadstoffausstoßes, die mit zusätzlichen Kosten verbunden sind. Ein ganzheitlicher Ansatz sollte bei der Bewertung dieser Kosten auch alternative Maßnahmen berücksichtigen. Dazu zählen Maßnahmen zur Reduzierung von Emissionen in Produktionsbereichen sowie bei der Energiegewinnung.

1 Introduction

1.1 Global warming
1.2 Green logistics
1.3 Selecting measures
1.4 Transportation rates and emissions

1.1 Global warming

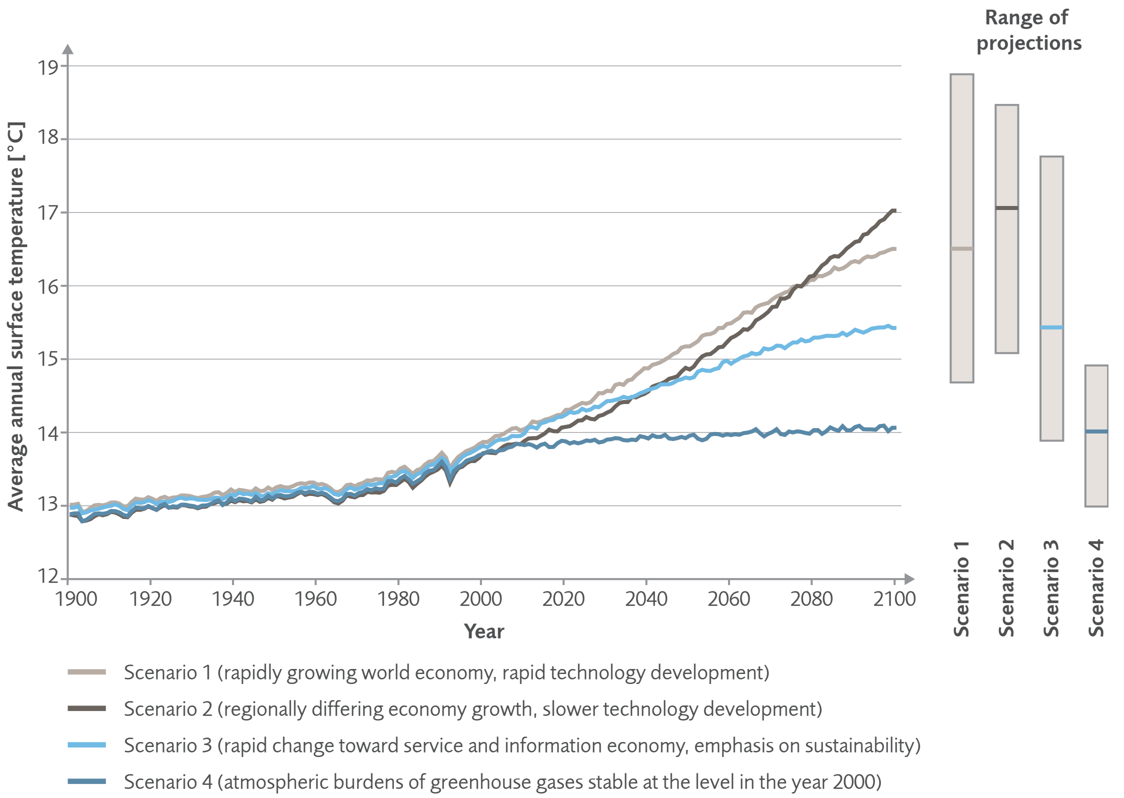


Figure 1: Different projections of average future surface temperature and variations of related simulations[1]

The four scenarios describe significantly different developments of Earth's average annual surface temperature. Each projection is the average of more than a dozen different simulation models with results that vary significantly, as can be seen on the right-hand side of the chart.

Climate change

With the alarming forecasts made by the International Panel on Climate Change[2], global warming is perceived as a major challenge in the 21st century, though projections of Earth's future surface temperature vary greatly (see figure 1). The latest report from the Club of Rome[3] warns that "business as usual" is not an option if we want future generations to live on a sustainable and equitable planet. Many researchers consider human-induced greenhouse gas emissions such as carbon dioxide (CO_2) or methane to be the major drivers of global warming. Therefore, politicians around the world are concerned with reducing emissions, but they have a hard time reaching a consensus on specific reduction goals.

The impact of logistics

Road cargo transportation's contribution to global greenhouse gas emissions is approximately 5% and is expected to grow in the coming years on both a relative and an absolute basis due to increased traffic.[4] This serves as a motivation to find new types of energy-efficient and low-carbon transportation.

Global warming potential

As one of several types of gases emitted, CO_2 has become the focus of most emission reduction measures, with annual emissions amounting to 30.4 gigatons in 2010 and still increasing. In order to compare different gas emissions, the global warming potential (GWP) has become the accepted unit for comparison. It denotes how much heat a greenhouse gas traps in the atmosphere. The reference is 1 kg of CO_2, which is equivalent to 1 GWP. It is also called a carbon dioxide equivalent or CO_2e.

What is 1 t CO_2e?

About 1 t CO_2e is emitted by a fully loaded truck over a distance of 1,000 km (see p. 20). To illustrate this, 1 t CO_2e can be visualized as the number of trees that would be needed to compensate for 1 t CO_2.

A 23-meter beech tree that is 30 cm in diameter at a height of 1.3 m has a mass of about 600 kg. This mass stores about 1 t CO_2. To reach this point, the tree needs to grow for 80 years. Constant growth assumed, it takes 80 beeches to store an annual emission of 1 t CO_2. Assuming a density of 1,000 trees per ha (hectare), an area of trees that equals the size of two basketball courts[5] is required to store the annual emission of 1 t CO_2. Ten tons of CO_2 would require an area the size of a soccer field.

Emissions trading with certificates in Europe

One market-based approach to control pollution is emissions trading with certificates, often referred to as cap-and-trade. A central authority defines a limit for the total amount of emissions in an area for a period of time. This amount is divided among a number of certificates that grant the right to emit a certain amount of pollutants. These certificates are then given to CO_2 emitters, either by auction or for free. They can use these certificates themselves to cover their pollution needs or sell them to other companies who cannot cover their needs with the certificates they hold. The latter is done at a climate exchange where a price is agreed upon for the right to emit 1 t CO_2. Since their introduction in the European Union in 2005, the price has always been below €30 per ton CO_2. In the U.S., the carbon credit price per metric ton of CO_2 peaked at $14.25 in May 2013.

The costs for the emission reduction in the 11 cases investigated in this study were all compared to the price of an emission trading certificate. For this calculation the average certificate price of €7.37 per one ton CO_2 at the IntercontinentalExchange, Inc.[6] of the year 2012 was applied.

1.2 Green logistics

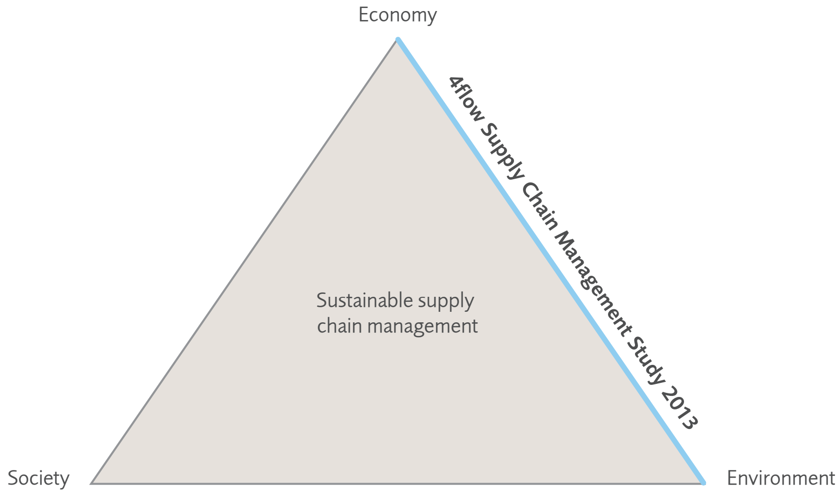


Figure 2: 4flow Supply Chain Management Study 2013 and the triple bottom line

The target system of sustainable supply chain management comprises economic, environmental and social goals. The 4flow Supply Chain Management Study 2013 investigates measures within the concept of green logistics. Economic and environmental sustainability of the measures are evaluated by the means of costs and emissions.

Logistics and sustainability

Logistics is an application-oriented scientific discipline dealing primarily with questions on the configuration and organization of networks transporting goods as well as the mobilization and control of flows. The ultimate goal of logistics is the balanced achievement of economic, ecological and social objectives.[7] This set of aims is also referred to as the triple bottom line.[8]

The joint consideration of these three objectives makes the measurement of goal achievements almost impossible due to the goal conflicts that arise and the different fields of action.[9] This study therefore considers economic and ecological objectives jointly. Economic objectives are represented by cost considerations, whereas ecological objectives are represented by greenhouse gas emissions. By focusing on these two goals, the study addresses the ongoing discussion on the broad topic of green logistics.

"Green" has become the word of choice to describe activities connected to environmental awareness such as actions that aim to reduce the impact of mankind on the environment. Green logistics deals with the production and distribution of goods in a sustainable way while also taking environmental and social factors into account.[10] This approach can be applied to the standard fields of logistics from the strategic to the operational level. These fields include network design, choice of transportation mode, warehousing problems, container management, and routing. The incorporation of environmental objectives into the classic solutions to these problems opens a new perspective on well-known trade-offs such as between delivery frequency, utilization, and inventory levels.

Green supply chain management

Green supply chain management comprises a large set of very different research fields such as green manufacturing and remanufacturing, reverse logistics, network design, waste management, life cycle assessment and others.[11] These research fields need to be distinguished from purely technical approaches to fuel reduction in vehicles such as making improvements to engines or tires.[12] In contrast, this study focuses on the core fields of logistics with the classic domains of transportation, transshipment and warehousing. Examples of measures from green logistics were explored concerning their ratio of implementation cost to effective emission reductions.

1.3 Selecting measures

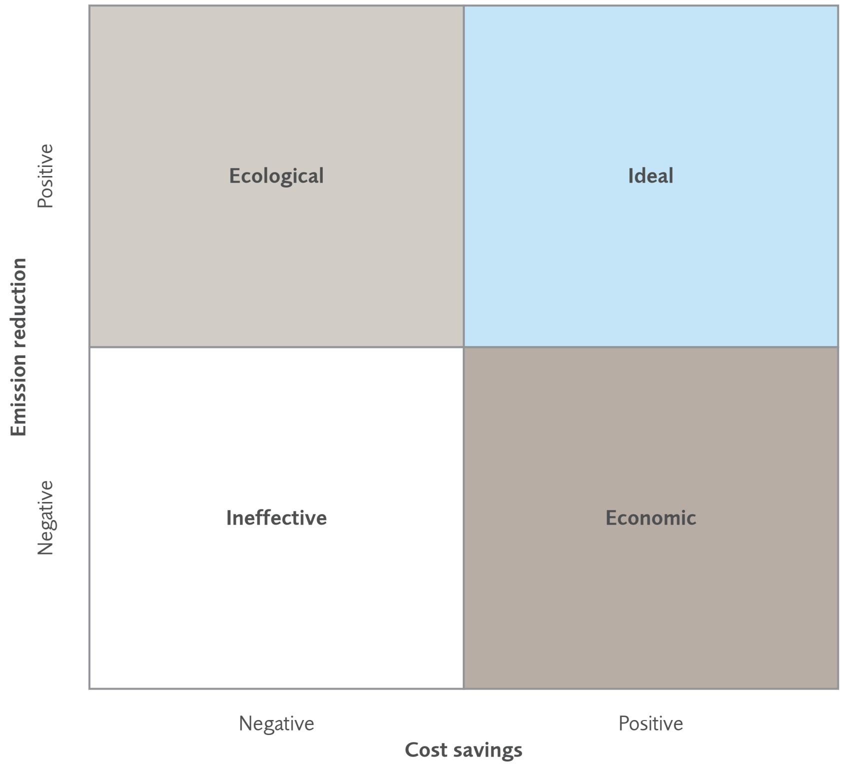


Figure 3: Categorization of measures according to their monetary and ecological impact

Measures can be categorized by their effectiveness in reducing costs and emissions. Ideal measures reduce both, while ecological and economic measures reduce emissions or costs respectively. Inefficient measures should be avoided at all times. The focus of this study is on ecological and ideal measures with positive emissions reductions.

Four types of measures

Green measures for reducing CO_2e emissions often lack a consideration of their cost effects. Usually, companies tend to implement cost-saving measures instead of measures that could increase costs. From an environmental perspective, measures that reduce emissions are worth implementing, while measures that increase emissions should be avoided.

Accordingly, measures can be grouped in a matrix with four categories (see figure 3). Ideal measures combine the best of both worlds: saving costs and reducing emissions. Economic measures can reduce cost at the expense of increased emissions. Analogously, ecological measures can reduce emissions at a certain cost. The ratio of cost to emissions for measures in this category can be compared to the price of 1 t of CO_2e at an emissions exchange to gain insight into the efficiency of the emission trading system or to find the most economic way to reduce emissions. Ineffective measures would increase costs as well as emissions and should therefore be avoided from an economic and an ecological point of view. Each measure could also be in more than one field, depending on the underlying parameters.

In this study, we looked at measures that are generally believed to reduce emissions while the cost effect might not be obvious at once. Only logistics measures were considered; technical improvements to engines, fuel or the like were not considered since they do not require logistics expertise.

The measures serve as concrete and representative examples of the three levels of logistics: strategic, tactical and operational. They are applied to real-world logistics scenarios and can be transferred to other settings. Other measures in green logistics that go beyond mere technical improvements are imaginable. Future research could explore additional measures that were not within the scope of this study.

The measures were grouped into four categories and explained in the following chapters:

Designing networks differently
- Eco-efficient network design
- Merging networks

Relocating production
- Backshoring
- Local production
- Local sourcing

Rethinking trucks and boxes
- Shifting from road transportation to intermodal transportation
- Shifting from standard trailers to longer combination vehicles (LCV)
- Switching from returnable to disposable containers

Considering routing and time restrictions
- Reducing driving speed
- Delivering less frequently
- Extending delivery windows

1.4 Transportation rates and emissions

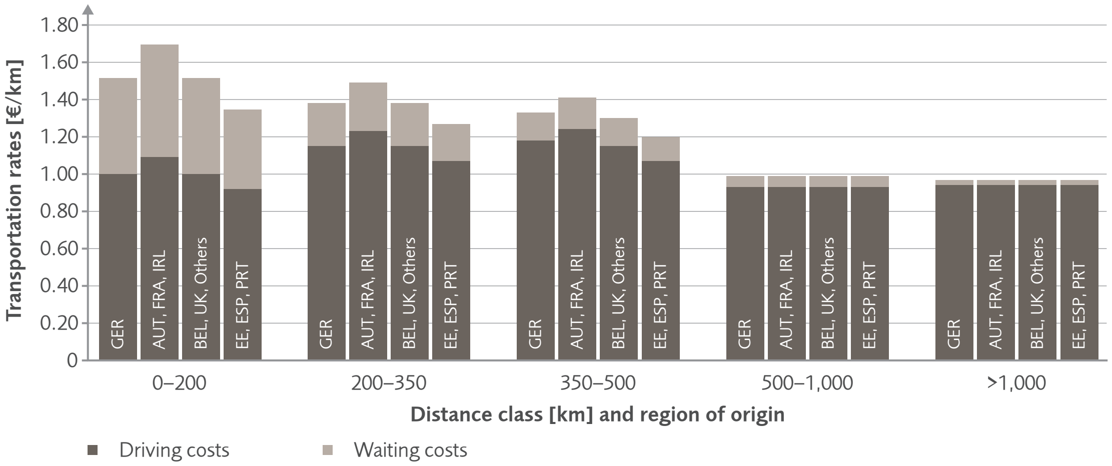


Figure 4: Transportation rates differ by region of origin and distance

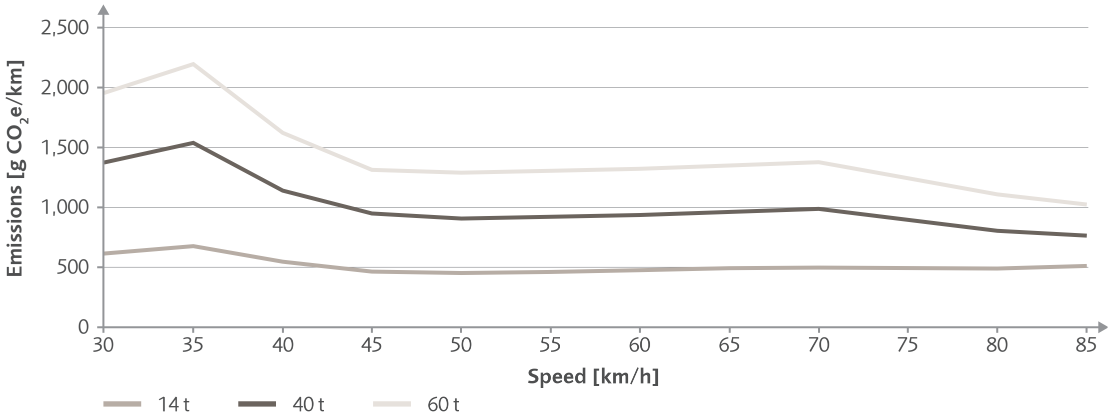


Figure 5: Emissions for several types of vehicles

The transportation rates were distinguished by region of origin and the distance from source to destination. Two sets of rates have been created for full truck loads (FTL) and less-than-truckload (LTL) shipments assuming that both rates are equal at a utilization of 60% of loading meters. While the cost data have been taken from an internal benchmark database, the emissions data were derived from the HBEFA database.[13]

Transportation rates

We derived the transportation costs in this study using data from an internal benchmark database. The rates were distinguished by region of origin and the distance from source to destination for FTL and LTL shipments.

The FTL rates are the linearized result of a formula considering different cost types including the fuel cost and capital cost for different means of transportation, repositioning risk, indirect costs, labor cost, and driving time. Values based on empirical data were used for all of these costs. For the frequency of shipments, customers' service level requirements for inbound and outbound transportation were considered individually. The resulting cost function can be seen in figure 4. The LTL rates, which rise linearly with loading quantity, were derived from the FTL rates assuming that both rates are equal at a utilization of 60% of loading meters.

Evaluating emissions

For the evaluation of transportation-related emissions, two main references were compared before the study. HBEFA 2010 is based on a large set of experiments, whereas DIN EN 16258[14] is a standard for calculating energy consumption and greenhouse gas emissions in transportation services. The experiment-based reference, HBEFA, has a longer track record and also provides fuel consumption data for several vehicle classes and traffic situations. The standard draft does not contain information on fuel consumption; other sources would have been needed for such information. Therefore, we decided to include data from the HBEFA 2010. Figure 5 illustrates the dependency of emissions and driving speed as stated in HBEFA 2010.

Means of transportation

In chapters 2 to 4, standard trailers with a total truck weight of 40 t including tractor and trailer were used for road transportation. The payload is 25 t for the standard trailer measuring 13.6 m long, 2.45 m wide and 2.6 m high, which amounts to a volume of 87 cubic meters (cbm) and a capacity of 68 pallets (stacked). In chapter 5, the routing measures were calculated with trucks that have a payload of 14 t and a volume of 40 cbm.

2 Designing networks differently

2.1 Eco-efficient network design

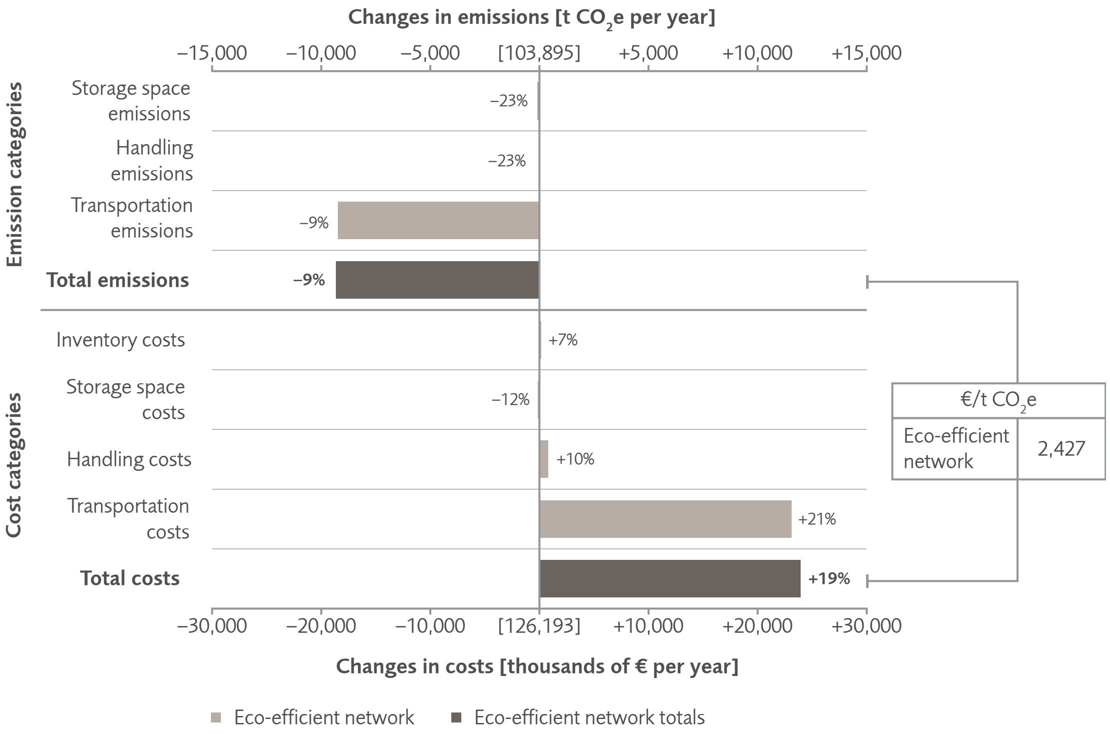


Figure 6: Potential reduction of emissions and increase of cost in the case considered

Eco-efficient network design is a strong lever to reduce emissions. Up to 9% of total emissions were reduced in the case considered. The total costs, however, increased sharply and accounted for approx. €2,500 per reduced ton of CO_2e. Transportation costs far outweighed handling and facility costs as well as emissions.
Cost-efficient network design tended more toward decentralized material flow than eco-efficient design since the transportation cost per km decreased while emissions per km remained constant. The total distance in the sample of the eco-efficient network was more than 107,000 km as compared to 138,000 km in the cost-efficient configuration. The utilization of trucks, however, was generally better in the cost-efficient network.

x 329

Reducing 1 t CO_2e with this measure is up to 329 times more expensive than the price of one emission permit.

Results

Costly eco-efficient network

A supply chain networks' costs, efficiency and ecological footprint are determined to a great extent during the network design phase. Today, networks are usually designed to minimize costs at a given service level. Shifting from this paradigm to a network design focused on minimal emissions instead is a costly yet potent measure to reduce emissions. In the sample case of an automotive original equipment manufacturer's (OEM) procurement hub network, emissions were reduced by up to 9% per year. Each ton of reduced CO_2e was accompanied by increased annual costs of €2,427.

Comparing two network configurations

The most cost-efficient and the most eco-efficient network configuration for a given demand and supply setting were compared. For both networks, the optimal configuration would be six hubs that serve ten production plants spread across Europe. The hub locations are only slightly different; the allocation of plants and suppliers to hubs varied greatly. In the cost-efficient network, material flow from suppliers to production plants was consolidated to maximize truck utilization. In the emission-efficient network, material flow was decentralized and suppliers are allocated to the closest hub to minimize the total transportation distance.

Most efficient solution depends on shipping rates

Transportation outweighs warehousing and handling both in terms of costs and emissions. Due to the linear increase of emissions parallel to transportation distance, the emission-efficient network structure was resilient to changes in emissions factors such as the use of another type of truck. Transportation costs, however, decreased per km with increasing distance. Thus, shipment rates have a major impact on the costs and savings of an eco-efficient network design. The stronger the regression, the greater the possible reduction of emissions through network redesign.

Reducing emissions without hub relocation

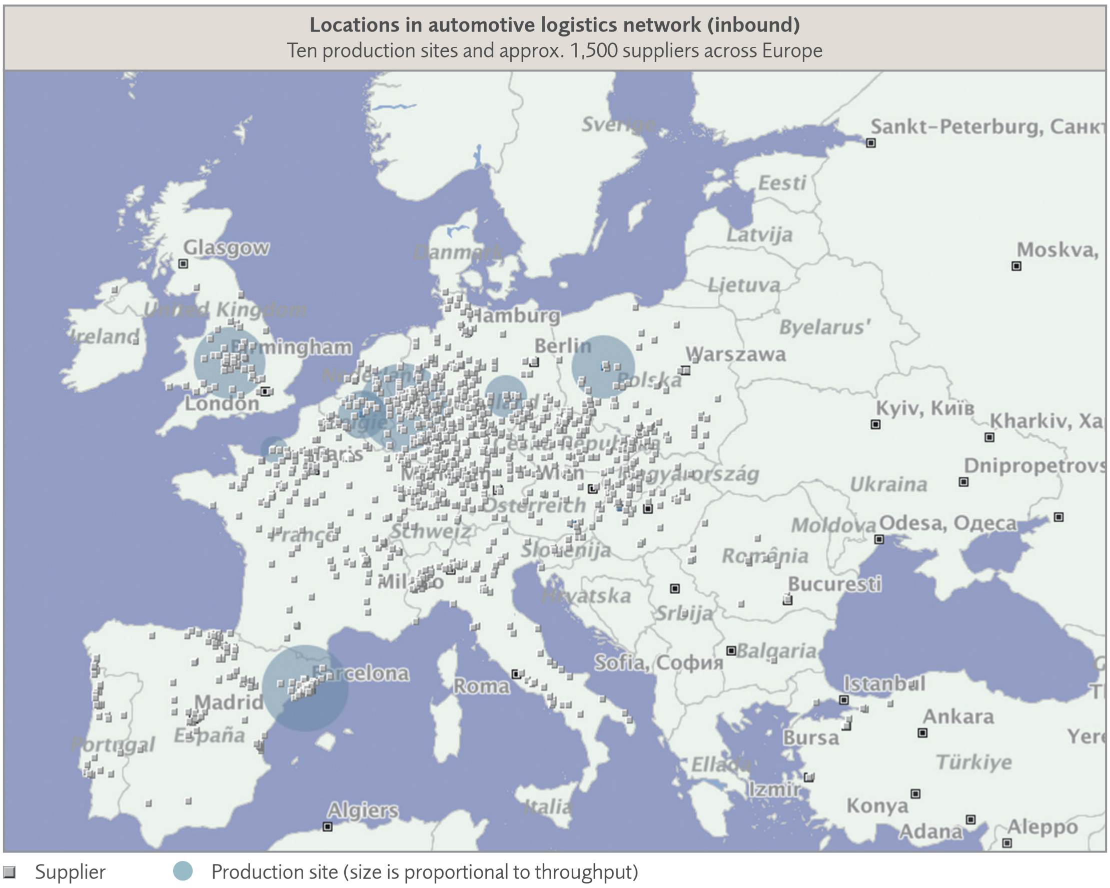
The allocation of suppliers and plants to the hubs effectuates the trade-off between cost-efficient and eco-efficient networks. Strategic allocation decisions define both supply chain costs and emissions. However, such decisions do not necessarily require investments such as new locations if the hubs can handle different material groups. This implies that a network designed for cost efficiency can be transformed – even gradually – towards ecological efficiency through reallocation. The challenge is finding a balance between cost-efficient and eco-efficient network design to improve supply chain sustainability and maintain network competitiveness.

In aller Kürze

Netzwerkplanung als Maßnahme zur Emissionsreduktion

Der Großteil der Kosten und der Emissionen wird bereits bei der Planung von Logistiknetzwerken festgelegt. Die Ausrichtung des Netzwerks auf minimale Emissionen ergab im untersuchten einstufigen Beschaffungsnetzwerk eine Reduktion der Emissionen um bis zu 9 % im Vergleich zum kostenoptimalen Netzwerk. Die Einsparungen waren jedoch mit hohen Mehrkosten von 2.427 €/t CO_2e verbunden. Es zeigte sich, dass in bestehenden Netzwerken Emissionen ohne aufwändige Neuplanung der Standorte allein durch die Re-Allokation von Lieferanten und Werken zu den Hubs eingespart werden können.

Eco-efficient network design:
How we achieved these results


Locations in automotive logistics network (inbound)
Ten production sites and approx. 1,500 suppliers across Europe

▪ Supplier ● Production site (size is proportional to throughput)

Figure 7: Baseline network for comparing cost-efficient and eco-efficient configurations (Source: 4flow vista®)

The network was optimized in two different ways: in the first scenario, the number of hubs and their position were determined minimizing transportation cost; in the second scenario, instead of costs, emissions were minimized while choosing the optimal number and position of the hubs.

Methodology

Automotive inbound network case studies

The transportation of goods in supply chain networks can be performed in a variety of different configurations. In a one-stage inbound network, these configurations are characterized by the degree of centralization, which reflects the total number of hubs, their regional distribution and the allocation of suppliers and plants to the hubs.[15]

The data used in the case study was derived from real-world inbound supply chains in the automotive industry. We looked at a network model of ten production plants in Austria, France, Germany, Spain, Poland and the United Kingdom as well as roughly 1,500 European suppliers. In total, approximately 1.8 million pallet-sized containers are shipped through the network per year.

A one-stage hub network was chosen in order to assure the required daily delivery to the plants. Costs and emissions for transportation, handling of material, stock, floor space, and energy consumption for lighting and heating of the hubs were considered. The data was based on a literature survey which considered regional differences in wage level and emissions caused by electric energy production. Since the inbound shipments occur weekly and outbound delivery takes place daily, the hubs have inventory on hand. The material in transit is included in the capital cost calculation.

Sensitivity analysis of two scenarios

We developed two scenarios based on the demand and cost data. In the first scenario, the network hub location and allocation were optimized according to transportation costs. Then, taking the frequency of shipments into account, the hubs were relocated to the optimal position. The built-in optimization algorithms in 4flow vista®, the integrated software for supply chain design, were applied for both steps. A set of seven networks with two to eight hubs was built following this procedure.

In the second scenario, another set of seven networks was constructed using emissions instead of costs for the optimization and relocation phase. Again, 4flow vista® was applied. Finally, the most cost-efficient network and the most eco-efficient network were compared in detail, taking costs and emissions into account.

2.2 Merging networks

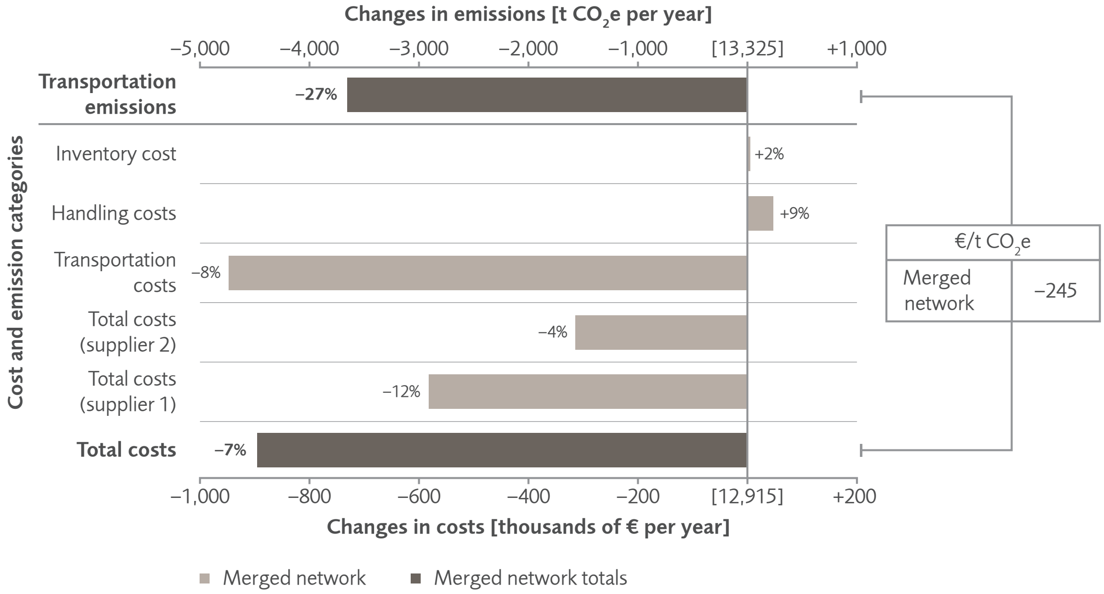


Figure 8: Changes in costs and emissions compared to baseline scenario

Independent automotive suppliers reduced costs and emissions in inbound logistics significantly with a collaborative approach by using joint hub networks. Costs were reduced through better utilization of shipments from hubs to assembly plants; inter-hub shipments were only slightly more efficient since their utilization was already high in the baseline scenario with their use of independent hub networks. The economic and ecological advantages were not distributed equally among the partners, but each partner was much better off than in the baseline scenario. This supports the case for working with a neutral fourth party logistics provider (4PL) that can balance the network utilization optimally.

x 33

The cost savings from reducing 1 t CO_2e with this measure is up to 33 times greater than the price of one emission permit.

Results

Increased efficiency through cooperation

A popular assumption is that a higher volume of shipments will result in lower transportation rates from logistics service providers (LSPs). Efficiency can improve through better routing and higher truck utilization on the part of the LSP. At the same time, increased efficiency leads to reduced emissions. This hypothesis was confirmed in this case in which two independent automotive parts suppliers agreed to use a joint hub network to improve their inbound shipment situation.

Joint networks reduce costs and emissions

Emissions related to transportation were decreased by 27% in the merged network. This was achieved by improving utilization of daily shipments from hub to plant. The total cost was reduced by 7% at the same time, resulting in savings of €245/t CO_2e.

Utilization of shipments from hubs to assembly plants increased by nearly 50%

The average utilization of hub to plant shipments in the independent networks was 33%, due to the need for daily shipments to the plant. It was improved to 49% in the joint network. This effect originates in the larger set of possible routings through the network allowing for the selection of a hub closer to the plant. By selecting a hub that was not available in the partner's original network, the total number of km driven from hub to plant was reduced by 54%.

Increased number of inter-hub shipments

The utilization of trucks on inter-hub shipments improved from 90% in the baseline scenario to 94% for transportation links that already existed in one of the independent networks. When new shuttles between hubs were created that did not exist in the independent networks, an average utilization of 49% was achieved. The average utilization of all inter-hub shipments decreased to 71%. Yet, since only the shipment frequency was optimized and the location of all hubs remained the same, there is still room for improvement through more strategic measures such as hub relocation in the joint network. This would require even more cooperation among the suppliers.

A case for 4PL

The results of this case study confirm the assumption that more transportation volume handled by an individual provider would allow for a better utilization of shipments and thus lower costs and emissions. A promising approach to transportation management is outsourcing to a 4PL.

In aller Kürze

Integration von Netzwerken

In der Regel führt ein höheres Transportvolumen zu besseren Konditionen bei Logistikdienstleistern und hilft, Emissionen zu reduzieren. Im vorliegenden Fallbeispiel wurde untersucht, wie sich die Integration der Beschaffungsnetzwerke zweier Automobilzulieferer zu einem gemeinsamen Netzwerk auswirkt, in dem die Hubs beider Partner auch für Transporte des anderen Partners zur Verfügung stehen. Für die Optimierung wurden die Zuordnung zu Hubs und das Routing durch das Netzwerk verändert. Die Maßnahme führte im vorliegenden Fall zu erheblichen Einsparungen von 7 % der Gesamtkosten und 27 % der Emissionen.

Merging networks:
How we achieved these results

Baseline scenario

Independent network supplier 1

Independent network supplier 2

Alternative scenario

Merged network of both suppliers

Figure 9: Supplier and hub locations of independent and merged networks (Source: 4flow vista®)

The independent inbound hub networks of two suppliers were merged to allow each partner the use of the other partner's hubs. Hubs were not relocated; instead, optimization was performed by re-assessing the delivery transportation frequencies and routing through the hub network.

Methodology

Two independent automotive suppliers

Two suppliers, each with their own hub network, planned to cooperate to improve their inbound logistics. They provided mutual access to their respective hub network without having to relocate or close any existing hubs.

The partners are not equal in size: one partner had about 70,000 t of inbound shipments per year through hubs, while the other had approximately half this amount. Their production plants were located relatively far apart at different sites in Europe, and their respective second-tier suppliers were scattered across Europe (see figure 9).

Baseline scenario

The independent networks were based on the real-world data of two global Top 20 automotive suppliers. Each second-tier supplier and each plant were assigned to the closest hub based on road distances. Then, the parts from the respective second-tier supplier of each partner were routed through the hub network using the optimization algorithm in 4flow vista®. The minimum frequency of shipments from hubs to plants was one per day, while the frequency of inter-hub shipments was fixed at three shipments per week. Second-tier suppliers ship to the hub once a week. Considering these constraints, the optimum number of shipments was calculated. The networks were simplified by removing shipments to hubs that have a utilization greater than 90% since consolidation effects cannot be expected for these shipments. The resulting networks for both partners are referred to as the baseline scenario.

Merge and reoptimize

The independent networks that were optimized previously were merged into a joint network with all suppliers, hubs and plants. Again, each second-tier supplier and each plant were assigned to the closest hub and parts were routed optimally. The mathematical optimization algorithm makes use of additional consolidation effects thanks to the increased transportation volume. It takes transportation costs, inventory costs and handling costs into account. It was assumed that each hub can be used by both companies without major adjustments to the infrastructure.

Modeling and optimization were performed using 4flow vista®. In addition to transportation costs, inventory costs and handling costs were considered as well.

3 Relocating production

3.1 Backshoring

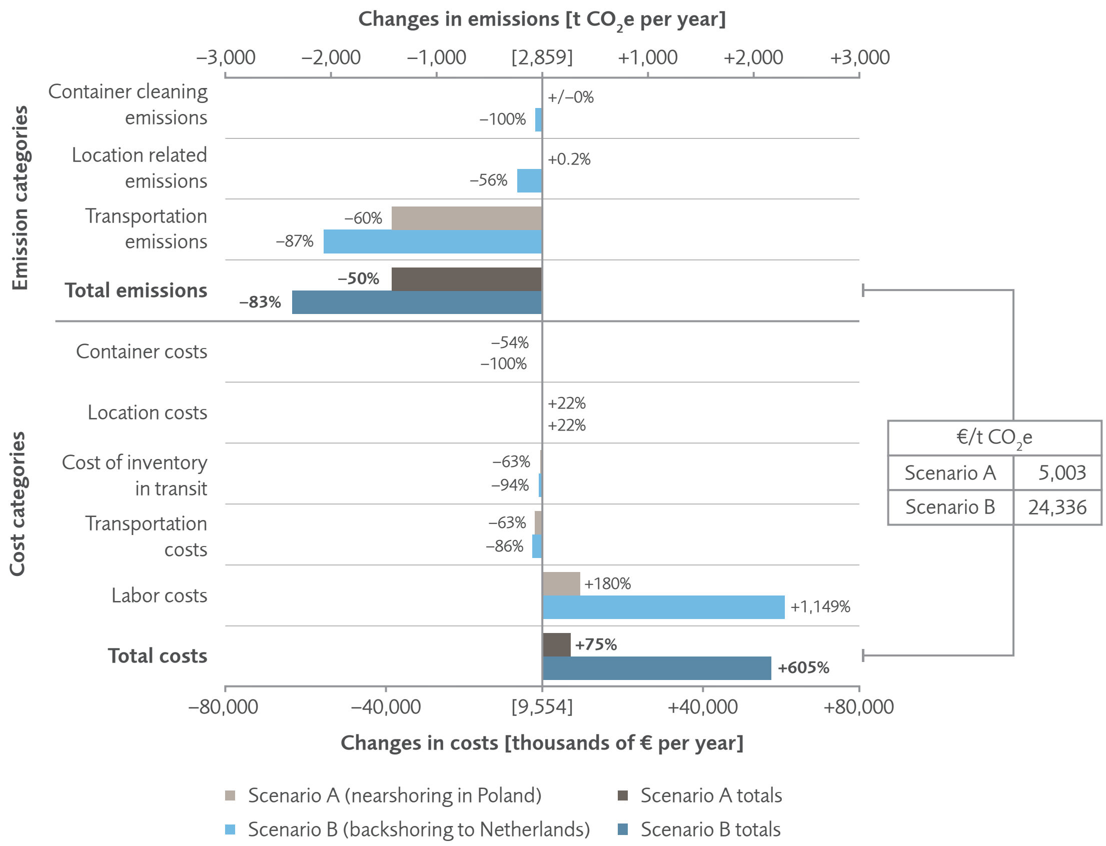


Figure 10: Changes in costs and emissions compared to baseline scenario where shrimp are peeled in Morocco

The labor costs at the new sites were dominant in both relocation scenarios and led to a strong increase in total costs. Therefore, the reduction of emissions by 1,400 t per year in the nearshoring scenario to 2,400 t in the backshoring scenario came with extra costs of €5,000 to €24,400 per t CO_2e. The additional labor costs exceeded the cost savings due to the reduction in transportation expenses and inventory holding costs in both comparison scenarios.

x 679

Reducing 1 t CO_2e with this measure is up to 679 times more expensive than the price of one emission permit.

Results

Reverse offshoring for reducing emission

Growing international competition has led companies to relocate working processes to low-wage countries thereby increasing transportation distances in their logistics network. In this case, offshore processes are brought back to a high-wage country (backshoring) and to a nearby medium-wage country (nearshoring) to realize emission saving potential. In the baseline scenario, a European seafood processing firm operates a shrimp peeling factory in Tetouan, Morocco. The effects on cost and emission of moving the peeling factory to Poznan, Poland and to the company's site in the Netherlands are calculated.

Forgo wage cost advantages for emission reductions

In both scenarios, emissions were reduced significantly. Moving the shrimp peeling to Poznan reduced emissions by more than 1,400 t CO_2e a year. Eliminating the additional shipment to the nearshore location by moving the site to the Netherlands leads to almost 2,400 less t CO_2e each year – a reduction of 83%. These ecological advantages are accompanied by economic drawbacks. When the site is moved to Poznan each ton of CO_2e costs €5,000. Despite the higher potential reduction of emissions, the cost of reducing one ton of CO_2e in the backshoring scenario is above €24,000.

Wage level dominates total cost

The total emission savings in the nearshoring and backshoring scenarios are based on the reduction of transportation emissions while labor costs are the main driver of total costs (see figure 10). In the applied model, the labor costs are influenced by the wage level and the hours worked at the peeling site. Since peeling shrimp requires several workers, wages are the key parameter in the total cost assessment.

A reduced transportation distance entails not only lower transportation costs and transportation emissions but also leads to less inventory and container costs due to shorter transit times. The decline in location-related emissions and container cleaning emissions in the comparison scenarios are caused by the country-specific carbon emission factors.

Why backshoring is worth considering

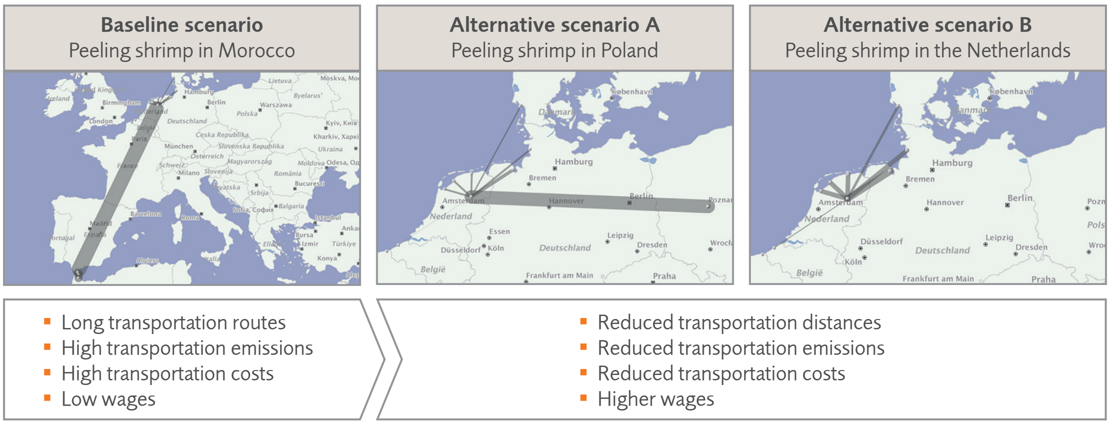
Although nearshoring and backshoring are clearly ecological yet costly measures in the selected cases, the positive potential of the measure should not be neglected. Even in the given cases, the results vary heavily while the distance between nearshoring location and backshoring location is less than 900 km. The cost disadvantages of backshoring diminish as transportation expenses and labor expenses converge.

In aller Kürze

Rückverlagerung von wertschöpfenden Tätigkeiten in Hochlohnländer

In den betrachteten Fallbeispielen wurde die Kosten- und Emissionswirkung für die Verlagerung eines Krabbenschälzentrums aus Marokko nach Polen und in die Niederlande quantifiziert. Bei der Rückverlagerung der Produktion entstehen höhere Arbeitskosten, die trotz gesenkter Transportkosten und Bestandskosten nicht kompensiert werden. Die Einsparung von Emissionen durch Rückverlagerung wertschöpfender Tätigkeiten nach Polen kostete in dem Fallbeispiel 5.000 €/t CO_2e, eine Verlagerung in die Niederlande sogar 24.400 €/t CO_2e.

Backshoring:
How we achieved these results



Baseline scenario
Peeling shrimp in Morocco

Alternative scenario A
Peeling shrimp in Poland

Alternative scenario B
Peeling shrimp in the Netherlands

- Long transportation routes
- High transportation emissions
- High transportation costs
- Low wages

- Reduced transportation distances
- Reduced transportation emissions
- Reduced transportation costs
- Higher wages

Figure 11: Scenarios for comparing an offshoring solution to nearshoring and backshoring (Source: 4flow vista®)

Comparing three scenarios, it is shown how cost and emissions change as offshored activities are relocated to a country with high wage costs. In the baseline scenario, a shrimp trading firm ships shrimp to Morocco to have them peeled. In the alternative cases the shrimp are peeled in Poland and at the company's transshipment point in the Netherlands.

Methodology

Three scenarios modeled

In order to highlight the effects backshoring has on costs and emissions, a baseline scenario was defined in which a shrimp trading firm buys shrimp from fishermen at the North Sea, consolidates the shrimp at its location in the Netherlands, and ships the consolidated volume to Morocco to have the shrimp peeled. The shrimp is hauled to Spain in chilled standard trailers, it crosses the Strait of Gibraltar on a car-ferry, and continues the trip to the peeling facility.

In the two alternative scenarios, the peeling facility is relocated to a location in Poland (nearshoring) and to the company's transshipment point in the Netherlands (backshoring). In the nearshoring scenario, the ferry transfer is omitted and the distance to the peeling facility is reduced. In the backshoring scenario, the peeling process is executed directly at the transshipment point.

It is assumed that the trading company buys 9,700 t of unpeeled shrimp per year at the North Sea.[16] After peeling the shrimp, 30% of the weight is shipped back as shrimp meat. The load is shipped in plastic containers combined to loading units on pallets in both directions.

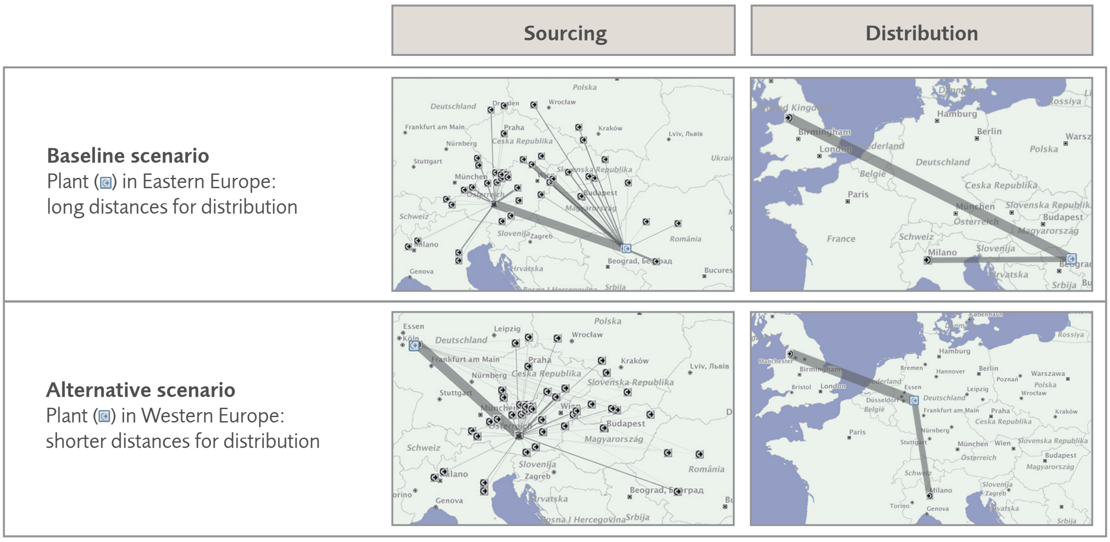
Emission drivers

In addition to transportation emissions, the emissions due to cooling are calculated, also considering the average consumption of diesel for powering the cooling aggregate and emissions effects caused by coolant loss. The emissions caused by the ferry is determined by taking its consumption of heavy fuel oil into account. The container-washing emissions and location-related emissions are derived from the estimated average energy consumption. Country-specific carbon emissions factors are applied to the calculation.[17]

Cost factors

For all road transportation, rates were expected to rise by 3% in comparison to the road transportation rates introduced in chapter 1 due to the required cooling equipment. The ferry rate applied is in line with the current market price. The labor cost for the Netherlands and Poland are calculated considering the country specific minimum wage and factors for incidental wage cost and overhead expenses. The labor cost factors were set at €1.64/h in Morocco, €4.60/h in Poland, and €20.53/h in the Netherlands.[18] Additional incidental labor costs and overhead expenses are incorporated. To estimate inventory costs, the value of shrimp in transit is determined based on wholesale and retail prices.[19] The location cost includes material handling costs, country-specific floor space costs as well as energy costs computed from the estimated energy consumption at the peeling site and country-specific energy rates.

3.2 Local production



Baseline scenario
Plant (▣) in Eastern Europe:
long distances for distribution

Alternative scenario
Plant (▣) in Western Europe:
shorter distances for distribution

Figure 12: Relocating the plant affects transportation flows for sourcing as well as distribution (Source: 4flow vista®)

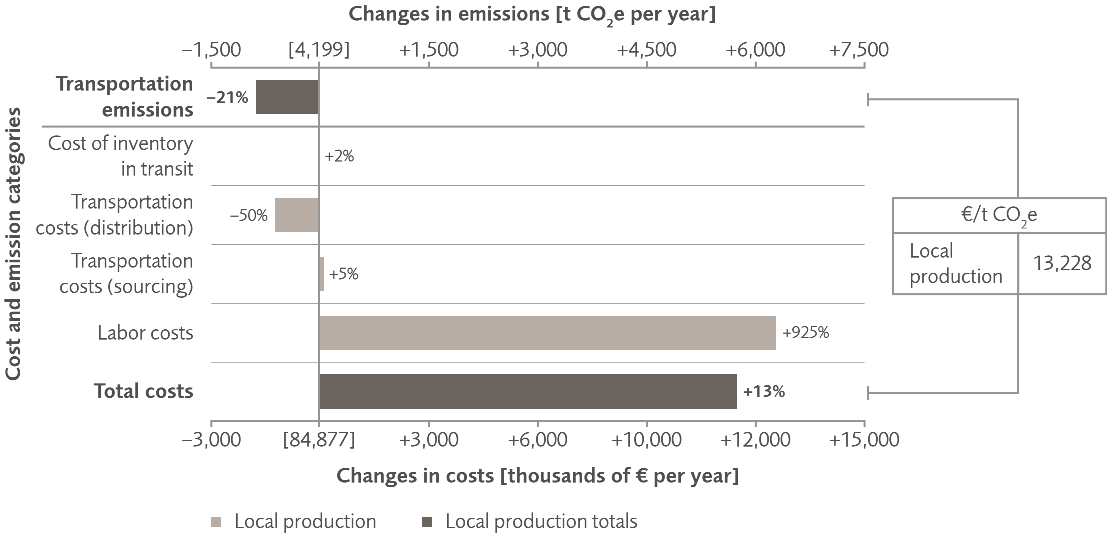


Figure 13: Costs and emissions compared to the baseline scenario with production in Romania

What impact does the relocation of a production site from Eastern Europe to Western Europe have on emissions and costs? In the case considered, we looked at a plant located in Romania which produces automotive equipment and shifted it to Western Germany, closer to the two main clients.

x 1795

Reducing 1 t CO_2e with this measure is up to 1,795 times more expensive than the price of one emission permit.

Results

Moving a plant from Romania to Germany

Based on the real-world network of a first-tier supplier in the automotive industry, we analyzed the baseline scenario in which a plant is located in Romania, a country with relatively low wage levels compared to Germany. Its suppliers are dispersed across Central and Eastern Europe, but shipments to the plant were consolidated at one central hub. The plant serves two main customers in Italy and the United Kingdom with 190,000 parts per year. In the alternative scenario, we moved the plant to Western Germany. The networks are visualized in figure 12.
Labor costs for Romania and Germany differ by a factor of almost ten.[21] A part price of €500 has been assumed with a labor cost share of 15%.[22] Producing each part thus costs €66 more in Germany than in Romania.

In calculating the cost-to-emissions ratio of plant relocation, transportation costs for sourcing and distribution as well as the inventory carrying cost and production cost were considered and correlated to transportation emissions. Emissions from production are not considered since the energy mix in the plant was considered to be constant.

Less transportation costs, but higher labor costs

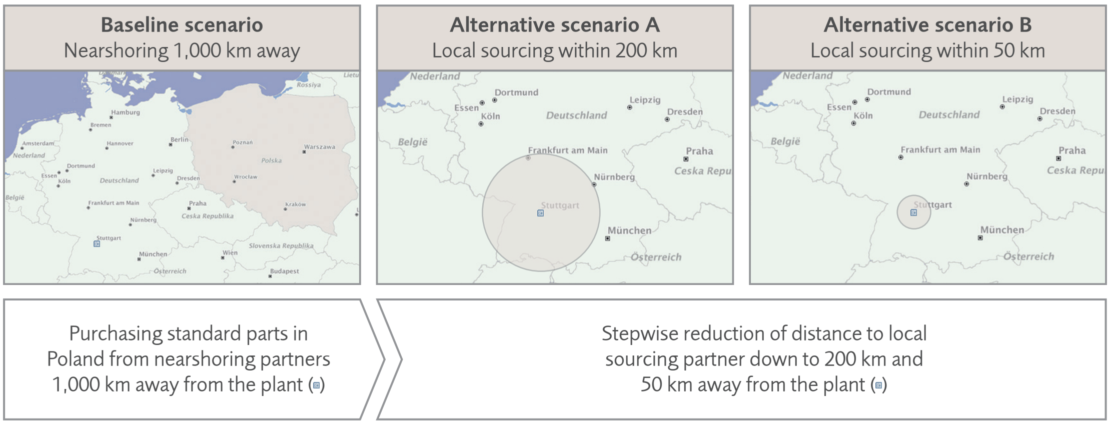
In the case considered, producing items closer to the final customer decreased the freight transportation output measured in ton-kilometers on the distribution side by almost 50%. Due to the topology of the supply network, the distances to suppliers scattered across Europe (thus the number of km driven) increased by only 5%. This resulted in a potential reduction in emissions of 860 t CO_2e. Yet, the large difference in labor costs between Eastern and Western Europe led to an increase in total cost of 13% or €11.5 million. This makes the measure very costly: each reduced ton of CO_2e comes at a price of more than €13,000.

In aller Kürze

Lokale Produktion eines Automobilzulieferers

Für einen Automobilzulieferer wurde die Verschiebung eines Werks, das zwei große Kunden in Großbritannien und Italien beliefert, von Rumänien nach Westdeutschland untersucht. Auf der Distributionsseite konnte durch diese Maßnahme rund die Hälfte der Transportkilometer eingespart werden, während auf der Beschaffungsseite lediglich 5 % mehr Transportkilometer anfielen. Der hohe Lohnkostenunterschied führt jedoch zu einer Gesamtkostenerhöhung von 13 % oder 11,5 Mio. €, sodass die möglichen Emissionseinsparungen von 860 t CO_2e einen Preis von 13.300 €/t CO_2e hätten.

3.3 Local sourcing of standard parts



Baseline scenario
Nearshoring 1,000 km away

Alternative scenario A
Local sourcing within 200 km

Alternative scenario B
Local sourcing within 50 km

Purchasing standard parts in Poland from nearshoring partners 1,000 km away from the plant (▣)

Stepwise reduction of distance to local sourcing partner down to 200 km and 50 km away from the plant (▣)

Figure 14: Local sourcing of standard parts explored in two alternative sourcing scenarios (Source: 4flow vista®)

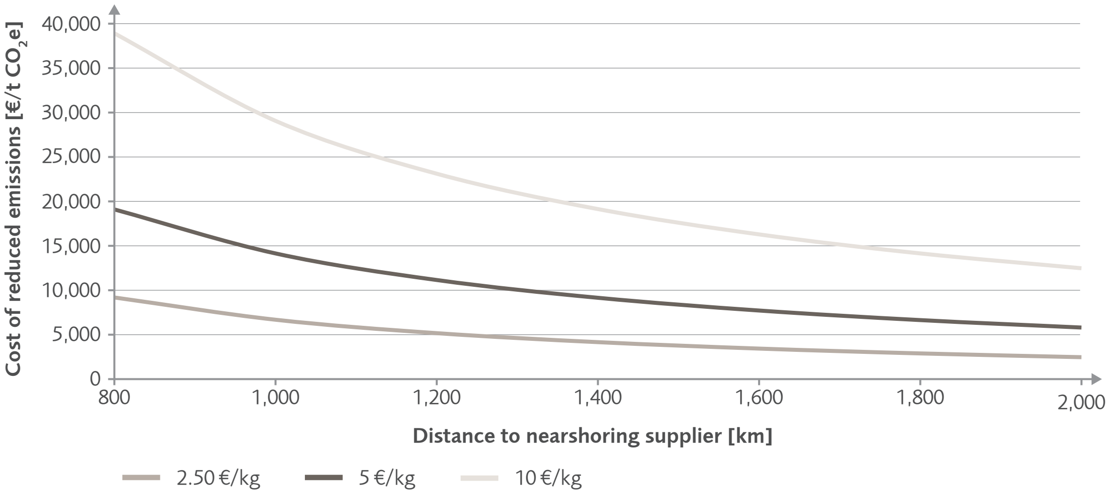


Figure 15: Overview of costs per reduced ton of CO_2e depending on distance and item prices

In the baseline scenario, standard parts were sourced from Poland and sent to Germany. To examine the effect local sourcing would have on cost and emissions, two alternative scenarios for local sourcing from the suppliers to the plant were tested, each with different distances. We carried out the analysis assuming three different item prices. The chart denotes the price per ton of parts.

x 905

Reducing 1 t CO_2e with this measure is up to 905 times more expensive than the price of one emission permit.

Results

Local sourcing of standard parts

There are many suppliers for standard parts such as screws and nuts in most industrialized countries. Because of this standardization, the main differences are in price. Therefore, expanding the pool of possible suppliers for these parts enables buyers to obtain lower purchase prices.

Usually, a total cost of ownership approach is pursued, which not only considers the item price but transportation and other logistics costs as well. This approach does not necessarily favor suppliers located close to the buyer's assembly plant since transportation costs make up a relatively small share of overall cost.

Three sourcing scenarios

In the initial scenario, a plant in Southern Germany sourced standard parts in Poland at an average distance of 1,000 km. We devised two additional scenarios where suppliers were situated at an average distance of 50 km and 200 km from the plant. A sensitivity analysis explored the effect distance has on the price per reduced ton of CO_2e.

Three cost scenarios

Three distinct weight-dependent item prices for standard parts ranging from €2.5/kg to €10/kg for sourcing in Poland were used in the calculation model. For sourcing in Germany a surcharge of 10% was assumed. A sensitivity analysis for the difference in price levels between the baseline sourcing region and the regions in the alternative scenarios was performed. We assumed that emissions resulting from production were the same at all sites, so only emissions caused by shipments from suppliers to the plant were considered in our evaluation.

Small price differences make greening expensive

As we expected, decreasing the sourcing radius led to lower emissions in all scenarios. The price per reduced t CO_2e was in a two-digit range only for part price differences below 1% between Poland and Germany.

As long as shipments are made in full trucks and shipment volume does not have an impact on the part price, the results are independent of the total sourcing volume.

Figure 15 compares the local sourcing scenario in which a plant is located 200 km from the supplier with nearshoring scenarios in which distances between the nearshoring supplier and the plant vary at a material price difference of 10%. Reducing emissions through local sourcing is a very costly measure, even at long distances up to 2,000 km.

In aller Kürze

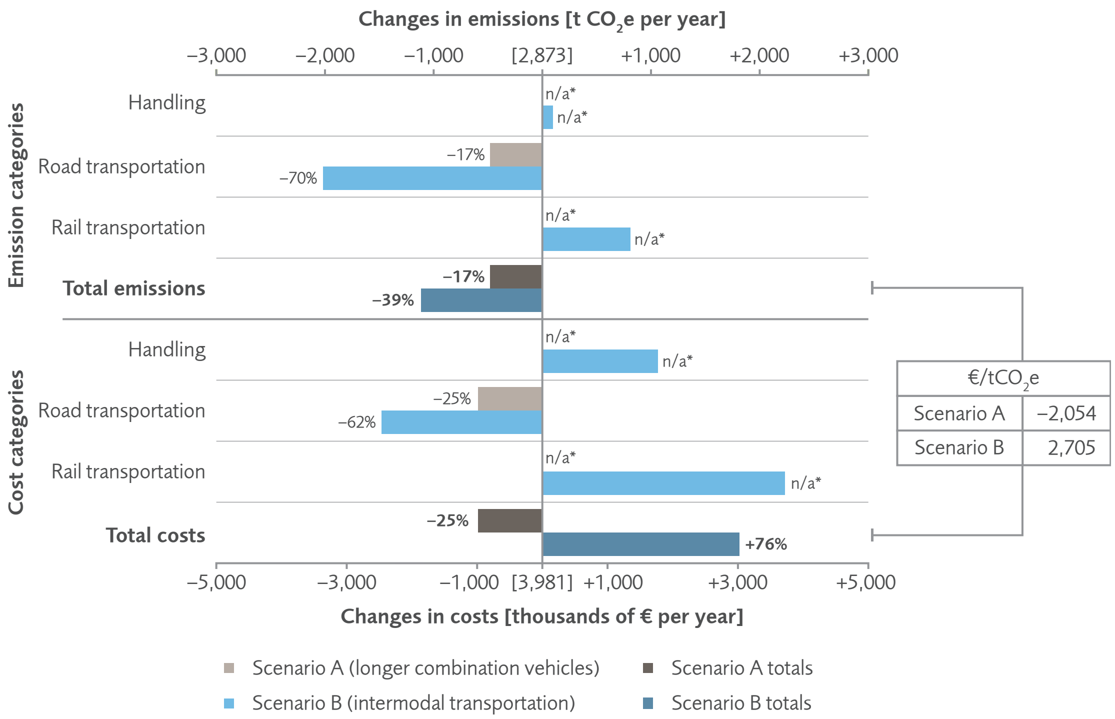
Regionale Beschaffung von Normteilen

Für Normteile wie Schrauben und Muttern wurden für je drei verschiedenen Entfernungen und Preise in Szenarien untersucht, welche Wirkung eine regionale Beschaffung auf Kosten und Emissionen im Vergleich zu einer Beschaffung aus Osteuropa hat. Zwar hatte diese immer Emissionseinsparungen zur Folge, im Ergebnis ist es jedoch schon bei geringen Unterschieden in den Teilepreisen ein teurer Weg, Emissionen zu sparen: Bei 10 % Preisunterschied kostet eine eingesparte Tonne CO_2e 6.672 €.

4 Rethinking trucks and boxes

4.1 Shifting to intermodal transportation or longer combination vehicles
4.2 Switching from returnable to disposable containers

4.1 Shifting to intermodal transportation or longer combination vehicles



€/tCO_2e	
Scenario A	−2,054
Scenario B	2,705

* Handling and rail transportation exist only in intermodal networks. Therefore, relative changes in costs or emissions are not applicable.

Figure 16: Comparison of costs and emissions when shifting from standard trailers to intermodal or LCV

Compared to standard trailers, LCVs decreased total transportation costs by about 25%, while intermodal transportation increased the overall costs by 76% due to the additional handling expenses it requires. Rail transportation resulted in less than 50% of the total emissions released by intermodal transportation. The switch from standard trailers to LCVs and intermodal forms of transportation reduced emissions by 17% and 39%, respectively.

x 279

The cost savings from reducing 1 t CO_2e with this measure is up to 279 times greater than the price of one emission permit.

Results

Shifting to other means of transportation pays off for the environment

Compared with the baseline scenario, shifting from standard trailers to LCVs or to intermodal transportation reduced emissions. In the baseline scenario, goods were hauled from point of origin to destination in standard trailers. With intermodal transportation, additional handling expenditures for the loading and unloading of rail cars were incurred at transload facilities amounting to about €3.7 million and 806 t CO_2e a year. At the same time, however, the costs and emissions caused by road transportation decreased by €2.5 million and 2,017 t CO_2e and a year, respectively, since the main portion of the shipment took place by rail.

The proposed use of more rail transportation and LCVs is widely debated by the public as well as by supply chain professionals. Other sources generally present rail transportation as an ecological means of carrying large volumes, in part because the European rail network is largely electrified. Intermodal transportation, however, has its limitations due to the additional cost of switching from one transportation network to another. The increased cost depends on the location of transload facilities and, furthermore, on the distance goods are carried. In this scenario, the costs per year increased by 76% compared to the baseline. In terms of emissions, intermodal transportation outperformed standard trailers only on long-distance hauls and on relations with short pre-haul distances between the transload facility and the hub location, provided the volume of goods shipped was high enough.

The use of LCVs is assumed to reduce the frequency of shipments since the max. volume and gross vehicle weight (GVW) of an LCV are greater than those of a standard trailer. Hence, besides a reduction of costs by 24.9%, the emissions were expected to decrease as well. The LCV and intermodal transportation scenarios show a reduction in emissions by 16.8% and 38.8%, respectively, compared with standard trailer transportation. Reducing emissions through intermodal transportation costs €2,705 per t CO_2e.

Decision based on ecological or economic criteria

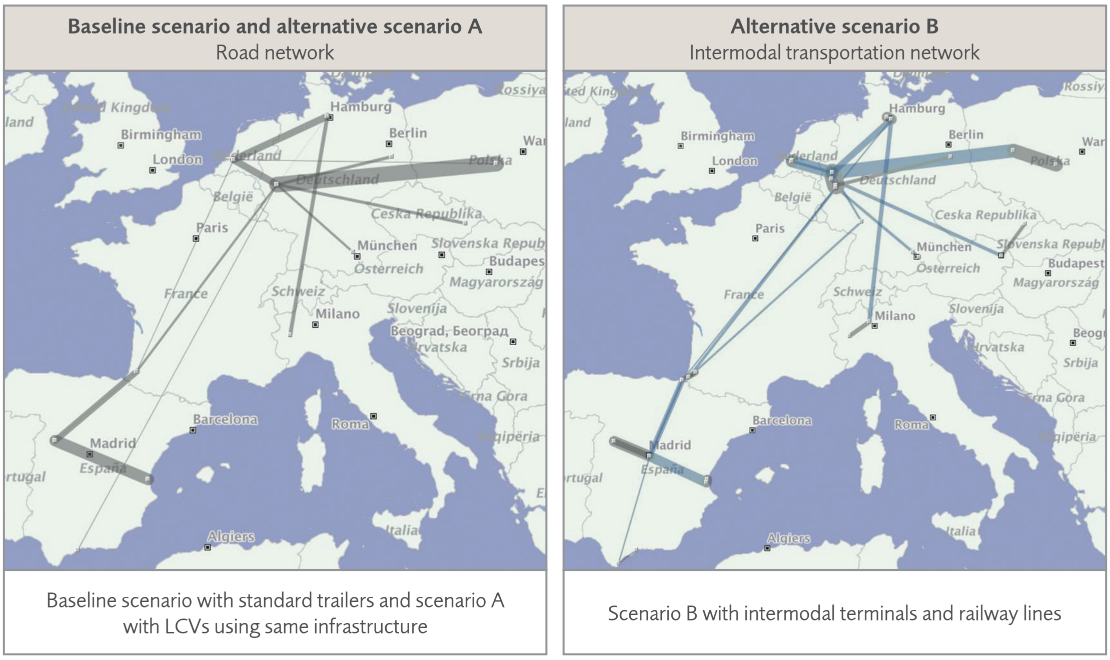
From an ecological perspective, intermodal transportation is clearly advantageous. However, while the use of LCVs results not only in a reduction of emissions, but costs as well, intermodal transportation sharply increased total costs compared to the baseline scenario. Intermodal transportation also suffers from longer lead times. The increased costs are attributable to the additional handling required and the applicable rail freight rate.

In aller Kürze

Umstellung auf Gigaliner-Transporte und intermodalen Verkehr

Der Transportmittelwechsel vom Standard-Trailer zum Gigaliner (LCV) und die Umstellung des reinen Straßentransports auf intermodalen Verkehr reduzierten die Emissionen im betrachteten Szenario um 17 beziehungsweise 39 %. Gigaliner und intermodaler Verkehr verringern durch eine höhere Ladekapazität die Anzahl an Fahrten. Während intermodale Transporte aufgrund des Handlingaufwands beim Warenumschlag höhere Kosten verursachen, reduziert der Einsatz von Gigalinern nicht nur Emissionen, sondern auch Kosten. Die so reduzierten Emissionen sind mit Kosteneinsparungen von 2.054 €/t CO_2e verbunden.

Shifting to intermodal transportation or longer combination vehicles: How we achieved these results



Baseline scenario and alternative scenario A
Road network

Baseline scenario with standard trailers and scenario A with LCVs using same infrastructure

Alternative scenario B
Intermodal transportation network

Scenario B with intermodal terminals and railway lines

Figure 17: Different structure of road and intermodal transportation networks (Source: 4flow vista®)

Two alternative networks were derived from the baseline network with standard trailers. In the first one, LCVs were used for shipments between hubs, while in the second network, intermodal transports were used between hubs.

Methodology

Baseline scenario: Main-haul standard trailer shipments in an automotive network

The baseline scenario consisted of a typical automotive hub network. The long-distance shipments over the main route provide a suitable basis for the use of LCVs since their increased capacity is useful for shipments involving a larger quantity of goods. Moreover, goods with a higher volume than weight are primarily carried in the network, which makes it possible to look at LCVs despite GVW limitations.

Alternative scenario 1: LCVs

We compared road transportation by LCVs with a GVW of 44 t (30.5 t payload) and dimensions of 21.72 m x 2.45 m x 2.6 m (138 cbm) instead of using standard trailers. The combination concept of LCVs allows for a longer vehicle consisting of two or three trailers not exceeding a total vehicle length of 25.25 m. Many studies claim that three standard trailers can be replaced by two LCVs, which would mean that traffic would be reduced while the same amount of goods would be carried. In order to compare the costs and emissions of these two scenarios, the calculations are depicted in figure 16.

Alternative scenario 2: intermodal transportation

Since this intermodal transportation scenario includes the use of a rail network, the underlying structure of the baseline network was modified. Transload facilities providing the link from road to rail were added according to origin-destination schedules. Consequently, the shipments were divided into three segments: the main haul as well as the over-the-road shipments to and from the transload facilities. This implies that the total distance is usually greater than the distance in the baseline network. The European rail network is not as dense as the road network, and has less entry points such as transload facilities. As a result, total transportation distances increase.

Legal restrictions for LCVs

In Finland and Sweden, for instance, LCVs have been constituting an integral component of road traffic for more than 40 years. In contrast, field tests to assess the performance of LCVs in daily traffic are currently being conducted in some other European countries including Germany. Since the size of the vehicles and their behavior in accidents are still debated, the GVW is assumed to be limited by regulations to 44 t in this study.

Costs and emissions drivers

Due to the locations added in the intermodal transportation scenario, new drivers of costs and emissions need to be considered. The costs for rail transportation were obtained from a large LSP's publicly available shipment rates. In addition to the rail transportation segment, the costs and emissions stemming from the transload facilities, due to handling, affect the outcome of the comparison as well. Drivers of costs and emissions situated before the pick-up of goods and after delivery along the transportation chain are not included in any of the scenarios.

Two different driving speeds for standard trailers and LCVs are looked at depending on the distance driven. Since emissions depend on driving speed, a driving speed of 50 km/h was used for distances up to 50 km, otherwise the speed was 66 km/h.

4.2 Switching from returnable to disposable containers

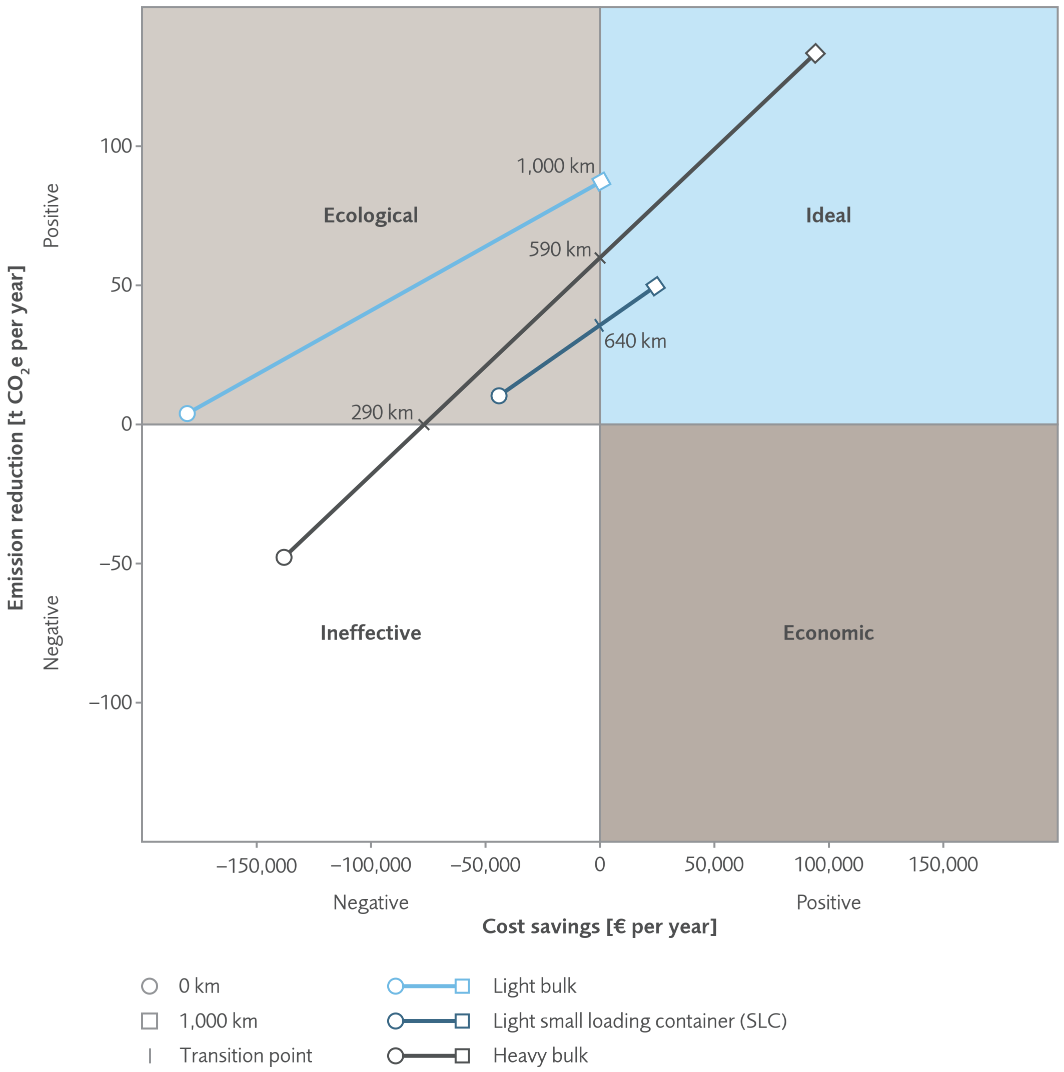
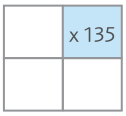


Figure 18: Impact of switching to disposable containers depending on distances for three cases

In most cases considered, the switch from returnable to disposable containers resulted in the reduction of emissions. Over medium and large distances, disposable containers even saved costs in two cases. For the case of heavy goods in SLC the reduction came at very high costs (not in figure). Switching to disposable containers when shipping heavy goods over short distances is ineffective as it led to higher emissions and increased costs.



The cost savings from reducing 1 t CO_2e with this measure is up to 135 times greater than the price of one emission permit.

Results

Disposable containers reduce emissions

Contrary to popular belief, disposable containers[23] usually account for fewer emissions than returnable[24] ones in the industrial application explored in this study. Returnable containers were environmentally advantageous only for short distances when they were foldable and contained very heavy goods. This resulted in a high-weight, low-volume utilization of the truck. In this case, switching from returnable to disposable containers would be neither ecological nor economic. In all other cases, the change could reduce emissions: producing returnable containers made of plastic emits five times as much CO_2e per kg of container material than disposable containers, whereas containers made of steel even emit an amount eight times greater. In addition to this, the production of disposable containers requires less material. The large fixed share of emissions for returnable containers in combination with the elevated emissions due to backhaul makes returnable containers ecologically uncompetitive when compared to disposable containers in regard to emissions.

As distance increases, costs diminish

On the cost side, a switch from returnable to disposable containers does not pay off for short and medium distances. On long hauls, where transportation costs increase, switching to disposable containers is economically sound. This is in line with a common observation in industry. For intercontinental shipments, disposable containers are the most frequent choice whereas for domestic and continental shipments, the share of returnable containers is higher.

When to use disposable containers

A switch from returnable to disposable containers led to fewer emissions in many cases. These savings, though, come at a high price of several thousand euros per ton of CO_2e. Despite their factual advantages, disposable containers are perceived to be less eco-friendly since they lead to pollution that is more visible. A shift to disposable containers requires a more thorough communication strategy since one-way packaging does not yet breathe the spirit of sustainability. When more indicators than emissions are taken into account, such as land use for production, the generally favorable view of wood-derived packaging may change. A customized quantitative analysis that takes the specific properties of the items and the supply network into account should be performed before a switch; this is important since considerable differences were already observed in the cases explored in this study.

In aller Kürze

Umstellung von Mehrweg- auf Einwegbehälter

Ob Mehrweg- oder Einwegbehälter mit weniger Emissionen verbunden sind, hängt unter anderem vom Artikelgewicht und der Verpackungsart ab. In vier Fallstudien (KLT/GLT; leicht/schwer) wurde anhand exemplarischer Artikel eine Umstellung von Mehrweg- auf Einwegbehälter in Abhängigkeit von der Entfernung für ein Automobilwerk geprüft. Mehrwegbehälter führten lediglich bei einer kurzen Entfernung mit sehr schweren Artikeln zu weniger Emissionen und Kosten. Einwegbehälter waren generell mit weniger Emissionen verbunden, führten jedoch nur auf großen Entfernungen auch zu Kosteneinsparungen.

Switching from returnable to disposable containers: How we achieved these results

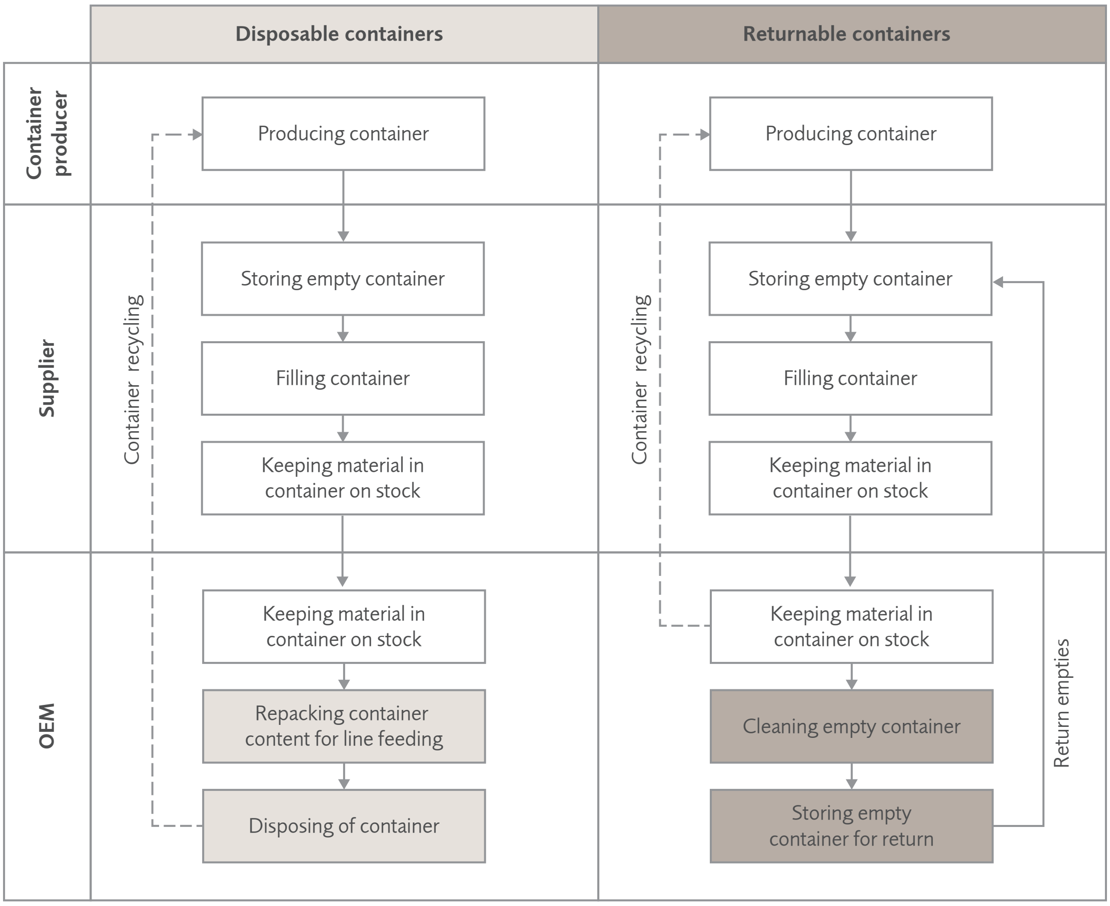


Figure 19: Two different business processes for containers

The business process differs slightly for each type of container: returnable containers need to be cleaned after a couple of uses while disposable containers are assumed to be repacked after delivery for easier handling at the production line. Four cases were selected to represent the variety of possible item densities and containers.

Methodology

Four cases considered

We selected four cases to shed light on the container switch from different angles. They can be grouped by container size (large or small) and part weight (light or heavy). For each of the four cases, a representative part from a standard car was selected. In three of the four cases, returnable containers are cleaned every fourth run.[25] Cleaning costs were determined based on indications by suppliers. The emissions data are based on the energy consumption of cleaning systems as indicated by a packaging service provider. Demand for each of the cases was derived from the production volume of an automotive OEM plant producing 250,000 cars per year.

We looked at the extreme case of hauling only one type of item per truck. Obviously, results would vary if load optimization was allowed, which would lead to a more balanced mix of weight and volume of parts. A higher utilization of loads generally reduces emissions and saves costs. Yet, in this study, load optimization and consolidation would have distorted the effect of packaging on emissions and costs.

Scope

Numerous sources of emissions were considered as shown in figure 19. The business process differs by container type, but always begins with the container's production before its actual use and ends with recycling at the end of its service life. Emissions from raw material production and disposal, transportation, and cleaning were considered whereas emissions from the production of components were not considered since they do not influence the packaging decision.

Distance as a key driver

Distance, of course, plays an important role in the outcome, and a sensitivity analysis can deepen the understanding of the impact packaging has on emissions and cost. Therefore, we varied the distance from the supplier in every case until cost and emissions changed sign. The results regarding the suitability of packaging according to distance were derived this way. For disposable containers, an average distance of 50 km to the next loading point was considered as a counterpart to the backhaul with empties.

Container emissions

Another key driver for cost and emissions of returnable containers is their amount in the loop, which we determined by multiplying the lead time by the demand per day in containers derived from the plant's and product's demand. We estimated the lead times based on benchmark data. Emissions data for container production and disposal were derived from one source to ensure comparability,[26] while container prices were taken from vendors.

Switching from returnable to disposable containers: The case of large and very heavy goods

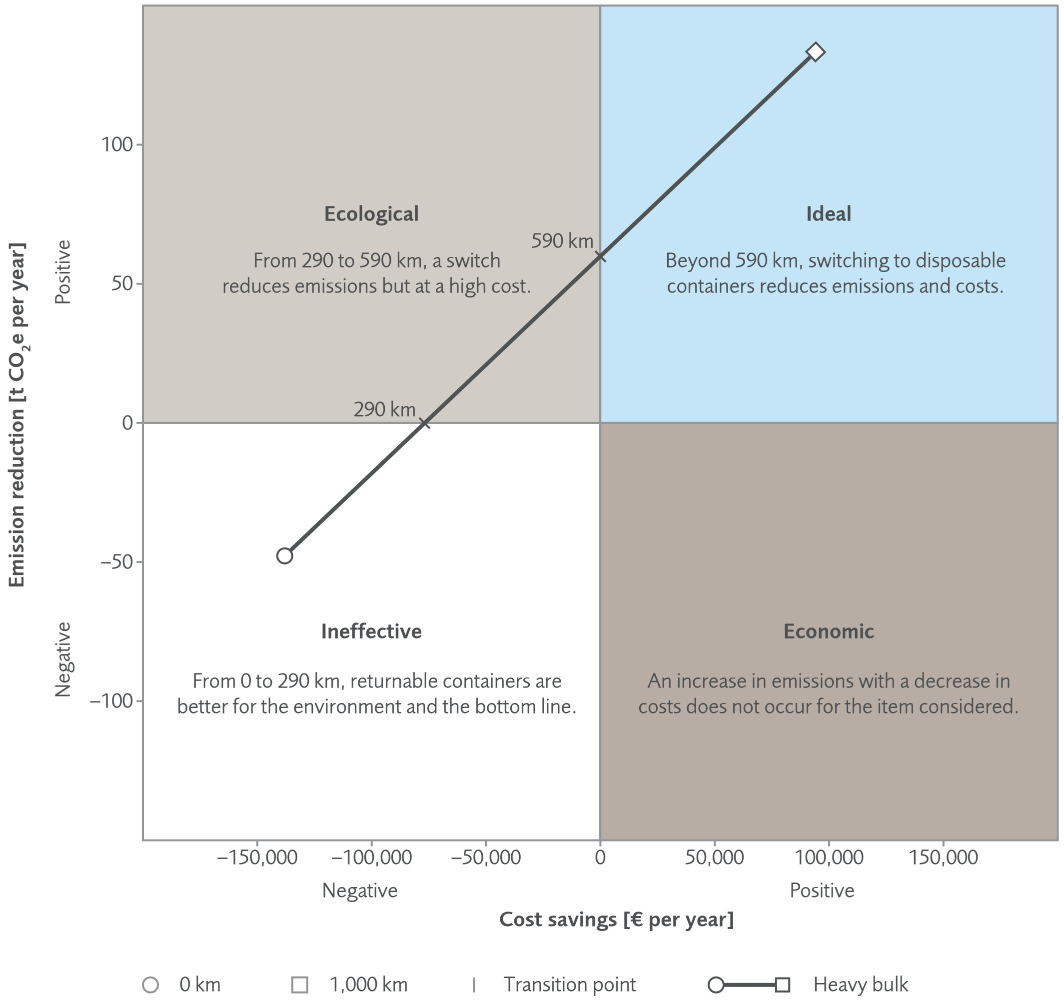


Figure 20: The multi-faceted case concerning large and heavy goods

For the case of large and very heavy goods, three sections can be distinguished: The lower left quadrant illustrates how returnable containers led to less emissions and costs, whereas the upper right quadrant depicts disposable containers as favorable. The upper left quadrant shows that emissions were saved at a rather high cost.

One case in detail

A multifaceted case

The most multifaceted case of the four considered dealt with large and very heavy goods. We looked at crankshafts as an example of this category of item. The returnable container for this case is a standard mesh pallet, whereas the disposable container is a combination of cardboard and wood. Stacking is not required since the truck is already fully utilized by the weight of less than one layer of containers.

For a shipment of very heavy goods, the truck utilization by volume is inevitably low, if there is no combined shipment with very light parts. Yet in any case, the number of containers required per truck is rather low for crankshafts. We identified three distance ranges to consider when deciding on a switch from returnable to disposable containers:

Over short distances, foldable, returnable containers win

Within a range of 290 km, returnable containers did not only cost less than disposable containers, they also led to less pollution because of their foldability, resulting in fewer return shipments. If the truck capacity were higher, thus resulting in more containers per truck or the mesh pallets were not foldable, more return shipments would be necessary and the cost and emission balance would shift in favor of disposable containers.

Over medium distances, disposable containers pollute less and cost more

For distances between 290 km and 590 km, switching from returnable to disposable containers led to less pollution yet entailed a significant increase in cost. The extra costs diminished while the distance between supplier and OEM increased. Only in a negligibly small range before the transition to the next section would the switch be more economic than buying emissions certificates.

Over long distances, disposable containers are the right choice

Beyond 590 km, returnable containers also lose their cost advantage. The use of disposable containers is economically sound and leads to less pollution. Both advantages increase as distance grows further. These advantages, however, are relative. A greater distance always increases transportation costs and emissions. Sourcing from local suppliers would lead to fewer transportation emissions, whereas total cost would increase significantly, as shown in the case study for local sourcing on page 40.

Saving a considerable share of emissions

The absolute amount of emissions to be saved by switching from returnable to disposable containers is considerable for large and very heavy goods. In the extreme case, at a distance of 1,000 km, 126 t CO_2e were saved annually by switching from returnable to disposable containers. This stands for 22% of the emissions considered, and is equivalent to the amount of CO_2 stored in a forest the size of 12 soccer fields.

5 Considering routing and time restrictions

5.1 Reducing driving speed

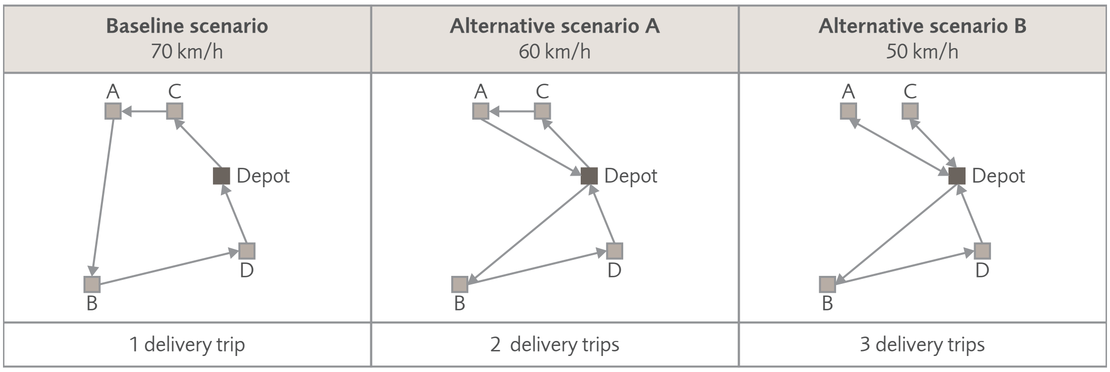


Figure 21: Different runs depending on reduced driving speed

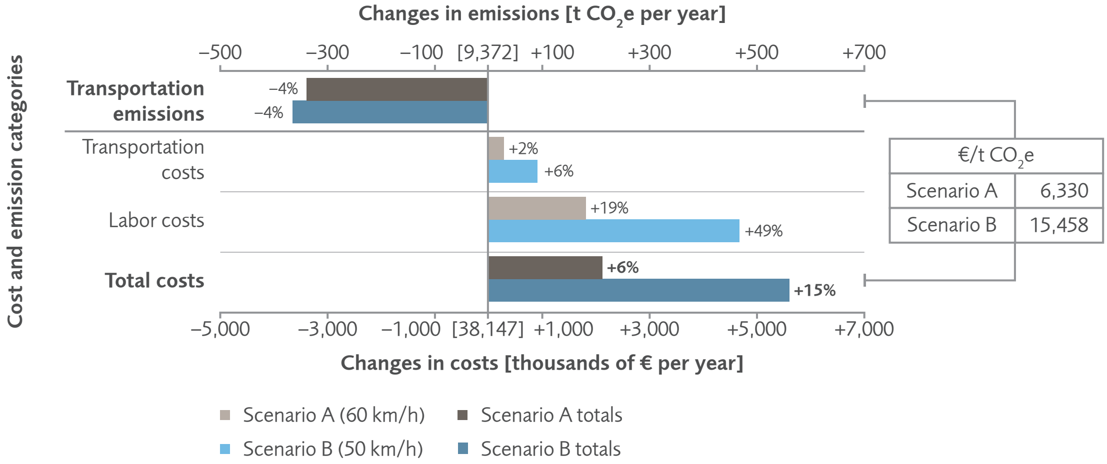


Figure 22: Changes in cost and emissions compared to the baseline with 70 km/h

Reducing driving speeds led to an increase in the number of runs and kilometers driven in total, which was outweighed by the reduced emissions per kilometer. Driving speeds between 50 km/h and 60 km/h reduced emissions by almost 4% compared to the baseline scenario of 70 km/h. However, it comes at a very high price. While a driving speed of 60 km/h led to 6% higher costs, a driving speed of 50 km/h resulted in an increase of up to 15%. Labor costs were the main driver of the cost increase.

x 859

Reducing 1 t CO_2e with this measure is up to 859 times more expensive than the price of one emission permit.

Results

A driving speed between 50 km/h and 60 km/h reduces emissions

Average driving speeds between 50 km/h and 60 km/h result in fewer emissions than the baseline scenario with 70 km/h. Although a similar reduction of emissions of almost 4% was achieved in both scenarios, the effect on costs varied greatly: a driving speed of 50 km/h led to 15% higher costs, while an increase of up to 6% was caused by a driving speed of 60 km/h. The cost-benefit ratio for both scenarios was €15,458 and €6,330 per ton of CO_2e, respectively.

Tight delivery time restrictions limit truck utilization

The development of total costs is not only explained by the increment of diesel consumption and driving time, but also by less possibilities of combining the stores on one route due to delivery time restrictions. Thus, a reduced speed in combination with tight delivery time restrictions leads to a higher number of delivery runs with lower truck utilization, resulting in longer total distance. When reducing the driving speed to 60 km/h, 7% more delivery trips were needed and truck utilization fell by 4%. At 50 km/h, the number of delivery trips increases 12% compared to the baseline scenario with a 5% lower average utilization.

Time is money

The comparison of the cost effect of a longer driving time in a high-wage country such as Germany is particularly interesting. The reduction of the driving speed caused an increase in transportation costs as well as labor costs, which included the cost of handling and driving time. However, in both scenarios labor costs increased significantly more than transportation costs.

When to slow down

The investigated distribution network is characterized by a large amount of highway kilometers driven, thus a baseline average driving speed of 70 km/h is assumed. Reducing speed to 60 km/h or 50 km/h seems to be a way to reduce transportation-related emissions. For both cases discussed, this came at a high price of several thousand euros per t CO_2e. The high cost increase is determined by the structure of delivery runs and their service requirements. Decreasing the driving speed for direct deliveries, where clients are served independently and are not grouped into a single run, is likely to provide similar environmental benefits at a far lower price per ton of CO_2e. In such a situation, stores' service requirements would no longer constrain shipping.

In aller Kürze

Fahren mit reduzierter Geschwindigkeit

Eine Verringerung der Geschwindigkeit vom Ausgangsszenario mit 70 km/h auf 60 km/h oder 50 km/h verringert die Emissionen um rund 4 %. Während die Kosten für die Emissionsreduktion bei 50 km/h um 15 % steigen, erhöhen sie sich bei 60 km/h nur um 6 %. Der Kostenanstieg wird durch die Änderungen der Tourenstruktur aufgrund von Kundenanforderungen verursacht. Der Preis pro vermiedener Tonne CO_2e liegt bei 15.458 €/t CO_2e bzw. 6.330 €/t CO_2e. Eine Verringerung der Geschwindigkeit bei Direktfahrten würde bei gleicher Umweltwirkung die Kosten weniger stark steigen lassen.

5.2 Delivering less frequently

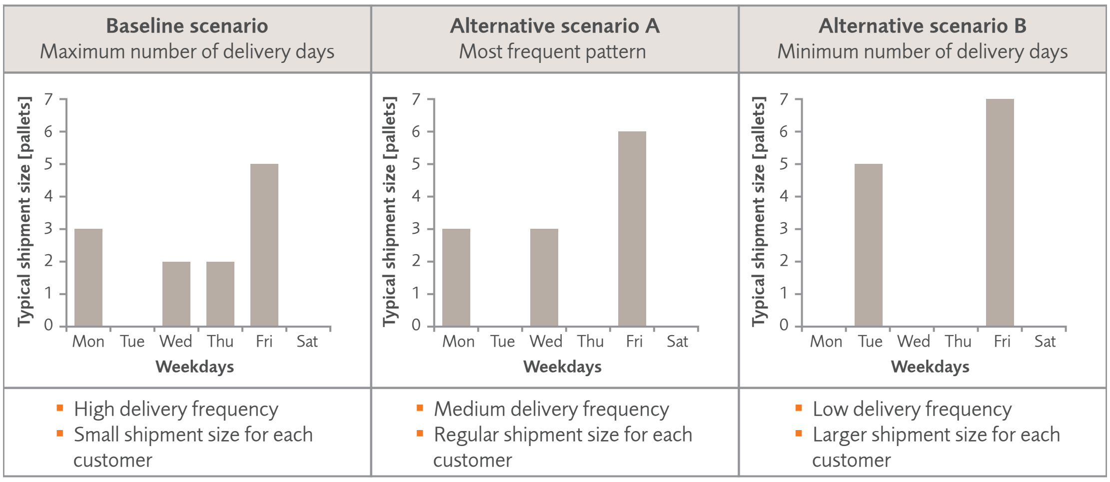


Figure 23: Implications of different delivery patterns

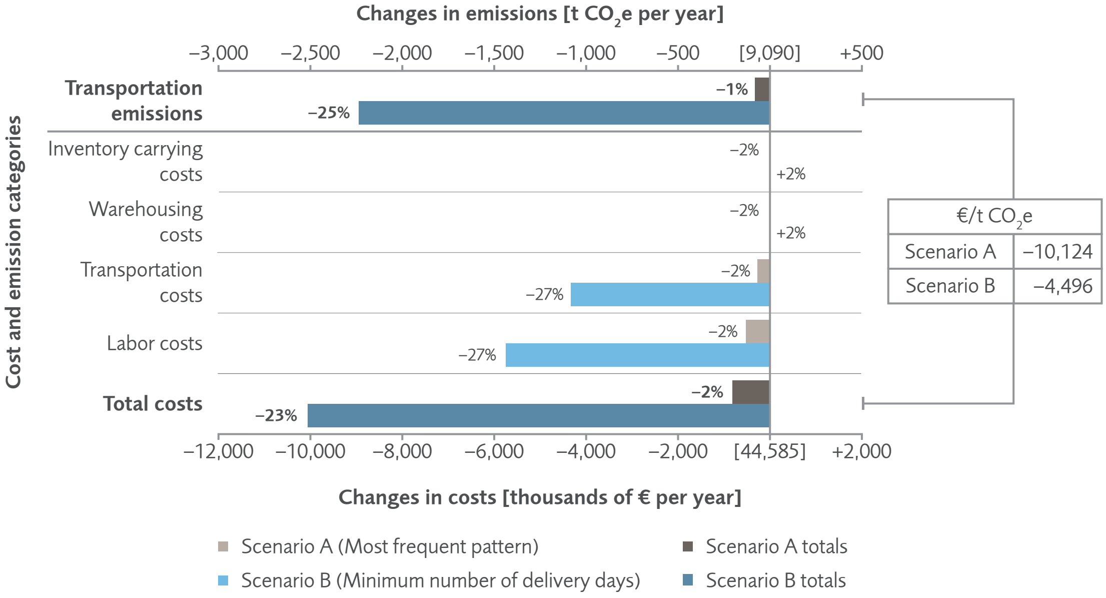


Figure 24: Cost and emissions compared to the baseline delivery pattern

Two alternative delivery patterns have been compared with the baseline scenario, differing in frequency as well as shipment size. The number of delivery days showed to be an ideal lever, since both scenarios reduce emissions and save costs. In the second scenario, up to 23% of the costs were cut while simultaneously reducing emissions by 25%.

x 1374

The cost savings from reducing 1 t CO_2e with this measure is up to 1374 times greater than the price of one emission permit.

Results

Delivering less frequently reduces costs and emissions

With high savings on transportation and labor costs, both alternative scenarios with less delivery days are greener and less cost-intensive than the baseline with the maximum number of delivery days. Thus, this measure is ideal. While in the scenario with the most frequently occurring delivery pattern a moderate reduction of costs and emissions was achieved, the delivery pattern with the minimum number of delivery days provides a lever to save up to 23% of total costs and reduce 25% of emissions. The latter scenario yields cost savings of €4,496 per t CO_2e.

Less time needed

With less trips needed to deliver goods, a reduced number of delivery days led to a decrease in handling and driving time. This contributes significantly to the total reduction of costs, especially in a high wage country such as Germany.

Further consolidation is possible

The average truck utilization increased from 43% in the baseline scenario to 44% in the scenario with the most frequent delivery pattern and 55% for the minimum number of delivery days, respectively. This suggests that there are further possibilities to consolidate shipments and reduce costs and emissions by diminishing the number of trips and total distance traveled. This could be achieved by relaxing time window constraints.

Less deliveries, less transportation costs

If enough shelf space or warehousing area is available in the stores, then a minimal delivery frequency is both cost- and emissions-optimal for the network studied. Fewer trips reduce the total distance traveled by 25% while the average number of stores per trip decrease. Furthermore, waiting time is reduced, and thus truck productivity is improved. Loading time is also reduced as a consequence of fewer visits to each store.

When to agree on fewer delivery days

The reduction of delivery days is an efficient measure to reduce costs as well as emissions. While planning such a reduction, the constraints of all parties affected need to be taken into account. The amount of storage space available at the retailer is of particular importance. The availability of the additional workforce required to unload larger quantities in one day needs to be ensured, too.

In aller Kürze

Weniger Anliefertage

Die Anzahl der Anliefertage hat bei der Belieferung von Filialen im Handel großen Einfluss auf die Transport-, Lager- und Bestandskosten sowie Emissionen. In dieser Maßnahme wurden für die Anliefertage in zwei Szenarien mit Optimierungsalgorithmen Touren unter Beachtung von Zeitfenstern ermittelt. Ein relativ großer Anteil sowohl der Kosten als auch der Emissionen kann durch eine Reduktion der Anliefertage eingespart werden. Die absoluten Einsparungen sind jedoch relativ gering. Die geringe Auslastung der Lkw von weniger als 50 % deutet darauf hin, dass weiteres Konsolidierungspotenzial vorhanden ist.

5.3 Extending delivery windows

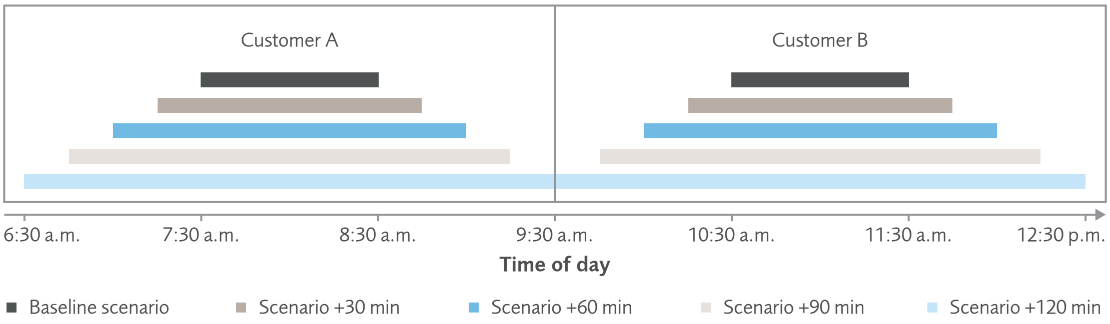
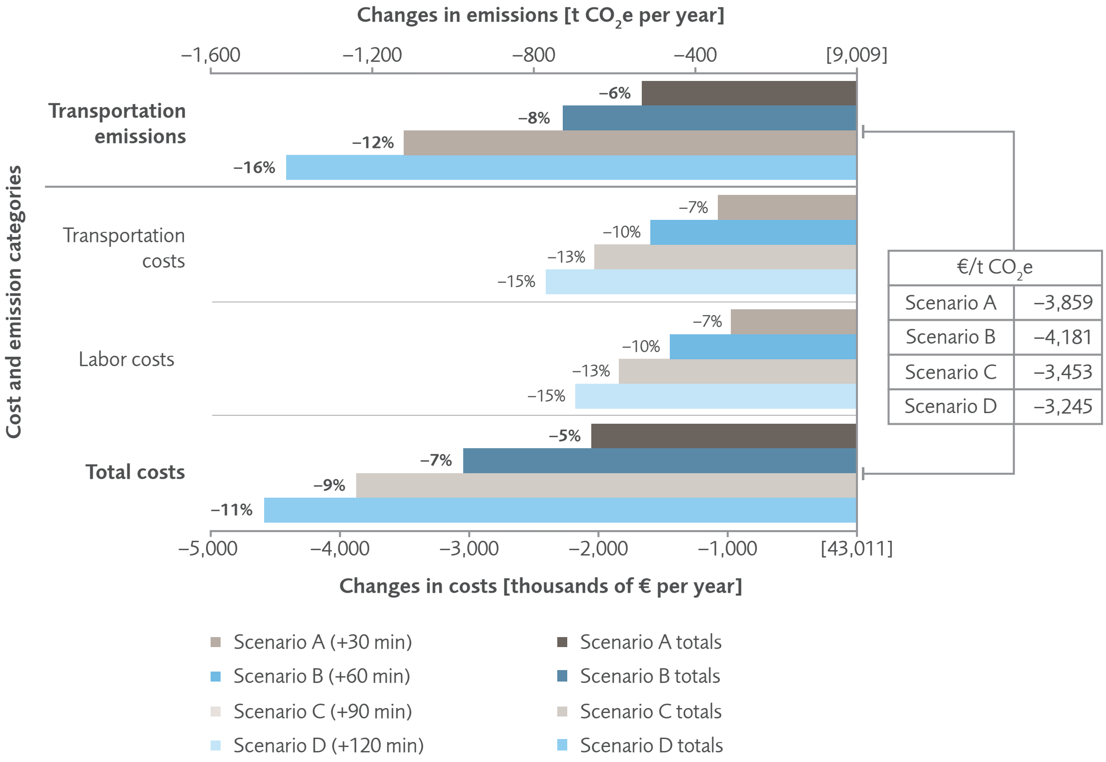


Figure 25: Length of delivery time windows investigated in this case



€/t CO_2e	
Scenario A	–3,859
Scenario B	–4,181
Scenario C	–3,453
Scenario D	–3,245

Figure 26: Changes in costs and emissions compared to the baseline scenario

For extended delivery windows, the retailer's service time requirements were loosened, allowing for more efficient routing. Cost savings up to 11% and emission reductions of 16% can be achieved. Scenario A with time windows extended by just 30 min holds almost half of the potential to cut costs.

x 567

The cost savings from reducing 1 t CO_2e with this measure is up to 567 times greater than the price of one emission permit.

Results

Extended delivery windows, better utilization

Extended time windows enable the combination of more customers into one delivery trip, resulting in less distance traveled and a higher utilization of trucks. This led to cost savings between 5% and 11%; emissions were even cut by 16%. Almost half of the cost reduction can be achieved in the first scenario with time windows being extended by 30 minutes. The scenario with the highest emission reduction yields cost savings of €3,245 per t CO_2e.

Cooperation does pay off

This shows that some flexibility in the design of the supply chain and the willingness to cooperate and share information with the LSP can evoke great cost advantages for the partners and is good for the environment as well. While 6% less emissions is the result of the actions in the first scenario, up to 16% of emissions can be reduced in the last one.

More stops per trip

The reduction of up to 15% of the distance traveled is mainly caused by the strong increase of average stores per trip and the parallel decrease of trips needed for delivery. This also leads to higher average truck utilization. The shorter distance traveled is linked to less driving time, while loading time remains constant. Interestingly, the increase of stores per trip does not cause longer waiting times. Contrarily, they are reduced by up to 30%.

Loosening delivery time requirements coupled to in-store logistics processes

Store delivery times are a very important constraint for LSPs when planning transportation processes. Often, delivery routes fulfill these service requirements at the expense of poor truck deployment, resulting in lower utilization of trucks, longer total distance traveled, and in the end, higher costs. The length of delivery times set by the stores is usually coupled to extra workforce required on site to handle deliveries. Potential bottlenecks at the store dock and traffic constraints also play a role. These aspects, among others, should be considered in a cost-benefit analysis when defining more flexible delivery processes.

In aller Kürze

Längere Anlieferzeitfenster

Anlieferzeitfenster stellen eine wesentliche Einschränkung bei der Belieferung von Filialen im Handel dar. In verschiedenen Szenarien wurden diese Zeitfenster verlängert, um die Auswirkungen auf die Touren zu untersuchen. Schon eine Verlängerung der Zeitfenster um eine halbe Stunde führte zu einer Kostensenkung um 5 %, die Emissionen konnten gleichzeitig um 6 % gesenkt werden. Eine weitere Verlängerung ermöglicht noch effizientere Routen. Zusätzliche Stopps pro Tour bei erweiterten Zeitfenstern führen, entgegen der Erwartung, nicht zu einer Erhöhung der Wartezeiten, sondern verringern diese sogar um bis zu 30 %.

5.4 Routing

	Parameters		
	Length of delivery windows	Delivery pattern	Average speed
Baseline	30 min 45 min 60 min	Maximum number of delivery days	70 km/h
Reducing driving speed			60 km/h 50 km/h
Delivering less frequently		Most frequent pattern Minimum number of delivery days	
Extending delivery windows	+30 min +60 min +90 min +120 min		

Figure 27: Parameters of the investigated routing measures

Three different aspects of time restrictions were researched in this study. For each measure, distinct parameters have been altered. The resulting scenarios were analyzed based on their impact on costs and emissions. The average driving speed in the first scenario was 70 km/h, which was reduced in two increments of 10 km/h to create different scenarios. In the delivery pattern scenario, the baseline had the maximum number of delivery days for each store. For each measure, the most frequent pattern and the pattern with the minimum number of delivery days possible at each store were explored. In the third scenario, the length of the time windows consisted of three distinct values with a probability of 1/3. The time of day was determined based on two normal distributions. The length was then increased in four scenarios.

Methodology

Retail distribution is characterized by some distinct traits: The small storing capacity at the stores requires a high delivery frequency in order to prevent stock-outs. Since only small quantities are delivered to a retailer, direct deliveries would have a very low utilization, and delivery runs that link several retailers in a cost-efficient way need to be found. These trips must respect delivery time constraints at the retailers to prevent work overload in the retail stores. Additional workforce to unload trucks can be used but it has to be planned in advance. Furthermore, the distribution of customer arrival at the retailer needs to be considered to avoid conflicts between customers looking for goods on the shelves and workforce filling the shelves. Each vehicle needs to return to the depot after delivery for reloading. Deliveries are made on a previously defined number of days throughout the week. Delivery on Sunday is not allowed. Sales peak on Friday and Saturday; therefore, higher quantities are shipped to the shop before the weekend than during the week to prevent stock-outs. Further replenishments take place during the rest of the week.

The baseline scenario

For the baseline scenario, the starting point of time windows was generated by concatenating two normally distributed probability functions with an expected value of 6 and 18 hours and a standard deviation of one and a half hours each. The length of time windows takes the discrete value 30, 45 or 60 minutes with a probability of one third for each of them. Starting points earlier than 6 a.m. and ending points later than 6 p.m. were cut.

The average driving speed differs in the baseline scenarios. While in the first, the average speed is 70 km/h, in the latter scenarios the baseline driving speed is 50 km/h. The number of delivery days is the maximum for each store.

Inventory carrying costs and warehousing costs are negligible compared to transportation and labor costs. Transportation costs comprise fuel expenses, while labor costs include truck drivers' wages.[27]

Reducing driving speed

For the measure "reducing driving speed", two additional scenarios were derived, each of them reducing the driving speed by 10 km/h. All other parameters remained unchanged.

Delivering less frequently

Two scenarios were derived from the baseline scenario, which included a delivery pattern for each store with its maximal number of delivery days allowed. Scenario A was built on the basis of the most frequent delivery pattern for each customer, and scenario B used a delivery pattern with the minimal number of delivery days for each customer.

Extending delivery windows

In order to assess the effect of longer delivery windows, four scenarios were derived from the baseline scenario, each of them symmetrically extending the duration of all time windows by 30 minutes.

6 Summary and conclusion

6.1 Research summary

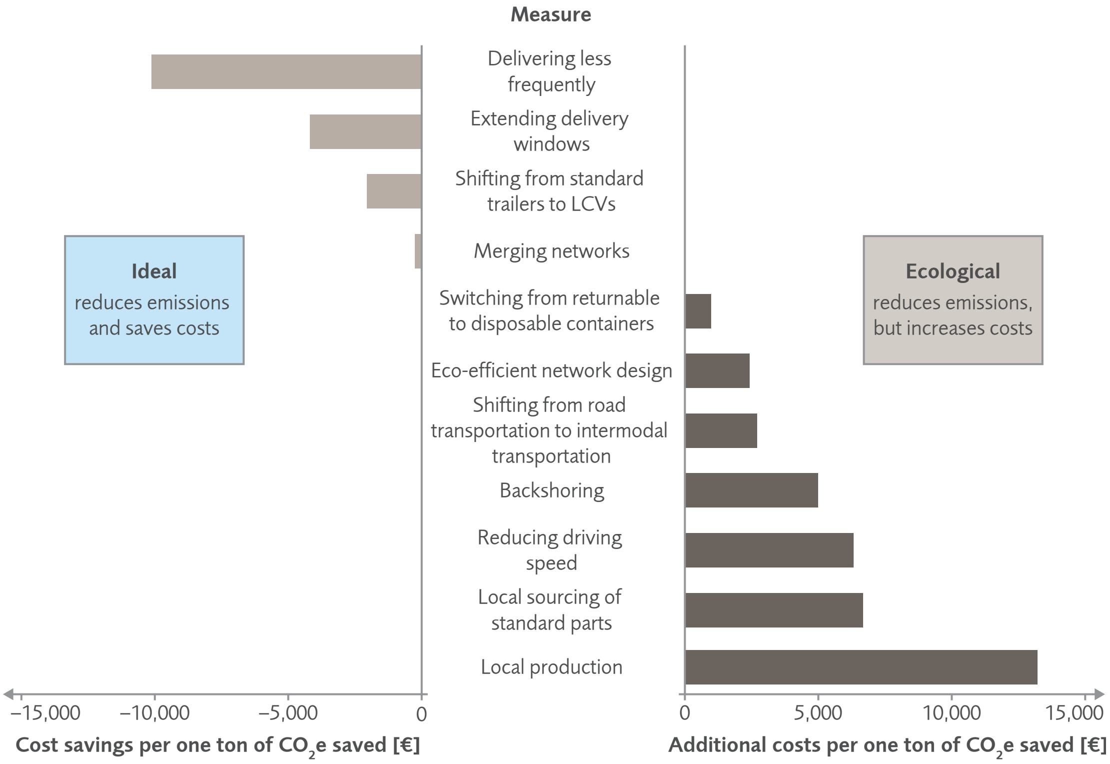


Figure 28: Summary of ideal and ecological measures

Some measures cost up to €13,300 per reduced ton of CO_2e emissions, other measures offer savings of up to €10,100 per reduced ton of CO_2e emissions. Since each measure has been investigated in a specific case derived thoroughly from real logistics networks, comparison of the measure requires caution. Prerequisites, constraints and side effects of the measures might vary in a different setting.

The 11 cases investigated in this study show a significant variation in both emissions reduction and the costs of green logistics measures. The ratio of cost to the amount of emission reduced is used as a key indicator to compare the measures. This indicator characterizes additional costs or savings per reduced ton of CO_2e if the measure is implemented. Some measures are accompanied by high costs while others even save costs.

Designing networks differently

The two network design measures, eco-efficient network design and merging networks concern strategic long-term decisions. Both measures bear the potential to prevent emission with increased truckload utilization being the main driver for emission reduction. Merging networks can save costs along with the emission reduction.

Relocating production

The focus of the relocation measures is the trade-off between sourcing and producing abroad, on the one hand, and transportation efforts, on the other hand. Backshoring, local production and local sourcing are among the most expensive logistics measures for emission reduction. When relocating production, the relatively low labor costs abroad outweigh cost savings realized in transportation and lead to very high costs per reduced ton of CO_2e.

Rethinking trucks and boxes

Logistics planning on a tactical level includes considering the use of alternative means of transportation and loading equipment. Two measures investigate the cost-saving and emission reduction potential of changing means of transportation. Shifting to intermodal transportation is costly yet clearly advantageous from an ecological perspective. LCVs are a viable option because they allow not only for the reduction of emissions but costs as well. Both measures are usually accompanied by longer lead times. Switching from returnable to disposable containers effectuates ambivalent results. The emission reduction is accompanied by cost savings for long distances in two cases.

Considering routing and time restrictions

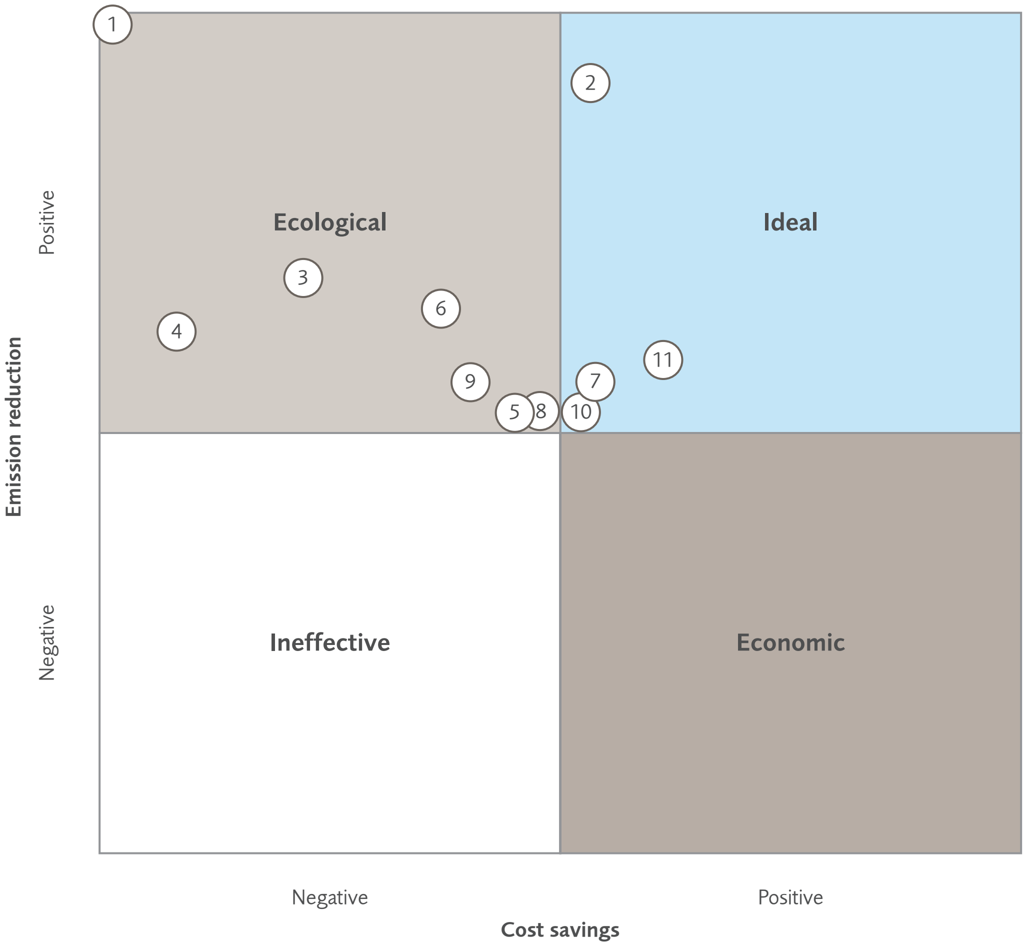
The planning of delivery routes at the secondary distribution level bears potential for emission reduction. Two of the three investigated measures cut costs: extending delivery windows at the destination and reducing the number of delivery days per week (delivering less frequently). Adjusting the driving speed affects fuel consumption and thus emission. However, the increase in driving time leads to higher costs.

In aller Kürze

Zusammenfassung der Untersuchungsergebnisse

In Fallstudien wurden elf Maßnahmen zur Emissionsreduzierung in der Logistik aus vier Einflussfeldern untersucht: Netzwerkgestaltung, Verlagerung von Produktions- und Zulieferstandorten, Wechsel von Transport- und Ladungsmitteln sowie Touren- und Routenplanung. Die Maßnahmen unterscheiden sich signifikant hinsichtlich der emissionsreduzierenden Wirkung und der damit verbundenen Kosten. Vier ideale Maßnahmen sind mit Kostensenkungen bis zu 10.100 € pro eingesparter t CO_2e verbunden, wohingegen sieben ökologische Maßnahmen zu Mehrkosten von bis zu 13.300 € pro eingesparter t CO_2e führen.

6.2 Conclusion



1 Eco-efficient network design
2 Merging networks
3 Backshoring
4 Local production
5 Local sourcing of standard parts
6 Shifting from road transportation to intermodal transportation
7 Shifting from standard trailers to LCVs
8 Switching from returnable to disposable containers
9 Reducing driving speed
10 Delivering less frequently
11 Extending delivery windows

Figure 29: Overview of investigated measures

Green logistics measures allow the significant reduction of CO$_2$e emissions. The investigated measures cover strategic, tactical and operational areas. Ideal measures even save costs while ecological measures are accompanied by increased costs.

Logistics is an essential factor for economically and ecologically sustainable supply chains. It allows companies to procure, produce and distribute globally in order to serve the demand of customers at any time. With continuous and enhanced optimization, logistics can even contribute to the vision of a more sustainable economy in the future.

Saving costs and reducing emissions at the same time

Ideally, green logistics measures reduce greenhouse gas emissions and costs simultaneously. Such measures include merging separate logistics networks, using LCVs in road transportation, and rethinking routing in distribution networks by extending delivery windows or reducing the number of delivery days.

Other emissions reducing measures are accompanied by a cost increase. Evaluated based on the ratio of cost to emission reduction, these measures turn out to be very expensive. Each ton of CO_2e reduced costs between €2,400 and €13,300. Reducing emissions in logistics comes at a price far above the reference price of purchasing emission permits.

Sustainability concerns in logistics planning

The costs and emissions of supply chains and logistics networks are mainly determined during the planning and design phase. Green logistics measures such as eco-efficient network design, intermodal transportation, and reduced truck driving speed have significant potential for reducing emissions at the strategic, tactical, and operational levels. Standard logistics planning processes can be enhanced by implementing emission reduction measures in order to choose the most suitable balance of economic and ecological sustainability. There is, however, no one-size-fits-all solution for achieving optimal logistics and supply chains as each company, network, and supply chain is different from the next one.

Emissions trading in logistics?

The fact that emissions reduction in logistics is possible, but not a viable business case, supports the idea of emission permit trading as a regulatory measure. The high cost of reducing emissions suggests that emission permit trading in logistics would not lead to less emissions in logistics but to increased demand for emission permits. Prices for logistics services and products would rise because companies would need to acquire permits on the market. Additionally, logistics companies are in fierce global competition and implementation costs would be high due to the lack of global standards for evaluating emissions.

In aller Kürze

Fazit

Die Ergebnisse der Studie zeigen, dass mit der Implementierung von Maßnahmen zur Emissionsreduzierung auch Kosten gesenkt werden können. Als ideale Maßnahmen wurden die Verschmelzung von Transportnetzwerken, der Wechsel von Standard-Trailern zu Gigalinern sowie die Verlängerung von Anlieferzeitfenstern und die Reduzierung von Anliefertagen in der Distribution identifiziert. Als ökologisch identifizierte Maßnahmen zur Emissionsreduzierung sind mit Mehrkosten verbunden, die wesentlich höher sind als die Marktpreise für Emissionszertifikate. Deshalb sind Zertifikate kein Anreiz zur Emissionsreduzierung in der Logistik.

7 Appendix

7 Appendix

7.1 Table of figures

7.2 Abbreviations and endnotes

Abbreviations

°C	Degree Celsius
$	US dollar
€	euro
%	per cent
4PL	fourth party logistics provider
a.m.	ante meridiem, before noon
AUT	Austria
BEL	Belgium
cbm	cubic meter
cm	centimeter
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
e.g.	for example
EE	Eastern Europe
ESP	Spain
FTL	full truck load
Fri	Friday
g	gram
GER	Germany
GVW	gross vehicle weight
GWP	global warming potential
FRA	France
h	hour
ha	hectare
IRL	Republic of Ireland
kg	kilogram
km	kilometer
km/h	kilometers per hour
LCV	longer combination vehicle
LSP	logistics service provider
LTL	less-than-truckload
m	meter
min	minute
Mon	Monday
OEM	original equipment manufacturer
p.	page
p.a.	per annum
p.m.	post meridiem, after noon
PRT	Portugal
Sat	Saturday
SLC	small loading container
t	ton
Tue	Tuesday
Thu	Thursday
U.S.	United States of America
UK	United Kingdom
Wed	Wednesday

Abkürzungen

°C	Grad Celsius
%	Prozent
€	Euro
a.m.	vor Mittag (0 bis 12 Uhr)
AUT	Österreich
BEL	Belgien
CO_2	Kohlenstoffdioxid
CO_2e	Kohlenstoffdioxidäquivalent
EE	Osteuropa
ESP	Spanien
FRA	Frankreich
Fri	Freitag
g	Gramm
GER	Deutschland
GLT	Großladungsträger
IRL	Irland
KLT	Kleinladungsträger
kg	Kilogramm
km	Kilometer
km/h	Kilometer pro Stunde
Mon	Montag
min	Minute
p.m.	nach Mittag (12 bis 0 Uhr)
PRT	Portugal
Sat	Samstag
SLC	Kleinladungsträger
t	Tonne
Tue	Dienstag
Thu	Donnerstag
UK	Großbritannien
Wed	Mittwoch

Endnotes

[1] IPCC 2001

[2] IPCC 2001

[3] Randers 2012

[4] Lenz et al. 2010

[5] A European basketball court is 28 m x 15 m.

[6] IntercontinentalExchange (NYSE: ICE) is a leading trading platform for emission permits in Europe.

[7] As defined by the working group of the Scientific Advisory Board of the German Logistics Association BVL in Delfmann et al. 2010

[8] Elkington 1998

[9] Bretzke 2011

[10] Sbihi/Eglese 2007

[11] Srivastava 2007

[12] They have been extensively described in a study by McKinsey and the Federation of German Industry (BDI) (McKinsey 2009)

[13] HBEFA 2010: The Handbook of Emission Factors for Road Transport (HBEFA) is a well known standard for the evaluation of emissions, published by the German Federal Environmental Agency

[14] DIN EN 16258 is a methodology for calculating and declaring energy consumption and GHG emissions from transportation services (freight and passengers)

[15] Gross et al. 2012

[16] Corresponds to approximately 38% of the yearly amount of landings of brown shrimp in the European Union. AND International and the Johann Heinrich von Thünen Institute estimate the total amount of shrimp landings in their study at approx. 30,000 t to 39,000 t per year between 2003 and 2010. According to them, two companies hold a total share of approximately 80% of the brown shrimp market (AND/vTI 2011)

[17] International Energy Agency (IEA 2011)

[18] Schulten 2012 and MIDA 2013

[19] Prices were estimated to be €1.40 per kg for unpeeled shrimp and €20 per kg for shrimp meat. See (AND/vTI 2011) for further information on wholesale prices and retail prices of brown shrimp.

[20] Deutsche Industrie und Handelskammer in Marokko (AHK 2010) and Europe's Energy Portal (EEP 2011)

[21] Eurostat 2011

[22] Federal Statistical Office 2010, p. 377

[23] Cardboard boxes were used as disposable containers.

[24] Except for heavy bulk returnable containers, for which steel box pallets were used, plastic returnables were used in the cases.

[25] Steel box pallets were not cleaned.

[26] Sevenster et al. 2007

[27] A detailed explanation of the data used is given in Hayden, C.; Zesch, F., (2012)

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7.5 Imprint

Wendelin Gross, Felix Zesch, Tobias Gelau, Cristina Hayden, Marco Bötel, Maximilian Brock
Costs and Benefits of Green Logistics –
4flow Supply Chain Management Study 2013

Published by
4flow
Hallerstrasse 1
10587 Berlin
Germany

4flow vista®, the integrated standard software for supply chain design, was applied for modeling, optimization and analysis. 4flow vista® is a registered trademark of 4flow.

The geographical representation of the logistics networks and the calculations of road distances in 4flow vista® were performed online using worldwide geographic data from the Nokia Location Platform (NLP). Nokia Location Platform® is a registered trademark of Nokia Corporation.

Second Enhanced Edition
August 2013

Order a print edition of this study from 4flow at www.4flow.com/scmstudy2013 for €20.
ISBN 978-3-9815969-1-5

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ISBN 978-3-9815969-1-5