Chapter 2

Supply chains and their impact on the environment

2.1 Supply chain management

According to Chopra and Meindl (2010, p. 20) “a supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only the manufacturers and suppliers, but also transporters, warehouses, retailers, and even customers themselves.” Supply chain management aims at designing, managing and coordinating material/product, information and financial flows to fulfil customer requirements at low costs and thereby increasing supply chain profitability. A definition by Simchi-Levi et al. (2008, p. 1) which is focused on the goods flow states that supply chain management comprises “[...] a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize systemwide costs while satisfying service level requirements.”

Supply chain management decisions are traditionally evaluated based on the economic performance which can be expressed by financial and non-financial measures, such as total landed costs and customer service (van Mieghem, 2008). Customer service is directly related to product availability which can be measured in different ways. Two very important measures are the fill rate, which shows the fraction of demand which is satisfied immediately from inventory, and the cycle service level, which is the fraction of replenishment cycles which end without any stock-outs. The cycle service level, therefore, is the probability that all demand is met during a replenishment cycle. In general, there is a trade-off between efficiency and responsiveness – in other words between costs and customer service (Chopra and Meindl, 2010). Also for Nahmias (2009) the main trade-off in supply chain management is between cost and response time which is similar to the approach of Chopra and Meindl (2010). Obviously, the trade-off between efficiency and responsiveness has to be solved depending on the product characteristics and in accordance with the competitive strategy. According to Fisher (1997) a supply chain of a functional product has to be cost-efficient whereby a supply chain of an innovative product should be designed to be responsive.
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According to Chopra and Meindl (2010) there are several key drivers of a supply chain which in combination determine the performance of a supply chain; they help to find the balance between efficiency and responsiveness that fits to the competitive strategy. The first three drivers (facilities, inventory and transportation) are denoted as functional drivers while the latter three (information, sourcing and pricing) are cross-functional drivers.

Facilities are the physical locations in a supply chain, which can be either production or storage sites. The decisions to be taken concern the role, the location, the capacity and the flexibility of a facility. By using only a limited number of facilities economies of scale can be achieved and benefits can result from risk pooling leading to lower total costs. However, the cost reduction, in general, comes at the expense of responsiveness due to an increased distance to downstream facilities and/or customers. A production facility can be either dedicated, flexible or a combination of the two. A flexible facility can produce a range of different products and thereby helps to increase the responsiveness in the supply chain but generally the company has to sacrifice efficiency for that. The opposite holds true for a dedicated facility which can only produce a limited number of products. In addition to that, the capacity of a facility has to be determined. Allowing for excess capacity increases flexibility and responsiveness but usually also increases the costs. Overall, it can be said that by increasing the number of facilities, facility and inventory costs increase but outbound transportation costs and response time can be reduced.

Inventory comprises all raw materials, work in process and (semi-)finished products in a supply chain. For the different types of inventory the adequate inventory policies have to be determined. Inventory generally results from a mismatch between demand and supply. This mismatch can be intentional to produce or order in large lots; or inventory can result from uncertainties on the demand side or in the production/procurement process. The level of inventory decisively determines the product availability which is directly related to responsiveness. However, the inventory held is also an important source of cost in a supply chain. So again, there is a trade-off between efficiency by lowering inventory and the related costs and responsiveness which can be achieved by holding high stock levels.

Transportation is the physical movement of goods between points in a supply chain. In order to realize the transport of goods, different modes (air, road, rail, inland waterways, sea or pipeline) and routes have to be combined either by the company itself when having its own fleet or by a logistics service provider. In addition to that, it has to be decided
whether the transport is carried out directly or whether the goods go via intermediate points. By using a fast transport mode, such as air transport, the responsiveness in a supply chain can be undoubtedly increased but at the same time this results in high transport costs. In this respect, the relation to the other drivers must not be neglected as, for instance, using a fast transport mode generally results in lower inventories.

**Information** includes the data about facilities, inventory, transportation, costs, prices, customers, etc. in the supply chain. This driver affects every part of the supply chain and can help to increase efficiency and responsiveness simultaneously. In order to provide, analyse and share information within a supply chain various enabling technologies can be used, such as electronic data interchange for transmitting orders, radio frequency identification for tracking and tracing of goods, enterprise resource planning systems to administer data internally and supply chain management software or advanced planning software to provide decision support.

**Sourcing** comprises the choice of who will carry out an activity and is the process required to buy goods and services. It is linked to the make-or-buy decision of a company which determines the tasks to be carried out in-house and the tasks to be outsourced, i.e. the degree of vertical integration. If a task is outsourced, the company then has to decide how many suppliers to use and where the suppliers are located. These decisions together with the delivery conditions of a supplier have a huge impact on efficiency and responsiveness.

**Pricing** relates to decisions of how much to charge for the goods and service and how to use promotional and marketing tools. This driver can help to match supply and demand by using revenue management techniques.

The decisions which have to be taken in a supply chain fall into three phases which are supply chain design, supply chain planning and supply chain operations, whereby these decisions differ with respect to the frequency of decision-making and the time horizon upon which a decision has an impact. During the first phase the structure of a supply chain together with the capacities and location of facilities are determined and make-or-buy decisions are made. All these decisions have a long-term impact. In the second phase, the company decides which markets will be supplied from which locations, if subcontracting of manufacturing is done and the inventory policies are fixed. These decisions have a mid-term time horizon of a quarter to a year. On the operational level, short-term decisions are taken. For instance, detailed production plans or delivery schedules are fixed (Chopra and Meindl, 2010).

Fleischmann et al. (2008) follow a similar categorization based on Anthony (1965) for supply chain planning decisions. Planning refers to the preparation of a decision and decision-support by the identification of alternatives and se-
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Figure 2.1: Supply chain planning matrix

Source: Fleischmann et al. (2008, p. 87)

lection of a good or the best solution (see, also, Domschke and Scholl, 2005). Planning can be supported by different operations research methods, such as linear programming, mixed integer programming, simulation, forecasting and similar. For an overview of operations research methods see, for instance, Hillier and Lieberman (2010). Fleischmann et al. (2008) distinguish between long-term (strategic) planning, mid-term planning and short-term planning. In addition to time horizon, the planning tasks for a supply chain can be categorized according to the supply chain processes, i.e. procurement, production, distribution and sales. By taking these two dimensions the supply chain planning matrix can be built which shows the different supply chain planning tasks. (see Figure 2.1). This matrix gives a good overview of the different decisions which have to be taken in order to design and operate a supply chain.

2.2 Sustainability of supply chains

According to the Brundtland Report (United Nations, 1987) sustainability is defined as “[...] development that meets the needs of the present without compromising the ability of future generations to meet their needs”. In this respect, sustainability comprises three dimensions, namely economic, social and environmental sustainability. For several years now, researchers and practitioners in the field of operations management have been facing the challenge to integrate the issues of sustainability into the traditional way of thinking.
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Based on the idea of sustainability approaches like the triple bottom line (3BL, TBL) (Elkington, 2004) which refers to reporting about the three Ps, i.e. people, profit and planet, have been developed (Kleindorfer et al., 2005). Studies have shown that the long-term success of a company can only be guaranteed if the concepts of sustainability are integrated in supply chain management. Companies which attempt to maximize the performance of all three dimensions outperform those only concentrating on economic performance or just achieving high social or environmental performance (Carter and Rogers, 2008).

Seuring and Müller (2008) present an extensive literature review and identify drivers and barriers for sustainable supply chain management which is defined as “[... ] management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainability, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements.” This means that sustainable supply chain management, in contrast to “traditional” supply chain management deals with a wider set of performance indicators and objectives. According to this survey the research is dominated by environmental issues; social aspects and the integration of all three dimensions in supply chain management are only rarely considered.

In this respect, Pagell and Zhaohui (2009) use case studies in order to develop a model of an integrated sustainable supply chain, whereby they consider both the environmental and the social aspects of sustainability. They, as well, point out that a sustainable supply chain “[... ] performs well on both traditional measures of profit and loss as well as on an expanded conceptualization of performance that includes social and natural dimensions.” For their study, they choose leaders in sustainable supply chain management from different industries and identify what distinguishes their business model from traditional supply chains. In more practical terms, in order to be sustainable a supply chain should seek to reduce greenhouse gases, the use of energy and water and avoid harmful substances in the design, manufacturing and distribution of products. In addition to that, sustainability goals should also include social responsibilities to employees, suppliers, customers and the community (Pedersen, 2009).

Also, Halldorsson et al. (2009) carry out a literature review about supply chain management and its relation to sustainability. In conclusion they point out that there are three approaches about how supply chain management can deal with the issue of sustainability distinguishing the integrated strategy, the alignment strategy and the replacement strategy. Following an integrated sustainability strategy means that current supply chain practices should be enhanced to consider environmental and social aspects. For that the notion of
supply chain efficiency has to be broadened by also considering environmental and social performance measures. A balance between costs, service and environmental as well as social aspects has to be found. By using an alignment strategy which can be referred to the triple bottom line approach economic, social and environmental aspects are considered as complimentary. Equal weight is assigned to the three goals. For that purpose, the three dimensions have to be part of the company’s mission statement. The replacement strategy assumes that supply chain management is in contradiction to sustainability assuming that, for instance, what is positive for the revenue of company automatically has a negative impact on the environment. So, in order to achieve sustainability a paradigm shift has to take place. This last strategy refers to more critical views on today’s business actions to achieve sustainability. According to Ehrenfeld (2005) all actions are rather focused on “[...] reducing the unsustainability of a flawed economic development system [...]” than creating sustainability. According to that idea, in order to achieve sustainable development a fundamental change has to take place.

In particular, the impact of operations and supply chains on the environment has received increasing attention from governments, society and consumers in the recent past. Environmental criteria become more and more important for the decisions which have to be taken in the field of supply chain management. In our work we leave out the social dimension of the term sustainability and restrict it to the economic and environmental dimension.

2.3 Concepts of green supply chain management

A literature review about green supply chain management is provided by Srivastava (2007). According to him green supply chain management can be defined as “[...] integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the customer as well as end-of-life management of the product after its useful life.” A topic which is very often covered in this respect is the recovery of used products, i.e. reverse logistics (see, e.g., Dyckhoff et al., 2004, Fleischmann et al., 1997), and the design and management of closed-loop supply chains (Flapper et al., 2005). In these works, it is assumed that the environmental performance is automatically improved when considering reverse flows in decision-making. According to Srivastava (2007) green supply chain management becomes more and more important because of various reasons. Firstly, the deterioration of the environment, such as the depletion of natural resources or higher levels of pollution, forces companies to consider the environment in their decisions. Secondly, regulations are
imposed by national and international authorities with which companies have to comply. Thirdly, customers and the society put pressure on companies.

In this respect, Walker et al. (2008) identify drivers and barriers of green supply chain management practices based on a literature review. Then an explorative study is conducted with a small number of private and public sector organizations in order to verify the importance of the drivers and barriers. In accordance with Srivastava (2007) they differ between internal, i.e. organizational factors, and external drivers, i.e. regulation, customers, competition and society. Environmental supply chain management might be pushed by the personal motivation of managers or by cost reduction initiatives. But Walker et al. (2008) conclude from the conducted interviews that the external drivers are by far more important. Regulations are passed by national and international authorities and impose restrictions upon companies which can be proactive or reactive towards the legislative initiatives. Business customers put pressure on companies by, for instance, requiring certification. Consumers might change their shopping behaviour demanding “green” products to a greater extent. Competition can also be seen as a driver for environmental supply chain management as companies using environmentally friendly technology might gain a competitive advantage. Further, the companies leading in technology might be responsible for new industry standards and/or regulations. Finally, society and various stakeholder representatives, such as non-governmental organizations, encourage companies to act “green” in order to keep a certain reputation. Often, costs are considered as major barriers to environmental supply chain management by assuming that there is a clear trade-off economy and environment (Porter and van der Linde, 1995). But also lack of commitment from management and partners in the supply chain or regulations might be a barrier to the successful development of a green supply chain by hindering innovations.

Based on the idea that there is a trade-off between economy and ecology Huppes and Ishikawa (2005, 2007) have developed the concept of eco-efficiency which can be used for the environmental sustainability analysis of systems, such as supply chains. Eco-efficiency refers to “[... a ratio between environmental impact and economic cost or value” (Huppes and Ishikawa, 2007). They refer back to a definition of eco-efficiency by Schmidheiny (1992) which was further developed by World Business Council on Sustainable Developement (2000) and Verfaillie and Bidwell (2000). Four types of eco-efficiency can be distinguished based on whether the focus is on value creation/cost reduction or environmental improvement. Environmental productivity and its inverse, environmental intensity of production, refer to the value creation aspect. Environmental productivity is defined as production or consumption value per unit of environmental impact; the environmental intensity is the environmental impact per unit of production or consumption value. In contrast to this, the
environmental improvement cost, which is the cost per unit of environmental improvement, and its inverse, environmental cost-effectiveness, which shows the environmental improvement per unit of cost, are related to environmental improvement measures (Huppes and Ishikawa, 2007).

The work of Bloemhof-Ruwaard et al. (1995) is one of the first reviews about how operational research and environmental management (might) interact. They also identify future legal requirements and consumer pressure as the main drivers for integrating environmental issues into supply chain management. The central idea is that two interlinked chains exist, i.e. the supply chain and the environmental chain. On the one hand the supply chain impacts on (“harms”) the environmental chain by producing waste, emissions and similar unwanted byproducts. On the other hand the environmental chain provides the resources for the supply chain to produce its output. Furthermore, changes in the environmental conditions have an influence on how a supply chain can operate and environmental regulations impose restrictions on supply chains. The same idea is reflected in the “inside-out/outside-in” relationship between companies and the environment which is suggested by Porter and Reinhardt (2007). Bloemhof-Ruwaard et al. (1995) point out different approaches of how the environment could be considered in company’s decision-making process. The “end-of-pipe approach” relies on the idea to incorporate environmental issues as constraints into existing models. In contrast to this, preventive approaches require the development of new models and the use of different techniques. In addition to the integration of environmental issues into supply chain modelling they point out that operations research can support environmental policy-making. Daniel et al. (1997) extend the work of Bloemhof-Ruwaard et al. (1995) by carrying out a similar literature review.

Also Wu and Dunn (1995) underline that several environmental problems have been enforced or even created by economic activity. There is a two-sided relationship between supply chains and the environment; on the one hand, resources are used and converted into desired output products and on the other hand, undesired byproducts, such as waste and emissions, are the result of supply chain processes. Due to stricter regulations and higher customer awareness, environmentally responsible logistics systems have to be created which also have to meet cost and efficiency objectives. For that purpose, environmental objectives have to be added to the decision-making process on the different stages of the supply chain, such as raw material procurement, inbound and outbound logistics, the production process and the after-sales service. Several small examples on how to reduce the environmental impact are given, ranging from local sourcing, to the use of alternative transport modes and packaging reduction initiatives.
Angell and Klassen (1999) point out that much of the research in the area of environmental operations management “[...]
has adopted a prescriptive tone, based on anecdotal evidence [...]” and they identify two perspectives, namely the external constraint perspective and the component perspective. While under the constraint perspective environmental performance requirements are considered as an externally imposed constraint, under the component perspective environmental issues are integrated into the operations strategy as a factor of its own. Based on a literature review and supported by a focus group, they develop a research agenda and identity research gaps. In their long list of research topics they point out several questions which refer to our work. These are, for instance:

- How do environmental issues impact supply chain management?
- How to integrate environmental issues into planning and decision-making and what are appropriate performance measures?
- How to include environmental variables in the objective function of traditional operations management and operations research?

Furthermore they underline the importance of applying environmental tools, such as life cycle analysis, in order to support environmentally sound decision-making.

Also, Inman (1999) point out that environmental considerations have to be included into production planning and control, inventory control and distribution and logistics. With respect to the first area he points out that existing models have to be adjusted in order to be applicable to disassembly processes. Concerning inventory planning he also focuses on the integration of the return flow into existing models (disassembly, reuse, recycling, repair, etc.). In the third area, the importance of integration of the two flows, i.e. forward and reverse, into logistics and transportation planning is underlined. This paper clearly shows that environmental supply chain management is often limited to the idea of considering return flows of supply chains. By doing that, it is assumed that the environmental performance of a supply chain is automatically enhanced. But this general statement has recently been doubted by, for instance, Quariguasi Frota Neto et al. (2009a).

The work of Klassen and Johnson (2004) highlights the past developments in green supply chain management and systematize green supply chain practices, i.e. environmental certification, pollution prevention, reverse logistics, life-cycle assessment and design for environment. They develop a framework for integrating supply chain orientation and environmental orientation. The supply chain orientation ranges from a transactional to a network orientation whereby the first refers to a short-term relation of the company with its partners in the supply chain and the latter denotes the establishment of long-term relations with key partners in order to exploit synergies. With respect to en-
environmental orientation either a proactive or a reactive attitude of companies with respect to the environment can be witnessed. A proactive orientation means that a company anticipates new environmental issues and integrates these concerns in its decision-making. It is concluded that a transactional supply chain orientation limits the potential improvements from green supply chain management. Overall, the supply chain orientation has to be aligned with the environmental orientation in order to be successful in implementing a green supply chain practice. They conclude that for decades environmental issues have only been considered in the form of pollution control within a single firm, but over the past years the scope has been broadened first from a single firm to whole supply chains and second from control to actively prevent negative environmental impacts (Klassen and Johnson, 2004). Related to this, Tsoulfas and Pappis (2006) present environmental principles which have to be considered in the field of product design, packaging, collection and transportation, recycling and disposal, greening the internal and external business environment. The different approaches, such as packaging reduction, reduction of hazardous materials or increasing of recycling quotas, and their applicability are supported by case studies.

Bloemhof-Ruwaard and van Nunen (2005) present a framework for sustainable supply chain management and state that (environmental) sustainability can be attained by changing the network design and/or modes of transportation. They define sustainability according to the Brundtland report and in their concept all forward and reverse supply chain processes are included. All the processes have to be optimized considering ecological, economic and social objectives. They distinguish two major fields, namely closed-loop supply chains, comprising reverse logistics, waste recovery management and product recovery, and the triple bottom line concept which includes green logistics, environmentally conscious manufacturing and industrial ecology. The first concept aims at the coordination of forward and reverse flows and thereby making the supply chain more environmentally friendly. The second concept, also known as the Triple E concept (economy, ecology and equity) has its focus on the forward supply chain whereby the optimization of the processes has to consider all three dimensions. Again, it is required that existing models are adapted to the new objectives.

Corbett and Klassen (2006) relate the development of environmental (operations) management to the developments which have taken place in quality and supply chain management. Both streams had a huge impact on the operations management community by broadening its perspective. For instance, ideas from quality management are closely related to environmental protection (see, e.g., quality and environmental management standards by ISO, 2010). But the question of how environmental performance is defined and measured has not yet been clearly answered.
Linton et al. (2007) relate environmental sustainability and supply chains in their work. They state that focusing on the whole supply chain can significantly contribute to sustainability. Furthermore, supply chains have to be extended to include by-products of the supply chain; the entire life cycle of the product has to be considered and the optimization has to be done based on total cost which includes the effects of resource depletion and the generation of by-products, such as pollutants and waste. Sustainability is a topic which relates to both, natural and social sciences and is linked by policy-making. The relationship between policy and operations and supply chain management is evident. Policies impose restrictions on supply chains which have to be considered in decision-making, whereas the latter can affect policy and science by presenting alternative ways of operating and innovations.

As shown by the literature review many conceptual papers about how to integrate environmental issues into supply chain management are available whereby most of them point out the need for extending “traditional” supply chain management by considering the impact of supply chain activities on the environment. In addition to that lots of work can be found which covers the issue of reverse logistics and closed-loop supply chains. To the best of our knowledge, less work has been done with respect to the forward supply chain, its impacts on the environment and how to integrate environmental issues and regulations into decision-making. With our work we want to contribute to this new and emerging field of research.

2.4 Carbon emissions resulting from supply chain activities

Supply chains have various impacts on the environment by, for instance, consuming natural resources and producing waste or emissions that negatively affect the environment. Life-cycle assessment is a method for gathering data on environmental impacts of products and their supply chain processes. It is used for the systematic evaluation of the effects which a product has on the environment over the entire period of its life. In the broadest sense the term life-cycle refers to a “cradle-to-grave” approach considering sourcing, production, transportation, usage and post-usage phase. A “cradle-to-gate” analysis represents a partial life cycle assessment whereby it takes into account all the upstream processes of the product’s life cycle until it is manufactured and reaches the factory gate (ISO, 2010). Guidelines for conducting a life-cycle assessment can be found in the ISO 14 000 series of the International Organization for Standardization (ISO, 2010), the related guidelines PAS 2050 (BSI Group, 2010) and the handbook for the International Reference Life Cycle Data
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System (European Commission, 2010b). By doing a life-cycle assessment the environmental impact of a product and the related supply chain processes can be measured and the results can be used for restructuring the supply chain processes or implementing new technologies in order to reduce the negative environmental impact (Hagelaar and van der Vorst, 2002).

A life cycle assessment consists of four phases, i.e. the definition of the goal and scope, the life cycle inventory analysis (data gathering), the impact assessment and the interpretation of the results (ISO, 2010). The first key element is to identify and quantify the environmental loads involved, such as the energy and raw materials consumed, the emissions and wastes generated. Several different methods can be applied for the life cycle inventory analysis (Suh and Huppes, 2005). As secondary data sources, life cycle inventory databases can be used which contain reference values for different products (see, for instance, Ecoinvent, 2011). Then, it is necessary to evaluate the potential environmental impacts of these loads and to assess the options available for the reduction of the environmental impacts. Environmental impacts include, for example, global warming/climate change, acidification, eutrophicaton or ecotoxicity (European Commission, 2010b).

Climate change, as one of the impact categories of a life-cycle assessment, is one of the biggest issues in today’s world and carbon emissions are considered to be one of the key factors intensifying global warming (IPCC, 2007). Therefore, especially the carbon footprint of products has become more important in recent years. The carbon footprint represents a sub-set of the data covered by a life cycle assessment. The carbon footprint is a measure of the total amount of carbon dioxide equivalent (\(CO_2e\)) emissions (in grams, kilograms or tons) that is directly and indirectly caused by an activity or is accumulated over the life stages of a product. The carbon footprint contains not only carbon dioxide emissions but also emissions of other greenhouse gases, such as \(CH_4\), \(N_2O\) and \(SF_6\) (Wiedmann and Minx, 2008). In order to sum up these gases to the single indicator \(CO_2e\) conversion factors have to be applied in order to represent the difference in the global warming potential of the greenhouse gases (IPCC, 2007).

The carbon footprint includes the carbon emission related to production, warehousing as well as transportation processes. In this respect, a distinction between direct and indirect emissions has to be made; direct emissions result from the combustion of fossil fuels while indirect emissions are associated with energy use and therefore, depend on the way the energy is produced (Wiedmann and Minx, 2008). The importance of a certain stage decisively depends on the product under investigation and the respective supply chain. In order to get a complete carbon footprint a life cycle assessment is necessary which requires a huge amount of resources, time and expertise for gathering...
and analysing the detailed process data. Instead of a life cycle assessment, very recently analytical models for determining the carbon footprint of supply chains have been developed (Sundarakani et al., 2010) whereby the results still have to be validated with real-world data. The carbon footprint of a product is directly related to the supply chain carbon efficiency which is the quantity of products produced divided by the total amount of carbon emissions. According to Craig et al. (2009) this ratio can be used as a new performance measure in the evaluation of supply chains and by reducing the product carbon footprint the carbon efficiency of a supply chain is automatically improved.

The (product) carbon footprint also receives increasing attention from the customer’s side and can therefore be used for marketing purposes. Several initiatives with respect to carbon labelling aim at showing the carbon content of a certain product in order to influence the customer’s product choice. In order to guarantee a reasonable application of such labels standardized procedures for measuring carbon emissions from supply chain processes still have to be developed (Halldorsson et al., 2009). There are different kinds of carbon labels, namely carbon labels showing the absolute amount of carbon emissions of a product during its life cycle, carbon intensity labels, carbon rating labels, carbon reduction labels and carbon neutral labels. These labels serve different purposes as a marketing instrument and display different kinds of information. And at the moment it is still doubted that carbon labels encourage a “greener” product choice of customers; they might rather lead to confusion of customers (Walter and Schmidt, 2008).

Beside the product’s carbon footprint, the emissions resulting from transport activities are in the focus of political debates on the European level. The carbon emissions from the transport sector within the EU-27 are the only ones which have grown significantly between 1990 and 2006 with an increase of 26%. Carbon emissions from international aviation and navigation have witnessed an even stronger increase of 102% and 60%, respectively, between 1990 and 2007. Furthermore, in 2007, transport (excluding international aviation and maritime navigation) accounted for almost 20% of carbon emissions within the EU and therefore was the second largest polluter behind heavy energy-intensive industries (EEA, 2008, 2009).

For determining the carbon emissions from transportation processes, carbon emission calculators have been developed. These calculators help to quickly determine the carbon emissions resulting from transportation activities based on several input parameters, such as transport mode and vehicle type used, distance travelled, load factor and type of product (weight and volume). But these transport carbon calculators differ very much with respect to the parameters such transport modes included and the geographical scope. Mtalaa et al. (2009) present an overview of carbon emission calculation models and
Treitl et al. (2010) show how a state-of-the-art carbon calculator for transport could be integrated with transportation management systems which are used for planning and controlling purposes.

Beside such tools which can be applied on the company level, the determination and forecast of the total carbon footprint which results from freight transport is an important issue. Piecyk and McKinnon (2010) use six factors which influence the freight transport carbon footprint to develop scenarios for the development of the UK road transport and the related carbon emissions by 2020. These factors are structural factors related to the number, location and capacity of factories, warehouses and other facilities in a supply chain, commercial factors which determine companies’ sourcing and distribution strategies and policies, operational factors which influence the product flow and functional factors which are related to the management of the transport. In addition to that, product-related factors, such as the packaging and the design of products affect the nature of the transport operation, and external factors, such as regulations, macro-economic trends and technology improvements, have to be considered. Most of these factors are directly related to supply chain management decisions which underlines the importance of these decisions for transport carbon emissions.

2.5 Environmental regulations impacting supply chain decisions

Environmental regulations are implemented by national governments or international bodies. These regulations aim at reducing the negative impact of economic activities on the environment and tackle problems, like global warming, depletion of natural resources or declining biodiversity. Of course, these regulations also have an impact on supply chains. Especially climate change is a global problem and therefore has to be tackled by global agreements, such as the Kyoto Protocol. The aim is to achieve economic growth while at the same time assuring environmental protection. But especially for developing countries other challenges, such as poverty or social unrest, might be more eminent. Therefore, a global agreement on common actions is difficult to achieve (The World Bank, 2008).

2.5.1 Overview of environmental regulations

According to Coase (1960) the core of an efficient market is that each subject is confronted by the total costs and utilities of its activities. This is not the case if the production or utility function of a subject also contains parame-
ters which are influenced by one or more other subject(s). These influencing parameters are denoted as positive or negative external effects. For instance, the external effects of transport are mainly negative ones. It is assumed that the negative externalities of transport impose costs upon the society, distinguishing between external costs of the infrastructure and external costs of the transport activity itself. The first includes mainly costs due to land use and soil sealing. The second comprises the costs of accidents, congestion, noise, air pollution and climate change due to carbon emissions. Further, external effects can be subdivided into psychological, pecuniary and technological externalities. In the case of externalities the private cost or utility are not in line with the social cost or utility and the resources are allocated in an inefficient way. Authorities try to increase the efficiency in the market with the help of policy measures aiming at the internalization of external costs (Eisenkopf, 2008).

Nagurney (2000) differs between demand-side and supply-side oriented environmental (policy) instruments. Supply-side oriented instruments include measures taken under technology and infrastructure (network design) policies. Concerning demand-side oriented policies, environmental regulations based on “command and control” are used to impose restrictions on enterprises. These instruments have already been or are now replaced by approaches based on economic incentives. The most popular instruments are to impose taxes on and grant subsidies to polluters or to use tradable pollution permits. These permits, also called allowances or certificates, are given to the polluters by regulatory authorities in order to limit the total amount of pollution (e.g. emissions, water pollutants, etc.). The permits can then be traded among the enterprises included in the regulation.

Similar to that, The World Bank (2008) differs between regulatory measures, fiscal measures, market-based instruments and voluntary agreements to combat climate change. Regulatory measures include regulations, standards, directives and mandates. These measures are mainly implemented to encourage energy efficiency and the use of renewable energy; they are commonly used in many OECD countries. For instance, the EU member states have committed themselves to cover 20% of their energy needs from renewables by 2020 and a directive regulating the labelling of household appliances according to their energy efficiency was agreed in 1996. In addition to that, fiscal policies and measures, which include environmental taxes and subsidies, are introduced in order to achieve different environmental goals. Market-based measures, such as emission trading and the use of tradable renewable energy certificates, are increasingly used as they can help to decrease the cost of mitigating emissions. Also voluntary agreements are becoming more popular at the moment. These agreements are negotiated directly between the authorities and the industry and they offer more flexibility to the companies than other measures.
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In general, research about environmental policies has a longer tradition in economics. An overview of environmental policy analysis from a macroeconomic perspective is given in Nijkamp and van den Bergh (1997). Due to the scope of this work, Sections 2.5.2 and 2.5.3 deal with two policy instruments directed at the reduction of carbon emissions, i.e. emission taxes and emission trading, respectively.

2.5.2 Emission taxes

As already stated, a tax on polluting activities can be used in order to internalize the external costs of environmental degradation. This charge which has to be paid per unit of emission can also be called Pigouvian tax or effluent tax. By this, a cost is assigned to a former byproduct of the operations of companies and therefore, it should become part of companies’ decision-making (Xepapadeas, 1992). Most works dealing with the modelling of emission taxes and its impact on the economy stem from the macroeconomic field. For instance, Verhoef et al. (1997) model production and emission taxes in a spatial price equilibrium model in order to show how these taxes affect production and trade in a network. They derive the optimal production and transport taxes so that emissions remain below a specified limit and welfare is maximized. In addition, it is shown that environmental transport policies conducted in isolation have indirect side-effects which can be positive or negative. In general, transport emission taxes lead to a reduction of transport activity and the related emissions. Whether the overall effect on the environment is positive or negative decisively depends on the difference of pollution from production of the regions under consideration. Only if the pollution from production is the same in the regions isolated transport emission taxes have the desired overall reduction effect.

Carbon or energy taxes which are based on the carbon or energy content of products are already used especially in Northern Europe where they are considered as an effective instrument. Already in the early 1990s, Finland, Sweden and Norway introduced taxes on the carbon content of fossil fuels. Of course, carbon tax rates vary largely across the countries and between sectors and also depending on the fossil fuel used. The effectiveness of this measure is to some extent reduced due to tax reductions, rebates, tax ceilings or exemptions which are also introduced by the respective countries (The World Bank, 2008).

In general, with the help of emission taxes the difference between private and social cost should be compensated in order to derive a socially-desirable level of output. For companies emission taxes are a financial incentive to reduce emissions and equate their marginal abatement costs with the tax level.
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Therefore, a tax should be preferred to imposing (absolute) restrictions on emissions or mandating certain technologies because such policy measures do not encourage companies to reduce emissions below the prescribed limit or invest in innovations. Furthermore, emission taxes are revenue-raising environmental policies where the revenues can be used to cut other taxes. But as a disadvantage, emission taxes lack precision with respect to emission quantities. This means that it is difficult to reach a specified reduction target with the help of an emission tax. Only if the policy-maker has complete knowledge of the abatement cost function of companies the effect of an emission tax on the emission quantity could be anticipated with certainty (Hoel, 1998). A further argument against emission taxes is that emission taxes which are imposed on producers directly lead to a cost increase and are, therefore, harmful to economic performance and in particular to employment. But this statement is not fully supported by economic theory (Hoel, 1998, Schneider, 1998).

An emission tax applied to the transport sector would have to consider the various transport modes as they produce a different amount of emissions. Making the transport modes pay their full external costs would increase the costs of the more polluting transport modes dramatically. For instance, a study from the UK has shown that this would require a doubling of the taxes on road transport (Piecyk and McKinnon, 2007).

2.5.3 Emission trading

The basic idea of emission trading is that a quantified physical constraint is set in the form of emissions allowances, permits or credits. These allowances are distributed among the agents who then have the right to trade these allowances amongst each other. One fundamental condition for the effective operation of emission trading is scarcity of emissions allowances (Knoll and Huth, 2008). The allowances are sometimes referred to as “pollution rights” as the holders of the allowances have the right to harm the environment (Raux, 2004, 2010). Crocker (1966), Dales (1968) and Montgomery (1972) are one of the first dealing with the formalization of pollution permit markets. They provide evidence that with such a system environmental damages can be reduced while minimizing abatement costs for the players in the market. Goulder et al. (1999) states that emission permits are as cost-effective as emission taxes given that the permits are sold to the producers at their market price through, for instance, an auction. Similar to emission taxes, also emission trading is usually preferred to performance standards or technology mandates.

One characteristic of an emission trading scheme, as a market-based instrument, is that it leaves freedom to the companies on how to comply with the regulation. The decisions over which strategy to use or which technology to
implement is left to the companies which best understand their business operations. Furthermore, an emission trading program requires an integrated approach from the companies which means that the emission reduction strategy has to become part of the overall business strategy. The system itself is easy to understand; a company simply has to hold enough emission allowances to match its emissions. Policy-makers just have to concentrate on monitoring and verifying emissions, tracking the transfer of emission allowances and assessing potential penalties without having to make detailed reviews of the company’s processes as in the case of technical specifications. But the flexibility of the system also increases the complexity for companies with respect to which compliance strategy should be chosen. Furthermore, the companies need to know their internal abatement costs in order to make a reasonable decision about buying and selling of emission allowances (Kruger, 2008). It is assumed that with the help of this system the most cost-effective way of emission reduction is chosen. The companies with high abatement costs prefer to buy additional allowances whereas those with low abatement cost reduce their amount of pollution and are then able to sell the remaining allowances (Nagurney, 2000, Raux, 2004). OECD (2001) summarizes the following benefits of tradable pollution permits:

- Environmental effectiveness: Such a system guarantees environmental performance by addressing environmental impacts directly through the setting of goals or quantified physical limits. For that, the strict monitoring of these quantified parameters is necessary.

- Decentralized flexibility: The agents have flexibility in the choice of means in achieving the environmental objectives.

- Economic efficiency: It helps to minimize the overall cost of compliance by encouraging the agents that can abate pollution more cheaply to do so first, while allowing those with higher costs to opt for buying additional allowances.

At the moment, several (local) emission trading schemes covering greenhouse gas emissions are implemented worldwide. The EU emission trading scheme (EU ETS) is the largest of the currently valid schemes (Antes et al., 2008). The EU ETS came into force on January 1, 2005 based on a directive from 2003 (European Community, 2003b) and it imposes restrictions on companies with respect to the carbon emissions they produce measured in tons of $\text{CO}_2e$. The EU ETS was implemented in order to reach the goals stated in the Kyoto protocol. Frankly speaking, it resulted from the failure of the European Commission to introduce an effective EU-wide carbon energy tax and it was also preferred from an industry-perspective over “command and control” measures (Convery, 2009). It is a cap-and-trade system of allowances for emitting $\text{CO}_2$ and other greenhouse gases whereby each allowance certifies the right to emit
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one ton of $CO_2e$. Up to now, only certain industries are included in this regulation. These industries are mainly heavy energy-intensive industries. The EU ETS covers refineries, power generation with fossil resources, metal production and processing, pulp and paper and mineral industry. Today, more than 11,000 sites that produce around 40% of the EU’s total $CO_2e$ emissions are covered by the EU ETS. At the moment, most of the emission allowances are allocated to the companies free of charge via national allocation plans. Those companies that produce fewer emissions than the number of allowances owned can sell them, whereas those producing more than the assigned limit have to buy additional allowances, get credits by engaging in emission-saving projects (through clean development mechanisms or joint implementation projects) or have to pay a penalty. The aim is to reduce the number of allowances constantly, in order to decrease the total $CO_2e$ emissions within the EU. The EU ETS is split into three trading periods; the first one ran from beginning of 2005 to the end of 2007, the second one lasts until the end of 2012 and the third one from 2013 to 2020 (European Community, 2005). During the first trading period, the market price for emission allowances witnessed a substantial decline due to oversupply (European Commission, 2006).

In 2007, the second largest “polluter” was transport accounting for nearly 20% (EEA, 2008). The EU is already planning to increase the number of companies and sectors which have to comply with the trading scheme, e.g. include civil aviation by 2012 (European Community, 2008). Beside the inclusion of additional sectors, also the mode of allocation will change in the future. At the moment, the allowances are allocated among the member states based on national allocation plans and then further distributed to the companies and the affected installations mostly free of charge. In the third trading period (2013-2020) more than half of the emission allowances will be auctioned instead of being allocated for free (European Commission, 2010a). Furthermore, instead of the decentralized allocation of the emission allowances by each member state the allocation could be controlled by a central authority (Malueg and Yates, 2009).

In addition to that, the ETS directive (European Community, 2003b) foresees the linking of the European ETS with other national or regional emission trading schemes via international agreements. This should encourage the creation of a global emission trading scheme. So far, the major hindrance of linking the existing trading schemes is that they differ in their design features, such as coverage of sectors and emissions, which makes them incompatible. In addition to that, for a global emission trading scheme to emerge, first a global climate change agreement has to be reached (Egenhofer, 2007).

Raux (2010) claims that an emission trading scheme could be particularly appropriate for the transport sector because the agents in the transport sec-
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tor are more sensitive to quantitative regulations than price signals, such as an emission tax. Furthermore, the acceptability of this instrument is higher compared to an additional tax and with this instrument the quantitative objective of emission reduction is guaranteed. But as a disadvantage high costs of administration may arise for the monitoring of the large number of mobile sources. While Perrels (2010) investigates the applicability of emission trading to passenger transport Raux (2010) analyse it for personal as well as for freight transport. In order to reduce administrative costs the emission trading system could be implemented at the upstream, where only a limited number of actors, such as fuel refiners or distributors, would be included in the emission trading. The disadvantage of this system is that the effect on the final emitter is very limited as for them it again results in an additional fee similar to a tax. In addition to that, considering free allocation of the allowances, the acceptability might suffer as those having to take effort for the reduction of emissions, namely the final emitters, do not benefit from the free allocation. In contrast to this, a downstream approach requires the monitoring and administration of a very large number of sources. Under a hybrid approach for emission trading fuel producers and vehicle manufacturers could be included. But this approach might also result in difficulties of, for instance, double counting. Under a downstream approach for freight transport, the most straightforward way is to target fossil fuel consumption as other potential targets, such as tonne-kilometres or vehicle-kilometres, are not easily accessible for regulators. Furthermore, logistics service providers or more specifically transport carriers could be the main parties involved in an emission trading for transport. But it has to be kept in mind that the carriers are limited in their actions by the requirements imposed by the shippers. So in order to guarantee the effectiveness of the systems the shippers have to be involved as well, especially when they carry out the transport themselves. Raux (2010) suggests that any freight vehicle user needs to present the necessary allowances at the time of fuel purchase. The transfer of allowances between transport carriers and shippers can become part of the contractual relationship and the trade of allowances would be based on a stock market.

Overall, emission trading can be a cost-effective measure to reduce carbon emission to a predefined level set by authorities also in the transport sector. But in order to achieve the desired effects and to not cause disadvantages for certain countries or regions emission trading has to be implemented on a global scale as argued by Sinn (2009).