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Logistic decisions' effects to the food supply chains' sustainable performance

Model and case studies

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Logistiikkapäätösten vaikutukset ruokaketjujen kestävään suorituskykyyn – Malli ja casetutkimuksia

Tiivistelmä

Tämän konstruktiivisen tutkimuksen tavoitteena on arvioida strategisten logistiikkapäätösten vaikutusta toimitusketjun kestävään suorituskykyyn. Aluksi tutkimuksessa esitellään malli, jonka avulla toimitusketjujen johtajat voivat arvioida logistiikkapäätöksiä kestävää suorituskykyä.

Teoriassa esitellään kestävää kehitystä ja toimitusketjujen johtamisen teorioita. Teorian yhteenvetona tutkimus esittelee mallin, jolla toimitusketjun kestävää suorituskykyä voidaan arvioida. Mallia sovelletaan MS Excelissä, kun ratkaistaan kolme casetutkimusta. Kaikki caset käsittelevät logistiikkapäätösten vaikutuksia toimitusketjun kestävän suorituskyvyn näkökulmasta. Ensimmäisessä casessa tutkitaan kertakäyttöisen kuljetuspakkauksen korvaamista kierrätettävällä ratkaisulla, toisessa tehtaan sijoituspäätöksen vaikutuksia ja kolmannessa toimitusrytmin vaikutusta. Kahdessa tapauksessa sekä kustannus- että hiilidioksidipäästövaikutukset olivat samansuuntaiset, mutta yhdessä tapauksessa päästöt lisääntyivät ja kustannukset laskivat. Tulos riippuu kuljetuksen roolista tarkasteltavassa ketjussa.

Tämä tutkimus tuo uuden menetelmän ja casetutkimusten tulokset aiheeseen liittyvän keskustelun pariin. Tulokset voivat rohkaista toimitusketjujen johtajia huomioimaan kestävän suorituskyvyn tekijöitä logistiikkapäätöksien tekemisessä.

Asiasanat

toimitusketjujen johtaminen, kestävä kehitys, logistiikkastrategia, elintarviketeollisuus

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Abstract

The purpose of this constructive research is to estimate strategic logistic decisions effects to the supply chain sustainable performance. Before that this research also introduces a model to support supply chain managers make more sustainable logistics decisions.

A literature review of the sustainability and supply chain management is presented. This research introduces a model for estimating sustainable performance as a conclusion of the literature review. The model is applied in MS Excel based data sheets as a method in three empirical cases. All of them handle strategic logistic decisions effects to the supply chains sustainable performance. The first case handles the effect of the replacing disposable transportation crates with recyclable ones, the second case effect of the plant location decisions and the third case effect of the delivery frequency. The cost and carbon dioxide effect in two cases costs were parallel, but in one case costs decreased and emissions increased. The results depends the role of the transportation in the case supply chain.

This research brings a new method and results of the case studies to this issue. The results may encourage supply chain managers consider more sustainable issues when making logistic decisions.

Keywords

supply chain management, sustainable development, logistic strategy, food industry

FOREWORDS

I had a score to settle with my licentiate thesis in 2007 when I created the very first file named "PhD" during my firstborn's afternoon naps. The process was paused, when the second child was born late in 2008, and the process almost stopped some time later when I had to cope with too many hard things of the life. However, this thesis has been accompanied with me during tough years in my life. I have learned a lot, but I will be happy to start a new chapter also in the academic sector.

My supervisor, Professor Petri Helo deserves great thanks. He has given his expertise and enthusiasm to this process and strengthened my mission whenever I have needed it. I also thank my friends and colleagues at the Tutkijahotelli, University of Vaasa and conferences especially at the ICMIE 2012 Singapore and EcoTech 10 in Kalmar for the academic, but also human, support and feedback.

I like to thank the Finnish Cultural Foundation South Ostrobothnia Regional Fund, Oiva Kuusisto Foundation, Kauhajoki Cultural Foundation and Seinäjoki University of Applied Sciences for the financial support of the thesis. Great thanks belong also to the family, especially to my mother Arja and my husband Petri.

I am also grateful to pre-examiners, professors Lauri Ojala and Angappa Gunasekaran

At the time of the first snow and third baby in Seinäjoki 22.11.2013

Hanne Ala-Harja

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1 INTRODUCTION

Food supply chain is remarkable issue in global economy and ecology (Baldwin, 2012; Ghosh, 2010; Spiertz, 2010). Food is consumed daily in every part of the world. Food is an essential part of consumption no matter if it is measured with money, consumption of natural resources, greenhouse gas emissions (GHG), other environmental effects or employment, (Seppälä et al., 2009, cf. Figure 20). Many of the food products have short self-life times. Food production is centralized and food supply chains (defined in 2.2) are globalized. Fragility and security of food system is an issue (Cohen & Garret, 2010). At the same need for sustainable development (defined in 2.1) has increased. Especially cutting the carbon dioxide emissions interests generally. These create great challenges for logistics.

This study aims to reduce environmental effect of the food logistics. It is not clear how logistic decisions effect to the environment. It is neither clear, how the carbon dioxide favorable decisions effect to logistic parameters such as the delivery time, quality, delivery reliability and costs. The effect of logistic decisions to for example to parameters mentioned before will be analyzed in three case studies.

Topic of this study is important because the volume of the food products is high and sustainable development cannot be just something desirable in companies; it has become an absolute necessity in the industry. Carter and Easton (2011) seem sustainability as license to do business in the twenty-first century and supply chain management is an integral component of this license. Krause et. al (2012) straightforwardly say that company is no more sustainable than its supply chain and effective sustainability integrating into firms requires action that exceeds organizational boundaries (Seuring & Gold, 2013).

Also supply chain focus will enhance logistics performance, which will ultimately result in improved organizational performance (Green, Whitten & Inman, 2008; Pedersen, 2009). Logistics is an essential part of the supply chain not only by the terms of money but it also has a role as part of environmental performance. Transportation produces 13,5% of global greenhouse gas emissions (defined in 2.1.2.2) of which road transportations comprise 72%, air transportation 12% and rail, ship and other transportation 17% (WRI, 2011). According to McKinnon and Forster (2007) the level of CO_2 emission from warehousing and materials handling operations may be closely correlated with those of freight transport. However, there are few studies connecting minimizing logistical costs and environmental effects (Bloemhof-Ruwaard et al., 2004; in Quanriquasi et al., 2007).

There is a growing need for integrating environmentally sound choices into supply chain management research and practice (Srivastava, 2007). Also McIntyre et al. (1998) have reported in El Saadany, Jaber and Bonney (2011) that "environmental concerns have been examined and treated separately in supply chain functions and there is as yet no integrative approach or mechanism that measures, controls, and improves the environmental aspects of an entire supply chain; a limitation that does not facilitate optimizing the green performance of a supply chain".

The link between economic and sustainable performance of companies interests researchers (Rennings, Schröder & Ziegler, 2003; Wagner & Schaltegger, 2003; Later Schaltegger, Bennet, Burrit & Jasch, 2008, El Saadany et al. ,2011, Klassen & McLaughlin, 1996, Rao & Holt, 2005, Ambec & Lanoie, 2008).

Also the connection between logistic costs and environmental performance interest researchers as well (Rodrigue, Slack & Comtois, 2001) . Green et al. (2012) say that green supply chain practices are both environmentally necessary and good business. Rao and Holt (2005) found that in their research context greening of the different phases of the supply chain led to competitiveness and better economic performance. Also they suggested more studies on the connection between green supply chain management practices and increased competitiveness and improved economic performance. McKinnon (2010) found that many of the GHG reduction measures also yield financial benefit. Also El Saadany et al. (2011) suggest, based on their literature study, that reducing environmental costs improves environmental performance and increases total profits. El Saadany et al. (2011) state that a company's environmental performance can affect its financial performance and cites King and Lenox (2001), who found there is an association between lower pollution levels and higher financial performance.

1.1 Research approach

This research will develop a decision support model for estimating the effects of logistics decisions on sustainable performance. The approach of decision support model building is constructive research. The results of the construction research is tested, and further developed, with three cases studies. On the other hand, the developed model is used as a method in the three cases introduced in this research. This report consists of the basic theories and concepts behind sustainable food supply chain performance evaluation. Also the construction developing process and sustainable food supply chain performance evaluation model as a result are introduced. After the model construction process description the construction validation process with three case studies as examples of the use of the model are described. Then the conclusions of the studies and the model are made and some results of the sensitivity analysis introduced. Finally, the discussion provides a picture of sustainable supply chain performance.

The constructive research is kind of action research. The basis of a constructive study is a real problem in the business environment. In action research the researcher participates or does the development work (Kasanen, Luukka & Siitonen, 1993). Construction is based typically on current studies.

The steps of a constructive study are (Kasanen et al., 1993 in Tervahartiala)
1. Find a practical problem with scientific potential
2. Read and create a comprehensive body of knowledge
3. Build a construction
4. Validate the construction
5. Connect the construction with theory and make scientific conclusions
6. Show the usability of the model

Labro and Tuomela (2003) divide the construction stages to preparatory, fieldwork and theorizing phases. The process starts with problem finding and ends to the theoretical contributions. In Kasanen et al.'s (1993) process they replace the validating model with implementing and testing the construct and examining the scope of applicability of the construct. For example, Lindholm (2008) has applied a constructive study process when she created core business relevant strategy and performance measures.

The construction of this study is a supply chain sustainable performance estimation model. Case studies are described in the following sections (stage 5 represents Kasanen et al.'s, 1993, construction validation processes). The results of the case studies show the usability of the model. Results from the case studies are based on the empirical data and give new information for sustainable supply chain development. The results of the case studies also give information on how different types of logistics decisions effect the supply chain sustainable performance.

The usability of the model and suggestions from the validation data are described in the conclusions. The empirical part of this study is a model validation process with three case studies. The usability of the model is called a market test. It is a way to prove if the construction has succeeded or not. A weak market test ascertains whether the construction is used or not. A strong market test indicates if the model has helped to improve profitability. (Kasanen et al., 1993.)

Srivastava (2007) has introduced methods used in green supply chain management. Some examples of them are according to his study linear programming, non-linear programming, markov chains, computer programs, LP solver such as Lindo, data envelopment analysis (DEA) and simulation. This study uses MS Excel based simulation model in the case studies.

1.2 Research problems and questions

This study attempts to increase knowledge about sustainable supply chain management as a part of the sustainable use of natural sources in the long term including social, environmental and economic issues.

The use of the supply chain sustainable performance estimation model is supposed to help set performance attributes and see the connections between performances of the different attributes. The way to improve sustainable development in the SCM is to develop measurement systems based on the idea that "it can be managed if it can be measured". This study attempts to improve sustainable development by accomplishing current SCM systems with sustainability issues and producing information on how sustainability related metrics should be taken into consideration in management of the food supply chain. The use of the model in case studies gives information about usability of the developed model and answer to question.

The model aims to give answers to the following research problems of the case studies:

How will strategic supply chain decisions effect to the supply chain sustainable performance?

This is related to understanding of sustainable performance and performance measurement in the context of supply chain management. An important part is to consider how decisions affect sustainable performance compared to other objectives and ultimately consider how this information should be implemented in strategic management of the supply chain.

The research problem is divided into several research questions. The developed model will be piloted with case studies. The developed model is applied in the case studies which have their own research questions.

The research question in the first case study is:

> *RQ1 - What effects are there on supply chain sustainable performance if the disposable transportation boxes are replaced with recyclable boxes?*

The second case study studies the following question:

> *RQ2 - What effects does the plant location decision have on the supply chain's sustainable performance?*

The third case study gives answers to the question:

> *RQ3 - What is the effect of the delivery frequency on the supply chains sustainable performance?*

The results of these three questions with three case studies produce new kinds of information about the effects of the logistic decisions on the sustainable performance of the supply chain. The results of the case studies help to understand the role of logistic decisions in the supply chain´s sustainable performance.

The validation process of model also pre develop the model and increase the body of the knowledge about sustainable supply chain management in the Finnish case food companies.

1.3 Stages of the research

This study introduces a theory based model which connects ecological and some parts of social performance into the supply chain performance model called SCOR 8.0 model (Supply Chain Council, 2007). The developed model will be later called the sustainable supply chain performance model.

The model will be validated with three case studies. It means the model will be used as e method in the case studies. The experiences from using the model in the cases also pre develop the model. The results of the case studies will introduce the effects of the food supply chains logistical decisions to the supply chains sustainable performance. The use of the model will help management to create a bigger picture of the supply chain performance and it will help to estimate how strategic logistic decisions in the supply chain will affect the supply chain's sustainable performance. The use of the model will help create more ecological and economically efficient business strategies.

This study will describe the theoretical framework and developing process of the model and introduces also the results from case supply chains using the model. The model will connect social, ecological and economic supply chain performance metrics. The model will be validated in three food supply chains. The validation process with the most central results and conclusions will be introduced. The validation process will also give some new ideas to special issues of food supply chain management.

Introduction part of this introduces a practical problem with scientific potential and then introduces a body of knowledge in theory. Then the construct building process is introduced and the developed construction validated in the three case studies. Then the construct is connected with theory and scientific, and practical conclusions made.

The stages of the study connect theories about supply chain management and sustainable development to the supply chain sustainable performance evaluation model. The developed model will be used as a method in the three cases of strategic food supply chain decisions.

In the first part after this introduction there is theory which includes sustainability and supply chain management theories and food supply chain part. Theoretical parts have been written mostly between years 2007 and 2009. After that there is model construction / method section, which has been mainly written in 2008 and 2009 excluding the current literature part. The constructed model bases on the theoretical study.

After model construction section there are introduced three case studies with their results. The case studies have been made in 2009 and 2010. The developed model has been used as a method in the case studies. The purpose of the case studies was also to validate developed model. During validation process, the developed theoretical model met needs to develop model further. As a result of this model's further development process, there is introduced a food supply chain sustainable management model in the end of the case studies part.

At the end of this study last there are conclusions and discussion written mainly in 2011 and 2012.

The results of the case studies give new information about the effects if the logistic decisions and the construction validate process give information about how the sustainable supply chain performance model works in the case companies and based on the validation process experiences the simplier food supply chain sustainable performance model is introduces.

The results are concluded in the form of the simple model at the end of the study and the conclusions are discussed. The discussion includes the contribution of the results achieved and their relationship to the previous body of knowledge in the field of sustainable supply chain management.

1.4 Limitations

The assumption of this study is that **supply chains and companies need to consider environmental and social issues, as well as economic ones, as part of supply chain management.** This study introduces a model which makes it possible to see the bigger picture of supply chain performance than individual companies' economic performance.

The results of this research are delimited to food supply chains and the number of pilot cases is three where the developed model has been used. There are only three cases and they are all delimited to the food industry. This study does not take sides on the measurements or climate change and the greenhouse gas effect itself. The developed model is suitable for comparing supply chain sustainable performance if the same methods are used in comparable supply chains. The main criteria for the model use have been usability, connectivity to current management systems, and availability of the data and market value of the outputs. The model developed in this study includes sustainability as performance attribute, but later in validation stage the eco-efficiency issues turn out to be more relevant in case studies. Therefore sustainability issues in cases are not paid attention as much as planned in the beginning of the study.

The triple bottom line model is used as an approach in sustainability and SCOR (Supply Chain Operations Reference Model developed by the Supply Chain Council) is used as a supply chain performance management model even if the triple bottom line model and supply chain management theory is handled more widely in the theoretical part.

During model construction process the social metrics are excluded from the model and environmental metrics are limited to few metrics. Also number of SCOR metrics is limited in the validated model.

The focus and results of the case studies are on economic and ecological issues. The results are limited on the changes caused by the logistic decisions. Economic performance is considered mainly through the SCOR model. The environmental performance is not equal to the greenhouse gas emissions, but in this study environmental performance is focused on GHGs. The greenhouse gas calculations are outlined for the most typical greenhouse gases and lot of GHG gases are excluded because their role in food supply chain GHG emissions are minimal.

Model construction and case study sections have been mainly written in 2008 and 2009. They base on the theory written mostly between years 2007 and 2009. Some of the theory is added after that and not included to model construction and validation processes.

2 THEORY

This chapter introduces the concepts and theoretical body of knowledge on sustainable food supply chain management in term of sustainability, supply chain management, food supply chain management, and introduces studies made in the field of sustainable supply chain sustainable performance management. Conclusions about the theoretical background are made in chapter 2.5 and finally the model for estimating sustainable supply chain performance is introduced in chapter 3.

Harzing Publish or Perish software is used in finding the most ranked or cited academic published research. Publish or Perish software uses Google Scholar as a raw citation database and makes analyses the data with citation metrics. The theoretical part consists mostly of research articles published in international journals found in the Science Direct, Ebsco Host and Abi Inform Emerald databases. Most articles cited in this study are published in journals which were also used in Maloni, Carter and Kaufmann's (2012) supply chain management and logistics author affiliation journal research as data. They outlined their research in the following journals: *International Journal of Logistics Management* (IJLM), *International Journal of Physical Distribution & Logistics Management* (IJPDLM), *Journal of Business Logistics* (JBL), *Journal of Supply Chain Management* (JSCM), *Transportation Journal* (TJ), and *Transportation Research Part E* (TRE).

2.1 Corporate sustainability

This study concentrates on sustainability issues of the supply chain. Sustainability in this study is defined from the company responsibility viewpoint:

Sustainable development aims to use natural sources responsibly in the long term. Corporate responsibility precedes sustainable development. Corporate responsibility consists of economic, environmental and social responsibility

Elkington 1997 (Figure 1) separates corporate responsibility into economic, environmental and social responsibility and this definition is used in this study. This triple bottom line model of sustainability is used in this and in many other studies.

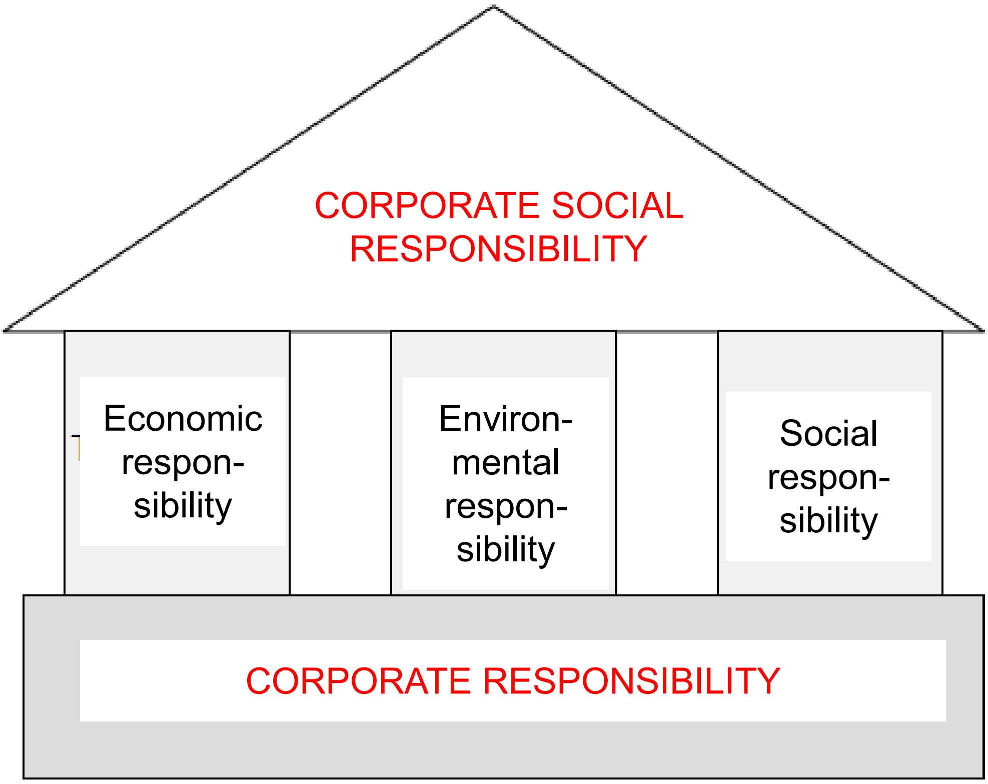


Figure 1. Company responsibility in the wider context (Elkington, 1997)

Sustainability from the viewpoint of economic, environmental and social responsibility is later defined in this research. In this study management is handled as an implication of responsibility and measuring makes it possible to manage and develop (Figure 2). In this study sustainable development is seen as a continuous dialogue between responsibility, management and measuring sustainability.

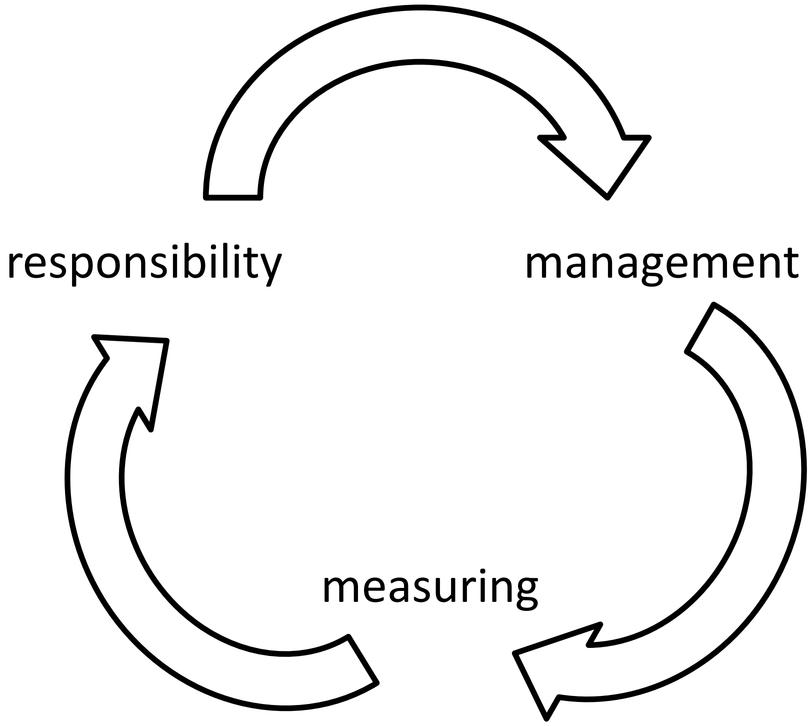


Figure 2. Sustainability development

Sustainable development aims at the responsible use of natural sources over a long time scale. The World Commission on the Environment and Development (1987) has defined sustainability as development that meets the needs of the present without compromising the ability of future generations to meet their needs. In the food chain responsibility issues can be divided into the environment, product safety, nutrition, working welfare, animal welfare, economic responsibility and locality (Heikkurinen et al., 2012). The same research group suggests that sustainable development of the food chain consists of these seven dimensions of sustainability and having more responsibility related operations than is legally required, in a time and place related context and noticing reference groups.

Corporate responsibility can be divided into three parts, which are economic, environmental and social responsibility (Elkington, 1997). Carter and Easton (2011) have made a review of sustainable supply chain management literature and found that the perspective of sustainable supply chain management (SSCM) has developed through corporate social responsibility to the beginnings of the convergence of perspectives of sustainability as the triple bottom line, for example in Forsman-Hugg et al. (2006). In Berger et al. (2001) sustainable development and ecological modernization are the two theoretical frameworks that underlie environmental policy making in industrialized countries.

Later, Elkington (2004) introduced the idea of triple bottom line concept which balances economic, social and environmental goals (Figure 3). Carter and Rogers (2008) introduced sustainability as the integration of environmental, social, and economic criteria that allow an organization to achieve long-term economic viability. According to Carter and Rogers (2008), 68% of 250 global companies generated a separate annual sustainability report (including social, environmental and economic issues) in 2004. Corporate responsibility promotes sustainable development in society and international affairs.

Carter and Rogers (2008) express the triple bottom line approach (Figure 3) connected into the four supporting facets of sustainability. They are risk management, transparency, strategy and culture.

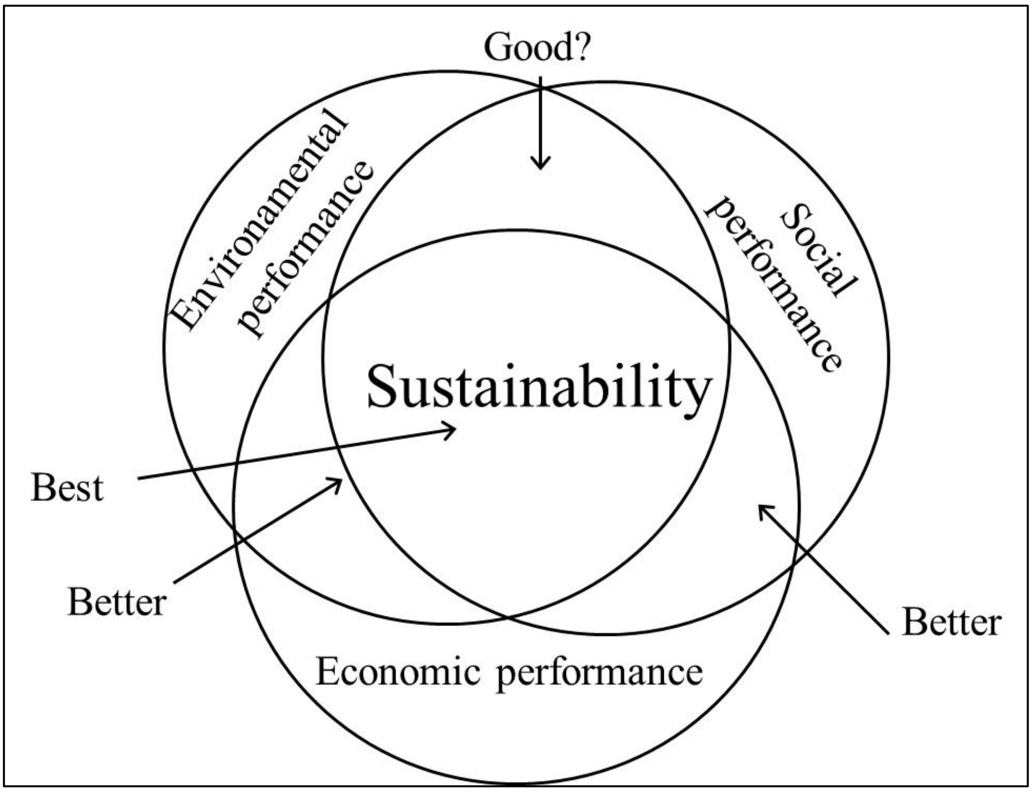


Figure 3. The triple bottom line approach connected into the four supporting facets of sustainability (bases on the Carter & Rogers, 2011)

Economic responsibility means taking care of economic sustainability and the consequences of business actions regarding the economic situation of the reference groups. Economic responsibility includes, e.g. profitability, compatibility, efficiency, the ability to respond to the owner's expectations of the return on investment and competitiveness. Economic responsibility is handled in more detail in supply chain management theory through the selected SCOR model.

2.1.1 Social responsibility

Social responsibility is the third part of sustainability according to the triple bottom line model. The extension of CSR to the supply chain is an emerging area of interest (Keating, Quazi, Kriz & Coltman, 2008). Social responsibility is specially related to animal welfare, the effects on reference groups, pricing, responsible investments, local welfare, and working conditions. Sethi (1995) defines corporate social responsibility as corporate activity and its impact on different social groups. The framework for social responsibility can be divided according to Carter (2005) into social responsibility as diversity, the environment, human rights, philanthropy, safety, organizational learning, supplier performance and cost reduction. Becker, Carbo and Langella (2010) integrates concepts of social responsibility and supply chain management with human resource development.

Carter (2005) firstly examined how socially responsible supply management activities in purchasing affect the firms costs. He found that there is no direct relationship between purchasing social responsibility and costs but it led, e.g. to improved supplier performance.

Company social responsibility means according to the WBCSD (2001) “the commitment of business to contribute to sustainable economic development, working with employees, their families and the local communities”.

Wiedmann et al. (2009) determined that sustainable performance of the company should take into account the direct impacts from on-site processes and also indirect impacts embodied in the supply chain of a company. The CSR approach can be seen as a triple bottom line approach to sustainability. Carter and Easton (2011) name cost savings associated with reduced packaging and more effective design for reuse and recycling, lower health and safety costs, reduced turnover and recruitment costs, improved working conditions and quality and better attractiveness for customers and suppliers as an example of the activity that fall within the triple bottom line. Company social responsibility (CSR) has motivated companies to focus attention on social issues. (Ganesan, George, Jap, Palmatier & Weitz, 2009).

Knoepfel (2001) and GRI (2003) describe CSR’s three dimensions and give examples of actions in Jamali (2006). Kleine et al. (2009) think the social responsibility (CSR) approach is an attempt to implement the vision of sustainable development on the corporate level and it creates a triple-bottom approach, creating a basis for sustainable corporate management policy. They suggest that the economic dimension of sustainability is moving beyond conventional financial accounting by focusing attention on new measures of wealth such as the human/intellectual capital that firms develop. It can be done, for example, by reducing the cost of doing business through rigorous business integrity policies and increasing productivity through a motivated workforce. The environmental dimension of sustainability means, according to them, studying the implications of resource consumption, energy use and the effects of the firm on ecological integrity, for example by environmental policy; environmental audits and management systems and environmental liabilities. The social dimension means maximizing the positive impacts of a firm's operations on broader society, for example with issues of public health, social justice and inter- and intra-organizational equity. Berger et al. (2001) say one reason why environmental policy does not automatically lead to positive-sum games, is that environmental policy pays too little attention to social contradictions.

Only two out of the 25 biggest food manufacturing, retail and service companies did not have stated Corporate Social Responsibility reports and/or general statements of purpose and values related to non-financial company goals, according to the Lang, Rayner and Kaelin (2006). This tells about the importance of company social responsibility but not the quality of the reports.

Halog (2009) has found, in the field of biofuel research, that current impact analysis does not consider all three dimensions of sustainability. The researcher thinks that a major challenge is to develop and implement an integrated set of performance measures that can direct efforts towards restructuring existing supply chains. He introduces OR/MS based metrics which can be used in sustainable supply chain environment with many expectations by the stakeholders.

Global Reporting Initiative (GRI) is the most commonly used and internationally applicable guideline for sustainability reporting (Isaksson et al., 2009; Lamprinidi & Kubo, 2008). GRI was launched in the public sector in 2003, but nowadays governments are pushing businesses to improve and publish their sustainability performance (Lamprinidi & Kubo, 2008). GRI proposes criteria to express sustainable development. For example, Isaksson et al. (2009) suggest that the guidelines are not sufficient to express how sustainable a company is and how quickly it is approaching sustainability. Erol et al. (2009) conclude their study on sustainability in the Turkish retail industry by introducing the best sustainability indicators.

In the field of social responsibility and sustainability, Lee (2008) says that improving social responsibility may not only incur cost but often it can also create savings. Improving sustainability is a long-term process. He thinks the way to improve sustainability is to construct new win-wins between suppliers and their customers, but e.g. distributors should be included more tightly in the new win-wins. Lee also says social responsibility and sustainability not only provide marketing and media potential but can also be used to improve the whole supply chain operations. He also says that solving and improving social responsibility and sustainability challenges cannot be solved in neat isolated departments but it needs a more holistic view.

Isaksson (2005) has reviewed synergies of the two concepts Total Quality Management and Sustainable Development. The triple-bottom-line approach is typically used also in accounting. For example, Wiedmann, Lenzen and Barrett (2009) have used it. Quinlan and Sokas (2009) have raised social issues such as the growth of contingent work, employer responsibility for worker health and safety, low-wage, ethnic minority, and immigrant workers in cases from the United States and Australia. They suggest community-based campaigns to meet these challenges.

Keeble, Tobiol and Berkeley (2003) also express their concern about the difficulty of measuring sustainability performance in complex organizational business environments and judgments beside the hard data. CSR issues integrated to the SC management system are an attempt of this study to answer the need proposed by Cumming (2005) and Keeble et al. (2003).

2.1.2 Environmental responsibility

Environmental responsibility means carrying environmental performance. Environmental performance includes several ecological issues. The Center for Environmental Law & Policy at Yale University ranks 163 countries on 25 performance indicators with the 2010 Environmental Performance Index (EPI). It includes both environmental public health and ecosystem vitality. (Figure 4).

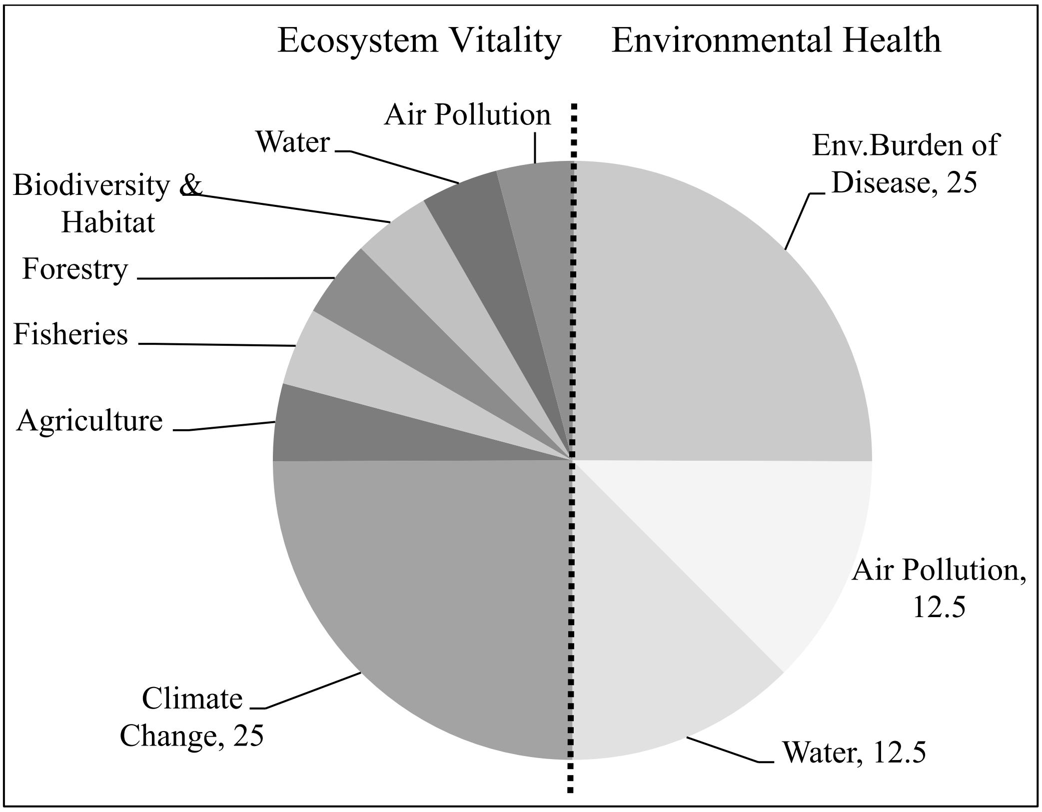


Figure 4. Environmental Performance Index, EPI (Yale Center for Environmental Law & Policy, 2012)

Environmental performance is not only the result of greenhouse gas emissions even if in this research the main metric for environmental performance is GHG emissions. Huang and Keskar (2007) divide environmental metrics into water and air pollutants, and waste and energy. They also suggest recognizing chemical and hazardous waste (Table 1).

Table 1. Environmental metrics (Huang & Keskar, 2007)

No.	Metrics	Definition
1	Conventional pollutants released to water	Average volume of conventional pollutants (suspended solids, biological oxygen demand, fecal coliform bacteria, pH, and oil and grease) per day during measurement period
2	Ambient air releases	Average volume in ppmv of ambient air releases per day during measurement period
3	Hazardous/non hazardous waste	Average volume of hazardous/non hazardous waste released per day during measurement period
4	Chemical releases	Average volume of chemical releases per day during measurement period
5	Global warming gases	Average volume in ppmv of global warming gas (carbon dioxide, methane) releases per day during measurement period
6	Ozone depleting chemicals	Average volume of ambient air releases per day during measurement period
7	Bio accumulative pollutants	Average volume of ambient air releases per day during measurement period
8	Indoor environmental releases	Average volume of ambient air releases per day during measurement period
9	Resource consumption (material, energy, water)	Resource consumption in terms of material, energy and water during the measurement period
10	Non renewable resource consumption	Resources not renewable in 200 years (fossil fuels minerals etc) consumed in terms during the measurement period
11	Recycled content	Percentage of materials that can be recovered from the solid waste stream, either during the manufacturing process or after consumer use
12	Product disassembly potential	Ease with which a product can be disassembled for maintenance, replacement or recycling
13	Product durability	Measure of useful life of the product
14	Component reusability	Percentage of reusable components in total number of components in the product and their frequency of reusability

Climate change according to the EPI index explains 25 % of the environmental performance. Responses to environmental pressures may be different in different countries (Qinghua et al., 2008). There are also differences (but also similarities) in responses to environmental challenges between private and public sectors (New et al., 2002). They suggest that green supply practices need to be implemented with regard to organisational structure and strategy.

This research focuses on climate change and the next chapters handle the climate change effect and measuring it.

2.1.2.1 Climate change and greenhouse gases

Climate change is according to the climate change glossary in Wikipedia change in the statistical properties of the climate system when considered over long periods of time, regardless of cause. The role of humans in climate change is discussed.

Climate change is driven by the emissions of anthropogenic greenhouse gases (GHG). According to the scientists cited by WRIs (2011), global GHG emissions must be cut to 85 percent below the 2000 levels by 2050 to limit the global mean temperature increase to 2 degrees celsius. Typical greenhouse gases are Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide Nitrous Oxide (N_2O), and Fluorinated Gases.

The World Resource Institute (WRI, 2011) describes world greenhouse gas (GHG)-emissions in Appendix 1. WRI divides greenhouse gas emissions into carbon dioxide emissions (CO_2), methane (CH_4), and nitrous oxide (N_2O). 77% of the emissions are CO_2. Electricity and heating, land use change and agriculture and transportation are the biggest sectors causing greenhouse gas emissions. Food supply chains have operations in many sectors and end use activities.

Figure 5 shows that the trend in CO_2 emissions has been strongly increasing in the world between the years 1753 and 2006. The importance of the USA, China and EU countries is remarkable.

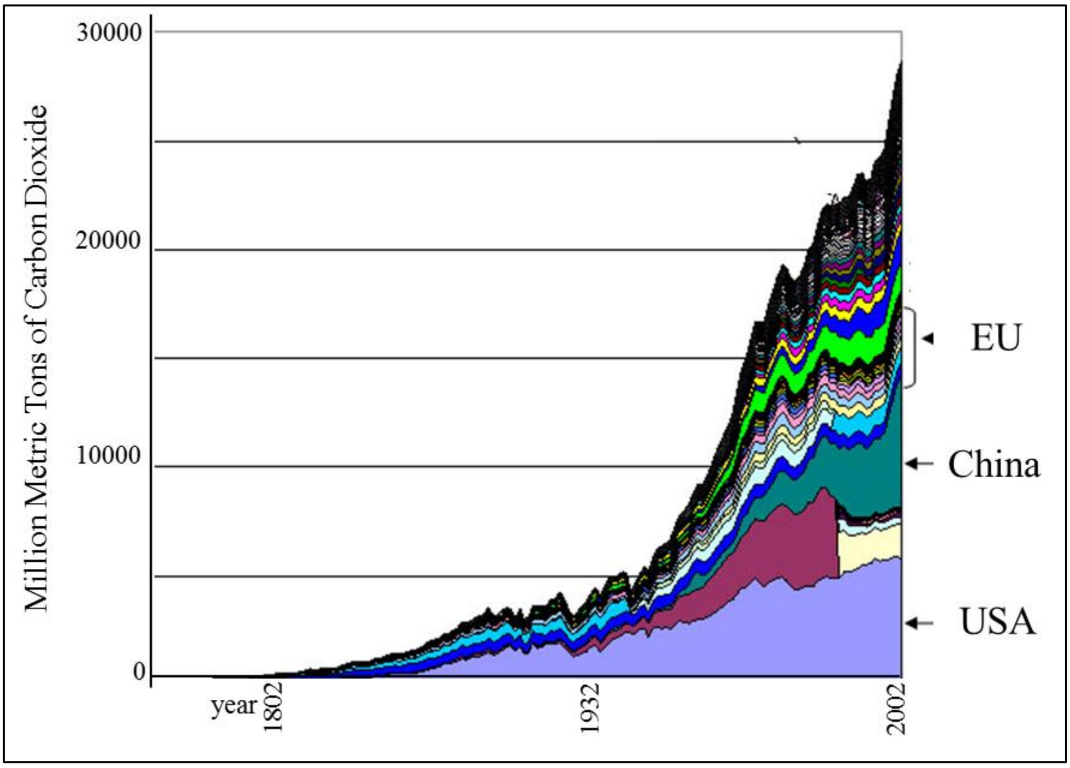


Figure 5. Global CO2 Emissions (edited from: Carbon Dioxide Information Analysis Center, 2009, in U.S. Environmental Protection Agency, 2009)

There are international agreements for preventing climate change. The United Nations Framework Convention on Climate Change (UNFCCC, 1992) is an international environmental treaty produced at the UN Earth Summit in Rio de Janeiro in 1992. The objective of the treaty is to stabilize greenhouse gas concentrations in the atmosphere. There are three kinds of countries in the UNFCCC: firstly, industrialized countries and economies in transition (40 countries + EU), secondly, developed countries which pay for costs of developing countries (23 countries + EU) and thirdly, developing countries. Developing countries are not required to reduce emissions unless developed countries supply funding and technology. (UNFCCC, 2012.)

2.1.2.2 Greenhouse gas sources

IPCC (2006) has given guidelines for making national greenhouse gas inventories. It divides emission sources into energy, industrial processes, solvent and other product use, agriculture, land use change and forestry and waste. Finnish statistics include use of energy industries, manufacturing industries and construction (emissions from energy use of fuels), transport, other use of energy, industrial processes excluding consumption of F-gases, consumption of F-gases, solvents and other product use, agriculture and waste management. The guideline says “the emissions are a product of activity data and emission factors”. (IPCC, 2006.)

The source of the carbon dioxide is typically the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g. the manufacture of cement) (U.S. Environmental Protection Agency, 2009).

Typically, methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and from the decay of organic waste in municipal solid waste landfills (U.S. Environmental Protection Agency, 2009).

Nitrous oxide is emitted during agricultural and industrial activities, as well as during the combustion of fossil fuels and solid waste (U.S. Environmental Protection Agency, 2009) and fluorinated gases such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride which are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances (i.e. CFCs, HCFCs, and halons) (U.S. Environmental Protection Agency, 2009).

According to the IPCC (1996), the key greenhouse gases are CO2, N2O and CH4. CO2 is primarily controlled by plant photosynthesis and is caused by respiration, decomposition and the combustion of organic matter. N2O emissions are caused as a by-product of nitrification and denitrification. CH4 is emitted, for example, through methanogenesis under anaerobic conditions in soils and manure storage, through enteric fermentation, and during incomplete combustion while burning organic matter.

NOx, NH3, NMVOC (non-methane volatile organic compounds) and CO are precursors for greenhouse gases in the atmosphere. Precursor gases cause indirect emissions, which are related to the leaching or runoff of nitrogen compounds, particularly NO3 and losses from soils and they can be converted to N2O through denitrification. (IPCC, 2006.)

Energy. Emissions of the used energy consist of fuel combustion and fugitive emissions. Fuel combustion emissions depend on the carbon content of the fuel. CO_2 emissions can be estimated from the energy supply data. The main fuel groups are coal, natural gas, oil and biomass. (IPCC, 2006.)

Industrial processes. Greenhouse gas emissions are produced also from non-energy related processes. The main GHG emission sources are industrial production processes which chemically or physically transform materials. During these processes, for example CO_2, CH_4, N_2O, and PFCs can be released. (IPCC, 2006.) Cement production and the reduction of iron in a blast furnace through combustion are examples of industrial processes which cause CO_2 emissions. Also halocarbons and ozone depleting substances used in industrial processes cause GHGs. IPCC (2006) notices that NMVOC, which is ozone and an aerosol precursor, is a potential emission of the food and drink industry. Emission factors for alcoholic beverage production (kg/HL) vary from white wines 0,035 kg/HL and wines and red wines 0,08 kg/HL to grain whiskeys 7,5 and spirits and malt whiskeys 15 kg/HL. Also NMVOC is also produced during the processing of cereals and fruits in preparation for the fermentation processes.

IPCC (2006) also gives emission factors for production processes, for example sugar has a factor of 10 kg/ton product (Table 2).

Table 2. Emission factors for bread and other food production (kg/ton)

food production process	***emission factor***
meat, fish and poultry	0,3
sugar	10
margarine and solid cooking fats	10
cakes, biscuits and breakfast cereals	1
bread	8
animal feed	1
coffee roasting	0,55

Partially fluorinated hydrocarbons (HFCs), perfluorinated hydrocarbons (PFCs), and sulphur hexafluoride (SF6) serve as alternatives to ozone depleting substances (ODS) which are being phased out under the Montreal Protocol. They are used in refrigeration and air conditioning, fire suppression and explosion protection, aerosols, solvent cleaning, foam blowing, gas insulated switch gear and circuit breakers, fire suppression and explosion protection. (IPCC, 2006.)

The Ilmastodieetti-calculator uses 300g CO_2ekv/kWh as electricity emissions because it includes fuel supply chain emissions which were also used in Nissinen et al. (2007) and Nissinen and Dahlbo's (2009) Mittatikku-calculator. For example, Suomi et al. (2008) use electricity emissions 200-250 g/kWh.

Agriculture. According to the IPCC (2006) agricultural processes cause CH_4 and N_2O emissions. They are enteric fermentation (CH_4), manure management (CH_4 and N_2O), rice cultivation (CH_4) and agricultural burning, which consists of emissions from the prescribed burning of savannas, agricultural residues and soils. Agricultural, forestry and land-use emissions (AFOLU) are caused by the livestock, land-use and aggregate sources and non-CO_2 emission sources on land (Appendix 1.).

Animal production causes N_2O emissions in three ways, namely the animals themselves, animal wastes during storage and treatment and dung and urine deposited by free-range grazing animals.

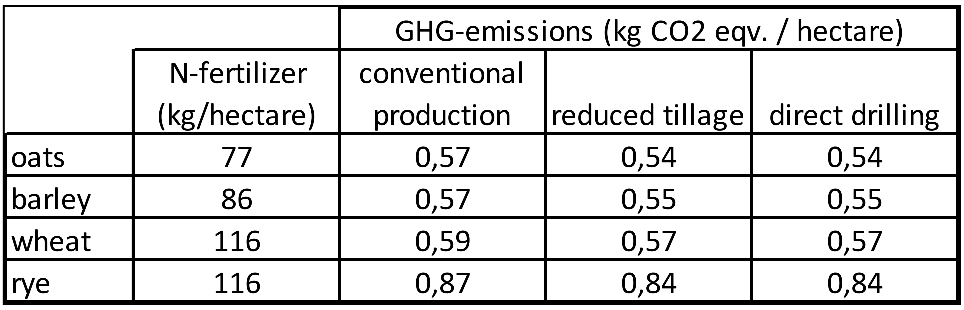
IPCC (2006) divides CH_4 and N_2O emissions for major animal types, e.g. dairy cows, other cattle, poultry, sheep, swine and other livestock (buffalo, goats, llamas, alpacas, camels, etc). Enteric fermentation emission factors for cattle from 25 to 118 kg/head/year vary, depending for example on whether the cattle are dairy or non-dairy and the region, cattle mass, feed digestibility, energy intake, feed intake, category population, and manure. For swine the emission factor is 1,0

- 1,5; for horses 18; for sheep from 5 to 8, and buffalos 55. The animal waste management systems include anaerobic lagoons, liquid systems, daily spread, solid storage, dry-lot, pasture/range/paddock, and other miscellaneous systems.

Rajaniemi et al. (2011) showed that grain production yield, fertilizers and soil have a strong impact on the carbon dioxide equivalent emissions per kilogram of grain. The GHG emissions varied from 0,54 to 0,87 kg CO_2 eqv. per produced grain, depending on the grain and production style. For example, the amount of N-fertilizers varied from oats with 77 kg/hectare to wheat with 116 kg/hectare, but also the effect of conventional production, reduced tillage and direct drilling varied from 0,54 to 0,87 kg/CO_2 eqv. / hectare (Table 3).

GHG emissions from soil were about half of all emissions of grain production. Agriculture not only produces emissions. It has also decreased emissions in other sectors. For example, agriculture can produce energy based on renewable energy sources. Land used in agriculture can also tie carbon and restrain global warming processes (Simola, 2006).

Table 3. Differences in GHG emissions by production style (Rajaniemi et al., 2011)



		GHG-emissions (kg CO2 eqv. / hectare)		
	N-fertilizer (kg/hectare)	conventional production	reduced tillage	direct drilling
oats	77	0,57	0,54	0,54
barley	86	0,57	0,55	0,55
wheat	116	0,59	0,57	0,57
rye	116	0,87	0,84	0,84

In Finland the relevant agricultural CO_2 emissions consist of the changes in the land use related to carbon warehouses, organic land cultivation, and chalking. CH_4emissions in agriculture in Finland consist of digestion and manure and N_2O emissions from manure treatment and land (IPCC, 2006, in Simola, 2006).

Waste. IPCC (2006) divides waste emission sources into solid waste disposal, biological treatment of solid waste, incineration and open burning of waste, and wastewater treatment and discharge (Figure 6.)

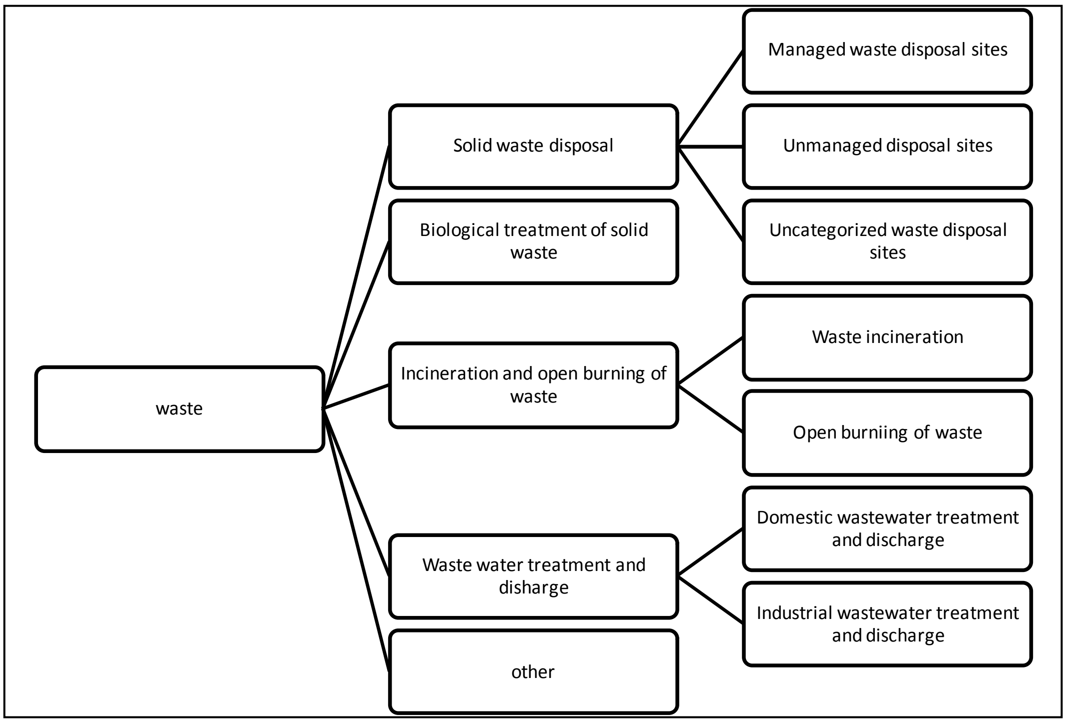


Figure 6. GHG sources of wastes (IPCC, 2006)

Solid waste disposal causes the most CH_4 emissions. Also wastewater treatment and discharge may be important. Incineration and open burning of waste containing fossil carbon, e.g. plastics, cause most CO2 emissions in the waste sector (IPCC, 2000). N2O emissions depend much on the type of treatment and conditions during the waste treatment. Non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NOx), and carbon monoxide (CO) and ammonia (NH3) can be caused by waste and wastewater treatment.

IPCC (2000/2006) divides waste influencing emissions from solid waste treatment into food waste, garden (yard) and park waste, paper and cardboard, wood, textiles, nappies (disposable diapers), rubber and leather, plastics, metal, glass (and pottery and china) and other (e.g., ash, dirt, dust, soil, electronic waste).

Food waste includes degradable organic carbon and fossil carbon. The waste composition in MSW (municipal solid waste) of the food waste (wet weight) varies between countries from southern Africa 23.0% to Oceania 67.5%. In different parts of Europe the rates of food waste are between 23.8% and 36.9% (IPCC, 2006).

The default dry matter content for food waste is 40% (Table 4). The DOC content in % of wet waste is 15% and dry waste 38%. The total carbon content of dry weight of food waste is 38% while, for example, rubber has 67%. The waste may include impurities, e.g., traces of food in glass and plastic waste.

Table 4. Default waste content, examples (IPCC, 2006)

	total carbon content in % of dry weight	
	default	range
paper	46	42-50
textiles	50	25-50
food waste	38	20-50
wood	50	46-54
garden and park waste	49	45-55
nappies	70	54-90
rubber and leather	67	67
plastics	75	67-85
other	3	0-5

According to the IPCC (2006), food industry waste includes DOC 15%, carbon 15% and water 60% of the total wet waste produced.

Municipal, industrial and other solid waste treatment and disposal methane (CH_4), solid waste disposal sites (SWDS) also produce biogenic carbon dioxide (CO_2) and non-methane volatile organic compounds (NMVOCs) as well as smaller amounts of nitrous oxide (N_2O), nitrogen oxides (NO_x) and carbon monoxide (CO). The decomposition of organic material derived from biomass sources (e.g., crops, wood) is the primary source of CO_2 released from waste. IPCC (2006) guides report it as a part of the AFOLU sector.

Waste water emissions are expressed as BOD5 (biochemical oxygen demand) values, which means grams per day per person. BOD values vary from Egypt's 34, Africa's 37 and Turkey's 38 g/person per day to the USA's 85, Italy's 60 and Sweden's 75 g / person / day.

Industrial wastewater may be treated on site or released into domestic sewer systems. Wastewater with significant carbon load and treated under intended or unintended anaerobic conditions will produce CH_4. Organics in industrial wastewater are often expressed in terms of COD, which is used here.

Industrial waste water CH_4 emissions in IPCC (2006) national inventories guide are calculated as follows:

(1)

$$CH_4\ Emissions = \sum_i \left[\left(TOW_i - S_i \right) EF_i - R_i \right]$$
where:

CH4 Emissions = CH4 emissions in inventory year, kg CH4/yr, TOWi = total organically degradable material in wastewater from industry I in inventory year, kg COD/yr, i = industrial sector, Si = organic component removed as sludge in inventory year, kg COD/yr, EFi = emission factor for industry i, kg CH4/kg COD for treatment/discharge pathway or system(s) used in inventory year, Ri = amount of CH4 recovered in inventory year, kg CH4/yr.

The IPCC (2006) gives examples for COD values (Table 5). For example, the meat industry generates 13 m^3 waste water per each ton and produces 4,1 kg/M^3 COD.

Table 5. Examples of industrial waste water data

Industry type	waste water generation (m^3/ton)	COD (kg/m^3)
alcohol refining	24	11
beer & malt	6,3	2,9
coffee	na	9
dairy products	7	2,7
fish processing	na	2,5
meat & poltry	13	4,1
organic chemicals	67	3
petroleum refiners	0,6	1
plastics & resins	0,6	3,7
pulp & paper	162	9
soap & detergents	na	na
starch production	9	10
sugar refining	na	3,2
vegetable oils	3,1	na
vegetables, fruits & juices	20	5
wine & winegar	23	1,5

Myllymaa et al. (2008) and Nissinen and Dahlbo (2009) find that waste transportation causes 5 g of CO2 emissions per kg of the waste. According to the same author the biowaste itself produces 19 g/kg methane emissions.

2.1.2.3 GHG standards and calculation

There are standards, protocols, guidelines, and applications for different scope and scale GHG calculations. The World Resource Institute has produced GHG protocols, for example, for corporate accounting and reporting (2004), product life cycle accounting and reporting (2011), project accounting (2005), the US public sector, guidelines for quantifying GHG reductions from grid-connected electricity projects (2007), land use, land-use change and forestry guidance for GHG project accounting (2006), and a guide to designing GHG accounting and reporting programs (2007). In 2011 WRI published the corporate value chain accounting and reporting standards. The model of this study was developed before the standard publishing but it is shortly introduced and compared to the developed model in the model conclusions chapter. A lot of different web-based calculators are available free of charge for consumers or companies. National, sectorial and international agreements aim to reduce emissions and energy consumption. For example, the transportation sector aims to decrease 9% of its energy consumption between 2008 and 2016 (Energiatehokkuussopimus, 2011).

There are many protocols and methods under construction for calculating CO_2-emissions. For example, the *Greenhouse Gas Protocol* (2009) provides instructions for carbon footprint calculation. For example, Walmart (2009) is using the method. He also has a supplier sustainability evaluation program and tools for supplier assessment.

Sustainability standards are needed. The US National Institute of Standards and Technology (2012) gives a hierarchical framework for the reasons for sustainability standards. The Institute thinks sustainability related policies such as carbon tax, cap, and trade are the next matter. They think global business has to be seen from the sustainability perspective. Cost and resource benefits are direct benefits but sustainability allows better partnering and supply chain management.

The sustainability regulations may be international (such as EU) or national state, federal or county level regulations. The policies may be cap and trade, carbon, hybrid model or tax incentives focused. The US National Institute of Standards and Technology (2012) also suggests a global sustainable business model allows better partnering and greener supply chains, branding and competitive edge by product labeling, resource minimization and cost reduction as well as better corporate social responsibility.

The National Organic Council (USDA) and Protected Harvest allow 3rd party certification for food companies. There are several standards for emission calculation systems and protocols, for example ISO 14040 and ISO 14044, and several instructions (e.g. TS Q 10010, PAS 2050) based on them, CFP and GHG protocols. They are typically life cycle assessment based and have wide scope and are not concentrated on logistics.

The US Environmental Protection Agency uses many kinds of economic models and tools to conduct climate economic analyses, such as Economy-Wide Models (Applied Dynamic Analysis of the Global Economy (ADAGE), Intertemporal General Equilibrium Model (IGEM)), Mitigation Models, Non-CO2 Projection and Abatement Models, Forestry and Agricultural Sector Optimization Model - Greenhouse Gas Version (FASOMGHG), Global Timber Model (GTM)), Integrated Assessment Model, Mini-Climate Assessment Model (MiniCAM) and Detailed Electricity Sector Model (Integrated Planning Model (IPM)).

ISO 14067 is a standard for the carbon footprint of products. The British Standards Institution published in 2008 ISO 14040 and ISO 14044 based on specifications for products and services and carbon footprint life cycle assessment. Also the *ILCD Handbook* (European Commission 2010) is based on the same standards. The Finnish Committee of Standards, SFS, has a committee for environmental management. It looks for environment management standards and participates in ISO 14000 standard preparations, for example creating CO2 standards.

Seppälä et al. (2009) have developed the ENVIMAT-model for estimating environmental effects of the Finnish national economy’s material flow. Rantanen (2011) has calculated the carbon footprint for Ilosaari Rock (concert). The Finnish Environment Institute (2012) has introduced a method called Y-hiilari for companies to calculate their carbon footprints. Suomi, Hietaniemi, and Hellgrén (2004) gave instructions to calculate emissions for individual items.

WRI (2011) has published CAIT, a guide for greenhouse gas sources and methods. Table 6 introduces typical GHG sources by categories.

Table 6. Summary of CAIT Sector Data

CAIT sector category	**CAIT sector contents**	**gas**
electricity and heat	electricity and heat plants	
	public plants	CO_2
	autoproducers	CO_2
	other energy industries	CO_2
manufacturing and contrsution	manufacturing and constrution	CO_2
transportation	transportation	CO_2
other fuel combustion	other sectors	CO_2
	biomass combustion	CH_4, N_2O
	stationary and mobile sources	CH_4, N_2O
fugitive emissions	gas ventint and flaring	CO_2
	oil and natural gas systems	CH_4, N_2O
	coal mining	CH_4, N_2O
industrial processes	cement	CO_2
	adipic and nitric acid production	N_2O
	other industrial non-agriculture	CH_4, N_2O
	all fluorinated gases	HFCs, PFCs, SF6
agriculture	eneteric fermentation	CH_4
	livestock manure management	CH_4, N_2O
	rice cultivation	CH_4
	agricultural soils	N_2O
	other agricultural sources	CH_4, N_2O
landuse change and forestry	all	CO_2
waste	landfills	CH_4
	wastewater treatment	CH_4
	human sewage	N_2O
	other	CH_4, N_2O
international bunkers	aviations bunkers	CO_2
	marine bunkers	CO_2

The US National Institute of Standards and Technology (2012) divides sustainability performance measures into what they measure, how they measure, how they report and how they verify and validate (Figure 7).

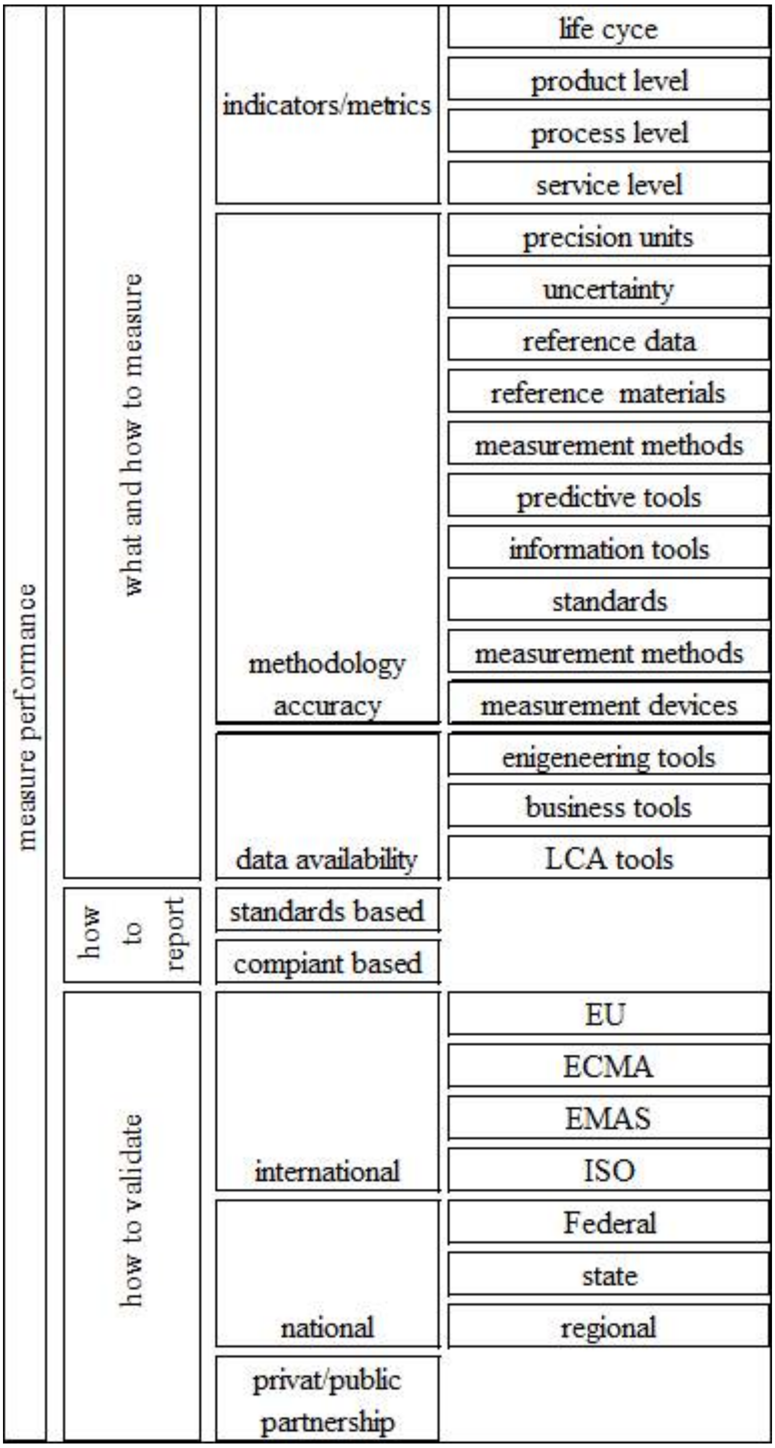


Figure 7. Steps for overall sustainability performance measure (NIST, 2012)

Deciding what to measure means, for example, the specific metrics and indicators, and level decisions. The second question is related to metrics applicability to specific situations related to data availability, business and engineering tools and measurement methods. The way to report defines in which format the measured data is reported. Validating and verifying data means selection between international, national or private levels.

Barba-gutiérrez, Adenso-díaz and Lozano (2009) have measured the eco-efficiency of electric appliances as the index of the product's economic value and the ecopoint LCA score as the assessment of its environmental impact. It is based on data envelopment analysis (DEA). Quanriquasi et al. (2007) have introduced a multi-objective programming (MOP) model for cost and environmental impact minimization.

A recent article introduces a warehouse carbon reduction program. The article scales the carbon emissions of the transportation compared to the buildings, but does not give solutions for carbon reductions in the supply chain level. (Supply Chain Standard, 2009.) Lenzen (2008) reports on and gives a solution to the double-counting problem of supply chain life cycle calculations.

The New Zealand Business Council (2010) has a supplier evaluation form for sustainable development. It has nine parts, namely employer practices, health & safety, working conditions for factories in developing countries, governance, environmental responsibility (energy efficiency), environmental responsibility (eco-efficiency), hazardous substances / chemicals / GMOs, supplier management and actions taken to address impacts and implement their policy. Rosenow (2012) argues practices in the regulation of genetically modified organisms (GMOs) and aims to elaborate on the potential of complexity discourses for challenging particular governmental rationales, manifested in both the resilience context and the GMO controversy.

The definition of eco-efficiency is to use products and production procedures which maximize eco-efficiency. This means, for example, audited and reviewed recyclable content of the product, avoiding over-packaging, using reusable trays, recovering a percentage for recycling, increasing timber products sourced from sustainably certified forests by x% p.a., sustainable sourcing of raw materials and reducing water consumption.

The New Zealand Business Council (2010) defines a sustainable supply chain as: "Management of raw materials and services from suppliers to manufacturer/service provider to customer and back with improvement of the social and environmental impacts explicitly considered". They define the indicators of the eco-efficiency as: reduction in waste to landfill year on year, packaging policy, product life cycle analysis, profit from waste to energy system, setting targets for waste management, FSC or other external accreditation, e.g. MSC, water usage per person. (New Zealand Business Council 2010.)

Huang and Keskar (2007) use three level metrics in supplier evaluation depending on whether the supplier integration level is not integrated, operationally integrated or a strategic partnership. They divide performance measures hierarchically to product related reliability, responsiveness and flexibility metrics, supplier related cost and financial and asset infrastructure, and society related safety and environmental levels. They categorize reliability into criteria regarding the performance of a supplier in delivering the ordered components to the right place, at the agreed time, in the required condition and packaging, and in the required quantity, and the responsiveness category is related to the velocity at which a supplier provides products to the customer.

They also define flexibility in terms of the agility of a supplier in responding to OEM demand changes. Cost and financial aspects relate to cost and the financial aspects of procuring from the supplier. Criteria regarding the effectiveness of the supplier in managing assets to support OEM demand are classified into assets and infrastructures. Environment in their classification is the supplier’s effort in pursuing environmentally conscious production and occupational safety at the supplier’s facility.

Francis (2008) discusses identifying, measuring and characterizing processes from the environmental perspective and also highlights the allocation, level and scope as problems of environmental measuring.

Each greenhouse gas has different global warming potential (GWP) and persists for a different length of time in the atmosphere. The use of CO_2 equivalents offers a way to equalize the effect of greenhouse gases from the viewpoint of global warming (Table 7).

Table 7. GHG as CO_2 equivalents

Greenhouse Gas	Formula	100-year GWP (SAR)	100-year GWP (AR4)
Carbon dioxide	CO2	1	1
Methane	CH4	21	25
Nitrous oxide	N2O	310	298
Sulphur hexafluoride	SF6	23,9	22,8
Hydrofluorocarbons (HFCs)			
HFC-23	CHF3	11,7	14,8
HFC-32	CH2F2	650	675
Perfluorocarbons (PFCs)			
Perfluoromethane	CF4	6,5	7,39
Perfluoroethane	C2F6	9,2	12,2
Perfluoropropane	C3F8	7	8,83
Perfluorobutane	C4F10	7	8,86
Perfluorocyclobutane	c-C4F8	8,7	10,3
Perfluoropentane	C5F12	7,5	13,3
Perfluorohexane	C6F14	7,4	9,3

2.1.3. Economic responsibility

Economic responsibility is third part of the sustainability. Gross domestic product (GDP) is the most widely used measure of economic activity. It measures market production. It correlates with many indicators of living standards. (Stiglitz, Sen & Fitoussi, 2009.) GDP is nation metric.

The link between economic and sustainable performance of companies interests researchers. Ziegler, Schröder and Rennings (2007) have found that the average environmental performance of an industry has a significantly positive influence on the stock performance. On the other hand, stock performance decreases if the social performance is average. Rennings et. al. (2003) have found that high environmental performance has a positive effect on the stock performance. Wagner and Schaltegger (2003) have suggested a phenomenological relationship between environmental and social performance and economic success. According to their assessment optimal economic success takes sustainability issues into account (Figure 8).

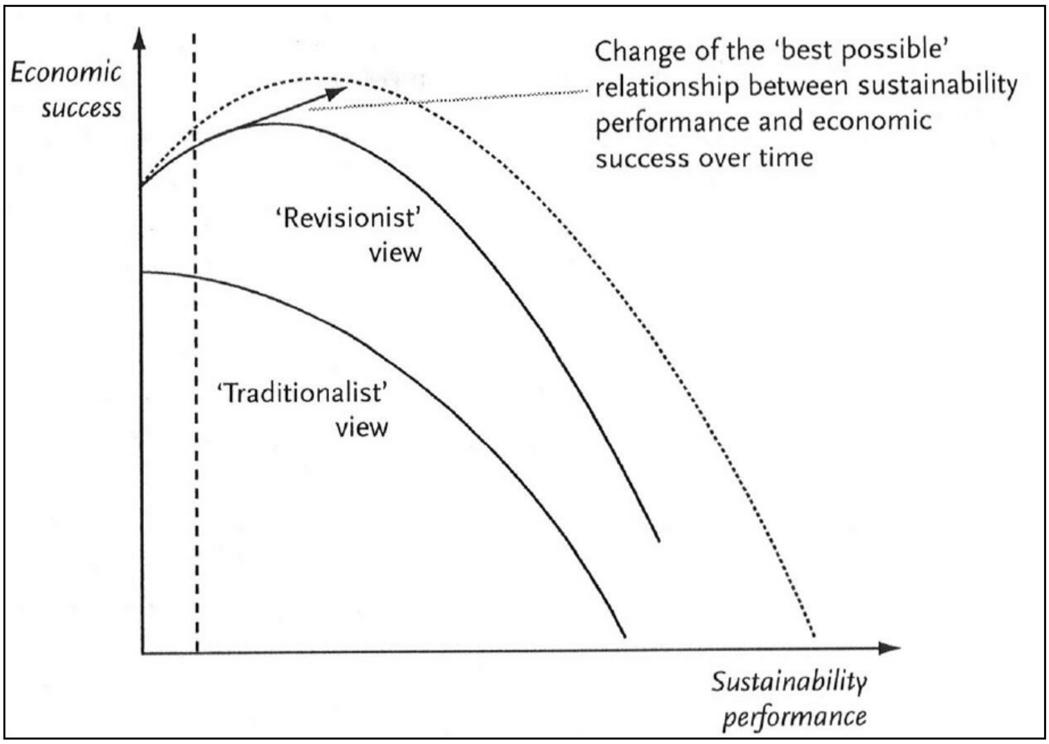


Figure 8. Phenomenological relationship between environmental and social performance and economic success (Wagner and Schaltegger, 2003)

Later Schaltegger et. al. (2008) have written that economic performance is a result of environmental improvements. They handle environmental improvements through the concept of cleaner production (CP). In other words, dirty production means insufficient production, and waste and pollution are the signs of insufficient production. They introduce examples where companies have improved environmental and economic performance at the same time. Rodrigue et. al. (2001) claim that the logistical trend toward hub formation is not green, but hub formation due to cost savings.

A Finnish study made by Hoffrén and Apajalahti (2009) concludes that in most Finnish publicly listed large or medium-size companies environmentalism or sustainable development is not an issue. The researchers think it is a remarkably low figure. They think eco-efficiency implementations, target setting and practical EE management tools among companies are needed. Also Rao and Holt (2005) say that adopting a green supply chain and a demonstrable link between measures and improving economic performance and competitiveness is necessary and Comas and Joana (2013) say firms are expected to expand the scope of their environmental strategies beyond organisational boundaries and to address more comprehensively environmental issues in their supply chains and product life cycles.

El Saaddany et al. (2011) carried out preliminary studies with the model they developed which support in their opinion Klassen and McLaughlin's, (1996), Rao and Holt's, (2005) and Ambec and Lanoie's (2008) studies, because they also found that reducing environmental costs results in improving environmental performance and increasing total profits.

2.2 Supply chain performance

In the 21st century supply chains compete and co-operate with others instead of individual companies and a supply chain focus will enhance logistics performance, which will ultimately result in improved organizational performance (Green, Whitten & Inman, 2008; Pedersen, 2009).

One of the managerial principals is that a thing which can be measured can be managed. Thus, performance measurement is part of management. Performance measurement of supply chain management (SCM) is a rapidly growing multi-criteria decision-making problem. There are a lot of factors which affect the decisions. The right choice of performance metrics and measures is critical to the success and competitiveness of firms in the global world (Bhagwat & Sharma, 2007).

The objectives of supply chain management (SCM) are to achieve a supplier and customer integrated value chain with the help of information technology and systems (Gunasekaran, Patel & McGaughey, 2004). Performance measurement is an essential part of supply chain management (Gunasekaran & Kobu, 2007). Suitable performance measures would help organizations to achieve better competitiveness in global markets (Giannakis, 2007).

A supply chain performance is measured often with money, time and quality. The performance of the supply chain can be measured from many viewpoints, for example supplier relationships (Ritchie & Brindley, 2007), supply chain risks (Gaiardelli, Saccani & Songini, 2007), and after-sales service network (Jeong & Hong, 2007). The customer is important in supply chain management. The impact of customer orientation and interactive system infrastructure throughout enterprise networks is not fully understood (Seeking modern financial tools, 2009).

Intangible and non-financial performance measures are nowadays more important (Ritchie & Brindley, 2007). Modern supply chain tools are needed, for example financial tools (Berrah & Clivillé, 2007). Approaches for expressing the overall performance of a SC are proposed (Hutchison, Farris & Fleischman, 2009). Better supply chains differ from the usual supply ones. For example, cash to cash strategies (C2C) are recommended in supply chain management (Elkington, 1997).

The SCOR model is a supply chain process reference model developed by SCC and it divides management processes into five major management processes and has three levels. The first level is the strategic level and the third level is the most detailed level. The first level includes metrics for customer-faced supply chain performance attributes, which are reliability, responsiveness and flexibility and internal-faced performance attributes costs and assets. Perfect order fulfilment is the reliability metric and order fulfilment cycle is the responsiveness metric. Upside SC flexibility is flexibility metric as well as adaptability of the upside and downside SC. Supply chain management cost and the cost of goods sold are cost metrics, and cash-to cash cycle time, return on supply chain fixed assets and return on working capital are asset metrics. (Supply-Chain Council, 2009.)

Reliability means, in the words of the Supply Chain Council, the performance of the supply chain in delivering the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer. Responsiveness means the speed at which a supply chain provides products to the customer. (Gunasekaran, Lai & Cheng, 2008) Flexibility means the agility of a supply chain in responding to marketplace changes to gain or maintain competitive advantage. Costs means the costs associated with operating the supply chain and supply chain asset management means the effectiveness of an organization in managing assets to support demand satisfaction. This includes the management of all assets: fixed and working capital. (Supply Chain Council, 2009.)

The objectives of supply chain management (SCM) are to achieve a supplier and customer integrated value chain with the help of information technology and systems (Gunasekaran, Lai & Cheng, 2008). The performance measurement is an essential part of supply chain management (Gunasekaran, Patel & McGaughey, 2004). Suitable performance measures would help organizations to achieve better competitiveness in global markets (Gunasekaran & Kobu, 2007). A supply chain performance is measured often with money, time and quality.

The performance of the supply chain can be measured from many viewpoints, for example supplier relationships (Giannakis, 2007), SC risks (Ritchie & Brindley, 2007), and after-sales service network (Gaiardelli, Saccani, & Songini, 2007). The customer is important in supply chain management. According to Jeong and Hong (2007) the impact of customer orientation and interactive system infrastructure throughout enterprise networks is not fully understood.

Gunasekaran and Gobu (2007) have made a review of supply chain and logistical performance measures and metrics. In their opinion, intangible and non-financial performance measures are nowadays more important. Modern supply chain tools are needed, for example financial tools (Seeking modern financial tools, 2009). Berrah and Clivillé (2007) propose approaches for expressing the overall performance of a supply chain. Shaw, Grant and Mangan (2010) have researched environmental performance measures integration within an existing supply chain performance framework. According to them there is a need to develop a "common" ESCP measure that captures the impact of the entire supply chain relative to these foregoing issues. Lack of direction and legislation on environmental management makes it very difficult for organisations to know what they should measure and how to measure. (Shaw, Grant & Mangan, 2010). Dey and Walid (2013) introduced analytical hierarchy process based green supply chain (GSC) performance measurement framework. It has environmental planning, environmental auditing, management commitment, environmental performance, economic performance and operational performance as the key level constructs

Grosspietsch (2009) identifies the best supply chains from the usual supply ones. The six most important broad practices are making supply chain strategy an explicit part of the business strategy, segmentation, optimizing the network, standard methodologies such as lean value chain, integrated planning, and talent management.

Hutchison, Farris and Fleischman's (2009) recommendation is cash to cash strategies (C2C) for supply chain management. C2C-calculation includes three balance sheet indicators which are inventory, accounts receivable, and account payable.

2.2.1 Supply chains' competition strategies

The role of logistics and supply chain performance is essential. Green, Whitten and Inman (2008) found that logistics performance is positively impacted by supply chain management strategy. Also logistics performance and supply chain management strategy impact positively on marketing performance, which in turn positively impacts on financial performance.

Competition strategy attributes help to set competitive strategy, but they cannot be measured themselves. Performance attributes consist a group of metrics used to express strategy. (SCC, 2011) Christopher (2005) describes supply chain management as a competitive advantage. He also uses a triangle model of three

Cs. The competitive advantage is the differentation of the organization´s costs and competition from the customer´s viewpoint. He summarizes that competition advantage is a cost advantage or value advantage (such as service) or both (Figure 9).

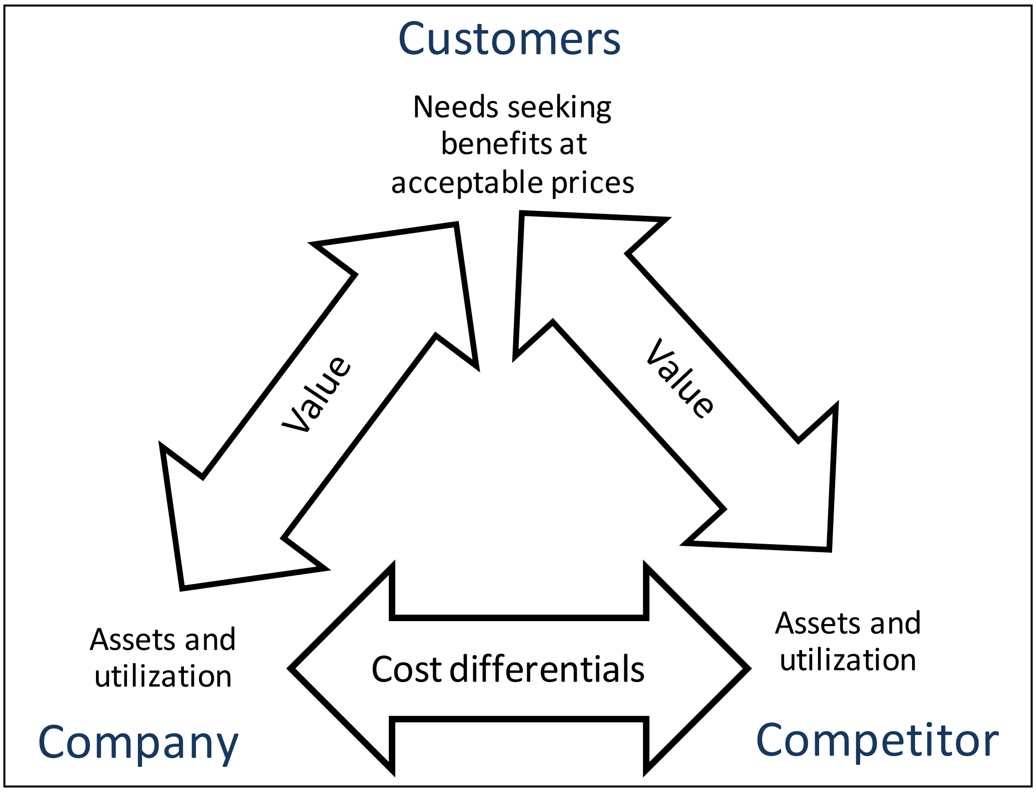


Figure 9. Competitive advantages with three C's (Ohmae in Christopher, 1995)

Christopher (1995) suggests that supply chain management can be a way to achieve competitive advantage itself (Figure 10). Logistic management value advantage provides opportunities, for example for tailored services, better reliability and responsiveness. Logistic leverage opportunities offer also cost advantages, for example through capacity utilization, asset turn and supply synchronization.

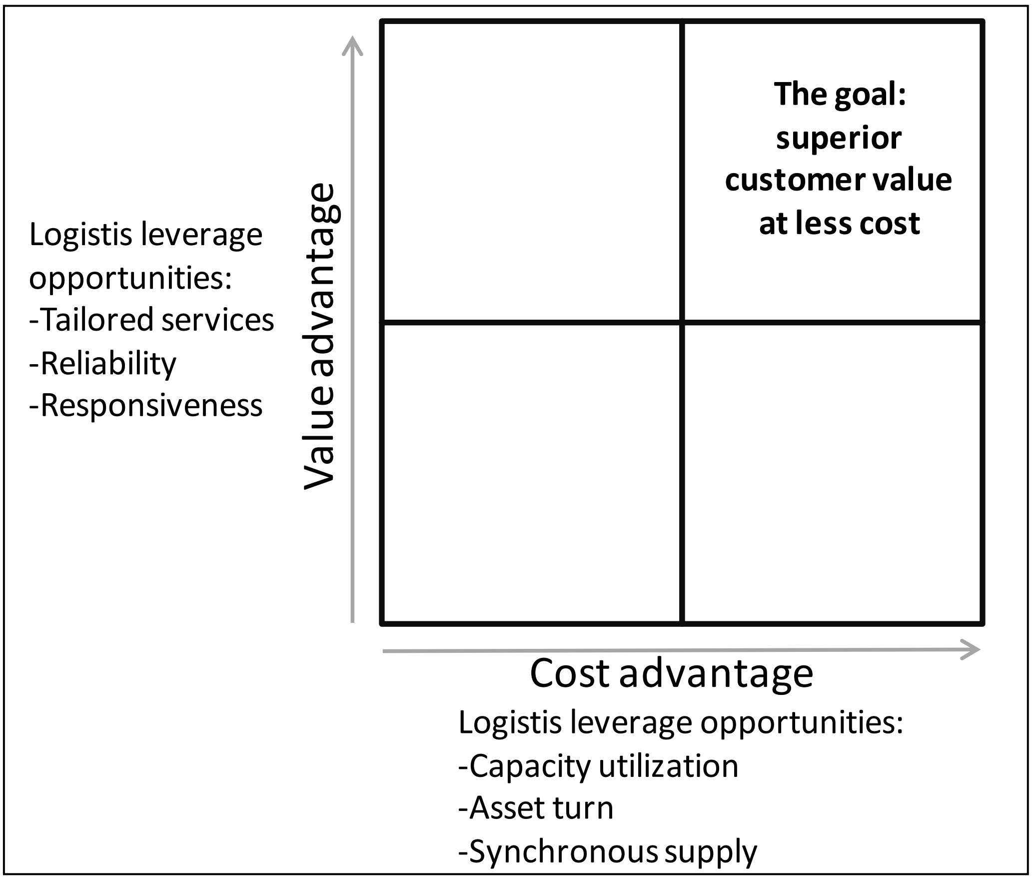


Figure 10. Gaining competitive advantage (Christopher, 1995)

The SCOR model defines competition advantages through performance attributes which are reliability, responsiveness, flexibility, adaptability, costs and assets.

2.2.2 Supply Chain Operations Reference Model, SCOR

Supply chain performance is often understood quite narrowly. The SCOR 8.0 model developed by the Supply Chain Council offers a wider perspective on supply chain management. It is a widely used and validated model for supply chain management (Zhou, Benton, Schilling & Milligan, 2011). For example, Coca Cola, Kraft Foods and Heineken are SCOR users (SCC, 2012). The SCOR model has three levels and it is organized around five management processes. The first level includes metrics for customer-faced and internal-faced supply chain performance attributes, which are reliability, responsiveness and flexibility and costs and assets (Bolstroff & Rosenbaum, 2003). The SCOR model divides management processes into five major management processes (Figure 11) which are plan, source, make, deliver, and return processes.

According to SCC organizations which use the SCOR model can identification performance gaps, can efficiently redesign and optimize supply chain networks and align supply chain team skills with strategic objectives (SCC, 2012).

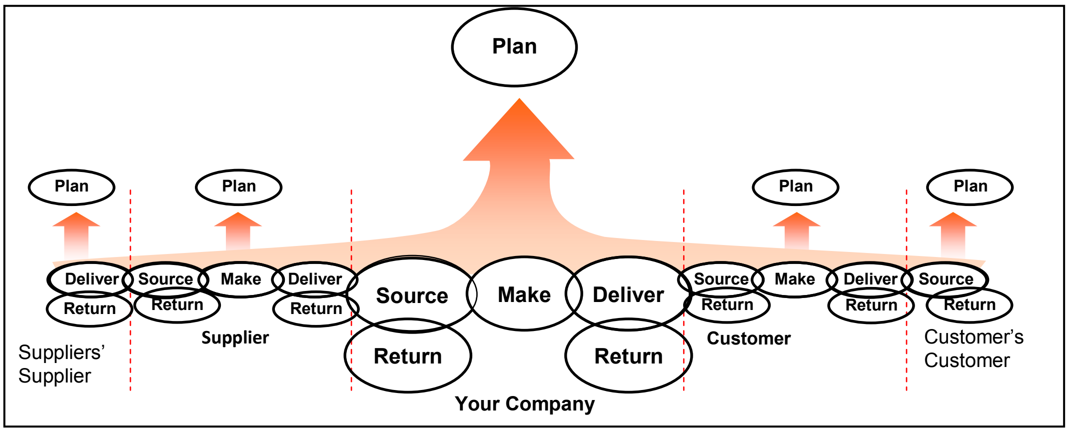


Figure 11. SCOR is organized around five major management processes (Supply-Chain Council, 2005)

The SCOR model has three levels (Bolstroff & Rosenbaum, 2003). The first level is the strategic level and the third level the most detailed one. The first level includes metrics for customer-faced and internal-faced supply chain performance attributes, which are reliability, responsiveness and flexibility and costs and assets (Table 8).

Table 8. SCOR. Level 1 metrics (Supply Chain Council, 2009)

Metrics	**Performance attributes**				
	Customer-facing			Internal-facing	
	Reliability	Responsiveness	Flexibility	Costs	Assets
Perfect order fullfillment	x				
Order fullfilment cycle time		x			
Upside supply chain flexibility			x		
Upside supply chain adaptibility			x		
Downside supply chain adaptibility			x		
Supply chain management cost				x	
Cost of goods sold				x	
Cash-to cash cycle time					x
Return on supply chain fixed assets					x
Return on working capital					x

The Supply Chain Council (2009) states that reliability means the performance of the supply chain in delivering the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer. Responsiveness means the speed at which a supply chain provides products to the customer. Flexibility means the agility of a supply chain in responding to marketplace changes to gain or maintain competitive advantage. Costs means the costs associated with operating the supply chain and the supply chain asset management means the effectiveness of an organization in managing assets to support demand satisfaction. This includes the management of all assets: fixed and working capital.

There are connections between lean, six sigma and SCOR methodologies, but they cannot replace others. SCOR has a supply chain viewpoint. Figure 12 describes the connections between six sigma, lean and SCOR methodologies.

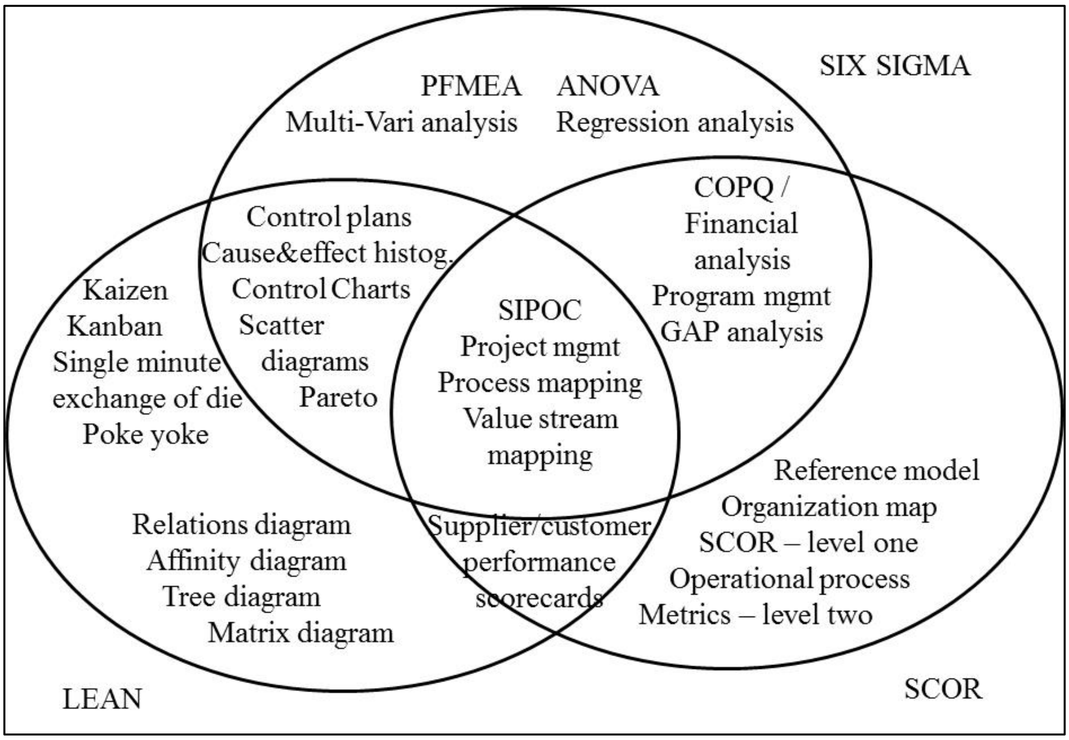


Figure 12. Convergence of SCOR, Six Sigma and Lean Methodology (edited from SCC, 2009)

When comparing the results of use of the SCOR model plan, source, and make deliver and return areas Li, Su and Chen 2010 have found positive impacts on customer-facing supply chain quality performance and firm level business performance in terms of the ISO 9000 standards. Lockamy and McCormack (2004) found planning processes that especially affected the supply chain performance were demand planning and forecast development, supplier transactional collaboration activities, and also the establishment of procurement by the process planning team had a significant effect on the supply chain´s performance. Scheduling and collaborative planning had effects on the effectiveness of the planning processes. Delivery process integration along the supply chain had a noteable role in supply chain performance.

2.3 Supply chains' sustainable performance

Sustainable development is often part of the strategy of the company and it is also a way to differentiate among competitors. Sustainability could be a performance attribute in the strategic management of supply chains. The weakest part of the food supply chain is the most essential part when talking about responsibility. That is why responsibility should part of every day practices in every part of the food supply chain. However sustainability issues turned out not so important in case studies than eco-efficiency and therefore sustainability issues are not so much handled in this study.

Environment and sustainable development are the top issues in international, national and organizational development programs as well as in supply chain management in industry (Kioto Protocol to the United Nations Framework convention on Climate Change, 1997) and increasing demands for environmental resource protection and sustainable development have been forcing enterprises to put sustainable supply chain management on their agendas in recent years (Li, 2013). However, supply chain performance models (in the beginning of this study) pay little attention to the supply chain's ecological performance and recent sustainability performance models do not include supply chains even if focusing on the environmental performance of individual firms is not enough (Seifert & Comas, 2010).

According to Carter and Easton (2011), supply chain managers have a lot of power to affect sustainable performance, for example by making supplier selection and development, modal and carrier selection, vehicle routing, location decisions and packaging choices. Later, for example in 2013 Winter has explored and categorized possibilities to integrate sustainability and supply chain management: and for example Ashby in 2012 investigated systematically the discipline of supply chain management (SCM) within the context of sustainability and supply chain management.

The focus on sustainability has shifted from local optimization to entire supply chains (Mann, 2010). Berger et al. (2001) say that without fully integrating HRD and corporate social responsibility (CSR) into the supply chain, organizations will not fully realize truly sustainable operations.

During 2008–2013 there have been 11 authors of at least two articles that have been cited at least 10 times according to Harzing Publish in the field of green logistics and sustainable supply chain management. Harzing Publish or Perish is a software program that retrieves and analyzes academic citations. It uses Google Scholar to obtain the raw citations, then analyzes these and calculates a series of citation metrics. The search was made using "all of the words"-search with the words green, supply chain, sustainable, and logistics. The results were limited to the 1000 most cited articles between 2008 and 2013. The authors are CR Carter, CW Hsu, G Kovács, H Walker, QF Neto, M Pagell, S Gold, S Vachon, WH Tsai, Q Zhu, and S Seuring.

A couple of Google searches illustrated the current situation. Google gives 481 findings for the "sustainability performance of the company" and only 6 for the "sustainability performance of the supply chain". Many fields of industries have agreements and programs to decrease, for example, energy consumption or emissions. For example, hospitality and catering have energy efficiency agreements in Finland but the goals have not been achieved (Motiva, 2011a; 2011b).

Recent literature deals with environmental issues, for example, as a part of green supply chain management (GSCM), industrial eco-systems, industrial ecology, product life cycle analysis, extended producer responsibility, eco-efficiency, Integrated Product Policy (IPP), and product stewardship. The LCA-model, ISO14001 (2009) and CDP are management systems related to the environment. EY published an energy efficiency directive (*2006/32/EY*) in 2006 and it aims to achieve 9% energy savings between 2008 and 2016.

Schaltegger and Wagner (2006) state that “sustainability performance management requires a framework which links environmental and social management with the business and competitive strategy and management and, secondly, that integrates environmental and social information with economic business information and sustainability reporting”. In Pedersen’s (2009) definition “sustainability initiatives seek to reduce the use of energy, water, greenhouse gas (GHG) emissions and harmful substances in the design, manufacturing, distribution, and service of their products. Sustainability also may include goals on social responsibilities to employees, customers, suppliers, and community”.

Even if there are lot of supply chain management studies, there were no standardized and generally accepted or used models or frameworks for supply chain management which measure, and in addition to this, develop sustainable performance of the supply chain in the beginning of this study in 2007. However, there was a Supply Chain Operations Reference-model (SCOR 8.0) which is the model for to describe, measure, and compare supply chain operations (SCC, 2007). Later it has been published new SCOR versions.

There is a lack of empirical studies and management tools and models which connect environmental performance to supply chain performance. It is the duty of companies and supply chains to maximize owners’ profits in the longer term. Making a profit requires (supply chain) management and an essential part of management systems is measuring. ***However, there is a limited number of studies showing how logistics decisions effect not only the economic but also the ecological performance of companies’ and supply chains’ performance.***

Also there are few studies connecting minimizing logistical costs and environmental effects (Bloemhof-Ruwaard et al., 2004; in Quanriquasi et al., 2007).

Research on logistics has just begun to pay attention to activities such as safety (Carter, 2005). Carter and Rogers (2008) also introduce logistical social responsibility, LSR, and purchasing social responsibility, PSR, but they miss out consideration of economic criteria. The GSCM is a broader inter-organizational approach for enterprises seeking to become environmentally sustainable and it includes also ethics and sustainability which incorporate other social and economic influences (Zhu, Sarkis & Geng 2005). Ahi (2013) has found that there is no complete definition for green supply chain management (GSCM) and sustainable supply chain management (SSCM). However, researcher's analysis showed that SSCM is essentially an extension of GSCM. Despite of this definitions for GSCM were narrowly focused than SSCMs'. Also environmental supply chain management (ESCM) practices have been under study (Qinghua, Crotty & Sarkis, 2008). Chen-Lung and Chwen (2007) referred concepts of collaborating with supply chain parties to improve manufacturing sustainability to Supply Chain Environmental Management (SCEM) or 'greening the supply chain'. They propose SCEM framework for planning and monitoring the development of environmental partnership.

2.3.1 Supply chains' environmental issues

Environmental supply chain issues are often handled as a part of green logistics. There are many advantages to making logistics into green logistics. Environmental advantages include energy saving and cost reduction; economic reasons are fuel efficiency and resource saving. The customers will benefit from increased logistical quality and better corporate brand image. (Sugata, 2008.)

The role of oil in logistics costs and environmental performance is essential. The oil price has more than doubled between 2001 and 2011. At the same time publications in the field of green logistics, reverse logistics and green supply chain management (defined in 2.3) have increased a lot.

Google Scholar gives 12 times more article hits for "green logistics" published in 2011 compared with 2001 compared to 2011. "Reverse logistics" hits were 6 times more popular in 2011 than 2001. "Green supply chain management" published in 2011 gave 31 times more hits than in 2001. (Fig. 1)

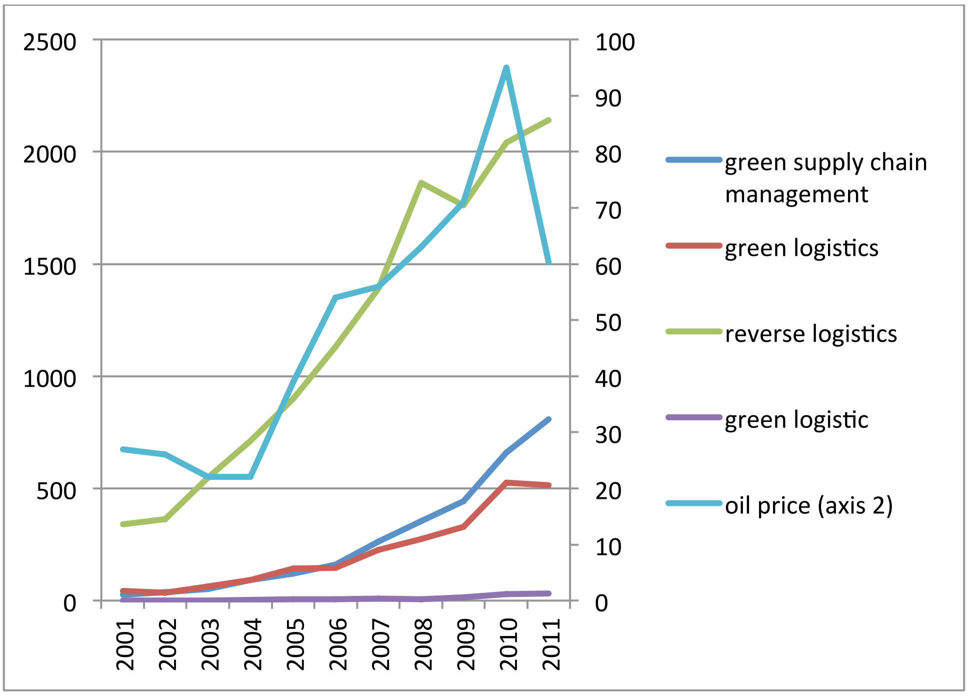


Figure 13. Number of Google Scholar hits 2001–2011

Rodrigue, Slack and Comtois (2001) define green logistics as “supply chain management practices and strategies that reduce the environmental and energy footprint of freight distribution. It focuses on material handling, waste management, packaging and transport”. Byrne and Deeb (1993) also (in Roqrique, Slack and Comtois, 2001) differentiate traditional logistics from green logistics in the way that traditional logistics seeks to organize transportation, warehousing, packaging and inventory management from the producer to the consumer. Green logistics includes recycling and disposal logistics, reverse logistics and other names for it are ‘reverse distribution’, ‘reverse-flow logistics’, and ‘green logistics’. El Saadany et al. (2011) define reverse logistics as collecting used items from the market to recapture value, and greening as a function which “refers to the forward supply chain functions such as production, purchasing, materials management, warehousing and inventory control, distribution, shipping, and transport logistics”. Srivastava (2007) formulates green supply chain management in that adding green means involving the influence and relationships between supply-chain management and the natural environment.

Ho and Tsan-Ming (2012) have used five R-model to find out why fashion companies would "go green". The model includes reduce, reuse, recycle, re-design and re-imagine segments. They found that fashion companies can seize competitive advantage through strategic management of environmental challenges. Their most important greening operations should be product development process and extend stewardship across the multiple life-cycles of products. Harms, Hansen and Schaltegger (2013) found that most of the Germany's largest stock companies supplier development represents a business-opportunity-oriented approach which means managing supplier chains for sustainable products. Curwen, Park and Sarkar (2013) researched sustainable product development and suggest that sustainable product development need clear mission, strong company mandate, and likeminded supply partners.

In van Hoek's (1999) opinion green logistics is not enough and supply chain perspective is needed. The approach change is from reactive to proactive and value-seeking and from product sales to product life scope, while company scope will be replaced with supply chain scope (Figure 14). His suggestions about green activities include material selection and re-use of materials in upstream, (design for) disassembly, scrap, shred, and transportation in mid-stream, and packaging and returns handling and returns shipment in downstream.

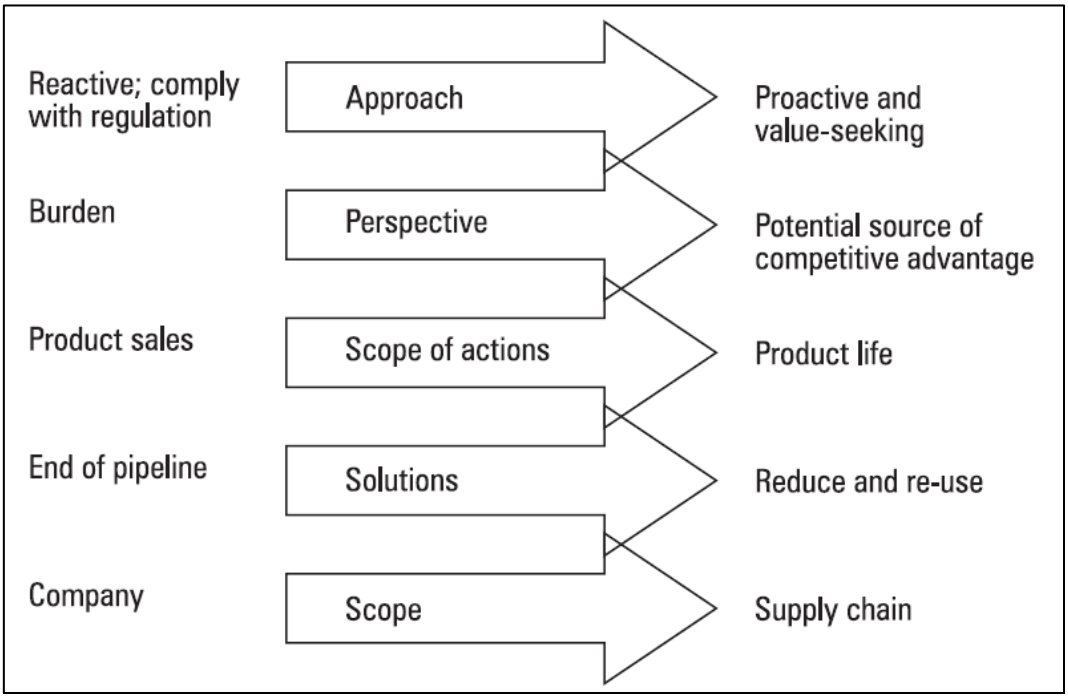


Figure 14. From reversed logistics to green supply chains (van Hoek, 1999)

Srivastava (2007) has made a wide state-of-the-art literature review about green supply chain management. He classifies green supply chain management into green design, the importance of green supply chain management and green operations which cover green manufacturing, reverse logistics, network design and waste management (Figure 15).

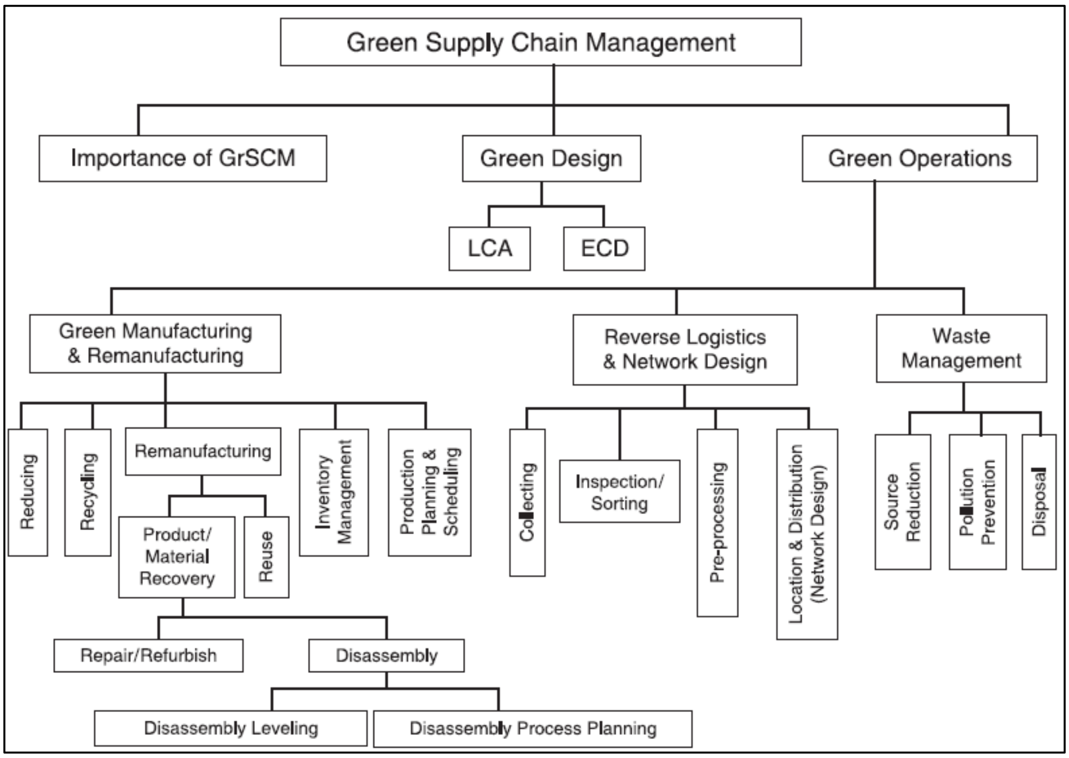


Figure 15. Classification of Green Supply Chain Management in problem context in supply chain design (Srivastava, 2007)

Rodrigue, Slack and Comtois (2001) introduce four paradoxes of green logistics. These are costs, time or speed, reliability and warehousing. The purpose of logistics is to lower transport costs and also service reliability and flexibility are further goals. Cost efficient hub-and-and spoke structures are not environmentally friendly in their opinion. They also say that reducing the time of the flow increases efficiency, especially by using the most energy efficient vehicles. They think that the more from door to door strategies and just in time strategies are applied the bigger are the negative environmental effects. The third paradox is reliability. They say the least polluting modes are regarded as the worst in terms of the delivery, lack of breakage and safety. The fourth paradox is reduction of inventories, which has led warehouses to be on the road. They cite McKinnon's (1998) survey which showed a 39% reduction in warehouses, but one third said truck traffic had increased. Rodrigue, Slack and Comtois (2001) think the environment and society pay the costs. They also think that e-commerce has the potential to increase packing and ton kilometres.

El Saadany et al. (2011) have developed an environmental quality and associated costs evaluation model which recognizes product, process, and environmental quality characteristics. It is proposed to use it as a managerial tool to reduce environmental costs and improve a system's environmental performance. They introduce an example where total quality level at 48 percent is required to increase total profits to 4,850 $/year. As environmental costs decrease, total profits increase, which emphasizes the importance of reducing environmental costs (Figure 16).

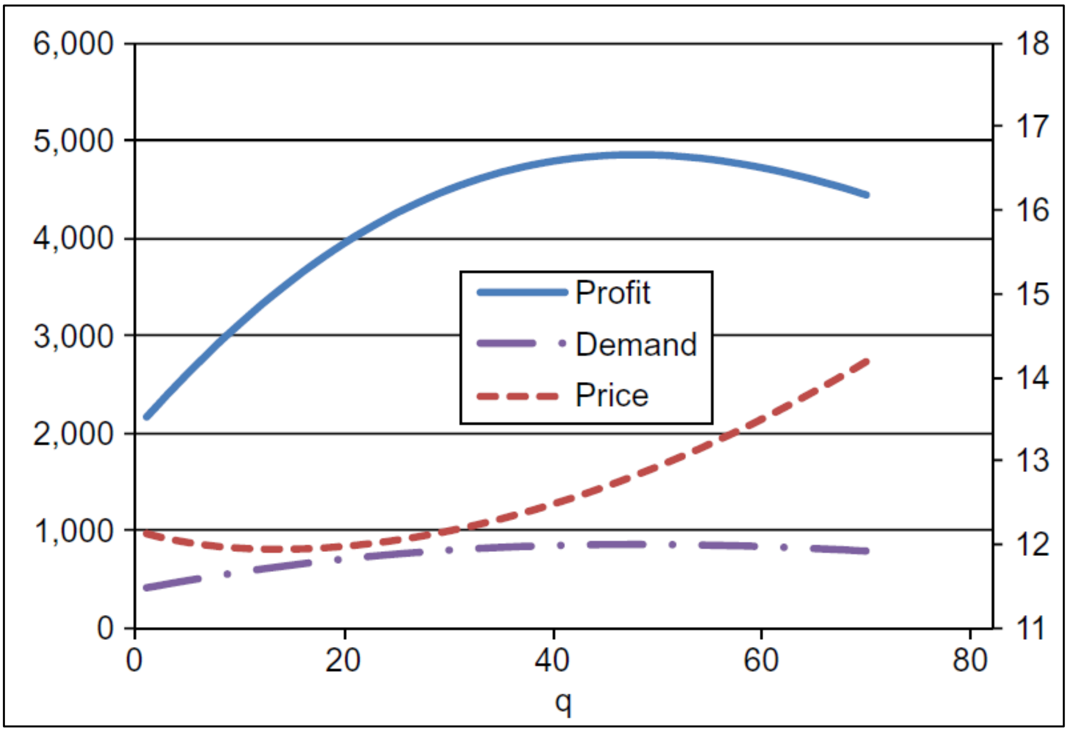


Figure 16. The behaviour of total profit, price, demand for varying q (El Saadany et al., 2011)

Chiarini (2013) identified five common patterns in optimizing the sustainability chain. The first two allow the supplier to remain in the company vendor list. The other three improve the environmental performances of the supplier. In the last stage the company can help supplier obtain the green partner status and can to introduce of new technologies for the reduction of environmental impacts, or can share environmental knowledge and research.

McKinnon (2010) presents a framework for decreasing the carbon emissions of the logistical activities of European companies. It is based on five key freight transport parameters, namely freight transport intensity, modal split, vehicle utilization, energy efficiency and the carbon intensity of the energy used in logistics. According to McKinnon (2010), freight transport typically accounts for 80-90% of logistics-related carbon emissions. The first is freight transport intensity, which is the ratio of freight movement (usually expressed as tonne-kms) and economic output.

The second is freight modal split, which can be expressed as the ratio of tonne-kms carried by more carbon-intensive modes such as road and air to tonne-kms carried by greener modes such as rail, barge, ship and pipeline. Vehicle utilization is the third parameter and it is the ratio of vehicle-kms to tonne-kms. The ratio is smaller when the vehicle´s load utilization rate is better and when outbound and return journeys are utilized more efficiently.

The fourth ratio is energy efficiency which is calculated as the ratio of energy consumed to vehicle-kms travelled. The fifth parameter is carbon intensity of the energy source, i.e. the amount of CO2 emitted per unit of energy consumed either directly by the vehicle or indirectly at the primary energy source for electrically powered freight transport operations.

There is a limited number of studies in the field of ecologically competitive supply chain management. Markley and Davis (2007) have described potential measures for sustainable supply chain management. In ISO standards, ISO 14040 is not sufficient for environmental logistical optimisation. A food mile as a term related to green food logistics. It is introduced later in the theory part. Beske (2012) suggests using dynamic capability concept to sustainable supply chain management. He defines dynamic capability in Helfats (2007) words "the capacity of an organization to purposefully create, extend, or modify its resource base".

Eco-efficiency means economic efficiency compared with ecological efficiency. According to the Schaltegger et al. (2008), the efficiency can be product or process, function or needs-related efficiency. From the material and flow perspective the eco-efficiency is emissions or resource consumption related to economic performance indicator. Murphy et al. (1994) in Rodrigue, Slack and Comtois (2001) found that the top environmental priority among managers of logistical activities was reducing packaging and waste. Pedersen (2009) says sustainable sourcing reduces cost and waste in the supply chain while benefiting the environment.

Veleva, Hart, Greiner and Crumbley (2003) state that companies are still predominantly measuring eco-efficiency and performance and not yet environmental effects and supply-chain/life-cycle issues. None of the companies in their study measured environmental effects at the sustainable system / carrying capacity level. The steps of the sustainable systems indicators are shown in Figure 17.

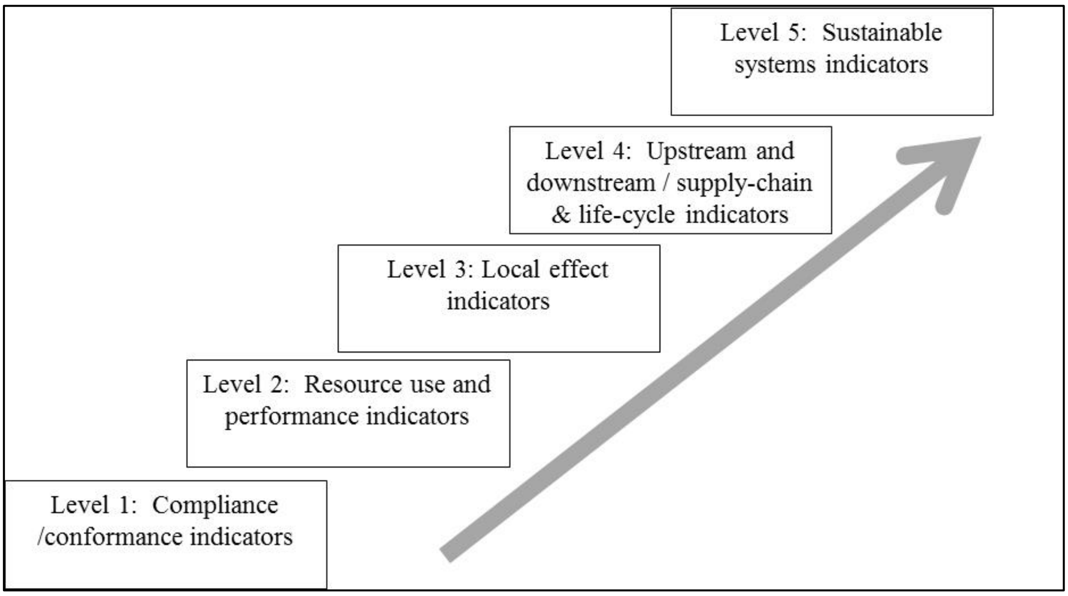


Figure 17. Sustainable indicator hierarchy (Lowell Center indicator hierarchy by Veleva, Hart, Greiner and Crumbley, 2003)

The role of eco-efficiency in firms' profitability in equilibrium is also scrutinized. Bréchet and Michel (2007) suggest that the usual eco-efficiency indicators are inadequate. Veleva et al. (2003) found that data availability is a major barrier to calculating supply-chain and product life-cycle indicators. The main steps in the SCM metric system development are to establish the right metrics, link metrics to strategic objectives and create a detailed metrics bank (Faldu & Krishna, 2007).

Transportation efficiency consists of the location, capacity and requirements for transportation. The requirements are based on scheduling and also the product amounts and features and also packaging effect. Also infrastructure issues such as vehicle, fuel and usage effect the transportation (Interaction, 2007). The energy efficiency decreases if the loading capacity increases; the bigger the vehicle is the better the eco-efficiency of the vehicle usually is (Kalenoja & Kallberg, 2006 in Interaction 2007).

Lee, Dong and Bian (2010) emphasize the role of integrating sample average approximation scheme with sampling strategy when designing a sustainable logistical network. Motiva (2006) has produced an information manual to report, measure and reduce energy consumption in transportation chains. It includes, for example, suppliers, energy, energy / tonkm, energy/year, CO2 / kg/ ton, CO2/ ton/tonkm, raw material tons/kg, price €/ton and €/km and €/year, distance km, consumption litre/tkm.

There is no standardized way of calculating transportation emissions when there are several products by several senders in the same load. Usually, the ton kilometers are calculated for each delivery. The return loads are also noticed. Welford (2004) thinks probably most challenging in environmental management of logistics is need to think about reverse logistics and reverse of material flows.

Halldórsson and Svanberg (2013) found energy resources are vital to power industrial processes in manufacturing and logistics, while their use is also a major contributor to carbon emissions. They also conclude that logistics flows are powered by energy and energy must be seen as a means towards achievement of environmental sustainability. Quanriquasi et al. (2008) have presented the main activities which affect logistic network costs and environmental performance. They are transportation, manufacturing, product use, testing and end-of-use alternatives. Transportation includes, for example, transport between suppliers and manufacturing, suppliers and consumers, and manufacturers and consumers. Manufacturing includes manufacturing at manufacturers and suppliers and end-of-use re-use, refurbishing, recycling and energy production.

Knaak, Kruse and Page (2011) have simulated alternative city courier logistical concepts, but did not find logistical strategies which would display economic and ecological benefits. The total kilometers of hub and shuttle model were biggest, and single central hub based inside and outside-model had fewer kilometers. They found the problem is a large number of the empty runs, which is a typical problem in many logistical cost optimization studies and later in sustainable logistic studies. Britoa, Carboneb and Blanquartd (2008) introduce fashion business stakeholders' views on sustainability. They think economic sustainability is the optimization of flow management and flow consolidation by logistical integration. The environmental part includes environmentally friendly transport and resource sharing solutions by clean transport modes and intermodal transport solutions. The stakeholders' social issues are related in their research to consumers' health and the security improvements with track and tracing systems.

Quanriquasi (2008) has published a dissertation on eco-efficient supply chains for electrical and electronic products. He found, for example, that the usage phase consumed more than 90% of the energy of the life cycle and that there are almost inevitable trade-offs between the increases in recovery volumes and CED, regardless of the incurred costs. The reason for such an apparent paradox is that transportation drastically increases with the volume recycled. He also found that the price of equipment that resembles the one being announced as an external reference price (ERP) increases the price of the latter.

2.3.3 SCM decisions affecting sustainability

The methodology developed by Quanriquasi, Walther, Bloemhof, van Nunen and Spengler (2009) for assessing eco-efficiency in logistics networks has three objectives. They are to minimize costs, cumulative energy costs and waste in reverse logistics.

Many companies have moved their production plants to Asia, Africa and Latin America and then the products are transported to customers in Europe and North America. The main reasons are lower costs and better availability of the resources. This has already been realised in most national economies. The methods and practices for estimating the environmental effects of plant location decisions are insufficient even if environmental competitiveness could lead to better economic competitiveness of companies and supply chains (Rao & Holt, 2005) and operational performance (Stephan, 2003). Quanriquasi et al. (2009) researched trade-offs between environmental impacts and economic activity. Bosona et al. (2013) evaluated the performance of an integrated food distribution network They found out that existing distribution center is located at best position.

Golicic and Smith (2013) found in their meta-analysis that sustainable supply chain management resulted in increased firm performance. Also Goh et al. (2012) found that the GSCM practices in manufacturing organizations lead to improved environmental performance and economic performance.

Qinghua et al. (2008) have compared ESCM practices in Chinese and UK automotive organizations. They found that Chinese implement generally higher levels of ESCM practices but do not have significantly greater performance improvements.

In the field of green logistics the improvements suggested by McKinnon (2005) are mainly to optimize the number of warehouses. The inventory and warehouse related emissions increase but transportation emissions decrease if the number of the warehouses increases. (Figure 18.)

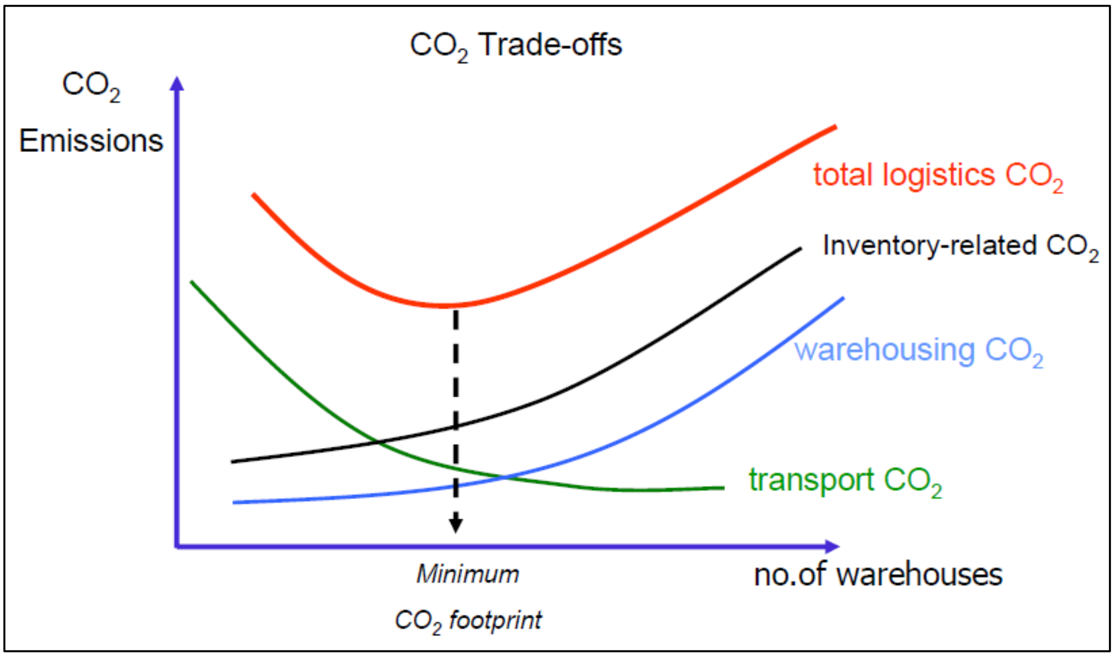


Figure 18. Optimizing the number of warehouses in the logistics system with respect to CO2 emissions (McKinnon, 2005)

Other ways to decrease carbon related emissions according to McKinnon (2005) are to change freight from high carbon intensity mode vehicles, such as air and road, to lower carbon emissions, such as rail and water-borne services (Figure 19). Also improving the loading of vehicles reduces the amount of traffic (measured in vehicle kms) and that is why it leads to a reduction in energy consumption and CO_2 emissions per tonne-km. He also suggests improving energy efficiency of the vehicles and using less carbon-intensity fuels.

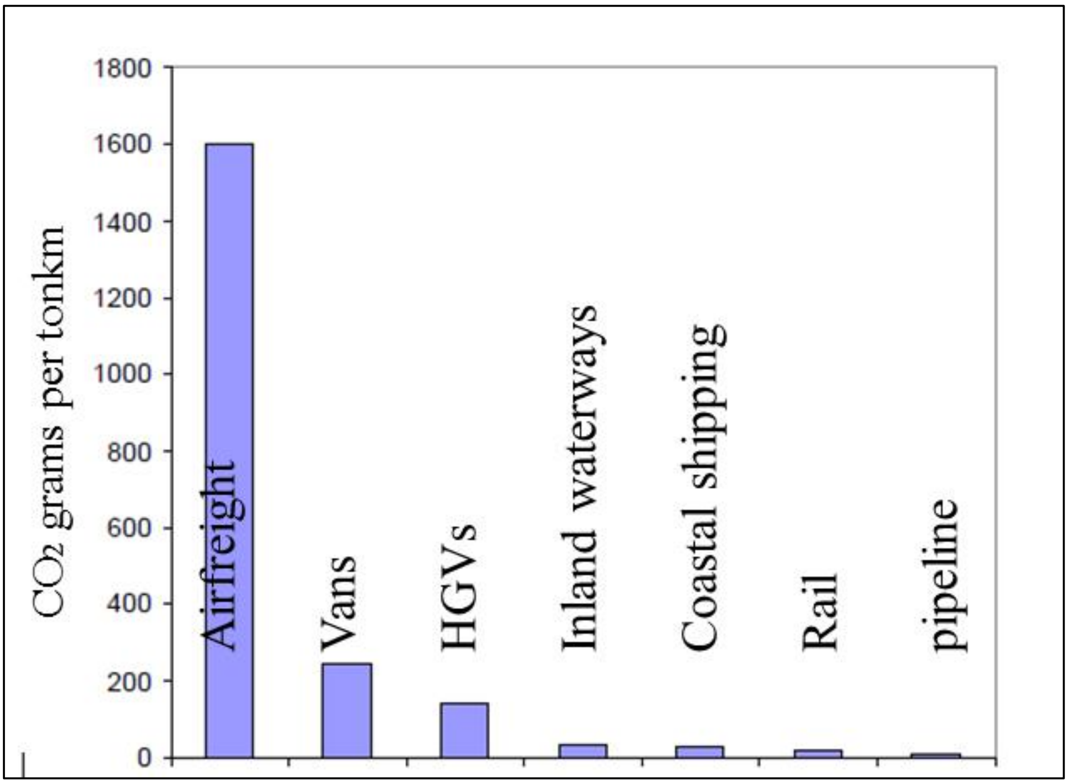


Figure 19. Variations in the carbon intensity of freight transport modes (McKinnon, 2007 in McKinnon, 2010)

For decarbonizing warehouses he suggests, for example, low carbon electricity supply progresses, “reducing the demand for heating through good insulation and airtight construction methods and reducing the need for artificial light by increasing the use of daylight supplemented by energy-efficient lighting systems”. He also mention use of wind turbines and solar panels, temperature-controlled warehouses (and vehicles) and energy efficiency of materials handling equipment.

Seifert and Comas (2010) say that for example the *Greenhouse Gas Protocol* (2011) includes scope 3 emissions. These encompass all GHG emissions from operations not owned or controlled by a firm. However, there is still a clear lack of well-established, robust methods for measuring and reporting supply chain environmental performance.

2.4 Food supply chains

This chapter describes specialities in the food supply chains and the challenges and opportunities which the food industry are faced with. In addition to the price of the food, attitudes and emotions (for example ecological and ethical issues) guide food consumers a lot. The world population is increasing and the need for food probably will double in the next decades. At the same time global warming is changing the growing conditions everywhere in the world, but most in areas closest to the poles. Traditional agricultural areas will not be so efficient when global warming is changing the growing conditions and it is possible to cultivate many crops in other parts.

Food supply chains, as well as supply chains in general, are globalised and compete in the retail and catering markets with global brands. Local and global policies and programs (e.g. EU) regulate agriculture and food importing and exporting. Food is needed every part of the world every day. Food products are often very fast spoiled and needs quick deliveries. The market shares of local food, ecological and ethnical food (e.g. bio food, local food, fair trade) have grown and have increased market share in several consumer segments. Consumers, and also shareholders of companies, have become increasingly aware of ethical and ecological issues. Companies need to improve their ecological performance.

Food production and supply chains are centralized and they are quite vulnerable to crises (BSE, ecological catastrophes, etc.). Aging also usually changes food products´ microbiological and sensitive quality. Freshness is usually an advantage. Food safety issues are linked, for example, to legislation and to the increasing traceability of the chains. The availability of food may need genetic manipulation. Packaging technologies, additives and efficient supply chains aim at the longer shelf life. At the same time there is a need to decrease the amount of waste. Food consumption is influenced by trends, brands, ethical, ecological and economic issues, and also by health issues, emotions and habits.

2.4.1 Characteristics of food supply chains

Food and the food business are faced with many facts which are typical in the food business environment. The world population is increasing and at the same time climate change is supposed to be changing farming conditions everywhere in the world remarkably. It is supposed that farming conditions will essentially get worse in current major farming areas. Everyone needs food, but few people are able to produce their own food.

Food logistics is global. Food is consumed every day in every part of the world but a lot of food production is centralized. This is main reason for the need of efficient food logistic even if the logistic costs and environmental wouldn’t be so essential compared to the whole products effects (for example Katajajuuri et al., 2007 introduced later in this chapter).

Life cycle of the food is short. Many of the food products are short-date products, which makes food logistic challenging. Because in many cases the environmental effects has concentrated in raw material production / agriculture the failure in end chain logistic won't only cause logistic losses but all the earlier stages. That is one main reason why there is need for reliable and fast supply chains and some lower carbon intensity vehicles, such as rail and water-borne services (Mc Kinnon, 2005) could not be possible.

Food consumption and food choices are complex issues. Finnish food consumers have eight everyday food choice strategies. Food quality and safety issues and the consumers' everyday practices in everyday lives have the greatest impact on food choices. The consumers' food choice strategies are avoiding, favouring, vigilance, active consumerism, moderation, variety, common sense, single criterion and unconcern (Järvelä, Mäkelä & Piiroinen, 2006). The professional food purchasers are buying according to the corporate policy, the price, quality and service (Bergström, Solér & Shanahan, 2005) Walker and Jones (2012) suggest that for SCM practitioners would be useful to explore the implementation of purchasing and supply activities that support sustainable SCM and train buyers in sustainable SCM. The purchasing and supply department needs also to ensure that sustainable SCM strategy aligns with the corporate strategy as well as cross-functional working within the company is needed. They also suggest that adopting a collaborative approach to sustainable SCM seems to be of benefit.

Fragility of food supply chains. Our food supply system is inherently fragile in the words of Rockefeller (2009). He means that a single failure would produce a large market interruption since our food supply system is inherently fragile. This is because our sources of food are centralized and corporations are distant and there is also political and financial uncertainty. He thinks there is a need to bolster local food sources.

Supply chain management is needed to manage increasing food consumption and challenging farming conditions. There is need for efficient supply chains with demand forecasts. The structure of supply chains will be under scrutiny in the current business environment where production is centralized and markets are decentralized.

Food safety and security issues have increased demand for locally produced food as an alternative to large scale food supply chains. Local food problems are often related to difficulties in reaching economic and ecological deliveries. In the study by Bosona, Gebresenbet, Nordmark and Ljungberg (2011) remarkable route distance and delivery time savings were achieved with the help of route optimization. Local food has effects, according to Coley, Howard and Winter (2009) on biodiversity, landscape, employment, fair trade and social justice. They found in their case study of farm shops and mass distribution approach that if customers drive more than 6.7 km to purchase local organic vegetables their carbon emissions are greater than when buying vegetables transported on a large scale. Locally produced food does not necessarily have the lowest carbon emissions, but carbon is not the only factor in making purchasing decisions. According to the authors also biodiversity, landscape, local employment and social justice should be considered.

The role of the consumer shopping trip plays a great role in the carbon footprint of food. Cairns (2005) has concluded that traffic levels would decrease if consumers could receive home shopping and deliveries.

Food wasting causes remarkable environmental effects. The MTT research group has made research on the responsible food sector (e.g. Koivupuro et al.,2010). According to them food wasting is more or less useless waste. Finnish people in households waste food to the extent of 120–160 million kilograms annually. Household food waste consists of vegetables (19%), homemade food (18%), milk products (17%), grain products and bread (13%) and fruit and berries (13%). The share of wasted fish, meat and egg products was 7% and convenience food 6%. People who sorted their household wastes produced less waste. Single women wasted most.

2.4.2 *Food supply chain sustainability*

Food is remarkable part of economy no matter if it is measured with money, natural resources, green house gas, employment and environmental effects or employment, (Seppälä et al., 2009, cf. Figure 20).

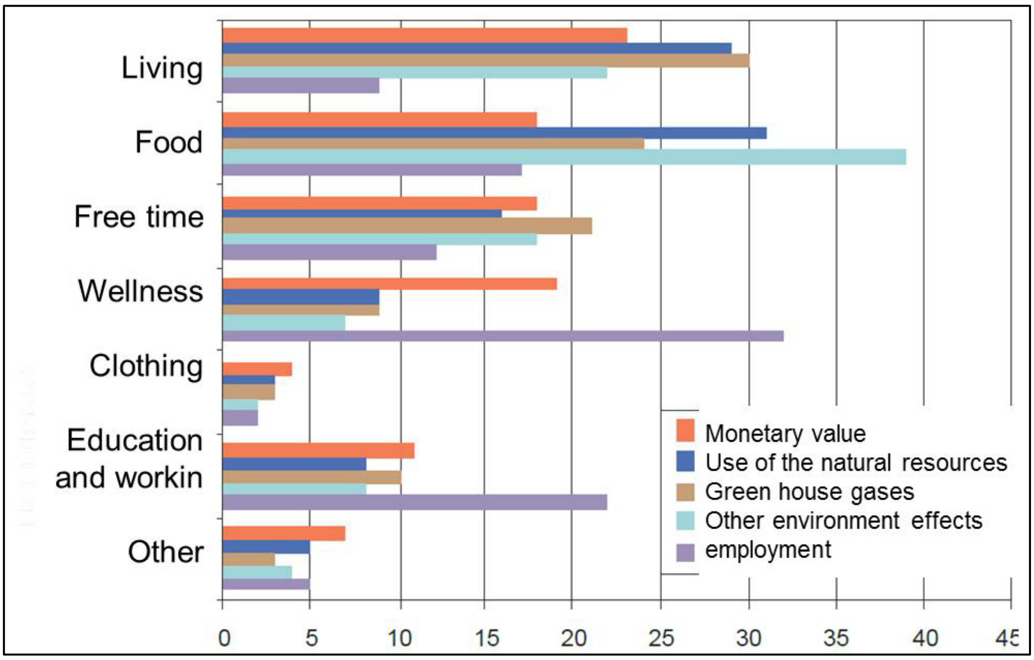


Figure 20. Distributions of the Finnish consuming effects (Seppälä et al., 2009)

The ConsEnv-project (Kurppa, 2009) shows basically that that which is good for you is good for the environment. Internationally there are several not easily comparable labeling systems in goods and services including food, which indicate, for example, better choice in or between product groups. There is a lack of any standardized calculation method and therefore there is a huge variation between the criteria to have the label. However, eco-labeling may encourage companies to improve sustainability performance (Proto, Malandrino & Supino, 2007) and sustainability accounting improves sustainability performance (Adams & Larrinaga-González, 2007).

The ecological information available for food consumers is not sufficient at the moment (Katajajuuri et al., 2006). According to the Global Commerce Initiative in the International Commerce Review the key performance metrics of future supply chains include environmental metrics such as CO_2 emissions and energy consumption besides the traditional metrics relating to cost efficiencies. Ljungberg, Gebresenbet, Kihlström and Oritz (2006) have optimizated routes and distribution/collection of emissions of agricultural products in Uppsala.

The greatest environmental effect may sometimes occur in the production stage and sometimes in transportation or retail. An example of that is in Figure 21. (Katajajuuri et al., 2006). Forsman-Hugg et al. (2006) have found that opinions about and roles of (environmental) responsibility issues are different in different stages of the supply chain. That is one reason for the need to be able to optimize the environmental effects of transportation and plant location decisions.

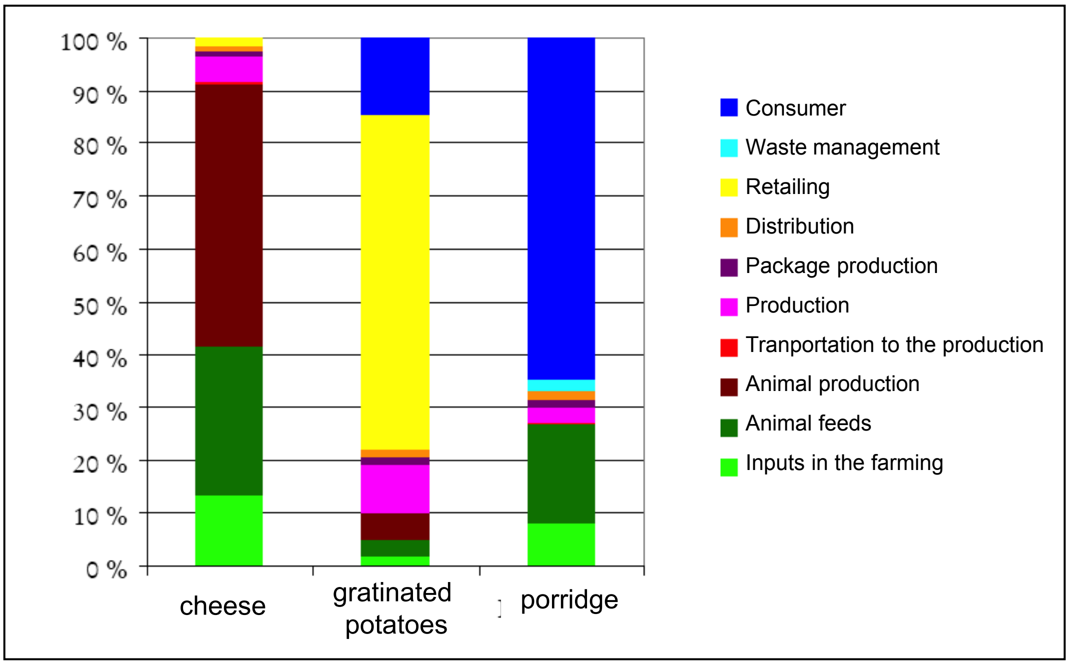


Figure 21. Example of climate change effects in different supply chains (Katajajuuri et al., 2007)

The impact of retailers on the *sustainability performance* of national economies is huge (Erol, Cakar, Erel & Sari, 2009). There is also a huge variation of emissions between different products and between the same product (Katajajuuri, 2009; Figure 22). For example, the carbon emissions of the tomatoes may vary a lot but it is still minor compared to beef. Wanhalinna (2010) estimates that the carbon footprint of bread is 1.4 – 1.7 kg CO2 eqv. / kg bread in which agriculture 45%, bakery 40%, and consumer 13%. In Pelletier, Ibarburu, Maro and Hongwei (2013) feed production and use in pullet and layer facilities represented the biggest share of the egg supply chain emissions. Nitrogen (N) use efficiency were one of the most critical element in that egg supply chain.

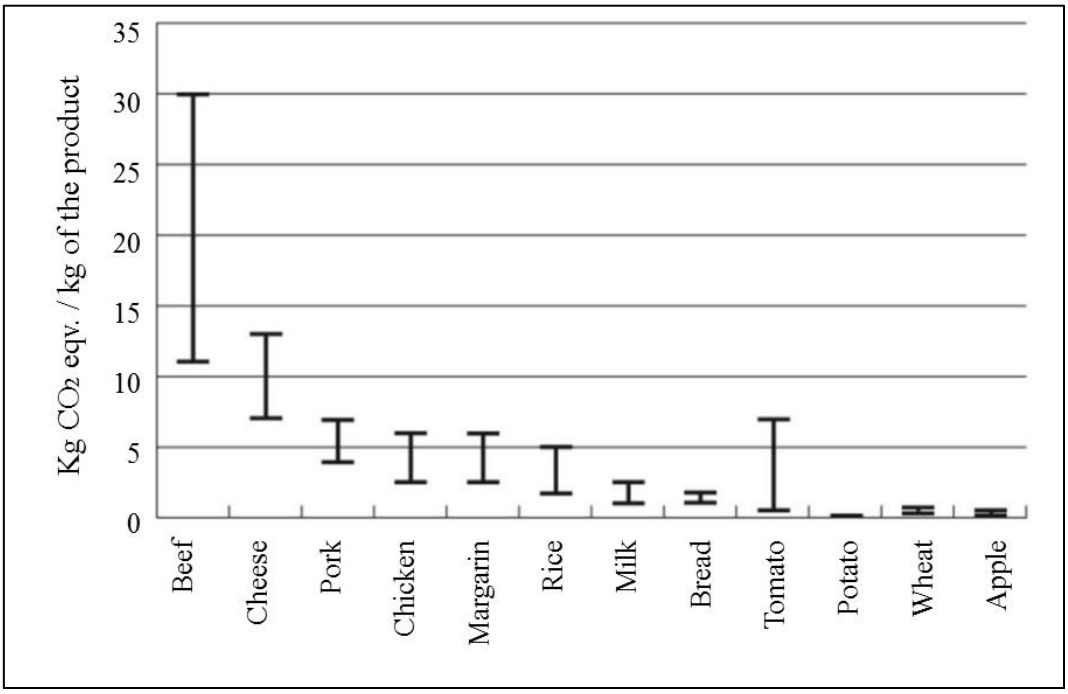


Figure 22. Some examples of carbon dioxide emissions by products (Katajajuuri 2009, Tulevaisuusselonteko)

The Mittatikku-method is a consumer-oriented method which helps consumers to estimate the environmental effect of the food chain (Nissinen et al., 2007). The MTT Foodchain research group has produced product related information for consumers to help them in their purchasing decisions. Kortelainen and Kuosmanen (2007) suggest a data envelopment analysis based method for measuring the eco-efficiency of consumer durables in terms of absolute shadow prices. Kainuma and Tawara (2006) suggest a multiple attribute utility theory method for lean and green supply chain management from a managerial and also from an environmental performance viewpoint.

Distance, loading capacity, and type of transportation vehicle also impact the transportation environmental performance (Seppänen et al., 2006). As a conclusion an example of the food supply chain's processes and their environmental inputs and outputs are presented in Figure 23.

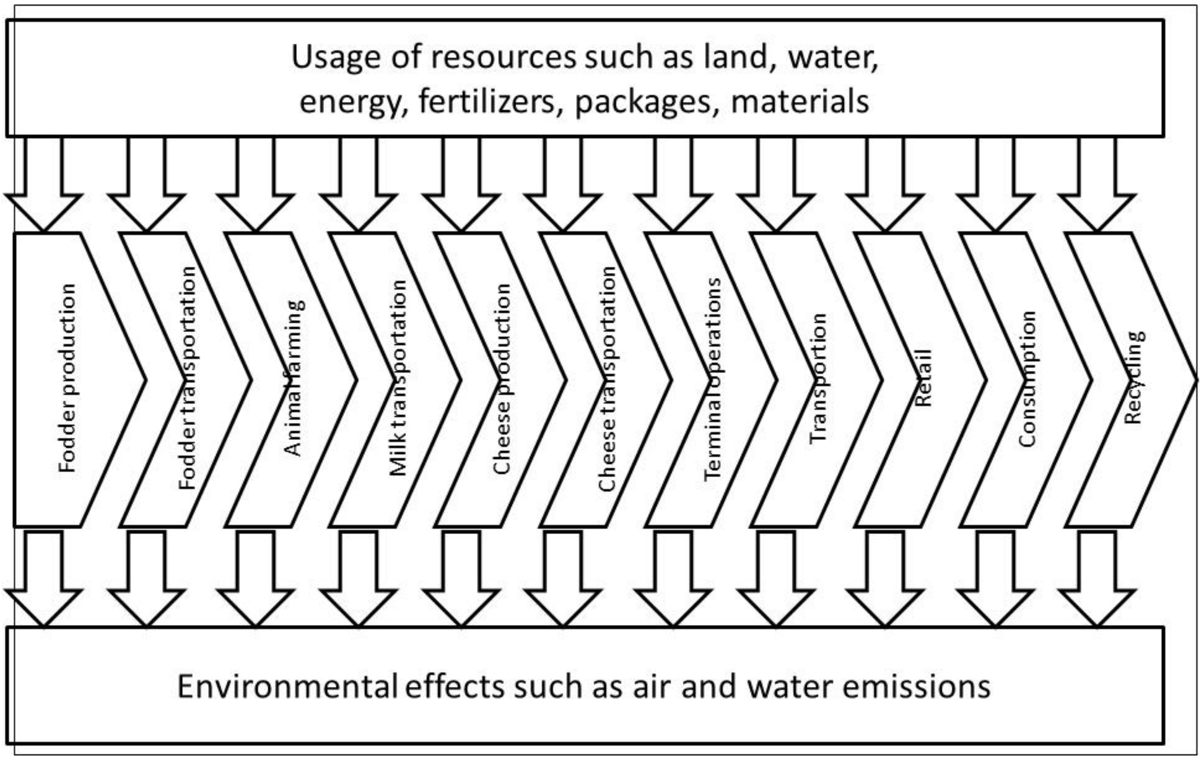


Figure 23. An example of the environmental effects of the cheese product flow

Food-mile is a term related to the distances of all food supply chain stages. The general assumption is that more food-miles are related to less environmentally efficient supply chains. Rodrigue, Slack and Comtois (2001) report about a yogurt case study made in Germany by Böge (1995) and published in World Transport Policy & Practice. The study showed that statements along the line that supply chains should be more locally and regionally focused can be misleading. It is based, for example, on input weight factors or (material index), which means that higher the input is the more important is the location. They highlight also a third point, namely economies of scale and regional specialization. It means that there are emerging regional specializations in food production. Some agribusiness employees in developing countries have a remarkable effect on the national economics. The benefits derived in terms of lower input costs and economies of scale may outweigh higher transport costs.

The environmental effect is divided into use (inputs) and emissions (outputs). The effect is produced in different stages of the supply chain.

Nissinen, Salo and Grönroos (2010) have developed the calculator called “ilmastodieettipuntari”. Nissinen has developed the Mittatikku method. Y-hiilari is a free Corporate Accounting and Reporting standard (scope 1 and 2) based tool for the calculation of companies’ carbon footprint. It has been developed by

Kontiokorpi (2011). Wanhalinna (2010) calculated the carbon footprint for bread. MTT has organized and performed several other food carbon print calculations in Finland, for example Elovena oat flakes and Pirkka potatoes. For example, Pirkka potato calculations include fertilizer production and transportation, potato growing and transportation, packaging, packing process, water treatment, waste management and transportation and product transportations to the distribution center.

The Japanese Ministry of the Environment (2010) defines sustainable development, for example, as a reduction of resource and energy consumption and prevention of global warming. It includes, for example, the development of environmentally harmonious products and environmental impact assessment with the purpose of reduction of resource and energy consumption and food production and land utilization (Figure 24).

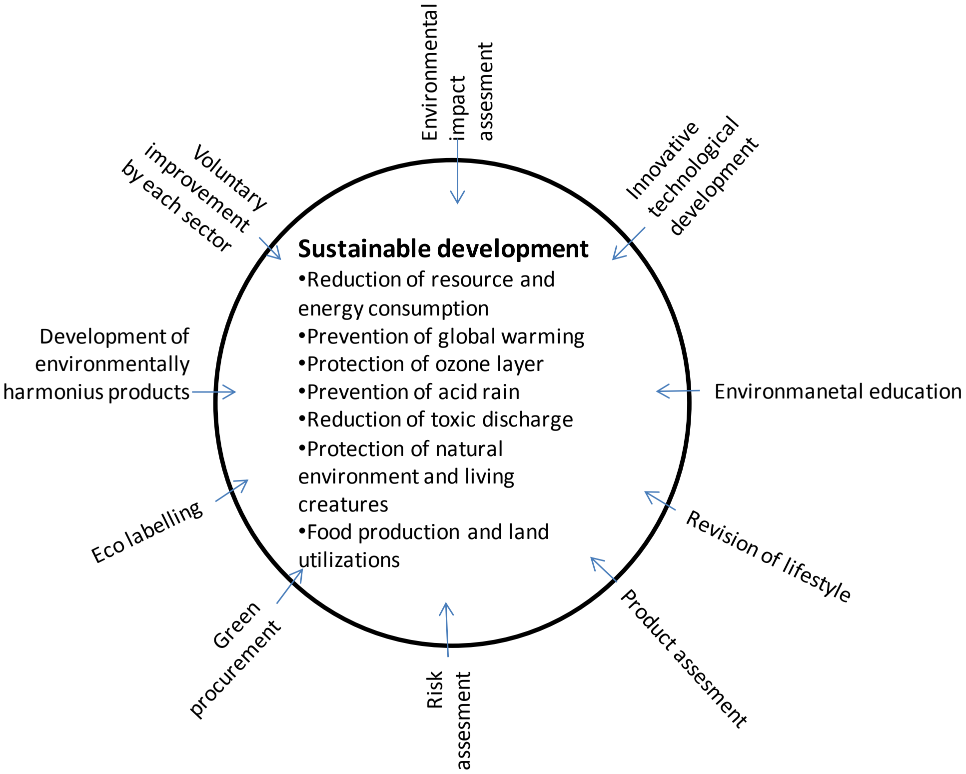


Figure 24. LCA for Sustainable Development (Quality of the Environment)

Life cycle analysis (LCA) is a commonly used (examples) method in the environmental effect research, which has a lot of potential for agricultural product evaluation (Katajajuuri et al., 2006). Wiedmann et al. (2009) mention carbon, ecological and water footprint analyses, but they claim that they extended data from all three dimensions of sustainability.

Kumaran, Ong, Tan and Nee (2001) have developed a life cycle environmental cost analysis (LCECA) model, which includes eco-costs into the total cost of products. The model includes costs of the product or part, effluent control, effluent treatment, effluent disposal, environmental management systems, eco-penalties, rehabilitation, energy, savings of reuse and recycling. LCA does not usually include economic and social issues. There are also frameworks for the software tool including carbon, ecological, and water footprinting in the case company in the UK. Kim and Dale (2008) have used life cycle assessment for researching the effect of nitrogen fertilizers on the greenhouse gas emissions associated with corn grain. They have defined optimal nitrogen rate as an eco-efficiency index, which is the ratio of economic return due to nitrogen fertilizer to the greenhouse gas emissions of corn cultivation.

The Carbon Disclosure Project (2009) has launched a Carbon Disclosure model to encourage companies in its supply chain to report climate change related information. Wal-Mart is piloting the results of the project.

Cummings (2005) concludes that a food retailer in his case study should set targets and action plans and communication policies in critical CSR issues, but one of his key findings is that management systems should integrate across business units and the performance relationship between the retailer's strategies and policies and its key targets and indicators should be clarified. Firms' attention to different supply chain or life cycle stages and stages subject to major regulation and public pressure, Seifert and Comas (2010) say that Nestlé feels consumer pressure and dedicate particularly high attention to the suppliers and the raw materials categories.

However, there are reports such as managing climate change in the supply chain, published by the Carbon Disclosure Project (CDB, 2009). Current research in the field of environmental supply chain is concentrated very much on improving product structures and usage of raw material. According to Darnall, Jolley and Handfield (2008) environmental improvements are limited inside the organisational boundaries instead of being extended to the supply chain level.

Van Hoek (1999) explains that reverse logistics is not enough. He cites Wu and Dunn (1995), who stated that to minimize the total environmental impact of a business it must be evaluated from a total system perspective. In van Hoek's opinion the supply chain represents this holistic system perspective and represents the focus for far-reaching green initiatives. Even if Huang and Keskar (2007) introduce supply chain environmental metrics, the environmental effects of food supply chains differ from other kinds of supply chains. On the other hand, models for calculating greenhouse gas emissions lack or have only a weak supply chain viewpoint.

3 SUSTAINABLE SUPPLY CHAIN PERFORMANCE ESTIMATION MODEL

The constructive part of this research is described in this chapter. The main focus is to **describe the model and the process of how the supply chain sustainable performance model has been constructed**. The model is later called the Food Supply Chain Sustainable Performance Evaluation Model.

The method is based on the supply chain operation reference model (SCOR) developed by the Supply Chain Council (2010). This chapter describes how the model was created and how to use it. The model is later applied in the case studies as a method.

The model connects sustainability performance attribute to supply chain performance attributes. The metrics of each performance attribute were chosen based on the theories of sustainable performance and supply chain performance studies and the general framework of the ecological goals and supply chain management described earlier in this study.

The general objectives for the sustainable supply chain performance model are to:

- manage and measure supply chains more sustainable
- create and implement sustainable supply chain objectives and strategies
- set sustainable supply chain objectives
- optimize sustainable supply chains
- estimate the effects of logistics strategy and to implement changes
- connect and respond and foresee the effects of changed customer behavior in supply chain strategies
- set values and have discussion on the values of companies
- see what are the effects of individual changes on the supply chain´s overall performance
- see a bigger picture of strategic decisions and model the complexity of the dependencies between the performance attributes.

The criteria for using the model are to allow scenario based evaluations and be simple enough to use. The sustainability analysis in the early stages of process design usually leads to more sustainable processes (Tugnoli, Santarelli & Cozzani, 2008), and that is one reason why scenario- based supply chain evaluation is recommended.

The aim of the model is to help to help supply chain partners consider economic and social issues besides economic ones. The developed model promotes sustainable development by helping to find answers to the question:

How will strategic decisions about the supply chain affect the supply chain's sustainable performance?

3.1 Model construction process

The first step of the model construction process is to establish the right metrics, the second is to link metrics to strategic objectives and the third is to create a detailed metrics bank (Doherty, Hoyle & Veillard, 2010). In this study this means choosing the best available indicators based on the literature and SCOR gives a strategic objectives framework. The framework will be accomplished by the environmental goals and metrics.

Faldu and Krishna's (2007) model developing process steps have been used in this research. They found that a model developing process has three steps, which are establishing the right metrics, linking the metrics to strategic objectives and creating a detailed metrics bank.

In this study establishing means choosing the best available indicators based on the literature and SCOR gives a strategic objectives framework. The framework will be accomplished by the environmental goals and metrics. The indicator selection is one of the most crucial steps to fulfill performance evaluations, as, for example, Erol et al. (2009) have found in the area of sustainability research.

The guidelines for constructing (steps 1-3) and model evaluating with case studies (steps 4-11) in this study comprises:

1. Defining the management framework and attributes for the supply chain.
2. Defining environmental performance management framework / attributes.
3. Connecting the chosen frameworks and attributes to the sustainable supply chain performance measuring framework.
4. Identifying of the supply chain's competitive advantage and setting the strategic goal of each performance attribute (attribute and metric selection).
5. Defining strategic change
6. Defining alternative supply chains (product, processes, customers, sources, need in before and after change situations).
7. Identifying differences in the processes of alternative supply chains.
8. Identifying significant changes

9. Collecting (or estimating the scenario) information of the selected supply chain for the model
10. Comparing supply chains with the set performance targets against selected indicators
11. Creating strategy and implementing changes

Kellen and Wolf (2003) found that there are four criteria for designing successful BPM systems along with 12 BPM system factors when building Business Performance Measurement (BPM) systems. The first is that the BPM system should help the firm accurately perceive relevant internal and external phenomena including threats and opportunities and shortcomings in its ability to perceive phenomena as well as shortcomings in its ability to control its actions (breadth, depth, coherence and predictability). Secondly, measurement information needs to be delivered, processed and acted upon within the time frame needed for market survival (latency: propagation and response). Thirdly, the BPM system must aid the decision-making process (provability, explainability, believability, communicability) and fourthly, the BPM system needs to operate self-reflexively and largely below the threshold of the firm's awareness (adaptability, measurability, autonomic).

There are various opinions about the right number of metrics in the strategic management tool. According to Bonadio's (2009) relatively wide survey (over 200 HR leaders), nearly two-thirds believed the optimal number to be between three and five, and nearly one-third believed six to ten metrics are the optimal number for a strategic HR management tool.

Moody (2003) found in his research on evaluating and measuring the quality of data models that the most common reaction by reviewers was that there were too many metrics in the models. His study was based on wide data and showed that a small but critical set of metrics was preferable instead of trying to measure all possible aspects. The final set of metrics was less than 20% of the number of metrics originally proposed. He highlights the difference between research and practice, which is that research tends to strive for completeness and closure, which means an attempt to measure all possible aspects. In practice, the focus is on what is necessary to get the job done and measuring only those aspects that are most important for improvement.

3.1.1 Attribute selection

Kellen and Wolf (2003), for example, suggest in their study about performance management systems that useful attributes in examining, selecting, designing and using measures are

- Objective/subjective
- Financial/non-financial
- Lagging/leading
- Complete/incomplete
- Responsive/non-responsive
- Inputs/process/output
- Critical/non-critical
- Tangible/intangible.

As well as the number of metrics so also the number of performance attributes was kept to a minimum. That is why it was decided to add only one strategic performance attribute to the model.

Shaw, Grant and Mangan (2010) there is a need to develop a "common" environmental supply chain performance measure that captures the impact of the entire supply chain relative to these foregoing issues. They say that measure must be comparable, robust, credible, valid and reliable and be applicable across all industries, sectors and countries.

3.1.2 Establishing the right attributes and metrics

The aim of this research was to keep the number of the metrics in the final model between 2 and 10, which may be more before validation (Bonadios 2009; Moody 2003.)

The concept of sustainability has been described earlier in this research. The selected approach for sustainability is Elkington’s (1997) triple bottom line approach which is generally used and accepted. For example, “the triple bottom line and sustainability” gives 1129 peer reviewed full text results in the Abi/Inform ProQuest database. Because it consists of economic, ecological and social scope only attribute sustainability itself was chosen beside the attributes in the SCOR model. The attributes in the SCOR 8.0 model are reliability, responsiveness, flexibility, costs and assets.

The SCOR model was selected because it is a widely used and validated model for supply chain management (Zhou, Benton, Schilling & Milligan, 2011) and many of the world's biggest food produces are using SCOR model, for example, Coca Cola, Kraft Foods and Heineken are SCOR users (SCC, 2012).

Sustainability is not a performance attribute in the SCOR model. Welford (2004) says that competitive strategy must be one of the differentiations where companies demonstrate their real commitment to environmental protection, social responsibility and sustainable development.

The developed model connects the corporate level sustainability approach (economic, social, and ecological responsibility) into the Supply Chain Operations Model Reference Model (SCOR). The strategic level of the model consists of economic (the SCOR model), ecological (e.g. CO_2 emissions), and social metrics (e.g. the share of companies having social responsibility program) The social responsibility program should include also human resource development which should be part of sustainable supply chain management according to the Becker et al. (2010).

The metrics were chosen based on the theories of ecological and supply chain performance studies and the general framework of ecological goals and supply chain management. The general objectives of the model are to help develop and manage more sustainable supply chains, create and implement sustainable supply chain objectives and strategies, set sustainable supply chain objectives, create and optimize sustainable supply chains, estimate the effects of supply chains and implement changes and connect and respond and foresee the effects of changed customer behavior on supply chain strategies (Figure 25).

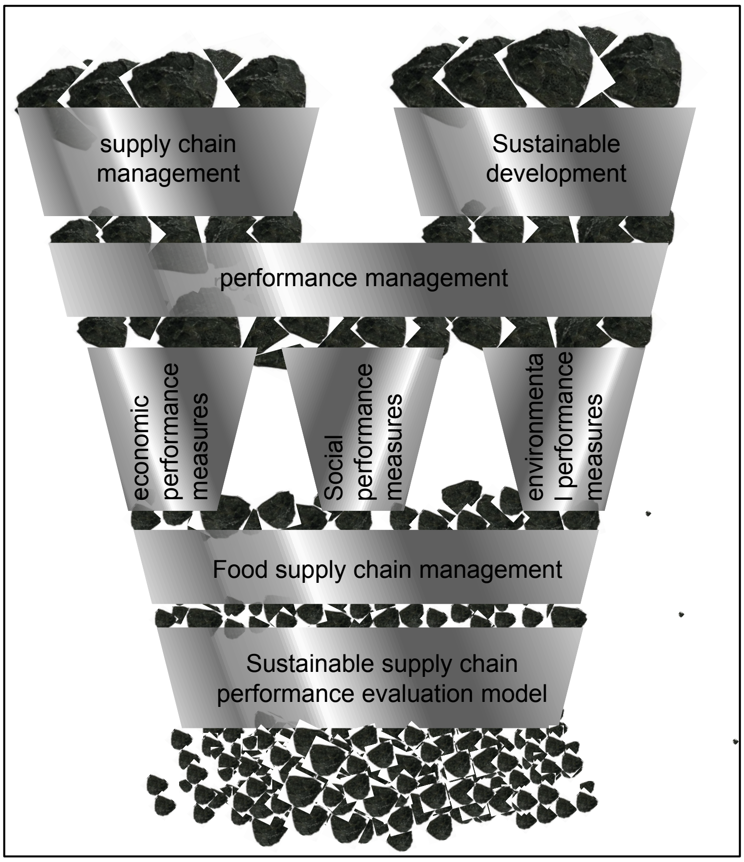


Figure 25. The model construction process

3.1.3 Linking metrics to strategic objectives

As mentioned before, the SCOR-model builds a basic framework and attributes for the new performance estimation model. The performance attributes help companies to set their sustainable competition advantage, strategy, vision and mission. The economic attributes and metrics are based on the SCOR model. They are reliability, responsiveness, flexibility, cost and assets. The sustainability attribute was added to the model to describe ecological and social performance and sustainability is essential for the long-term profitability of a supply chain like for example Becker et al. (2010) say. The selected metrics characterize different attributes and give a general view of the performance of the attribute. There are 14 metrics in the model, but only a few to describe each performance attribute. The aim was to cover sustainable systems indicators, upstream and downstream / supply-chain & life-cycle indicators, local effect indicators, resource use and performance indicators (Veleva et al., 2003)

The sustainability attributes and metrics were placed between the SCOR performance attributes (reliability, responsiveness, flexibility, costs and assets).

Sustainability was considered to describe both internal- and customer-facing performance. For this reason in the model the sustainability performance attribute is placed between internal and customer-facing performance.

3.2 Framework of the model

The framework of the model consists of the performance attributes. They help companies to set out their competitive advantage, strategy, vision and mission. Selected metrics characterize the attributes and a give general view f the performance of the attribute. Selected attributes for describing the performance of the supply chain are reliability, responsiveness, flexibility, costs, assets and sustainability (Figure 26). Sustainability was selected because its potential as the competitive advantage is shown in literature review.

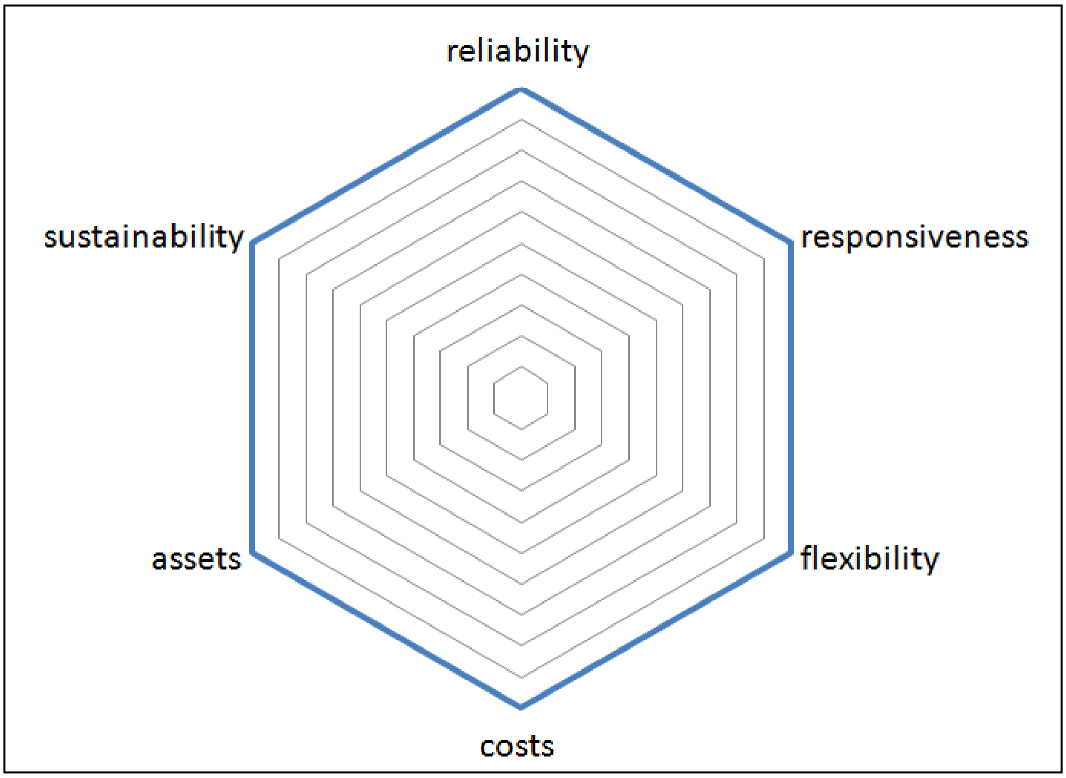


Figure 26. Performance attributes of the supply chain

The SCOR-model defines reliability as the performance of the supply chain in delivering the correct product to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation to the correct customer. Responsiveness means the speed at which a supply chain provides products to the customers and flexibility the agility of supply chain in responding to marketplace changes to gain or maintain competitive advantage. Supply chain costs are defined as costs associated with operating the supply chain. Asset management is defined in the SCOR model as the effectiveness of an organization in managing assets to support demand satisfaction and it includes both management of fixed and working capital.

The SCOR-model builds up a basic framework for the new performance estimation model. This means connecting the most commonly used and accepted sustainability indicators such as CO2-emissions to the metrics of the SCOR-model.

The SCOR-model was accomplished with the environmental performance attribute and metrics. Sustainability was chosen as the performance attribute and the related metrics are climate change effect, energy use and use of natural sources. The metrics and attributes were placed between the SCOR performance attributes (reliability, responsiveness, flexibility, costs and assets). Sustainability is considered as a public attribute, which means combining corporate responsibility with internal- and customer-facing performance.

Table 9. Attributes of the Model (SCOR + environment)

Metrics	**Performance attributes**					
	Customer-facing			Public	Internal-facing	
	Reliability	Responsiveness	Flexibility	Sustainability	Costs	Assets
Perfect order fullfillment	x					
Order fullfilment cycle time		x				
Upside supply chain flexibility			x			
Upside supply chain adaptibility			x			
Downside supply chain adaptibility			x			
Supply chain management cost					x	
Cost of goods sold					x	
Cash-to cash cycle time						x
Return on supply chain fixed assets						x
Return on working capital						x
co_2-emissions				x		
waste				x		
CRS programs				x		

3.3 Metrics bank creation

The selected metrics in the developed (Table 9) model are perfect order fulfillment (%), order fulfillment cycle time (hours), upside supply chain (SC) flexibility (days), upside SC adaptability (%), downside SC adaptability (%), SC management costs (€), cost of goods sold (€), cash-to-cash cycle time (days), return on SC fixed assets (%), return on working capital (%),CO_2-emissions (eqv. tons/year), waste (kg), and existence of CRS programs in the supply chain.

The 10 first listed metrics are based on the 1st level of the SCOR model. They are related to economic performance. Because the aim of this study was to develop the SCOR model more sustainably it builds a framework for the sustainable supply chain performance evaluation model itself.

CO_2 emissions and amount of waste were selected as metrics to describe the ecological performance of the supply chain. Energy resources are vital to power industrial processes in manufacturing and logistics and their use is also a major contributor to carbon emissions (Halldórsson & Svanberg, 2013). Energy use and waste also affect CO_2 emissions, makes measuring CO_2 emissions more relevant. CO_2-emissions were selected because most food supply chain processes use carbon based fuels and the distribution processes are essential from the food supply chain point of view (WRI, 2011). CO_2 equivalent includes also other GHG gas effects such as methane, which is important in food supply chains. Also the market or customers recognize and are looking at the CO_2 emissions. The unit of CO_2 emissions in this study is CO_2 equivalent unit. As was introduced in the theoretical part of this thesis, many food carbon footprint studies notice the use of electricity, heating, water, waste water and waste (for example, Wanhalinna, 2010). CO_2 is also metric in Huang and Keskar's (2007) list of metrics.

Energy efficiency is an essential principle of sustainable development and that is why energy consumption is important and affects at level 1 through the CO_2 effect. It is also an important cost driver in some supply chains. Food waste is a critical element of the supply chain's environmental performance, especially in fresh food supply chains because of the short shelf life and production of climate change gases. Wasted food has a negative environmental effect itself but also damage to food and replacing it also has many negative effects.

The existence of the company social responsibility program represents the metric of social performance of the supply chain. The share of companies having a company social responsibility program was selected to describe the supply chain's sustainable performance from the social performance viewpoint. The CRS program itself does not guarantee social performance but indicates the social interests of the company. The selected metric also fulfills the attributes which Kellen and Wolf's (2003) sets for metrics.

3.4 Model description

The SCOR model was chosen because it is a commonly used and accepted model in supply chain management. However, the SCOR model does not promote sustainability issues. Integrating sustainable development as a part of current and accepted management systems is usually an easier way to develop sustainability of the supply chain than adopting a completely new management system.

That is the main reason why the SCOR model was chosen as the basis of the system. Because the use of the model has strategic aims, the metrics were restricted to those at the strategic level. The selected sustainability metrics illustrate the possibility of the supply chain's environmental and social risks. The assumption is that the possibility of risks correlates the performance in the long term. The sustainability metrics of the model are restricted to the strategic metrics as well.

The developed model consists of two parts, which are SCOR and sustainability metrics. The SCOR-model is divided into different levels. The developed method includes SCOR first level metrics. The metrics are:

- Costs of the goods sold
- Perfect order fulfillment
- Order fulfillment cycle time
- SC adaptability
- SC flexibility
- SC management costs
- Cash-to-cash cycle time
- Return on SC fixed assets
- Return on working capital

The sustainability metrics in the developed model are:

- GHG effect as carbon dioxide equivalent emissions including, for example, the effects of waste, energy, ruminants, and energy
- Share of the companies in the SC with CRM-strategy

These two groups of metrics together formulate the ***supply chain sustainability performance model*** which is the method used in the cases in this study. The formulae and definitions of the models metrics are below.

Costs of the goods sold	*TSCMC = Sales – Profits – Cost to Serve (e.g., marketing, selling, administrative)*
Perfect order fulfillment	*(Perfect Orders) / (Total Number of Orders) x 100%*
Order fulfillment cycle t.	*Order Fulfillment Cycle Time= (Sum Actual Cycle Times for All Orders Delivered) / (Total Number Of Orders Delivered)*

SC adaptability	*Adaptability measures are based on the actual number of returns compared to the maximum number of returns which can be achieved within 30 days. The weakest component determines the overall volume. Note: The calculation of Supply Chain Adaptability requires the calculation to be the least quantity sustainable when considering Source, Make, Deliver and Return components.* *Upside Source Adaptability: The maximum sustainable percentage increase in raw material quantities that can be acquired/received in 30 days.* *Upside Make Adaptability: The maximum sustainable percentage increase in production that can be achieved in 30 days with the assumption of no raw material constraints.* *Upside Deliver Adaptability: The maximum sustainable percentage increase in quantities delivered that can be achieved in 30 days with the assumption of unconstrained finished good availability.* *Upside Source Return Adaptability: The maximum sustainable percentage increase in returns of raw materials to suppliers that can be achieved in 30 days with the assumption of unconstrained finished goods availability.* *Upside Deliver Return Adaptability: The maximum sustainable percentage increase in returns of finished goods from customers that can be achieved in 30 days.*
SC flexibility	*Total elapsed days between the occurrence of the unplanned event and the achievement of sustained plan, source, make, deliver and return performance. Note: Elapsed days are not necessarily the sum of days required for all activities as some may occur simultaneously.*

	Upside Source Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in quantity of raw materials. *Upside Make Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in production with the assumption of no raw material constraints.* *Upside Deliver Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in quantity delivered with the assumption of no other constraints.* *Upside Source Return Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in the return of raw materials to suppliers.* *Upside Deliver Return Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in the return of finished goods from customers.*
SC management costs	*order management costs + material acquisition costs + inventory carrying (Indirect Plan) costs + planning/finance costs + and information technology costs (Indirect Enable) costs*
Cash-to-cash cycle time	*Cash-to-Cash Cycle Time = Inventory Days of Supply + Days Sales Outstanding – Days Payable Outstanding*
Return on SC fixed assets	*Return on Supply Chain Fixed Assets = (Supply Chain Revenue – COGS – Supply Chain Management Costs) / Supply-Chain Fixed Assets*
Return on working capital	*The excess of current assets over current liabilities, representing the funds available for financing business activities*
Carbon dioxide emissions	*Equivalent carbon dioxide emissions of the SC processes = source process emissions + make process*

emissions + deliver process emissions + return process emissions + plan process emissions

Waste in the SC *Amount of waste per product = Amount of waste from the SC processes / product units per year *100*

Share of the companies in the SC with CRM-strategy

Share% of the companies which are involved in the supply chain and have audited CSR strategy.

The GWP tables in Appendix 5 have been used in the CO_2 equivalent calculations. The applied method is AR 4; for example, the lifetime (AR 4) of methane (CH_4) is 25 times, and nitrous oxide (N_2O) 298 times as big as the lifetime effect of carbon dioxide (CO_2), which is 1 year.

3.4.1 Costs of the goods sold

Costs (€ / $ / £ etc.) are the difference between profits and sales. they can be calculated from

(2) $\boldsymbol{C_{SC} = \sum_1^n (S_{p_1} + \cdots + S_{p_1}) - (P_{p_n} + \cdots + P_{p_n})}$, in where

$C_{SC} = total\ supply\ chain\ costs, S_{p_x} = sales\ of\ the\ product\ x, P_{p_x}$= profit of the product x.

Supply chain costs can also be defined as a cumulative sum of the process costs in the following way:

(3) $\boldsymbol{C_{SC} = \sum_1^n (C_{p_1} + \cdots + C_{p_n}),}$ in where

C_{p_x} = costs of process x.

For example, production costs may consist of personnel costs, material costs, energy costs, investments, fixed costs, management costs, etc. The processes can be combined into sets of processes according to the units used in the accounting; for example, one organization may build up an accounting unit and the share of an individual product's costs can be defined as a share of the company's costs if the cost structure among the product variety is similar.

3.4.2 Perfect order fulfillment

Perfect order fulfillment expresses the percentage (%) of orders which have been delivered to the customer at the right time to the right place in the right way and the order meets the expected quality and quantity. The maximum value of the perfect order fulfillment is 100%.

(4) $\boldsymbol{PO_{SC} = \sum_1^n (PO_{c_1} + \cdots + PO_{c_n}) / (O_{c_1} + \cdots + O_{c_n}) * 100}$, in where

PO_{c_x} = Perfect fulfilled orders for customer x, and O_{c_x}, total number of orders of customer x.

3.4.3 Order fullfillment cycle time

Mean order fulfillment cycle time (usually days) of the one delivery is the sum of cycle times of all ordered deliveries divided by the total number of deliveries. It can be calculated in the following way:

(5) $\boldsymbol{ct_{SC} = \sum_1^n (ct_{o_1} + \cdots + ct_{o_n}) / n}$, where

$ct_{SC} = order\ fullfillment\ cycle\ time$, ct_{o_x} = *cycle time of the order x, n= number of deliveries in the selected time*

3.4.4 SC adaptibility

Adaptability measures are based on the actual number of returns compared to the maximum number of returns which can be achieved within 30 days. The weakest component determines the overall volume. The calculation of supply chain adaptability requires the calculation to be the least quantity sustainable when considering source, make, deliver and return components.

Upside Source Adaptability describes the maximum sustainable percentage (%) increase in raw material quantities that can be acquired or received in 30 days. Upside Make Adaptability is the maximum sustainable percentage increase in production that can be achieved in 30 days with the assumption of no raw material constraints. Upside Deliver Adaptability means the maximum sustainable percentage increase in quantities delivered that can be achieved in 30 days with the assumption of unconstrained finished good availability.

Upside Source Return Adaptability is the maximum sustainable percentage increase in returns of raw materials to suppliers that can be achieved in 30 days with the assumption of unconstrained availability of finished goods. Upside

Deliver Return Adaptability is the maximum sustainable percentage increase in returns of finished goods from customers that can be achieved in 30 days.

3.4.5 SC flexibility

Supply chain flexibility is the total of elapsed days between the occurrence of the unplanned event and the achievement of sustained plan, source, make, deliver and return performance. The elapsed days are not necessarily the sum of days required for all activities as some may occur simultaneously.

Upside Source Flexibility means the number of days required to achieve an unplanned sustainable 20% increase in the quantity of raw materials. Upside Make Flexibility means the number of days required to achieve an unplanned sustainable 20% increase in production with the assumption of no raw material constraints. Upside Deliver Flexibility describes the number of days required to achieve an unplanned sustainable 20% increase in quantity delivered with the assumption of no other constraints.

Upside Source Return Flexibility means the number of days required to achieve an unplanned sustainable 20% increase in the return of raw materials to suppliers and Upside Deliver Return Flexibility means the number of days required to achieve an unplanned sustainable 20% increase in the return of finished goods from customers.

3.4.6 SC management costs

SC management costs (€/year) are costs related to the supply chain management. SC management costs include order management costs, material acquisition costs, inventory carrying (Indirect Plan) costs, planning/finance costs, and information technology (Indirect Enable) costs.

(6) $\boldsymbol{MC_{SC} = \sum_i^n (MC_{p_1} + \cdots + MC_{p_n})}$, in where

MC_{p_x} = Management cost of process x where:

(7) $\boldsymbol{MC_{p_x} = (C_{o_x} + C_{m_x} + C_{i_x} + C_{f_x} + C_{it_x})}$, in where

$C_{o_x} =$ order management costs $C_{m_x} =$ material acquisition costs, $C_{i_x} =$ inventory carrying costs, $C_{f_x} =$ planning and finance cost, $C_{it_x} =$ information technology costs.

3.4.7 Cash-to-cash cycle time

Cash to Cash Cycle Time is calculated as days (d). It is calculated as follows:

(8) $$\boldsymbol{t_{CtoC} = t_i + t_{so} - t_{po}}$$, where

t_{CtoC}= cash to cash cycle time, t_i = inventory days of supply, t_{so}= days sales outstanding, t_{po} = days payable outstanding.

3.4.8 Return on SC fixed assets

Return on Supply Chain Fixed Assets = (Supply Chain Revenue – COGS – Supply Chain Management Costs) / Supply-Chain Fixed Assets

(9) $$ROA_{SC} = (R_{sc} + COGS_{sc} - MC_{sc}) \ / \ FA_{sc}$$, where

ROA_{SC} = return on Supply Chain Fixed Assets, R_{sc} = Supply Chain Revenue, COGS= costs of the goods sold, MC_{sc} = Supply Chain Management Costs, FA_{sc} = Supply-Chain Fixed Assets

3.4.9 Return on working capital

Return on working capital expresses the excess of current assets over current liabilities, representing the funds available for financing business activities.

3.4.10 Carbon dioxide emissions

In this study supply chain CO_2 emissions mean the carbon dioxide equivalent greenhouse gas emissions of the food SC processes. In this model food supply chain CO_2 emission equivalents are calculated from methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions. The same limitation is used in several GHG research items and they are defined as the main outputs of the processes involved in the chain.

The food supply chain's emission source recognition process includes evaluation of typical emission sources in different parts of the supply chain. The emissions source checklist of this model is a conclusion of the IPCC (2006) guidelines and other research introduced in the literature review.

The emission sources of the food supply chain noticed in this model are:

- ruminants′ digestion (CH_4)
- use of fertilizers (N_2O)

- fodder production (N_2O)
- emissions from the transportation (CO_2)
- energy used in the SC processes (cooling, production, warehousing, etc.) (CO_2)
- waste (CH_4) and waste water

CO_2 equivalent emissions in the model are calculated as follows:

(10) $\boldsymbol{e_{sc} = e_s + e_m + e_d + e_r + e_p}$, in where

e_{sc} = *supply chain annual emissions as* CO2 equivalents, e_s = source process CO_2 eqv. emissions, e_m make process CO_2 eqv. emissions, e_d = deliver process CO_2 eqv. emissions, e_r return process CO_2 eqv. emissions, e_p = plan process CO_2 eqv. emissions

In this research the unit of emissions is carbon dioxide equivalent unit (CO_2 eqv.). It describes the global warming effect of greenhouse gas emissions of the supply chain processes. The equivalents are calculated by using the above formula. The used values base on the AR 4, for example lifetime (AR 4) of methane (CH_4) is 25 times, and nitrous oxide (N_2O) 298 times as big as the lifetime effect of carbon dioxide (CO_2), which is 1 year.

The CO_2 eqv. emission of any of the source, plan, make, deliver or return process is:

(11) $\boldsymbol{e_x = e_e + e_i + e_u + e_a + e_l + e_w}$, where

e_x= CO_2 eqv. emissions of the process x, x = source, make, deliver, plan or return process, e_e= emissions from the energy use, e_i= emissions from the industrial processes, e_u =emissions from the solvent and product use, e_a =emissions from the agriculture, e_l =emissions from the land use change and forestry, e_w = emissions from the waste.

Further, where the emissions (CO_2 eqv.units) of the energy used in the process x are

(12) $\boldsymbol{e_{e_x} = \sum_1^n E_1 e_{E_1} + \cdots + E_n e_{E_n}}$, in where

E = energy (kWh)used in the process x , e_E = emissions of the used type of energy in the process (CO_2 eqv./ kWh), in where:

(13) $\boldsymbol{E_x = P_x t_x d_x}$, in where

P_x = power of the machine x (W) in the process x's subprocess m, t_1 = daily time of the use of machine (h) x in the process x's subprocess , d= annual using days of the process x (pcs.).

Emissions from the industrial processes of the used energy in the process is

(14) $\boldsymbol{e_i = \sum_1^m i_1 e_{i_1} + \cdots + i_m e_{i_m}}$, where

i_x = amount of the industrial subprocesses of the process x with GHG effects, e_i= effect of industrial process (co_2 eqv / year).

Emissions from the solvent and product use of the process x

(15) $\boldsymbol{e_u = \sum_1^n u_1 e_{u_1} + \cdots + u_n e_{u_n}}$, where

u_x = solvent and product x used in process (kg), e_{u_x}= CO_2 eqv. effect of used solvent or product x in the process (co_2 eqv / kg).

Emissions from agriculture from process x

(16) $\boldsymbol{e_a = \sum_1^n a_1 e_{a_1} + \cdots + a_n e_{a_n}}$, in where

a_x = agricultural process x, e_{a_x}= CO_2 eqv. effect of the agricultural process x.

Emissions from land use change and forestry of process x

(17) $\boldsymbol{e_{l_x} = l_x e_{l_x}}$, where

l_x = land use (ha) of the process, e_{l_x}= CO_2 eqv. effect of used land (co_2 eqv / ha).

Emissions (annual) from the waste of process x are

(18) $\boldsymbol{e_{w_x} = \sum_1^n W_{p1} e_{p1} + \cdots + W_{pn} e_{pn}}$, in where

$W_{px} = waste\ from\ process\ x\ \left(\frac{kg}{year}\right)$, *$e_{px}$ =emissions (kg co_2 eqv/kg) of the waste of the process x.*

In the waste emission calculation data from the Martti Material Flow Accounting system has been used. It is a database maintained by the Helsinki Region Environmental Services Authority.

The emissions (*e*) as CO_2 equivalent units of each process and subprocess are calculated as a cumulative sum of individual greenhouse gas emissions:

(19) $\boldsymbol{e_x = m_{x_{CO_2}} + 25 m_{x_{CH_4}} + 298 m_{x_{N_2O}}}$, where

m_{CO_2}= mass (g) of the carbon dioxide emissions of the process x, m_{CH_4} = mass (g) of the methane emissions of the process x, and m_{N_2O} = mass of the nitrous oxide emissions of the process x.

3.4.11 Waste

The amount of waste in the supply chain is expressed as %. It can be calculated in the following way:

(20) $$W\%_{\boldsymbol{SC}} = \frac{W_{SC}}{m_{SC}}\,100, \text{ where}$$

$W\%_{SC} =$
$share\ (\%) of\ the\ waste\ compared\ to\ the\ product\ amount\ of\ the\ products\ in\ the\ supply\ chain\ , W_{SC} =$
$amount\ of\ the\ waste\ (kg) in\ the\ supply\ chain, m_{SC} =$
$mass\ (kg) of\ the\ products\ of\ the\ supply\ chain.$

(21) $$W_{SC} = \sum_1^n W_{p1}s_{p1} + \cdots + W_{pn}s_{pn}\ , \text{ in where}$$

$W_{px} = waste\ from\ process\ x\ \left(\frac{kg}{year}\right), s_{px}$
$= share\ (\%) of\ the\ waste\ caused\ annual\ waste\ in\ \ the\ process\ x\ by\ the\ product\ x$

3.4.12 Energy used in the SC

The unit of energy used in the supply chain is kWh. First there is a need to identify all the energy sources of the supply chain process, number the machines m1, m2, etc.. Then it is necessary to ascertain the energy consumption of each machine, find out the operating time of each machine, the annual number of days using the machines, and the share of energy consumption of the product under research.

(22) $$\boldsymbol{E_{SC} = \sum_1^n E_{p_1} + \cdots + E_{p_n}}, \text{ where}$$

$E_{SC} = energy\ used\ annual\ in\ the\ supply\ chain\ (kWh), E_{p_x} =$
$annual\ energy\ used\ in\ the\ process\ x$

The energy use of every process (E_{p_x}) can be calculated as follows:

(23) $$\boldsymbol{E_{p_x} = \sum_1^n P_1 t_1 t_1 + \cdots + P_n t_n d_n}, \text{ where}$$

$E_{p_x} = Annual\ energy\ (kWh)\ used\ in\ the\ process\ x, P_x =$
$power\ of\ the\ machine\ \ x\ (W)\ in\ process\ x's\ subprocess, t_1 =,$
$daily\ time\ of\ the\ use\ of\ machine\ (h)\ x\ in\ the\ process\ x'ssubprocess,$ *d= annual using days of the process x (pcs.).*

3.4.13 Share of companies in the SC with CRM-strategy

The share of companies which are involved in the supply chain and have audited CSR strategy is expressed with %. It can be calculated as follows:

(24) $\boldsymbol{CSR_{SC} = \frac{C_{CSR}}{C}\ 100}$, in where

CSR_{SC}= share (%) of companies in the supply chain which have CSR strategy, C=number of companies in the supply chain

4 Case studies and validation

This chapter describes the case studies and main results of them. The developed model for supply chain sustainable performance evaluation has been used in the case studies. The sustainable performance of each case study is modelled and calculations done in MS Excel. The views from each case's Excel-tables are purposed to illustrate the use of the model and are named as "Figures". The other tables which do not include cases' Excel-tools are named as "Tables".

The model validation presents a weak market test (more about research approach later in the chapter) from the model construction viewpoint. The market test means implementation of the model in the case supply chains.

4.1 Introduction of the cases

The model was validated with three case supply chains. The case supply chains are food supply chains: One is a multi-product supply chain and the other ones operate with very fresh products, but there are fewer items to manage in the supply chain. The companies operate mainly in their domestic markets. The cases represent different levels of management and supply chain levels, which are, according to Baily et al. (1998), strategic, tactical and operational levels.

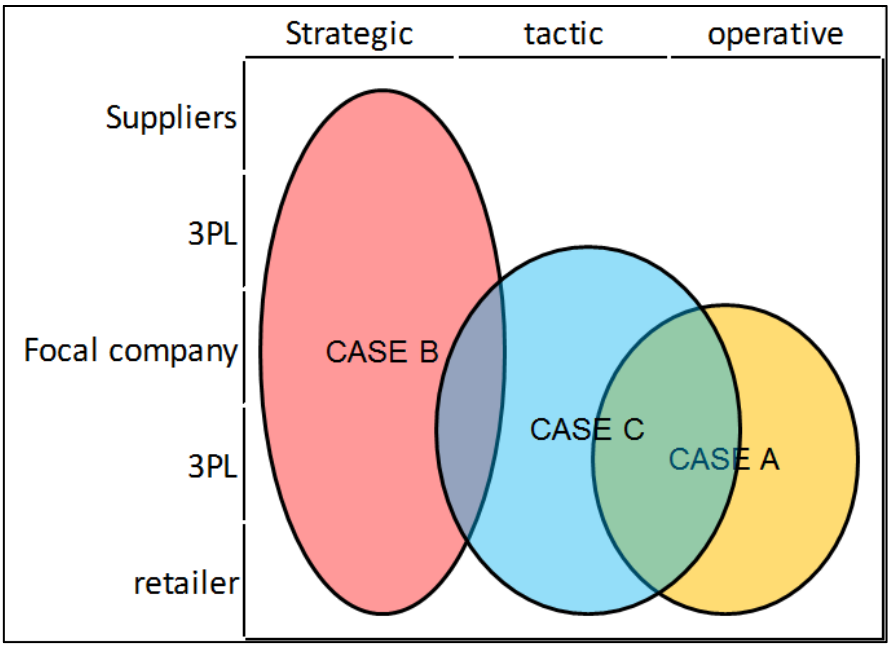


Figure 27. Focus of the cases on the management and supply chain level tactical and operational in the above figure

The strategic level includes location decisions, which concerns case B, and the tactical level includes, for example, capacity optimization problems and operational level route optimization problems (Figure 27).

The descriptions of the case studies include the background of the problem in the case study, definition of the research problem, objective of the case study research, process description of the case study, the method used (sustainable supply chain performance model) and results of the case study. Table 10 introduces the cases. The companies have different strategic goals and they wanted to use different metrics.

Table 10. Introduction of the cases

	case A	case B	case C
Description	delivery box system desicion	plant location desicion	delivery cycle desicion
Desicion to make	disposable or recyclable delivery boxes	one or two production plants	24 delivery cycle or 48 delivery cycle
Desicion level	tactic	strategic	strategic
Product	many types of food products, self-life 14-21 days, cool storing	fresh food, self-life 7 days, cool storing	fresh food, self-life 7 days, cool storing
Methods	SFSCM	SFSCM	SFSCM + half-structured phone interview
Product strategy	high quality food	fresh food with quick deliveries	fresh food with quick deliveries
Processes under research	make, deliver, return	source, make, deliver, return, plan	make, deliver, return
Main outputs	co_2, water usage, waste	costs, co_2, delivery time	delivery time, waste, $co_{2,}$ cost

The main focus of the each case is to find out how supply chain decisions affect the supply chain sustainable performance, but each case has more focused goals.

The focus of the model is sustainability, but in the cases the main attention is paid finally to cost and carbon.

4.1.1 Use of the model in strategic decisions

The developed model is a tool for supply chain strategic management. The model is used in the strategic decision making process. This section describes shortly the strategic decision making process with the model, and the case study descriptions later give real life case examples of the applications of use of the model.

(1) The problem definition is the first step when using the model. This includes answering the questions *"what is the planned strategic change of the supply chain and why it should or should not proceed?"*

(2) The second step is to define the scenarios and main processes and the structures of them. The sustainable performance of each sub-process will be estimated from the social, economic and ecological viewpoint.

(3) The third step is identification of processes which would be subject to change.

(4) The fourth step is to estimate how strategic change in the supply chain would impact on the identified processes (in the third step) and sub-processes of each defined supply chain scenario.

Identification of the key processes is done after that. Each sub process is estimated as significant or not significant from every sustainable performance attribute´s (such as energy consumption) viewpoint as well as IPCC (2000) guides to recognize the significant categories which influence a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals in national inventory calculations. Significant meant in this study that the estimated sub-process belongs to among those sub-processes which cause (over) 80% cumulative effect of the attributes in the supply chain level. The significance classification of the performance attributes also causes limitations for use of the study but also gives a more practical tool for companies making strategic decisions.

(5) The fifth step is mark the processes which differ from others and to calculate the values for each selected metric according to the model.

(6) After calculating, the supply chains' sustainable performances are compared and decisions are made. The use of the analytic hierarchy

> process (AHP) method could be useful in comparison and value discussion.

AHP is also used for example in Dey and Walid's (2013) green supply chain performance measurement framework. The model makes it also possible to choose those attributes and the metrics describing them.

4.1.2 Data sources

The emission data for the case studies were collected from IPCC's (2006) regional and sectorial emission factor tables and guidelines, the Helsinki Region Environmental Services Authority's Martti Material Flow Accounting database and Technical Research Centre of Finland's VTT. IPCC's (2006) GWP tables were applied when emissions were converted to CO_2 equivalents.

The emissions and energy consumption of all domestic traffic modes base on the database Lipasto (VTT, 2011). Emission data was also collected from vehicle, material and energy suppliers. Some input information based on the assumptions was analysed with Oracle Crystal Ball.

Sensitivity analysis was made for the models with the purpose of estimating the uncertainty of the models' results. It aims to explain the role of changes of the input values against the output values. Sensitivity analysis can be, for example, partial sensitivity analysis, best-and worst case analysis, or Monte Carlo analysis.

Oracle Crystal Ball is a Microsoft Excel based add-in tool for Monte Carlo analysis. Monte Carlo sensitivity analysis is based on Monte Carlo analysis. The parameters are picked from statistical distributions which are set to the parameters of the model. The result of the model is calculated from the stochastically picked values. The analysis is driven many times when the result for the model (output) is a distribution. Monte Carlo sensitivity analysis is applied in this study.

4.1.3 Limitations of the model

Any model is an attempt to picture reality. The accuracy compared to reality of the model developed in this study is a conclusion of the accuracy of the selected processes of the supply chain and selected metrics to describe the performance attributes. The developed model is meant for strategic decision making, but the calculations can be taken to the part of strategic management system.

Ecological performance, as described earlier in this study, can be measured in several ways. This developed model includes the following climate changes measures: CH_4, N_2O and CO_2 converted into CO_2 equivalents. In this study public databases of emissions were used. The uncertainty of the input values will be later estimated with Crystal Ball calculations.

The results of the model are not necessarily comparable to the results with other methods, but the model gives the possibility to compare and develop supply chains and compare the current performance with the earlier one and set the future targets. Similar strategic decisions may lead to different results if the input values are different. Emissions from waste-to-energy, where waste material is used directly as fuel or converted into a fuel are recognized in the CO_2 effect of the used energy type.

The case study descriptions illustrate the way to use the sustainable food supply chain performance model as a tool in practical problem solving situations. The results, screenshots and inputs are examples. The case studies are based on real companies' strategic decisions and there are non-disclosure agreements between the researcher and the case companies.

Figure 28 describes the direction problem of the transportation. If a vehicle delivers company A's deliveries to A's customers and then has a return trip with B's products, how should the emissions, or also costs be allocated.

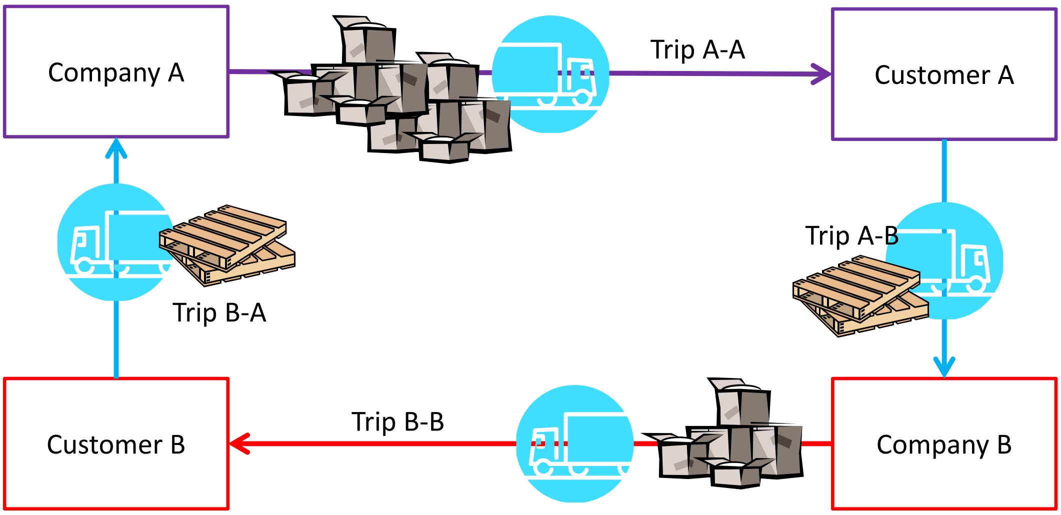


Figure 28. Direction problem in transportations

In this research the whole route is calculated (A-A, A-B, B-B and B-A) and emissions are directed to the products in the relation of ton kilometers (The product relations of companies A and B is A:B 2:1). Other solutions are discussed in the conclusion chapter.

4.2 Case A: Transportation crate system comparison

The case study describes the qualitative and quantitative strategic changes which the case food supply chain meets if disposable transportation boxes are replaced with recyclable transportation crates. This case study is an example of the use of the sustainable supply chain performance evaluation model. It introduces a case study which illustrates the way to include environmental and social issues as a part of strategic supply chain decision making.

The case company is a medium sized Finnish food production marketing, and logistic company. It has several production plants and they pack their products themselves, move productions to their terminal and transport products to the customers' terminals where the products are sorted and repacked and warehoused until they are at the markets. The company operates mainly in the domestic market. The product variety of the company is relatively wide and the company has several production plants and terminal and transportation equipment.

The data were collected from *source, make, plan, deliver and return* processes. The case study is limited to the supply chain processes from crate production to box recycling/destruction processes. The data was collected from interviews with crate suppliers, management group, documents, ERP systems, personnel interviews, expert discussion panel, general databases (e.g. emissions per vehicle type), and accounting systems. In the case of uncertainty input information is replaced by estimation. Some input data is expressed as a distribution by the Oracle Crystal Ball.

The data was collected with the help of a structured interview sheet (Appendix 4). The method in this case study was the sustainable supply chain performance-model, which is described earlier in this research, but the management wanted to focus emissions and costs.

The collected data in both scenarios included e.g. crate production, shelf-life and destruction information and also information on dimensions, volume, capacity and palletizing. Information was collected from the production, packing, crate labeling, crate sourcing, plan and management.

The collected information also included distances and transportation capacity and shares and route information in the supply chain between crate supplier, factory, warehouse, terminal, market, washing department, crate destruction, and crate storage. The data was inserted into an MS Excel-based data sheet. Many input values included uncertainty. This was taken into account with a Monte Carlo based Oracle Crystal Ball MS Excel add-in tool. The Crystal Ball allows setting distributions values and the application runs a simulation and produces a distribution graph as a result.

4.2.1 Process description

The focal company makes an order for the production of several products in several production plants. Each production plant packs the products into consumer packages and then packs the consumer packages into transportation boxes, and then sends them to the focal company's terminal twice per each production day (Figure 29). The production companies pack the products into consumer packages (Figure 30) and the consumer packages into disposable transportation cratees (Figure 31), and the transportation cratees are put onto pallets which are moved to the focal company's terminal.

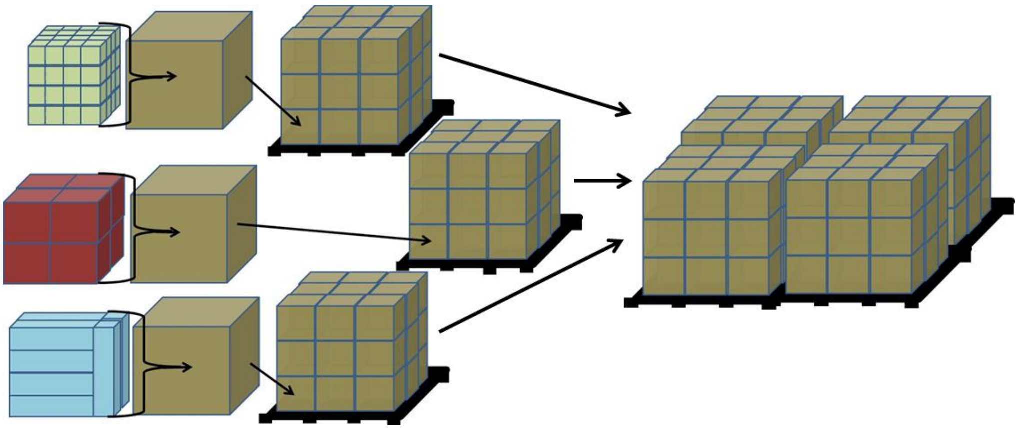


Figure 29. Production companies deliver the pallets to the focal company's terminal

The products are unpacked, sorted and repacked in the focal company's terminal according to the customer order. The products are packed into disposable transportation cratees by the customers' terminal order.

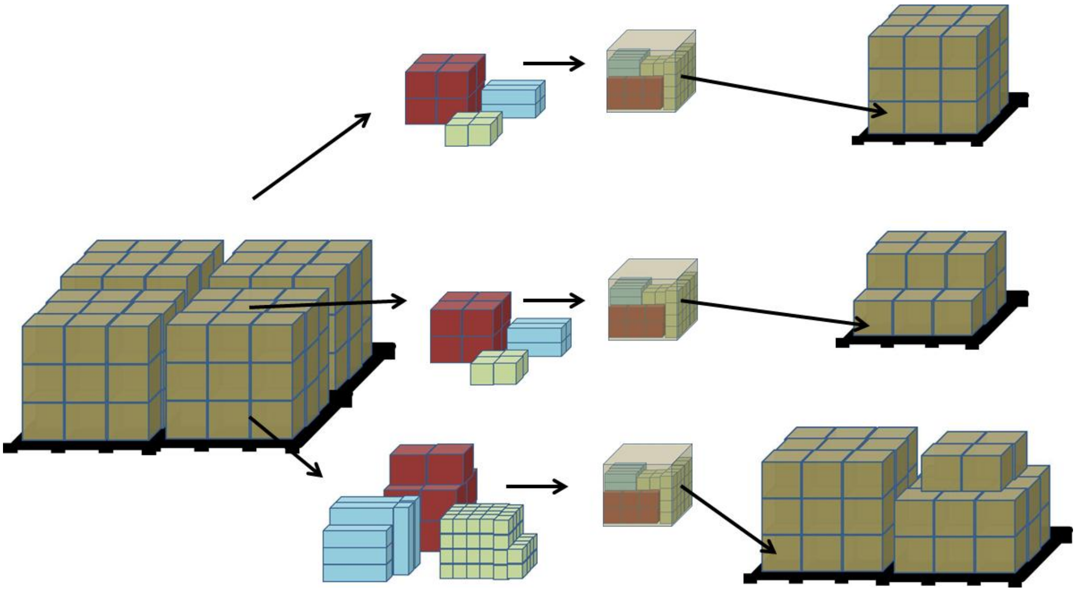


Figure 30. Order picking process in the focal company's terminal

In the terminal the products will be unpacked from the transportation crates and sorted according to the customer orders in the company's terminal. The orders of the same customer (order lines in the same order) and same kind of product (same department in the food store) will be put into the same crate. The crates of the same customer will be stacked and put onto the pallet. Orders which have the same destination terminal will be stacked on the same pallet.

The focal company transports the pallets to the customers' terminal, where the pallets are unloaded and sorted according to the customers (food retailers). Food retailers or 3PL companies transport the orders in disposable crates with the pallets and orders with plastic crates without pallets to the food retailers (Figure 31). The food retailers unload the boxes or pallets and set out the products onto the display shelves.

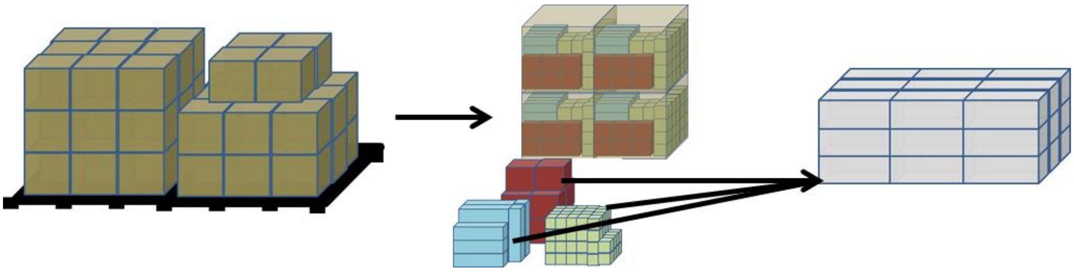


Figure 31. Customers' terminal sorting and order picking process

The production companies and the focal company order the disposable crates and the food retailer transports them to the recycling plants to be burned. The focal company considered replacing the disposable transportation crates with recyclable ones and the following section describes the process and results of the evaluation.

4.2.2 Differences between the scenarios

Change to the transportation crate system has changed many operations in the supply chain (Figures 32 and 33). Disposable transportation (DB) crates are destroyed or recycled from markets but recyclable crate (RB) washing and returning is a new process in the alternative recyclable crate supply chain. Probably there is a need for new dirty and clean crate transportation routes, but at the same time some recycling flow will decrease. The washing process, not only transportation from markets to factory via the washing department, will need water and energy and also personnel hours.

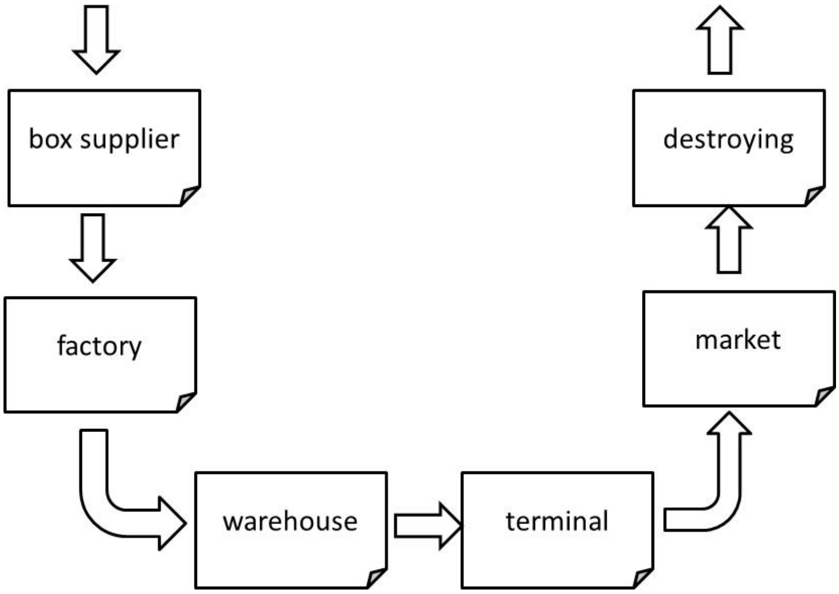


Figure 32. Disposable transportation (DB) crate route

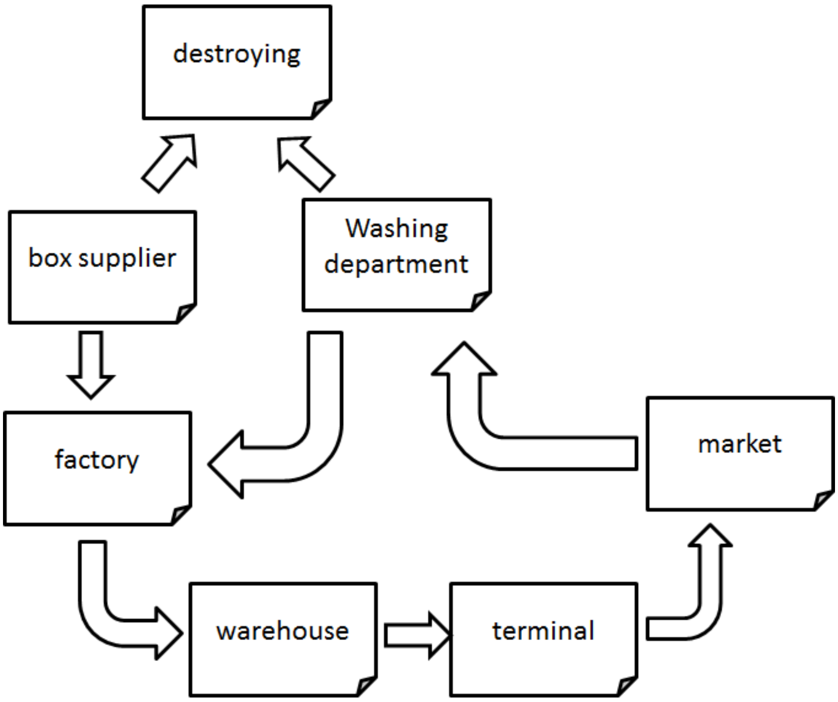


Figure 33. Recyclable transportation crate (RB) route

The number of crates needed and crate warehousing space and conditions are different in the case of RB. The RB system needs new investment, but also improves traceability and delivery reliability in customer order collection and identification, the crate preparing process, packing, unpacking and sorting operations. The systems also cause different effects in the production and destruction stages even if the crates do not have the same capacity measured with number of case products. RBs need more space in the vehicle but it is possible to make higher piles with recyclable crates in the case study than with disposable crates. RB and DB systems have some differences in their ability to protect product quality. RB protects products better from shocks and getting lost but the DB system keeps the temperature more stable.

4.2.3 Formulae and results

Costs and emissions were selected as key outputs from the sustainable supply chain performance evaluation model. The aim was to compare the disposable crate-system (DB) with the recyclable crate-system (RB). The calculations had to be made twice; first with the disposable crate (DB) and then recyclable crate scenario. At first basic information about the supply chain processes and crate systems was collected.

The case study was modeled and the calculations made with the Excel based tool. The basis of the tool is the sustainable supply chain performance evaluation model. A print screen of the tool is in Appendix 5. The idea is to compare recyclable and disposable transportation crate systems and recognize differences in the processes.

The main outputs of the case are cost effect (€/year) and co_2 equivalent emissions g/year. The total cost effect is the sum of the cells which have been written with red font. The emissions consist of the values which have been written with green color. All input cells have the yellow background color.

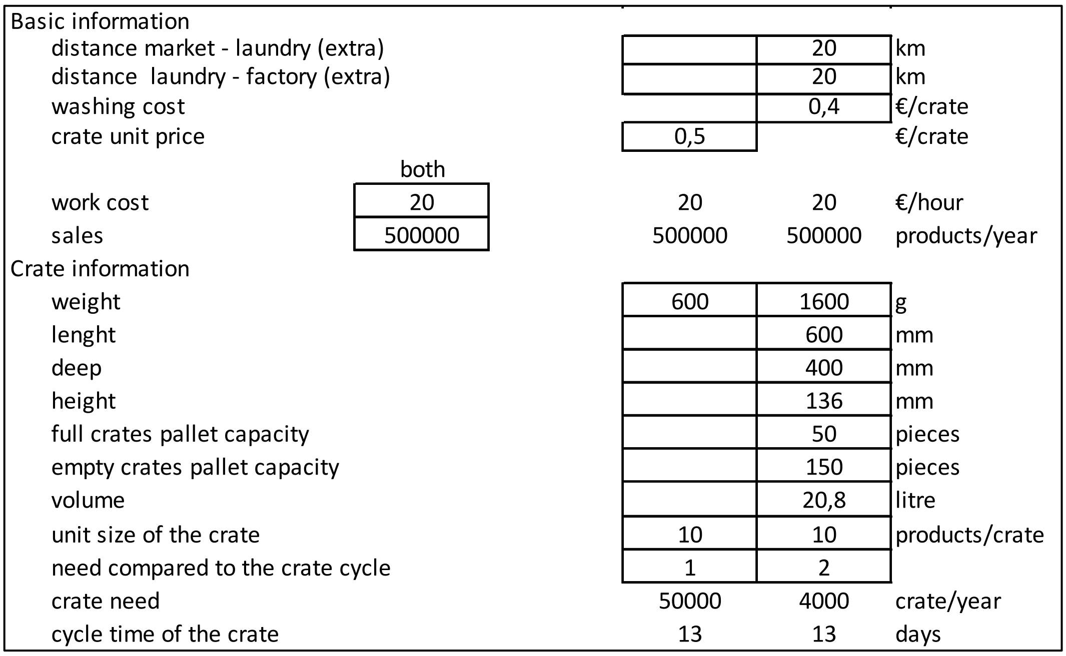
The costs consist of source, make, plan, deliver and return process costs of the crates, so that

(25) $\boldsymbol{C_B = C_s + C_p + C_h + C_d + C_r + C_m}$, in where

C_B= Crate related costs (€/year), C_s= sourcing costs of the crates (€/year), C_p= crate preparation costs (€/year), C_h= Crate (€/year), C_d= crate depend delivery costs (€/year), C_r= recycling costs of the crates (€/year), C_m= it systems / management costs related to the crate system (€/year).

There are some general inputs which are used in several parts of the calculations. The basic input information includes:

C_B= cost of working hour (€/h), s = sales of the product (units / year), n = crate need compared to the crate cycle (times compared to the crates which are in the use), D_{ml} = (cumulative) distance from market to the laundry (km), D_{lp} = (cumulative) distance from laundry to the production plant (km), p_x = purchase price of the crate x (€/crate), c_w = washing cost of the crate (€/crate), s_f = sales factor (%), w_p = weight of the product (g), h_p = height of the product (mm), l_p = length of the product (mm), d_b = deep of the product (mm), u_b = unit size of the crate (products/ crate b), p_f = full crates pallet capacity (crates/pallet), p_f = empty crates pallet capacity (crates/pallet), and v= volume of the crate (dm^3/crate).



Basic information				
distance market - laundry (extra)			20	km
distance laundry - factory (extra)			20	km
washing cost			0,4	€/crate
crate unit price		0,5		€/crate
	both			
work cost	20	20	20	€/hour
sales	500000	500000	500000	products/year
Crate information				
weight		600	1600	g
lenght			600	mm
deep			400	mm
height			136	mm
full crates pallet capacity			50	pieces
empty crates pallet capacity			150	pieces
volume			20,8	litre
unit size of the crate		10	10	products/crate
need compared to the crate cycle		1	2	
crate need		50000	4000	crate/year
cycle time of the crate		13	13	days

Figure 34. Basic information sheet

Information on the crate system related factory operations is collected in Figure 34. Factory costs consist of the crate preparation (assembling disposable crates to the right shape), crate labeling (recyclable crates have fixed codes), system management, warehousing system costs, management costs, investment costs and crate costs. The emission effect consists of the delivery frequency and distance, order size, and delivery unit emissions.

(26) $\boldsymbol{C_f = C_p + C_l + C_m + C_b}$, where

(27) $\boldsymbol{C_p = C_w(n\ /s_a/60)}$, where

C_w = *working costs* $\left(\frac{€}{hour}\right)$, n = *number of boxes*, s_a *=assembly speed (crates/min),*

(28) $\boldsymbol{C_l = \left(l_m + \frac{l_w C_w}{60}\right) n}$, in where

l_m *= labeling material cost (€/crate),* l_w*= labeling work (min/crate)*

C_m*= system management cost (€/year).*

(29) $\boldsymbol{C_b = n_{pb}\ C_{pb} + n_{rb}\ C_{rb} + C_f}$, in where,

C_b*= crate cost (€/year),* n_{pb} *=number of bought crates (crates/year),* C_{pb}*= cost of bought crate (€/crate),*n_{rb} *=number of rent crates (crates/year),* C_{rb} *= cost of rent crate (€/crate), and* C_f*=fixed or time based cost of crate system (€/year).*

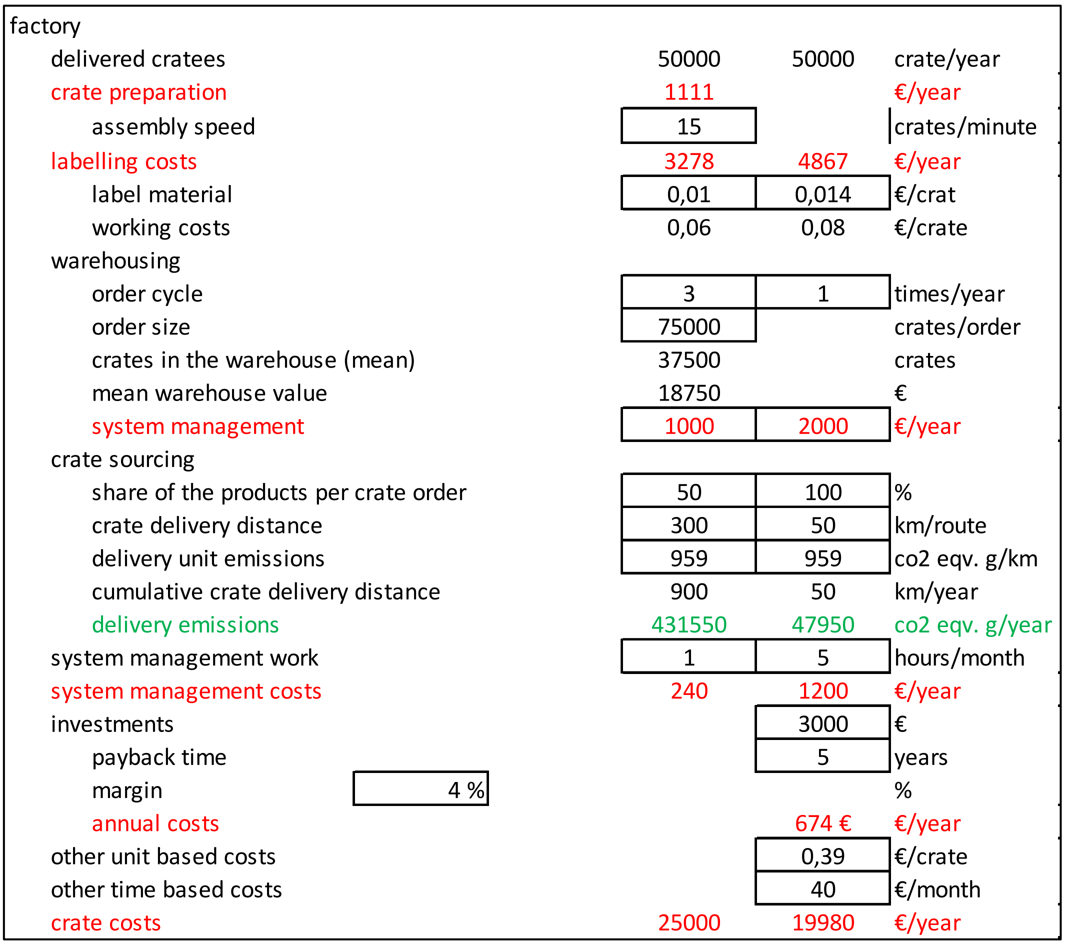
Emissions consist of the crate deliveries from supplier to the factory so that CO_2 equivalent emissions are:

$$e_f = ds/100 * e_u, \text{ where} \tag{30}$$

d= driven distance (km/year), s= share of the products in the load (%),e_u *= unit emissions (*CO_2 *eqv.g/km), where*

$$d = d_b o \text{ where} \tag{31}$$

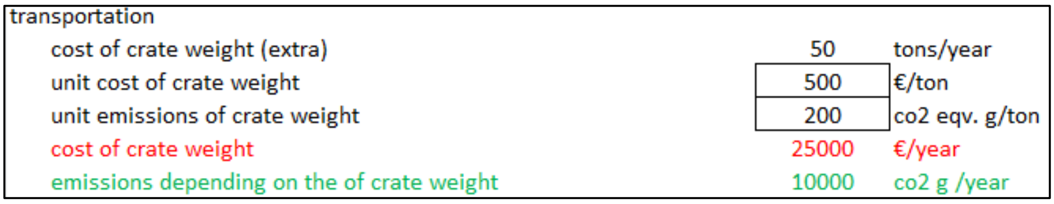
d_b *= driven distance of the one delivery(km), order cycle (times/year) driven distance (km/year).*



factory				
delivered cratees		50000	50000	crate/year
crate preparation		1111		€/year
assembly speed		15		crates/minute
labelling costs		3278	4867	€/year
label material		0,01	0,014	€/crat
working costs		0,06	0,08	€/crate
warehousing				
order cycle		3	1	times/year
order size		75000		crates/order
crates in the warehouse (mean)		37500		crates
mean warehouse value		18750		€
system management		1000	2000	€/year
crate sourcing				
share of the products per crate order		50	100	%
crate delivery distance		300	50	km/route
delivery unit emissions		959	959	co2 eqv. g/km
cumulative crate delivery distance		900	50	km/year
delivery emissions		431550	47950	co2 eqv. g/year
system management work		1	5	hours/month
system management costs		240	1200	€/year
investments			3000	€
payback time			5	years
margin	4 %			%
annual costs			674 €	€/year
other unit based costs			0,39	€/crate
other time based costs			40	€/month
crate costs		25000	19980	€/year

Figure 35. Factory information sheet (DB left / RC right)

The crate weights differ in each system. This causes some changes to the costs and emissions. Annual change has been calculated and then multiplied with unit cost or emission factor (Figure 35).

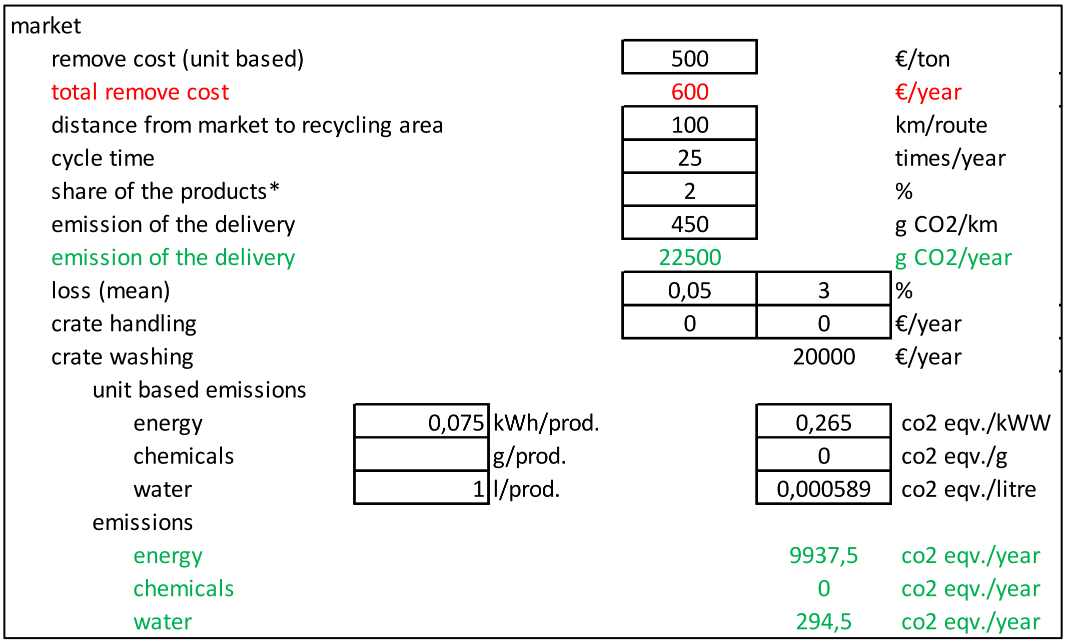


transportation		
cost of crate weight (extra)	50	tons/year
unit cost of crate weight	500	€/ton
unit emissions of crate weight	200	co2 eqv. g/ton
cost of crate weight	25000	€/year
emissions depending on the of crate weight	10000	co2 g /year

Figure 36. Extra weight transportation information sheet

There are also differences in market operations between the crate systems (Figure 36). The crates have to be removed, folded, and moved to the recycling points. The recycled crates have to be transported to the recycling center.

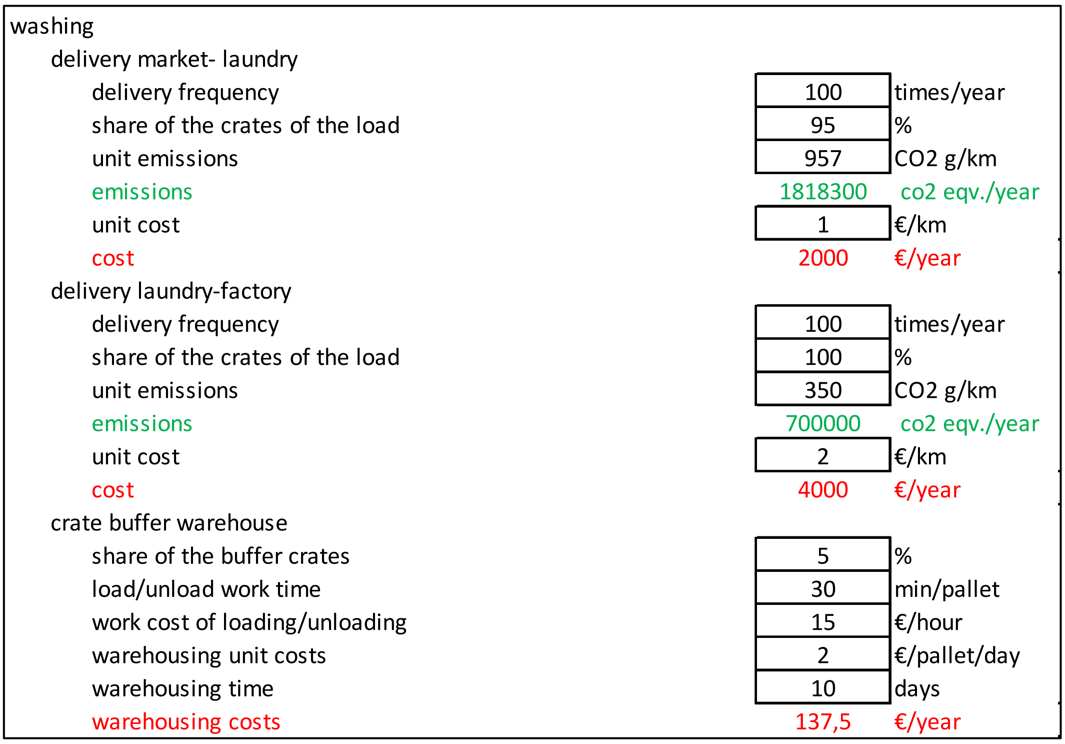
The cost effect consists of the work and transportation. The emissions consist of the recycling cycle, recycling point distance and the effects are directed to the products under research by using coefficient value.



market					
remove cost (unit based)			500		€/ton
total remove cost			600		€/year
distance from market to recycling area			100		km/route
cycle time			25		times/year
share of the products*			2		%
emission of the delivery			450		g CO2/km
emission of the delivery			22500		g CO2/year
loss (mean)			0,05	3	%
crate handling			0	0	€/year
crate washing				20000	€/year
unit based emissions					
energy	0,075	kWh/prod.		0,265	co2 eqv./kWW
chemicals		g/prod.		0	co2 eqv./g
water	1	l/prod.		0,000589	co2 eqv./litre
emissions					
energy				9937,5	co2 eqv./year
chemicals				0	co2 eqv./year
water				294,5	co2 eqv./year

Figure 37. The market information sheet

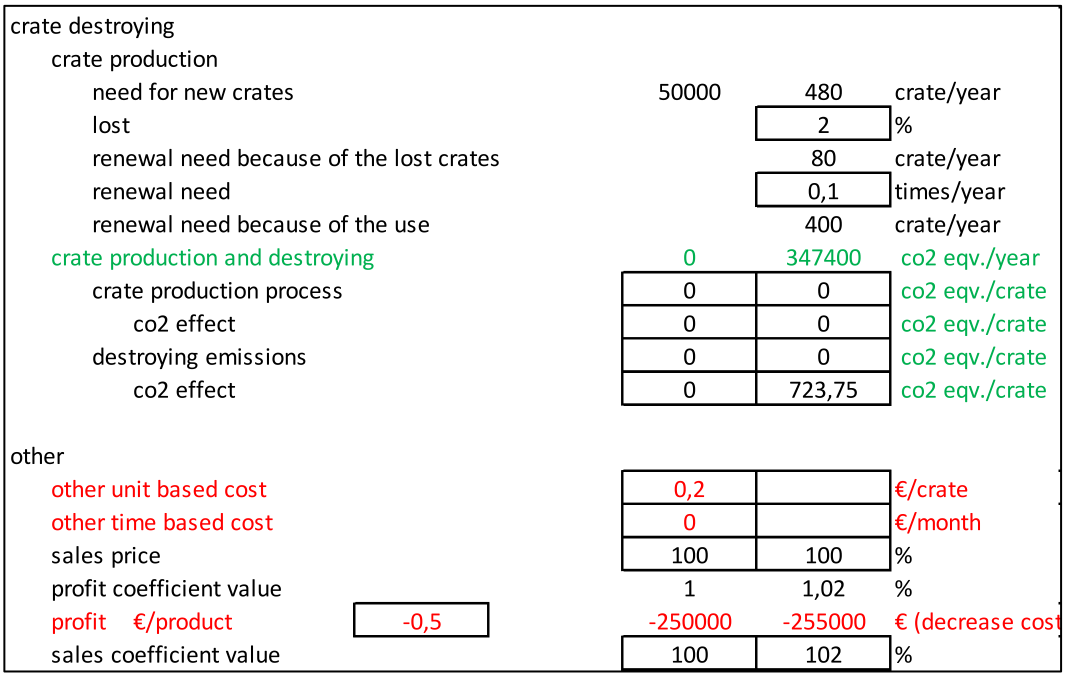
The recyclable crates have to be washed. In the case study the crates have to be transported to the crate laundry, which produces differences compared to disposable crates (Figure 37).



washing		
delivery market- laundry		
delivery frequency	100	times/year
share of the crates of the load	95	%
unit emissions	957	CO2 g/km
emissions	1818300	co2 eqv./year
unit cost	1	€/km
cost	2000	€/year
delivery laundry-factory		
delivery frequency	100	times/year
share of the crates of the load	100	%
unit emissions	350	CO2 g/km
emissions	700000	co2 eqv./year
unit cost	2	€/km
cost	4000	€/year
crate buffer warehouse		
share of the buffer crates	5	%
load/unload work time	30	min/pallet
work cost of loading/unloading	15	€/hour
warehousing unit costs	2	€/pallet/day
warehousing time	10	days
warehousing costs	137,5	€/year

Figure 38. Crate washing operation related information sheet

There is also some loss of crates and the crate system can also affect the profit margin and sales (Figure 38). The CO2-eqv. effect of crate destruction is 1158 g CO_2-eqv./kg of plastic waste according to Punkkinen et al. (2011) and the burning of wooden waste does not cause a CO2-effect according to the same study. The CO2 effect of crate production is excluded.

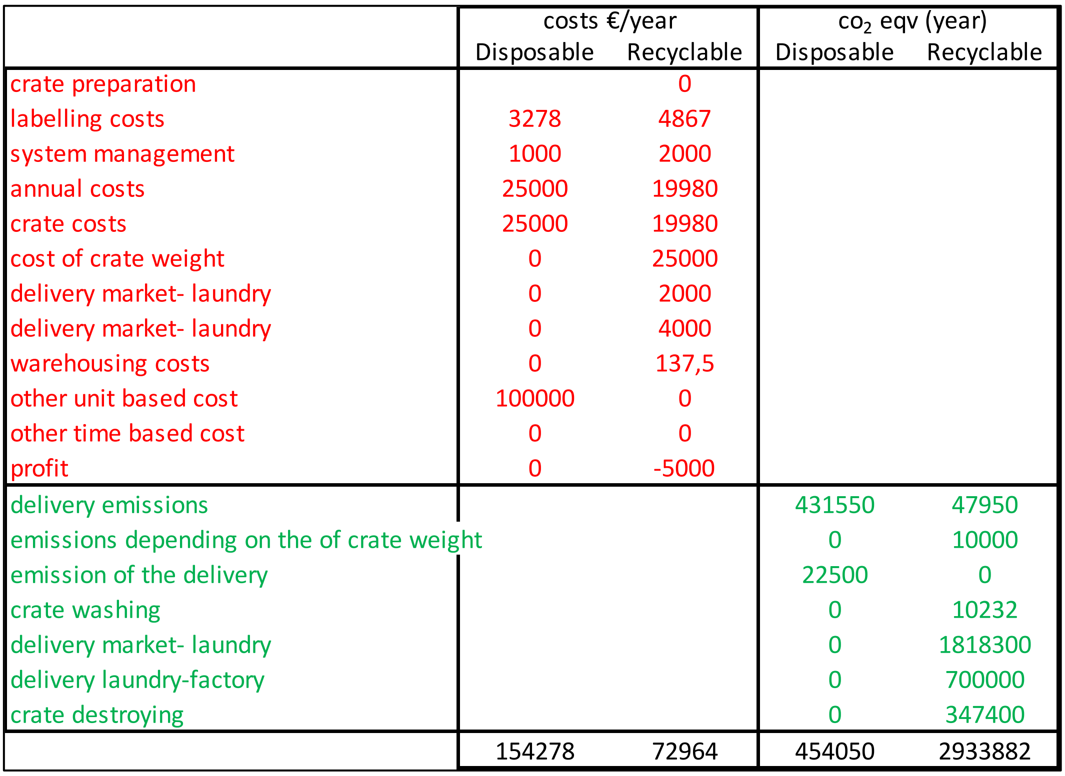


crate destroying				
crate production				
need for new crates		50000	480	crate/year
lost			2	%
renewal need because of the lost crates			80	crate/year
renewal need			0,1	times/year
renewal need because of the use			400	crate/year
crate production and destroying		0	347400	co2 eqv./year
crate production process		0	0	co2 eqv./crate
co2 effect		0	0	co2 eqv./crate
destroying emissions		0	0	co2 eqv./crate
co2 effect		0	723,75	co2 eqv./crate
other				
other unit based cost		0,2		€/crate
other time based cost		0		€/month
sales price		100	100	%
profit coefficient value		1	1,02	%
profit €/product	-0,5	-250000	-255000	€ (decrease cost
sales coefficient value		100	102	%

Figure 39. Other differences in crate operations

4.2.4 Results

The results were collected in the model's table (Figure 40). The results showed that a recycleable system would be cheaper than a disposable crate system but would cause more emissions.



	costs €/year		co_2 eqv (year)	
	Disposable	Recyclable	Disposable	Recyclable
crate preparation		0		
labelling costs	3278	4867		
system management	1000	2000		
annual costs	25000	19980		
crate costs	25000	19980		
cost of crate weight	0	25000		
delivery market- laundry	0	2000		
delivery market- laundry	0	4000		
warehousing costs	0	137,5		
other unit based cost	100000	0		
other time based cost	0	0		
profit	0	-5000		
delivery emissions			431550	47950
emissions depending on the of crate weight			0	10000
emission of the delivery			22500	0
crate washing			0	10232
delivery market- laundry			0	1818300
delivery laundry-factory			0	700000
crate destroying			0	347400
	154278	72964	454050	2933882

Figure 40. An example of the results

The results were sensitive in terms of crate laundry operations. Especially integration to the current logistic routes (how the crates would be delivered and how far away), and the price of outsourced crate washing are critical elements in economic and environmental success. For example, if the distance between laundry and factory increased from 20 km to 100 km, the emissions from the recyclable crate system would increase by 35% and the costs by 8% (Table 11). If the crate laundry costs increased by 67% (€/crate) the total would increase by 24%.

Table 11. An example of the effects of the distance between laundry and factory

km	costs	emissions
10	83783	9094590
20	85283	10092090
100	90533	13583340

After calculations and quantitative process analysis the information was collected into the supply chain sustainable performance table (Table 12).

Table 12. Example of the case supply chain's sustainable performance

	recyclable boxes (RB)	disposable boxes (DB)		change %
perfect order fullfillment	78	72	%	8
order fullfillment cycle time	18	19	days	-5
upside supply chain flexibility	60	84	days	-29
upside supply chain adabtability	35	33	%	6
downside supply chain adabtibility	22	20	%	10
supply chain management cost	8	5	%	60
cost of goods sold	75	78	%	-4
casg-to-cash cycle time	51	55	days	-7
return on supply chain fixed assets	12	11	%	9
return on working capital	10	9	%	11
carbondioxide emissions	5	6	eqv./product	-17
energy use	0,95	1	kWh/product	-5
number of impacted countries	3	2	pcs.	50
waste	0,1	0,15	kg	-33

Sustainable performance of the transportation crate system mostly depends on the possibilities of integrating current systems in the supply chain and operative infrastructure, and the materials used in the crates. The most important individual aspects affecting sustainable performance were how and where the crate returning washing systems were organized and how well it was possible to take advantage of the existing routes and increase the load capacity.

Sensitive variables when estimating the effects of the change are also the number of products, location and costs of the crate washing, integration to the current supply chain structure, loss of the crates and the capacity of the truck load (does the change need more transportation capacity.)

Possible change provides the potential for supply chain structural and operational changes such as moving sorting from the terminal to the production plant. This case study also shows that the economic and environmental success of the proposed transportation crate change depends most on how well the crate recycling is possible to fit into the supply chain infrastructure, for example the volumes and how and where the crate cleaning is arranged.

If the distance between the crate markets and laundry and factory changed, the differences between disposable and recyclable crate systems would also change (Figure 41).

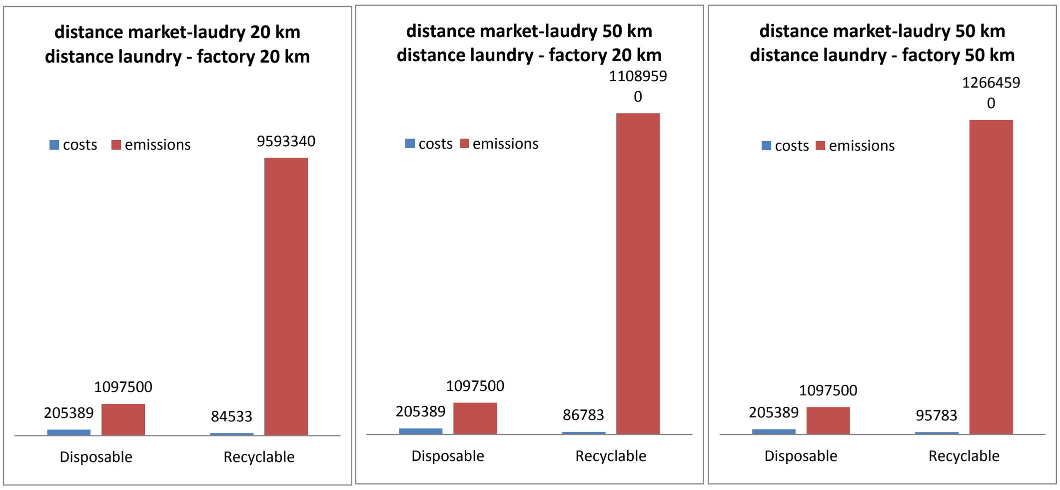


Figure 41. Effect of distance on crate system cost and CO_2 performance

If the distances between locations change then the role of logistical integration and co-operation will increase. It is also useful to estimate washing at the production plant. If the laundry costs increase or decrease by 50%, the total recyclable costs will increase or decrease linearly (Figure 42).

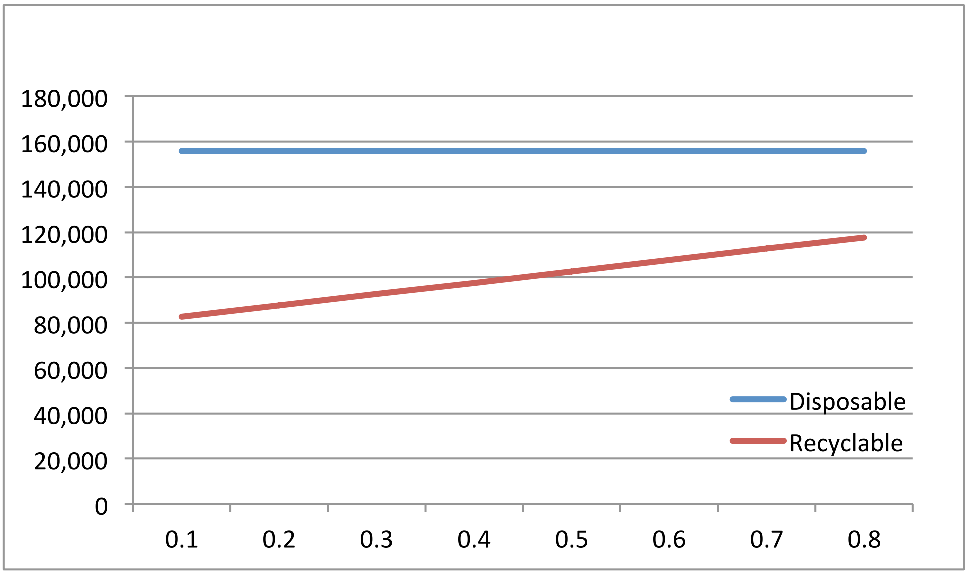
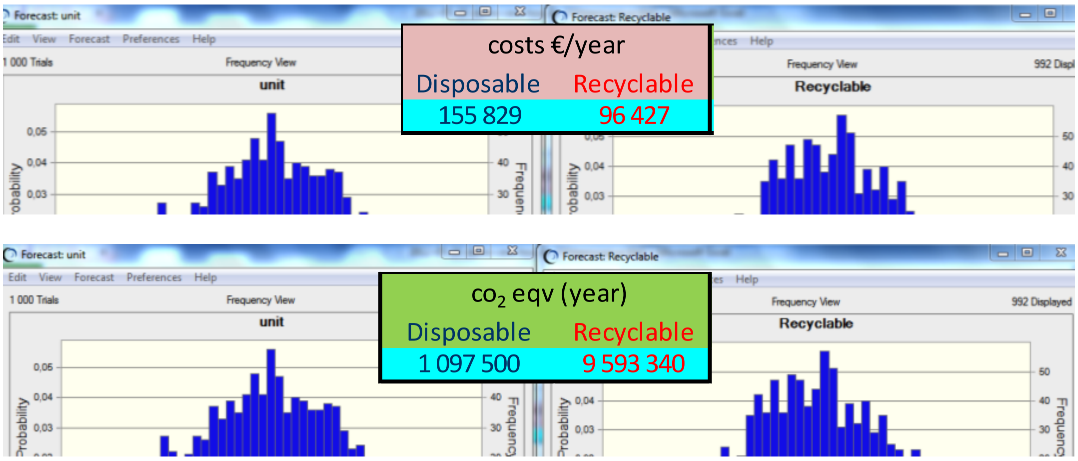


Figure 42. Effect of distance on crate unit laundry cost and SV costs

Every input cell was set to +/- 10% of normal distribution to describe uncertainty of the input values. Uncertainty includes distance from the market to laundry and from laundry to factory, laundry cost and crate unit price. Uncertainty caused costs in terms of disposable box variation (90% probability) of 120 000 – 190 000 €/year and a recyclable crate variation of 91 000 – 103 000 €. Emissions from the recyclable crate system varied from 9 400 to 9 850 kg/year. (Figure 43.)



costs €/year	
Disposable	Recyclable
155 829	96 427

co_2 eqv (year)	
Disposable	Recyclable
1 097 500	9 593 340

Figure 43. Effect of uncertainty to costs and GHG's

The results of disposable system costs were most sensitive to product sales (66.1%), and other unit based costs, which were set to 0.20 €/unit (23.3%). Recyclable crate costs were most sensitive to sales price (-24.4%) and sales coefficient value (this was set to 102%, because it was estimated sales would increase because of the transportation system) 23.3%.

CO2 equivalent emissions were most sensitive to unit size of the crate (-36.3%), and sales of the product (34.0%). Emissions from the disposable system were most sensitive to the effect of chemicals (54.6%) and sales (28.8%) and energy usage (5.6%).

4.3 Case B: Location decisions

The aim of the second case is to find out how the decision on a fresh production plant location affects the sustainable performance of the supply chain. The aim was to find out how the supply chain's sustainable performance would differ if there were two production plants instead of one. The focal company operates in the growing fresh food sector in Finland. The supply chain consists of the production plant, suppliers, 3PL logistic providers, and a few retailers. The study was mainly done during 2010.

The focal company has one production plant, but is considering also opening another one. The markets are national but concentrated on the focal company's local (less than 200 km distance) production plant. **The aim of case B is to find out how the sustainable performance would change if there were two production plants in places A and B (scenario 1) instead of the one plant** which could be located either in A or B. The developed sustainable performance measurement model gave the framework for the case study.

The case scenarios were modelled using MS Excel and the Oracle Crystal Ball. The causalities in the first scenario were that there would be two production plants in places A and B, in the second scenario one plant in place A, and in the last scenario one plant in place B. An assumption is that the market situation would be the same but the logistical service providers and material suppliers could change. The case study was limited to business and to domestic consumer customers who receive most of the deliveries.

Emissions were directed on logistical operations based on WEF instructions and the logistical emission data was collected from a database called Lipasto (VTT, 2011). The causalities between input and output values were modelled in MS Excel, where both scenarios were compared. The sensitivity analyses were done using MS Excel.

At first the strategic change was defined by the strategic management team; the supply chain processes of each scenario were described based on the interviews with representatives of the supply chain, and the differences between the scenarios were described and the data from those processes collected. The focus of the management team was set to cost and CO2 effects. For example, CO_2 emission sources were recognized from those processes which met the changes. Data were modeled and causalities made between inputs and outputs using MS Excel. The results were written and clarified with screenshot figures. Finally, the effects of uncertainty of input values on the results were clarified with Crystal Ball. First the processes were analysed before and then after the change situations. The changed processes would be directed to sourcing, making, delivering, returning and planning processes. The changes were identified and those which affected the carbon dioxide equivalent emissions or profits were identified. The differences between customer groups and seasonal effects were excluded.

4.3.1 Process description

The production company receives orders from customers once per day. The preparations for production begin before receiving the order. The production company produces and customizes the ordered products and packs them into customer packages and customer packages into the delivery crates. The logistics company delivers the products to the terminal for order picking. The orders are picked according to the customers' terminal orders. (Figure 44.)

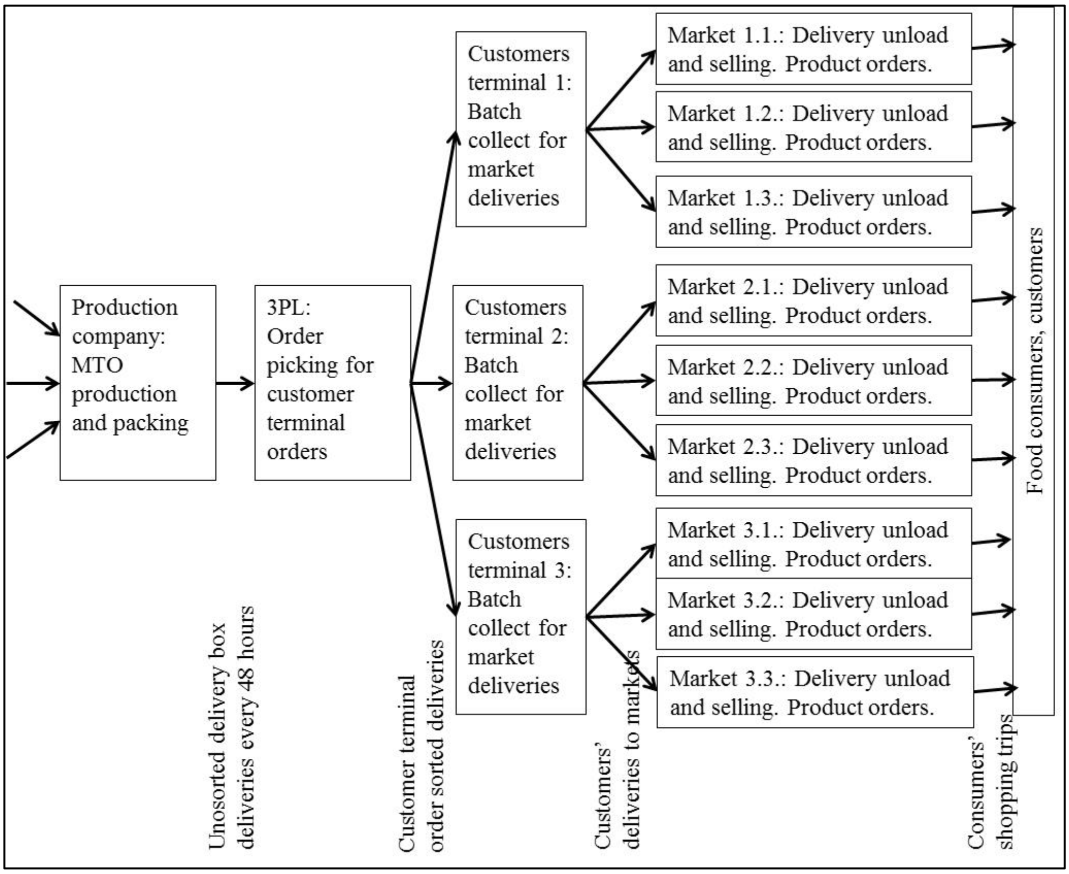


Figure 44. Process chart of the delivery

The products are delivered to the customers' terminals (an example is shown in Figure 45), where they are collected and connected to the market orders. The customer delivers the market orders according to their route schedules. The loads are unpacked and put onto the display shelves in the markets. The market receives an order 48 hours after an order has been placed.

Figure 45. An example of the location of customers' (Inex) terminals

4.3.2 Differences between the scenarios

The decision between one (Figure 46) or two (Figure 47) production plant models causes changes in the supply chain structure. In the one plant model there is one production company which delivers products to the terminal for order sorting. The sorted orders are delivered to the customers´ terminal where the market orders are collected and send to the markets for selling. The differences between one or two production plant scenarios were identified and described. Some new suppliers and logistics service providers were involved in the two plant scenarios. The market area, customers and retailers did not change.

The assumption is that all the products for one customer would be produced in the same plant.

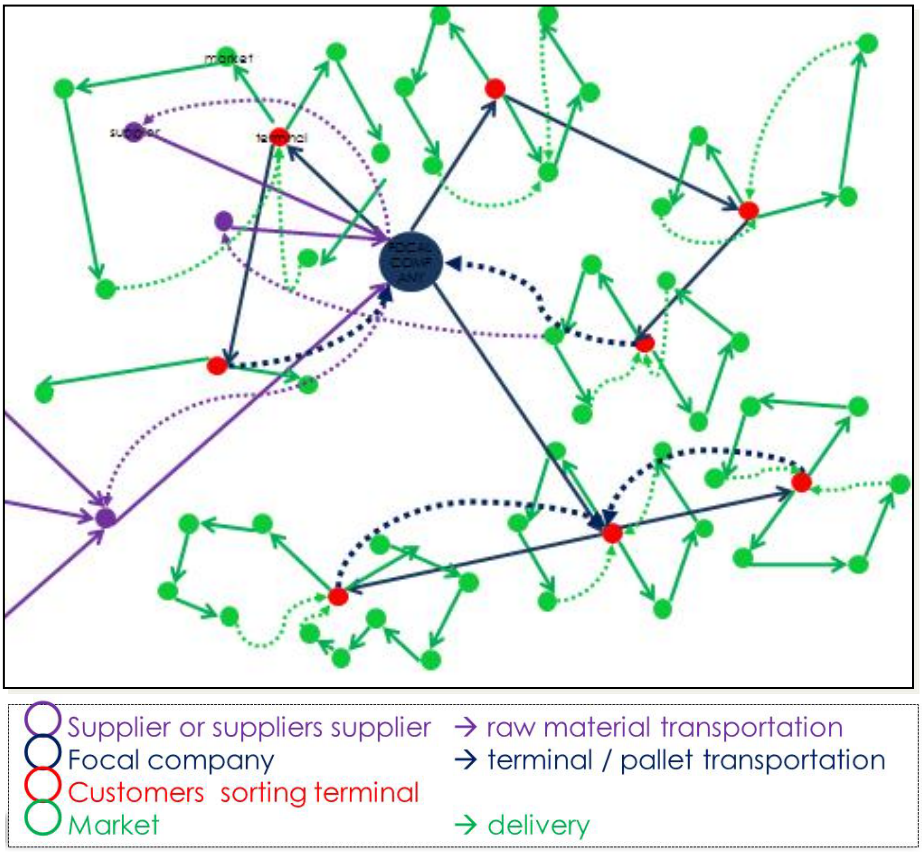


Figure 46. One plant model

In the two plant model the "old plant's" sorting channels, and product deliveries to the terminal for terminal delivery sorting would not change, but the new plant would produce part of the old plant's orders and have some new suppliers and sorting terminal where orders would be sorted according to the terminal orders and then delivered to the customers terminals for market delivery collecting.

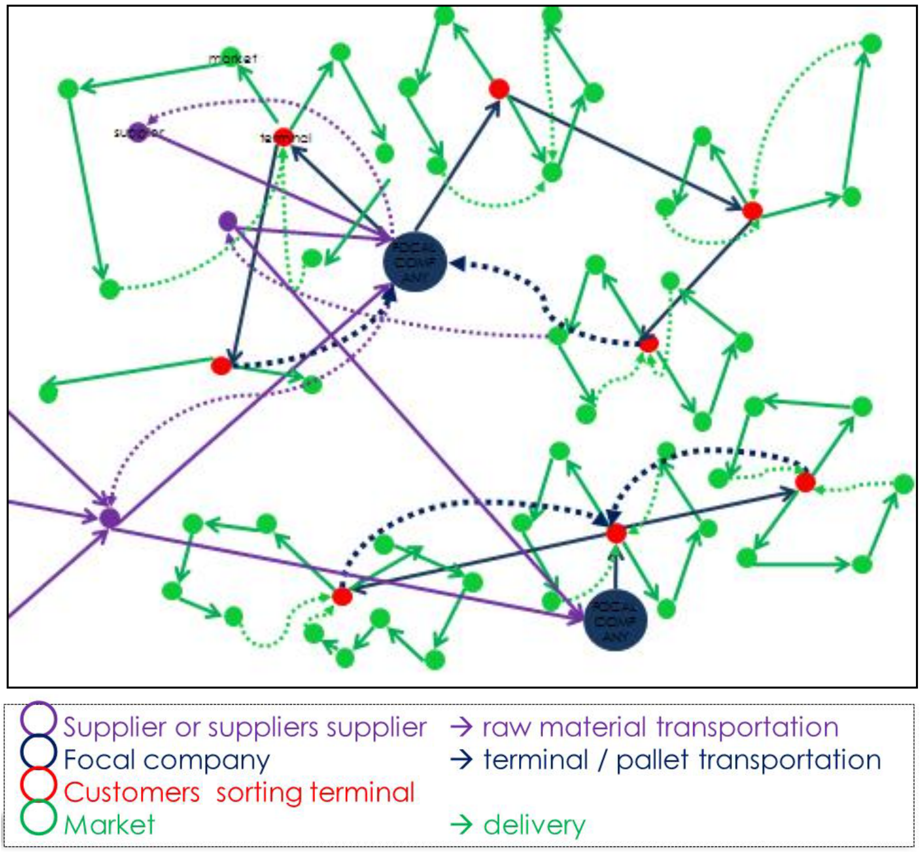


Figure 47. Two plant model

Because the change in each part of sustainable performance depends on changes in the supply chain processes the causalities are illustrated in Figure 48. The causalities are expressed as mathematical formulae in the following section.

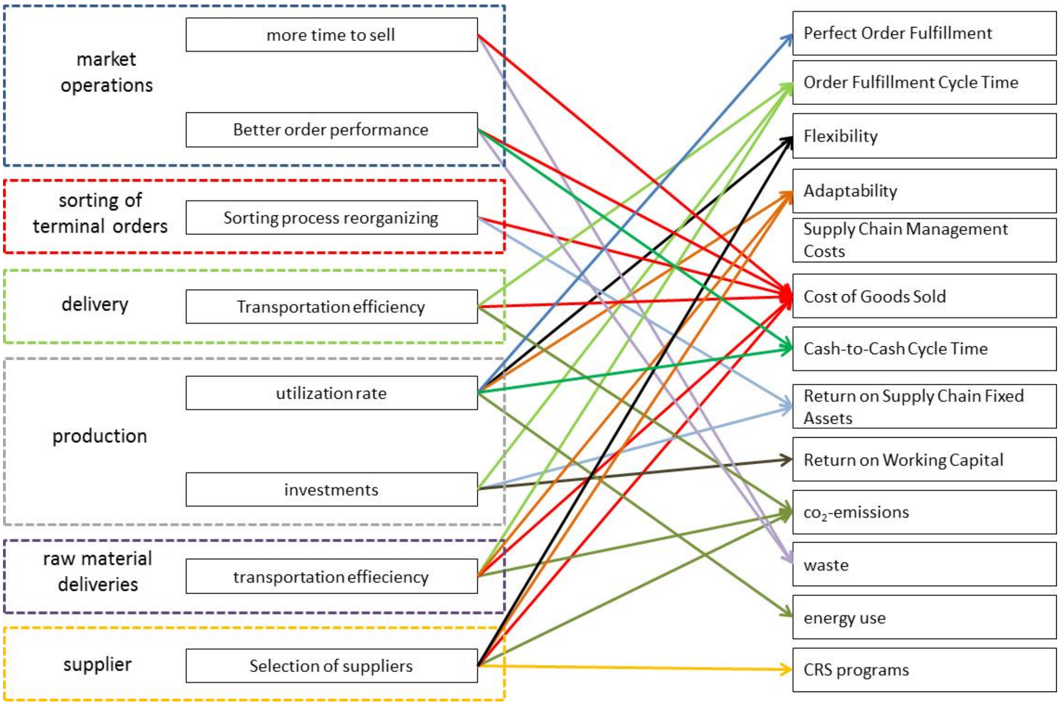


Figure 48. Changes in the processes and their main effects

Data is collected from those processes which are supposed to change significantly.

4.3.3 Formulae and results

First the customer terminal order information was collected (Table 13). The order distribution is based on the statistics of the PTY's (Suomen päivittäistavarayhdistys, 2008) sales (€). Distribution and the distance information is based on the Eniro.fi-service. The sales are divided by the areas they were connected to so that they were equal to the locations of the customer terminals.

Table 13. Customers' terminal location information

% sales	market area	terminal	% of deliveries	distance (km) from plant A's sorting terminal	distance (km) from plant B's sorting terminal
26,7	Uusimaa, Itä-Uusimaa and Päijät-Häme	Vantaa	16,1	173	18
3,8		Espoo	16,1	179	45
1,7					
8,7	Varsinais-Suomi	Turku	8,7	153	186
4,5	Satakunta	Tampere	16,6	0	158
3,2	Kanta-Häme				
8,8	Pirkanmaa				
3,6	Kymenlaakso	Kouvola	6,2	187	119
2,6	Etelä-Karjala				
3,1	Etelä-Savo	Mikkeli	3,1	258	200
4,6	PohjoisSavo	Kuopio	7,7	292	353
3,1	Pohjois-Karjala				
5,0	Keski-Suomi	Jyväskylä	5,0	151	241
3,6	Etelä-Pohjanmaa	Seinäjoki	8,2	182	340
3,2	Pohjanmaa				
1,4	Keski-Pohjanmaa				
6,8	Pohjois-Pohjanmaa	Oulu	12,4	491	579
1,6	Kainuu				
3,9	Lappi				
100,0			100,0		

4.3.3.1 Customers in two plant scenario

Customers of the plants in the two plant scenario had to be divided into plant A's customers (distribution terminals) and plant B's customers (distribution terminals). The production costs are excluded from the calculations and it is supposed that only one plant delivers to one customer's terminal.

(32) $C_d \sum_1^n C_{d1_n} + C_{d2_n} + C_{s_n}$, where

n= number of customers' terminals, C_{d1} *= cost of delivery from plant A or B to sorting terminal (€/year) A or B,* C_s *= sorting costs of terminal order sorting (€/year),* C_{d2} *= cost of delivery from sorting terminal to customer's terminal (€/year) where,*

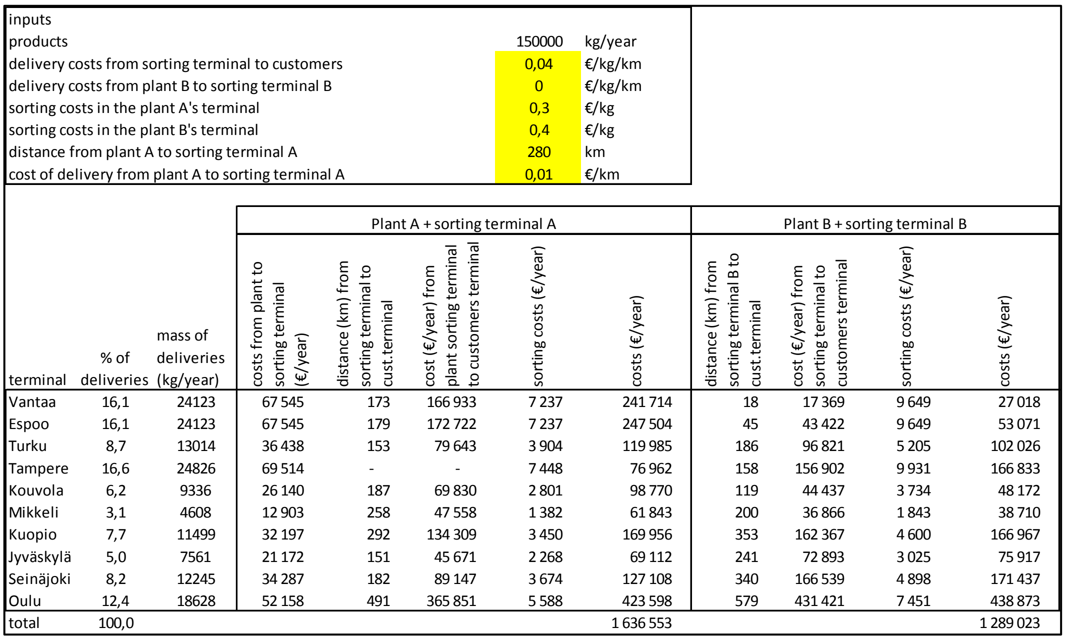
(33) $C_{dx} = mdC_{km}$, in where

d = distance between plant and sorting terminal or sorting terminal and customers terminal (km), C_{km}*= distance based cost of the route (€/km/kg), and m = mass of products in the route x. (kg/year).*

(34) $C_{s_n} = mC_s$, where

m= mass of sorted products in the sorting terminal (kg/year), C_s= cost of sorting (€/kg).

The previous calculations and inputs are shown in Figure 49 below.



inputs		
products	150000	kg/year
delivery costs from sorting terminal to customers	0,04	€/kg/km
delivery costs from plant B to sorting terminal B	0	€/kg/km
sorting costs in the plant A's terminal	0,3	€/kg
sorting costs in the plant B's terminal	0,4	€/kg
distance from plant A to sorting terminal A	280	km
cost of delivery from plant A to sorting terminal A	0,01	€/km

			Plant A + sorting terminal A					Plant B + sorting terminal B			
terminal	% of deliveries	mass of deliveries (kg/year)	costs from plant to sorting terminal (€/year)	distance (km) from sorting terminal to cust.terminal	cost (€/year) from plant sorting terminal to customers terminal	sorting costs (€/year)	costs (€/year)	distance (km) from sorting terminal B to cust.terminal	cost (€/year) from sorting terminal to customers terminal	sorting costs (€/year)	costs (€/year)
Vantaa	16,1	24123	67 545	173	166 933	7 237	241 714	18	17 369	9 649	27 018
Espoo	16,1	24123	67 545	179	172 722	7 237	247 504	45	43 422	9 649	53 071
Turku	8,7	13014	36 438	153	79 643	3 904	119 985	186	96 821	5 205	102 026
Tampere	16,6	24826	69 514	-	-	7 448	76 962	158	156 902	9 931	166 833
Kouvola	6,2	9336	26 140	187	69 830	2 801	98 770	119	44 437	3 734	48 172
Mikkeli	3,1	4608	12 903	258	47 558	1 382	61 843	200	36 866	1 843	38 710
Kuopio	7,7	11499	32 197	292	134 309	3 450	169 956	353	162 367	4 600	166 967
Jyväskylä	5,0	7561	21 172	151	45 671	2 268	69 112	241	72 893	3 025	75 917
Seinäjoki	8,2	12245	34 287	182	89 147	3 674	127 108	340	166 539	4 898	171 437
Oulu	12,4	18628	52 158	491	365 851	5 588	423 598	579	431 421	7 451	438 873
total	100,0						1 636 553				1 289 023

Figure 49. Customer division calculations

4.3.3.2 Delivery time of the order

(35) $$\mathbf{d_t = t_p + t_{t1} + t_s + t_{t2}}$$, in where

t_p = time used in production (hours) until all the products of the order have been finished, t_{t1} = time used in transportation from plant to terminal for customer terminal order sorting (hours), t_s = time used in sorting (hours) until the order is sorted for delivery, t_{t2} = time used in transportation from sorting terminal to customer's terminal (hours), where

(36) $$\boldsymbol{t_p}\ \sum_1^{\boldsymbol{n}} \mathbf{n}(\mathbf{p_1} + \cdots + \mathbf{p}_{\boldsymbol{n}})$$, where

n= number of products ordered, p_x = process x's production efficiency (hours/products).

In the case the production stages were divided into two stages based on the production strategy. The buffer made wip production is stage 1 and the products are made before the order closing because those wip products are not so expensive to prepare and every finished product is made from those WIP products. The process time calculations include, for example, set up times, production variety, capacity of personnel and production technology (Figure 50).

		scen.A	scen B		
timing		A	A	B	
production		44,9	44,9	44,9	hours
	of which prod.stage.1	2,2	2,2	2,2	hours
	prod.stage 2	42,7	42,7	42,7	hours
transportation from plant to terminal		5,6	2,0	0,3	hours
sorting the customer terminal orders		6,9	8,7	6,9	hours
transportation to customers' terminal		7,2	6,9	7,2	hours
total time		**64,7**	**62,5**	**59,3**	hours
time - (production stage 1)		62,4	60,3	57,1	hours
time of deliveries and sorting		19,8	17,6	14,4	hours

Figure 50. Process times of the supply chain processes

Transportation time is calculated as
(37) $= \mathbf{vd}$, where

v= mean speed of transportation (km/h) and d= distance between start and endpoints.

In the case calculation the used mean speed is 80 km/hour. The time counting starts from the moment when the order is closed in the factory. The customer gives the times when the orders have to be in their terminals (Figure 51).

Based on this the production starting moment has been calculated as follows:

(38) $\boldsymbol{t_p = t_c - t_{t2} - t_s - t_{t1} - t_{p2}}$, in where

t_p = latest time to start production, t_c = moment when order has to be in customers terminal, t_{t2} = time used to deliver order from sorting to customers terminal, t_s = time used to sort orders for customers' terminals, t_{t1} = time used to deliver products from plant for customer terminal sorting terminal, time used in MTO production processes.

	scen.A	scen B	
timing	A	A	B
production stage 1	-2,2	-2,2	-2,2
closing the orders	0,0	0,0	0,0
production stage 2	42,7	42,7	42,7
transportation to terminal	48,3	44,6	42,9
sorting the customer terminal orders	55,2	53,3	49,9
transportation to customers' terminal	62,4	60,3	57,1

Figure 51. Order closing time as a starting point of the timing

An example of the times when the order has to be in customers' terminal is in Figure 52, and the production starting moments of both scenarios are on lines 3 and 5. The production starting moment affects the production costs because the working costs vary between day and night.

	delivery has to be at customers terminal before	production starts latest			deliveries stars from customers terminal to markets
		if plant in A	if plant in B	if plant in A and B	
Vantaa	22:00	16:08	20:56	20:56	5:00
Espoo	20:00	8:32	10:56	10:56	5:00
Tampere	19:00	13:56	23:56	23:56	5:00
Turku	20:00	2:56	16:32	16:32	5:00
Oulu	21:00	10:20	19:32	10:20	5:00
Seinäjoki	19:00	18:20	17:08	18:20	5:00
Jyväskylä	19:00	2:20	23:08	23:08	5:00
Kuopio	22:00	6:56	14:56	14:56	5:00
Mikkeli	20:00	16:08	12:08	12:08	5:00
Kouvola	20:00	18:08	12:32	12:32	5:00
Kajaani	22:00	16:32	13:44	16:32	5:00
Lahti	19:00	13:08	0:44	0:44	5:00

Figure 52. Timetable of production starting moments in the scenarios

4.3.3.3 Perfect order fulfillment rate

Perfect order fulfillment rate is supposed to change because order errors typically concern ordering the wrong amount, or at the wrong time or with the wrong quality. When the delivery time gets shorter the supply chain may become more vulnerable and it is possible that orders are not at the right time at the right place. However, the shorter delivery time is the result of shorter delivery routes. When the plant is nearer it is possible to correct mistakes by using another plant as a backup-plant or another supplier as a backup supplier.

4.3.3.4 Costs

The cost differences between scenarios consist of the production costs, delivery costs and costs in the market.

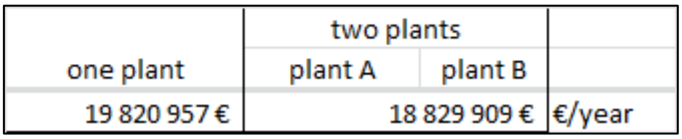
(39) $\boldsymbol{C = C_s + C_d + C_p + C_m}$, where

C_d = costs of deliveries and sorting as in section x.x.x, C_d = costs of production, C_d = costs of the market operations where,

(40) $$c_s \sum_1^n o_n(s_n(c_{m_n}+ c_{d_n} d_n) + c_{df_n}),$$

o= orders from supplier x (pcs/year), s= order mean size (kg/order), c_m =material cost (€/kg), c_{df} = delivery costs (€/delivery), c_d = delivery costs (€/kg/km), d= delivery distance of the plant and supplier 1.

The supplier costs decrease a little and the supplier selection gets wider (Figure 53). Some raw materials can be delivered through plant A.



	two plants		
one plant	plant A	plant B	
19 820 957 €	18 829 909 €		€/year

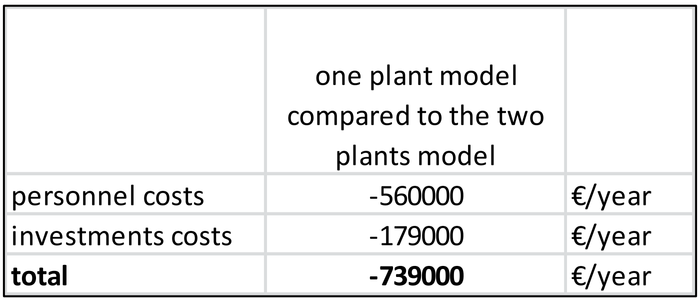
Figure 53. An example of the supply costs between scenarios

And,

(41) $$C_p = c_{w1}t_{w1} + c_{w2}t_{w2} + pc_e(t_1 + t_2) \text{ where}$$

c_{w1}= cost of working hour in higher paid hours, t_{w1} = daily working hours in higher cost time (hours), c_{w2}= cost of working hour in standard paid hours (€/hour), t_{w1} = daily working hours in standard cost time, $p = power\ need\ of\ production\ (kWh), c_e$ = cost of power (€/kwh)

In the case, the production stage in the two plant model would be 739 000 €/year more expensive than the one plant model when the investments are divided over 15 years (Figure 54).



	one plant model compared to the two plants model	
personnel costs	-560000	€/year
investments costs	-179000	€/year
total	**-739000**	€/year

Figure 54. An example of the production costs between the scenarios

The cost effect in the markets consists of the costs and lost profits and waste

(42) $$\mathbf{C_m = ((npd/100)s_f/100+ (npd/100)0{,}5s_h/100- (npd/100)s_e /100– up)- (npd/100)s_e/100c_w,} \text{ where}$$

n= number of products sold, p= price of the product, d= demand, s_f *= share of products sold full price,* s_h *= share of products sold half price%,* s_e *= share of expired products%, u = unsold products because of sold out situations,* c_w *=waste costs (€/kg).*

There are differences between the one and two plant scenarios in the return on fixed assets because the fixed assets would increase with another production plant and sorting terminal investments.

4.3.3.5 Energy, waste and emissions

Changes in the emissions between the scenarios consist of the transportation (raw materials, unsorted products and sorted products), energy use of the processes, and waste effect.

(43) $\boldsymbol{e_{sc} = e_s + e_m + e_d + e_r + e_p}$, where

e_{sc} = *supply chain annual emissions as* CO2 equivalents, e_s = source process CO_2 eqv. emissions, e_m make process CO_2 eqv. emissions, e_d = deliver process CO_2 eqv. emissions, e_r return process CO_2 eqv. emissions, e_p = plan process CO_2 eqv. emissions.

In this case sourcing process differences are calculated as:

(44) $\boldsymbol{e_s = e_{rmp} + e_d}$, where

e_{rmp}*= carbon dioxide equivalent emissions of the raw material production,* e_d*= carbon dioxide equivalent emissions of the raw material transportation.*

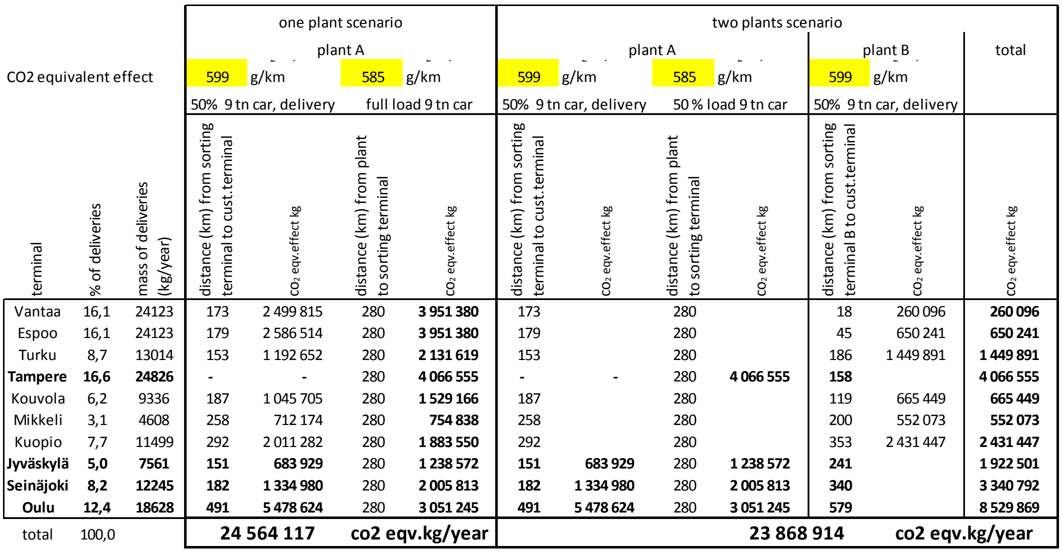
(45) $\boldsymbol{e_m = e_e = e\sum_1^n p_{p_n}}\, e_{p_n}$, where

$\boldsymbol{e_e}$ = *carbon dioxide equivalent emissions of the energy used in the production plant which consists of the energy used in the production processes and the unit emissions of the energy type used.*

(46) $\boldsymbol{e_d = e_{t1} + e_s + e_{t2}}$, where

e_{t1}*= emission effect of the transportation between plant and sorting terminal,* e_{t2} *= emission effect of the transportation between sorting terminal and customer terminal,* e_s*= emission effect of the sorting*

For example, the difference in the emission effects of the deliveries in scenario B is 695 ton/year so that the two plant model produces less emission because the cumulative delivery distance is less and there would be no transportation between the plant and sorting terminals in plant B even if the capacity of the loads is lower (Figure 55).



			one plant scenario				two plants scenario						
			plant A				plant A				plant B		total
CO2 equivalent effect			599 g/km		585 g/km		599 g/km		585 g/km		599 g/km		
			50% 9 tn car, delivery		full load 9 tn car		50% 9 tn car, delivery		50 % load 9 tn car		50% 9 tn car, delivery		
terminal	% of deliveries	mass of deliveries (kg/year)	distance (km) from sorting terminal to cust.terminal	CO_2 eqv.effect kg	distance (km) from plant to sorting terminal	CO_2 eqv.effect kg	distance (km) from sorting terminal to cust.terminal	CO_2 eqv.effect kg	distance (km) from plant to sorting terminal	CO_2 eqv.effect kg	distance (km) from sorting terminal B to cust.terminal	CO_2 eqv.effect kg	CO_2 eqv.effect kg
Vantaa	16,1	24123	173	2 499 815	280	**3 951 380**	173		280		18	260 096	**260 096**
Espoo	16,1	24123	179	2 586 514	280	**3 951 380**	179		280		45	650 241	**650 241**
Turku	8,7	13014	153	1 192 652	280	**2 131 619**	153		280		186	1 449 891	**1 449 891**
Tampere	**16,6**	**24826**	-	-	280	**4 066 555**	-	-	280	**4 066 555**	**158**		**4 066 555**
Kouvola	6,2	9336	187	1 045 705	280	**1 529 166**	187		280		119	665 449	**665 449**
Mikkeli	3,1	4608	258	712 174	280	**754 838**	258		280		200	552 073	**552 073**
Kuopio	7,7	11499	292	2 011 282	280	**1 883 550**	292		280		353	2 431 447	**2 431 447**
Jyväskylä	**5,0**	**7561**	**151**	**683 929**	280	**1 238 572**	**151**	**683 929**	280	**1 238 572**	**241**		**1 922 501**
Seinäjoki	**8,2**	**12245**	**182**	**1 334 980**	280	**2 005 813**	**182**	**1 334 980**	280	**2 005 813**	**340**		**3 340 792**
Oulu	**12,4**	**18628**	**491**	**5 478 624**	280	**3 051 245**	**491**	**5 478 624**	280	**3 051 245**	**579**		**8 529 869**
total	100,0			**24 564 117**		**co2 eqv.kg/year**					**23 868 914**		**co2 eqv.kg/year**

Figure 55. Delivery emission effects of the scenarios

Most waste comes from markets and it is a result of the extended shelf-life of the product. If the total delivery time does not change as a result of two plants there will be no difference in waste caused by extended shelf-life.

4.3.3.6 Flexibility and adaptability

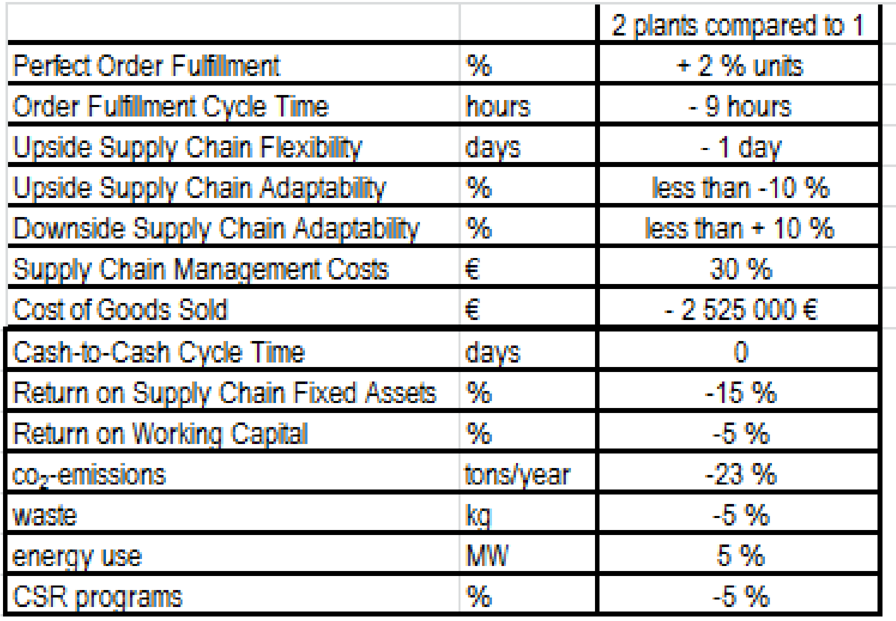
Adaptability of the supply chain is the weakest component. However, it would improve because the actual number of returns compared to the maximum number of returns which can be achieved within 30 days would improve. The percentage of increase in raw material quantities that can be acquired / received in 30 days would most likely increase because of increased number of suppliers.

The make adaptability would improve because the maximum sustainable percentage increase in production that can be achieved in 30 days with the assumption of no raw material constraints would increase in the two plant scenario. Also the maximum sustainable percentage increase in quantities delivered that can be achieved in 30 days with the assumption of unconstrained finished good availability would increase because of the doubled delivery channels.

The flexibility of the upside source would improve a little because of shorter distances and ability to response faster and the increased number of suppliers. Also the plants could response better to an unplanned 20% increase of orders as well as deliveries for unplanned deliveries because of the free capacity.

4.3.4 Results

The results of the case study show, e.g. that if one production plant would be replaced with two plants the delivery time and delivery costs, waste and carbon dioxide emissions would decrease and sourcing, production and investment costs would increase (Figure 56). At the same time, the return costs and amount of waste would decrease at the supply chain level.



		2 plants compared to 1
Perfect Order Fulfillment	%	+ 2 % units
Order Fulfillment Cycle Time	hours	- 9 hours
Upside Supply Chain Flexibility	days	- 1 day
Upside Supply Chain Adaptability	%	less than -10 %
Downside Supply Chain Adaptability	%	less than + 10 %
Supply Chain Management Costs	€	30 %
Cost of Goods Sold	€	- 2 525 000 €
Cash-to-Cash Cycle Time	days	0
Return on Supply Chain Fixed Assets	%	-15 %
Return on Working Capital	%	-5 %
co_2-emissions	tons/year	-23 %
waste	kg	-5 %
energy use	MW	5 %
CSR programs	%	-5 %

Figure 56. An example of the case study supply chain level comparison

Some previous studies show that the carbon footprint may be quite concentrated among the supply chain processes and be very different with different food products. The same results can be seen in this case study. Also the increased costs were concentrated in the supply chain in the focal company because of the production investments. A strategic decision changed the economic, ecological and social performance of the supply chain. The changes were pointed out in different parts of the supply chain.

The results depend on, for example, how fast the markets can be reached from each production plant, how long the shelf life of the fresh food product is and what the amount of waste is, especially in case of food spoiled because of the expired selling days. Also the possibilities of integrating the supply chain with existing supply chain infrastructure such as sorting terminals, supplier network and retailers supply cycle from order to supply and the location of the markets compared to the terminals, suppliers and production plants.

This study shows that individual measures of environmental or economic performance are not enough when optimizing supply chain sustainable performance. A more holistic way to measure overall sustainable performance is needed.

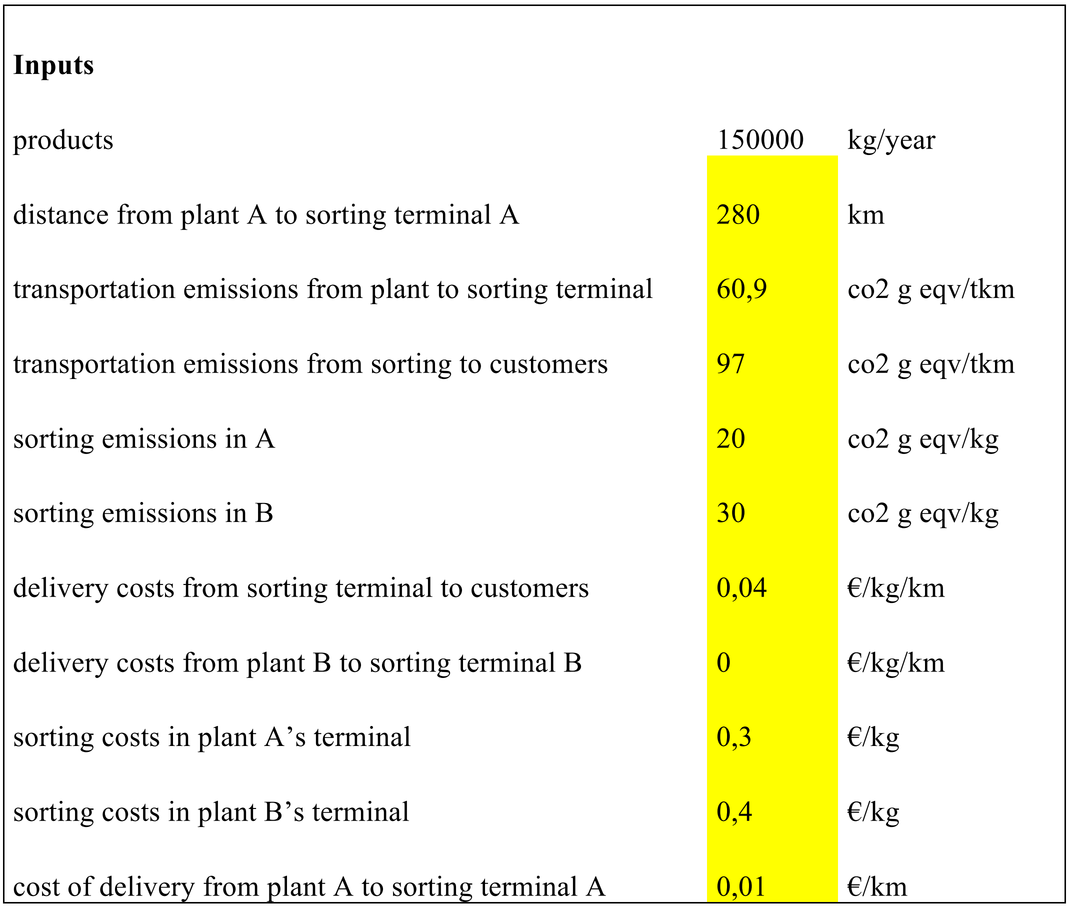
If all customers had to be delivered to in 24 hours, there would have to be two or more plants because the delivery time alone from place A to B takes almost 10 hours through the sorting terminal. Calculations show that in the two model scenario 42% of plant B customers would be maximum 2.5 hours from plant and 58% of plant A's customers not further away than 6 hours from the plant.

The difference between raw material costs is not very remarkable, but the time and money used to sort ready products are. If the achieved time benefit is be lost in other supply chain processes the products will be available earlier to the customer. It means that the quality and freshness of the product, and the probability that it will be sold will increase in the two plant model.

There could also be possibilities of variation in the plants or their product varieties. Production stage 1 could be done only in one plant or then the whole product variety could be divided between the plants. It is also possible that pre-produced products could packed and then they could be turned into ready products faster, but the microbiological and sensitive quality of the product would decrease.

The two plant scenario improves the delivery time and share of perfect orders and lower costs. The business strategy of the company is the most important criterion when comparing sustainable performance with a metric describing competitive attributes. If the freshness and possibility of faster deliveries are the most important value then the two plant scenario is better.

Decision criterion as to why the products would be produced in plant A or B is essential. In this case study the products were produced in the factory which was cheaper. The following analysis estimates in what situations and how the emissions would change. Because the products are moved from plant to sorting terminal with large fully loaded delivery vans (15 ton) the emissions are, according to the Lipasto database (VTT, 2011), 60.9 co_2 eqv/ton kilometer instead of the 75% loaded delivery drive 97 co_2 eqv/ton. The estimations include a lot of uncertainty, such as sorting emissions. If the sorting efficiency is 2000 kg/m2/year in a cool sorting terminal and the emissions of the sorting terminal 200 kWH/m2 (Itella ca. 175 kWh/m2), the effect of the emissions would be 0,1 kWh/kg, which is ca. 25 g co_2 eqv./kg sorted product. The inputs (Figure 57) have different estimations for sorting terminal A and B because A is more specialized in food sorting, but on the other hand terminal B could be more energy efficient.



Inputs		
products	150000	kg/year
distance from plant A to sorting terminal A	280	km
transportation emissions from plant to sorting terminal	60,9	co2 g eqv/tkm
transportation emissions from sorting to customers	97	co2 g eqv/tkm
sorting emissions in A	20	co2 g eqv/kg
sorting emissions in B	30	co2 g eqv/kg
delivery costs from sorting terminal to customers	0,04	€/kg/km
delivery costs from plant B to sorting terminal B	0	€/kg/km
sorting costs in plant A’s terminal	0,3	€/kg
sorting costs in plant B’s terminal	0,4	€/kg
cost of delivery from plant A to sorting terminal A	0,01	€/km

Figure 57. Inputs of case B

If the distance between plant A and sorting terminal A changed from 0 to 500 km the costs would increase from an annual 90 7925 euros to 1 236 381 euros (and emissions from an annual 5699 kg CO2 eqv. to 7669 kg CO2 eqv. The route via plant A and A’s sorting terminal would be the more inefficient the longer is the distance between the plant and sorting terminal (Figure 58).

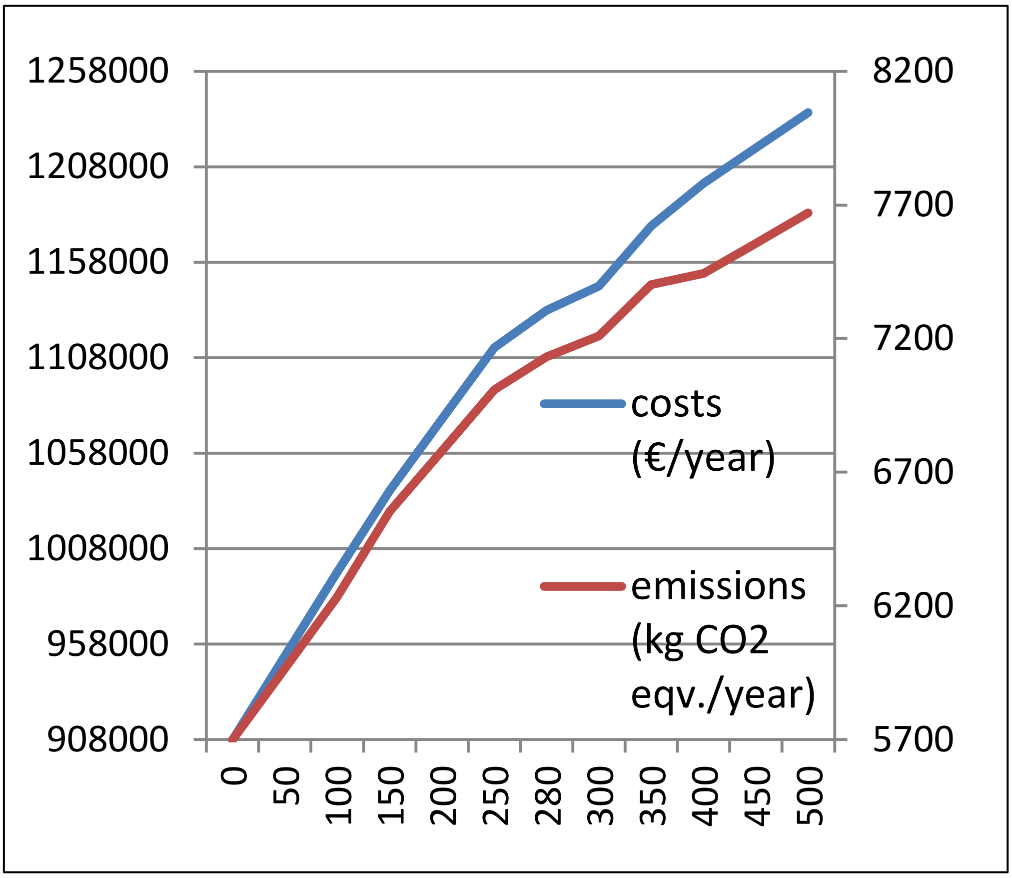


Figure 58. Emissions and route length

Because the load capacity of the changes is not noticed the costs and emissions change linearly. If there were no other products but the focal company's in the deliveries from plant to sorting terminal the emissions would increase, but on the other hand in another plant the emissions would decrease. If the production moves from one plant to another but the amounts are still same, the total delivery efficiency does not change.

If the uncertainty distribution of +/-100% were set to sales volume and delivery costs there would be over 90% probability that the costs would vary from -2 000 000 € (savings) to 5 500 000 € (costs) in one plant scenario, and from -800 000 to 2 000 000 € in the two plant scenario. (Figure 59.)

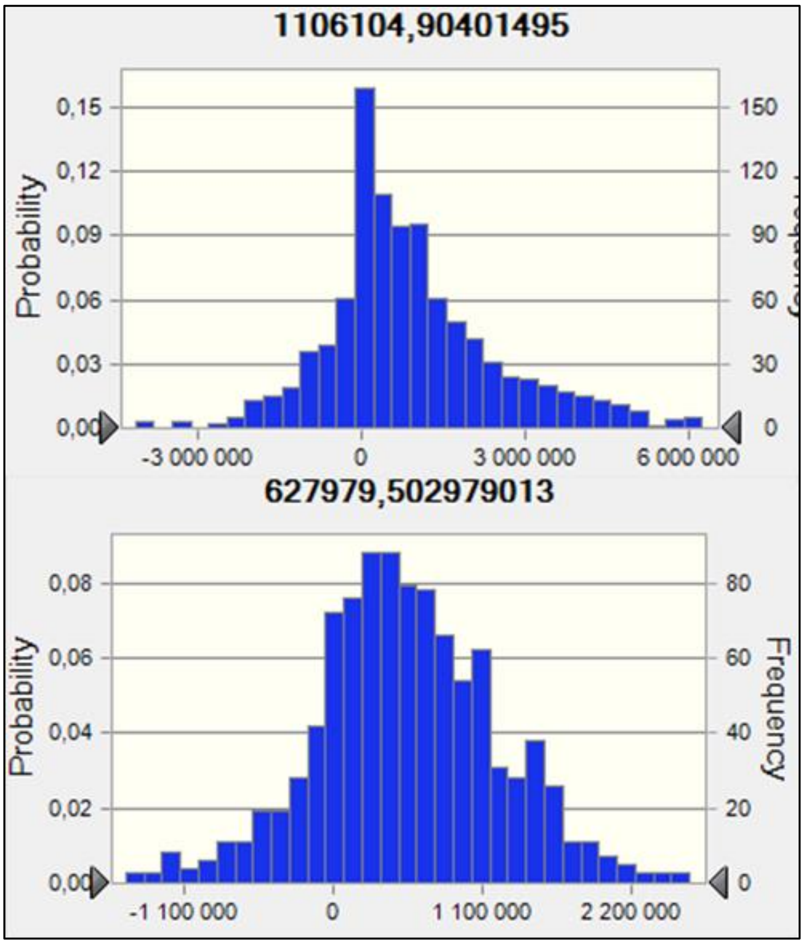


Figure 59. Cost variation in one plant (above) and two plant (below) scenario

4.4 Case C: Effects of doubling delivery cycle

The purpose of the third case study was to find out how profit and CO_2 equivalent emissions would change if the delivery cycle doubled from 24 hours to 48 h delivery time and the delivery cycle from every second day to every day deliveries. The selected retailers were Kespro, Ruokakesko, Inex, Meira Nova, Tuko, Rautakirja, Minimani, Wihuri and Aarnio. Each buyer, assortment manager, sourcing manager, buyer or product line manager (15) was called three times and four of them were reached.

The representative of the production company was also interviewed and gave default data which were used in the calculations. The effect of delivery cycle was modelled in MS Excel.

4.4.1 Process description and differences

First, the processes were analysed before and then after the change situations. The changes were identified and those which affected the carbon dioxide equivalent emissions or profits were identified.

The production company receives orders from customers once per day. The preparations for product production have begun before receiving the order. The production company produces and customizes the ordered products and packs them into customer packages and customer packages into delivery crates. The logistics company delivers the products to the terminal for order picking. The orders are picked according to the customers' terminal orders. (Figure 60.)

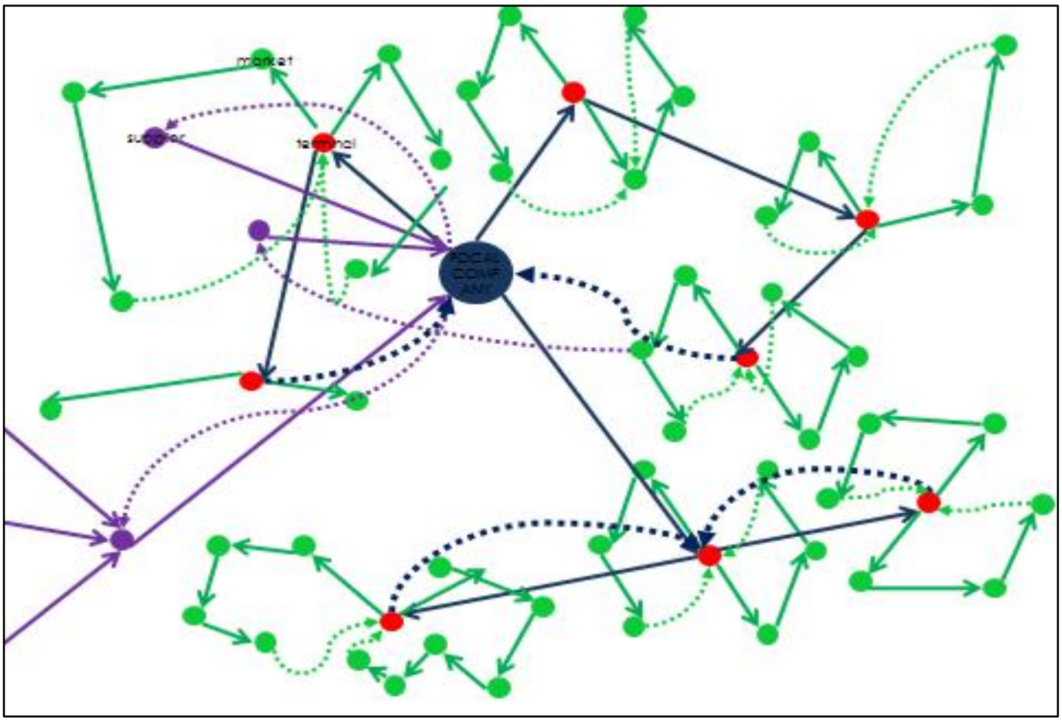


Figure 60. Process chart of the delivery cycle (an example)

The products are delivered to customers' terminals, where they are collected and connected to the market orders. The customer delivers the market orders according to their route schedules. The loads are unpacked and put onto the display shelves in the markets. The market receives an order 48 hours after it has been made.

If the delivery cycle doubled from 1 to 2 deliveries in 48 hours the supply chain would meet some changes (Figure 61). There would be many possibilities in the make and source stages to improve the delivery time. They include, e.g.

increasing or changing working hours, using work in process buffers, and increasing the efficiency of the production processes. Further, increasing raw material delivery cycles, starting new production plants nearer to the customer, and starting to sort orders in the production plant would be possible ways to improve delivery time. However, in this study the effects are limited to processes after the products are packed and sold or destroyed.

There are daily deliveries from the production plant to the terminal for order picking. If the delivery cycle doubled the load capacity would halve. The number of deliveries would double. Sorting in the terminal would be done faster and the timing of the sorting operations would change and cause increased working costs.

After the change, there would be one extra day in the products' shelf-life. Arriving the day before in the market means that there is one extra day to sell the product. It decreases the amount of waste, which means more sales and less emissions and waste costs and better probability of being sold. The more shelf-life is left the bigger is the probability of the product being sold, because many consumers prefer to buy products with a longer self-life.

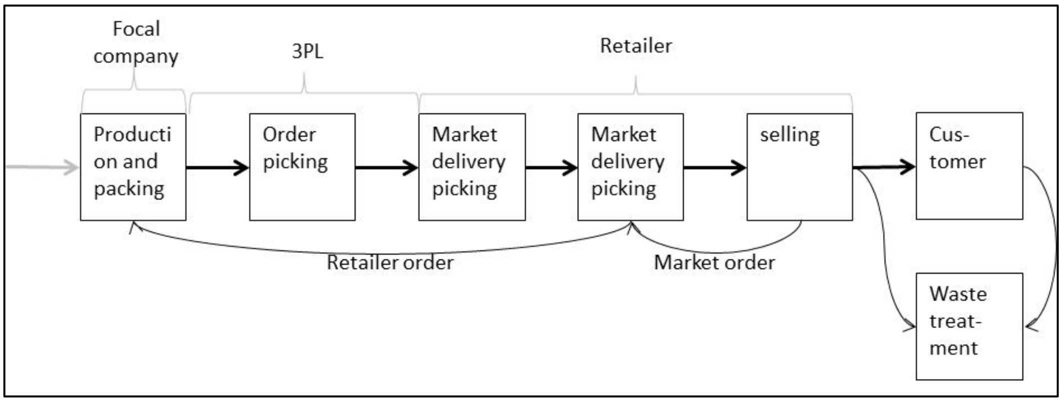


Figure 61. The main processes of case C

4.4.2 Formulae and results

The carbon emission effect of the case supply chain changes consists of the changes in the waste amounts and energy use. Energy use changes in deliveries, sorting processes and cooling costs (Figure 62). Profit would change because of the changed delivery and sorting costs. The sales number is also expected to be better because of the decreased number of "sold out" items and extra shelf-life/selling days.

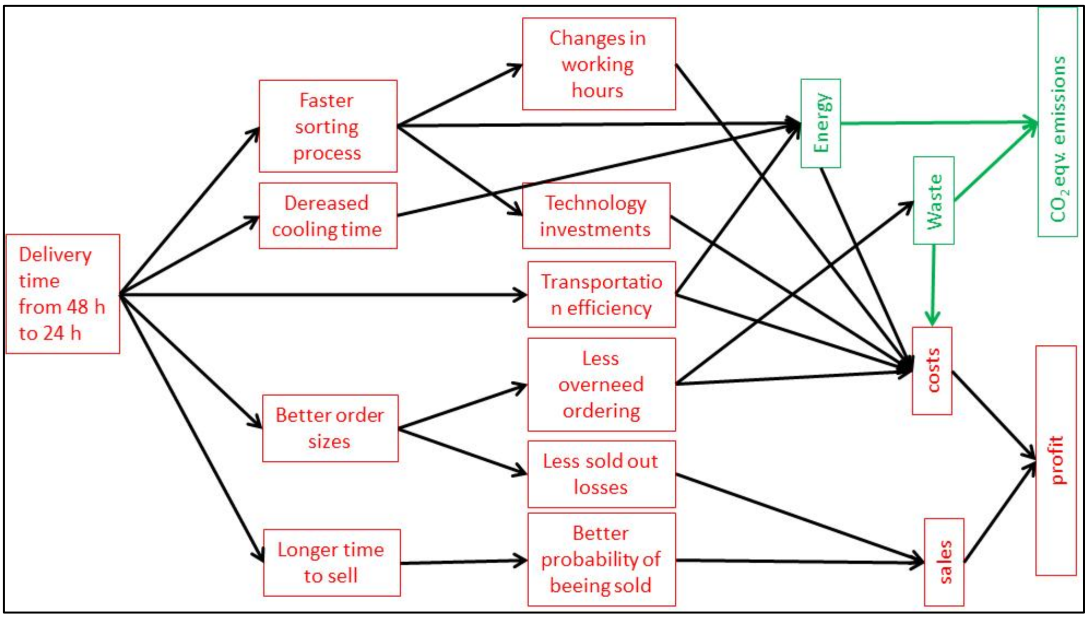
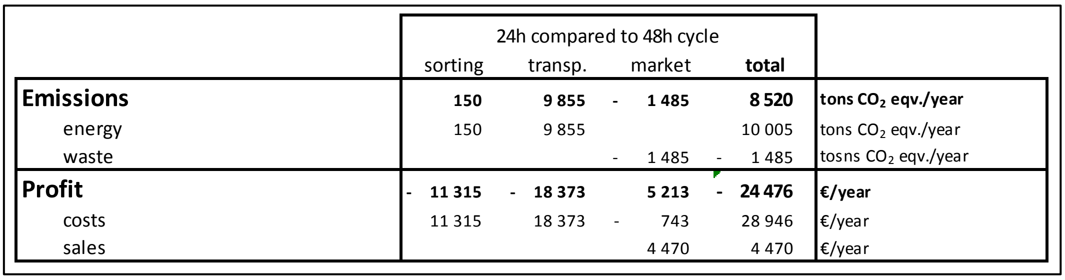


Figure 62. Effects of the delivery cycle change

In this case the focus is in the difference between scenarios. That is why the difference between scenarios has been calculated (S1, S2).

(47) $d = S_1 - S_2$

The main outputs in the case are differences between scenario emissions from waste and energy use and changes in profit as a sum of costs and sales (Figure 63).



	24h compared to 48h cycle				
	sorting	transp.	market	total	
Emissions	**150**	**9 855**	**- 1 485**	**8 520**	**tons CO_2 eqv./year**
energy	150	9 855		10 005	tons CO_2 eqv./year
waste			- 1 485	- 1 485	tosns CO_2 eqv./year
Profit	**- 11 315**	**- 18 373**	**5 213**	**- 24 476**	**€/year**
costs	11 315	18 373	- 743	28 946	€/year
sales			4 470	4 470	€/year

Figure 63. Output table of case C

The dependencies between the emissions and process changes can be modelled as follows:

(48) $e = e_w + e_e$, where

e = supply chain's total emissions (CO_2 equivalents/year), e_w = emissions caused by used energy (CO_2 eqv. /year), e_e = emissions caused by the waste (CO_2 eqv. /year), in where

(49) $\boldsymbol{e_e = \sum_1^n E_1 e_{E_1} + \cdots + E_n e_{E_n}}$, where

$E = energy\ (kWh) used\ in\ the\ process\ x$, e_E *= emissions of the used type of energy in the process (*CO_2 *eqv./ kWh),* where:

(50) $\boldsymbol{E_x = P_x t_x d_x}$, where

$P_x = power\ of\ the\ machine\ \ x\ (W)\ in\ the\ process\ x's\ subprocess\ m, t_1 =$ $daily\ time\ of\ the\ use\ of\ machine\ (h)\ x\ in\ the\ process\ x'ssubprocess$, *d= annual using days of the process x (pcs.).*

The emission effect of waste is calculated as follows:

(51) $\boldsymbol{e_w = \sum_1^n W_{p1} e_{p1} + \cdots + W_{pn} e_{pn}}$, where

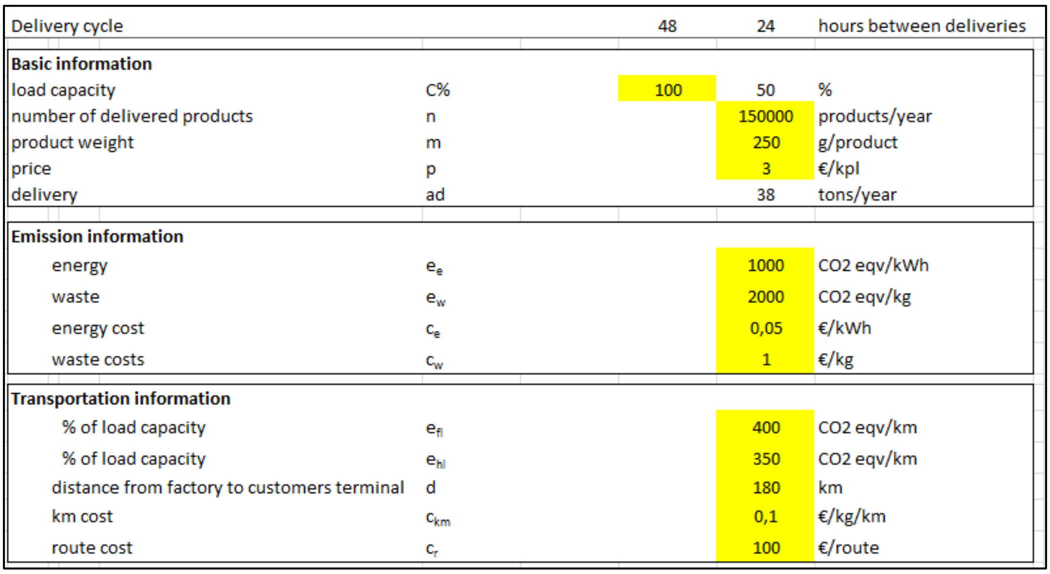
$W_{px} = waste\ from\ process\ x\ \left(\frac{kg}{year}\right), e_{px}$ *=emissions (*co_2 *eqv/kg) of the waste of the process x.*

The effect of strategic change to the profit is calculated

(52) $\boldsymbol{P = \sum_1^n (S_{p_1} + \cdots + S_{p_1}) - (C_{p_1} + \cdots + C_{p_n})}$, where

$C_{px} = change\ in\ costs\ of\ process\ x\ \left(\frac{€}{year}\right), S_{p_x} = change\ in\ sales\ of\ the\ product\ x(\frac{€}{year}).$

The basic information includes delivery information, emission and transportation information (Figure 64) such as load capacity C%, number of delivered products (p), product weight (w), price (p), delivery annual mass (ad), emissions of used energy (e_e), produced waste (e_w), cost of energy c_e, and waste c_w and emission information of full load transportation (e_{fl}), half load transportation (e_{hl}), distance from factory to customer´s terminal (d), and costs of transportation (c_{km}) and route (c_r).



Delivery cycle		48	24	hours between deliveries
Basic information				
load capacity	C%	100	50	%
number of delivered products	n		150000	products/year
product weight	m		250	g/product
price	p		3	€/kpl
delivery	ad		38	tons/year
Emission information				
energy	e_e		1000	CO2 eqv/kWh
waste	e_w		2000	CO2 eqv/kg
energy cost	c_e		0,05	€/kWh
waste costs	c_w		1	€/kg
Transportation information				
% of load capacity	e_{fl}		400	CO2 eqv/km
% of load capacity	e_{hl}		350	CO2 eqv/km
distance from factory to customers terminal	d		180	km
km cost	c_{km}		0,1	€/kg/km
route cost	c_r		100	€/route

Figure 64. An example of basic information sheet

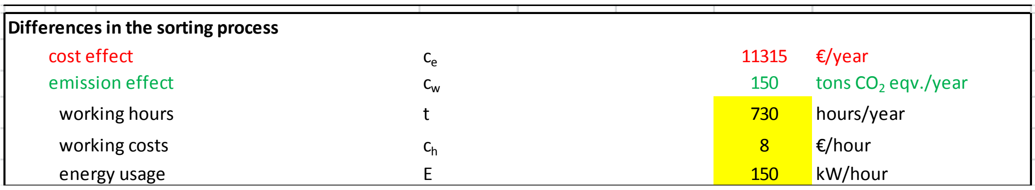
The sorting process costs consist of change of working hours (t), and energy (E) consumed in the sorting process, which also causes an emission effect (Figure 65).

The emission effect caused by changes in the sorting process is:

(53) $$\Delta e = \Delta E \Delta t e_e.$$

The cost effect is:

(54) $$\Delta c = \Delta E \Delta t c_e + \Delta t c_h.$$



Differences in the sorting process			
cost effect	c_e	11315	€/year
emission effect	c_w	150	tons CO_2 eqv./year
working hours	t	730	hours/year
working costs	c_h	8	€/hour
energy usage	E	150	kW/hour

Figure 65. Sorting process output table

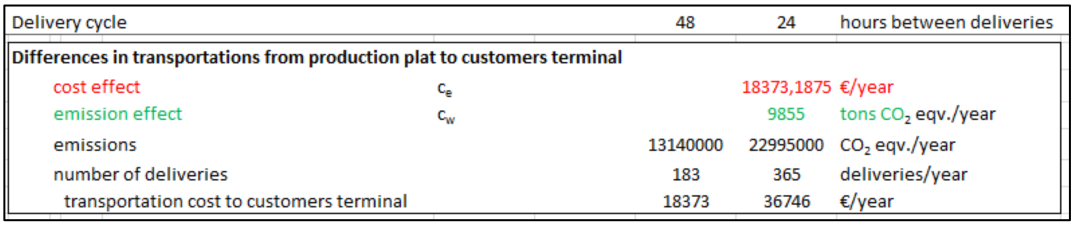
Emission effect of transportations consists of the changes in the number of the deliveries and load capacity.

(55) $$e = n_{fl} d e_{fl} - n_{hl} d e_{hl}, \text{ where}$$

n_{fl} = number of deliveries with full load, n_{hl}= number of half load deliveries, d= transportation distance, e_{fl} = unit emissions with full load, and e_{hl} unit emissions with half load.

The cost effect of transportation changes consist of the distance based costs and route based costs, as follows (Figure 66):

(56) $\mathbf{c= (n_{hl}dc_{km} + n_{hl}c_r) – (n_{fl}dc_{km} + n_{fl}c_r)}$.



Delivery cycle		48	24	hours between deliveries
Differences in transportations from production plat to customers terminal				
cost effect	c_e		18373,1875	€/year
emission effect	c_w		9855	tons CO_2 eqv./year
emissions		13140000	22995000	CO_2 eqv./year
number of deliveries		183	365	deliveries/year
transportation cost to customers terminal		18373	36746	€/year

Figure 66. Transportation output sheet

Changes in the market processes cause emission because of the waste and cost effects and sold out or discount price cause profits tp decrease. It is also possible that demand (d) will change because of increased shelf-life.

(57) $\mathbf{c = c_{24} – c_{48}}$, where

c = cost effect, c_{24} *= costs of 24 delivery* c_{48} *= costs of 48 delivery*.

The cost effect is

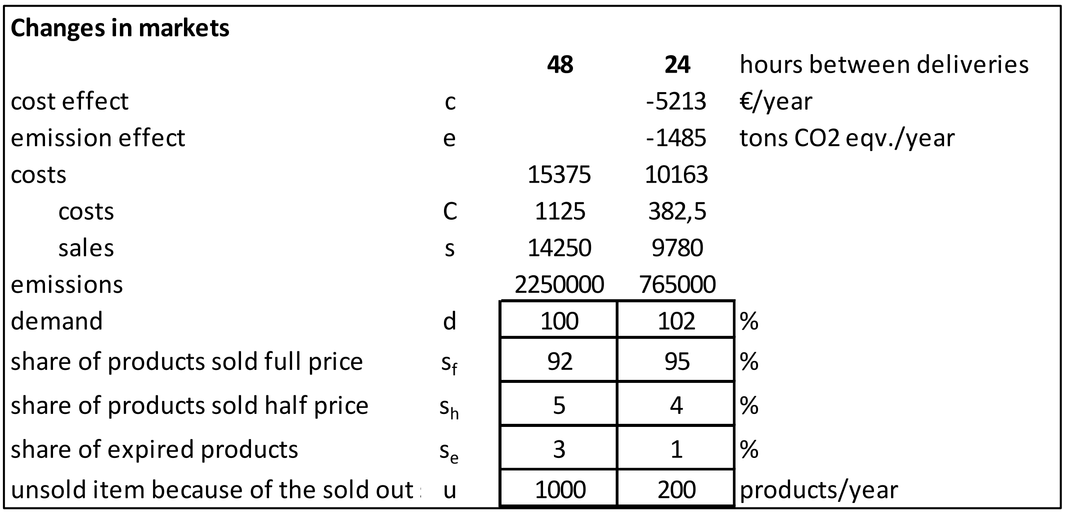
(58) $\mathbf{c = ((npd/100)s_f /100+ (npd/100)0{,}5s_h/100- (npd/100)s_e /100– up)- (npd/100)s_e/100c_w}$, where

n= number of products sold, p= price of the product, d= demand, s_f *= share of products sold full price,* s_h*= share of products sold half price%,* s_e *= share of expired products%, u = unsold products because of sold out situations,* c_w *=waste costs (€/kg).*

The emission effect consists of the wastes:

(59) $\mathbf{e = (npd/100)(s_e /100)e_w}$, where

e_w *= waste depend factor which represents amount of carbon dioxide equivalent emissions of kilogram per product (*CO_2 *eqv/kg)* (Figure 67).



Changes in markets

		48	**24**	hours between deliveries
cost effect	c		-5213	€/year
emission effect	e		-1485	tons CO2 eqv./year
costs		15375	10163	
costs	C	1125	382,5	
sales	s	14250	9780	
emissions		2250000	765000	
demand	d	100	102	%
share of products sold full price	s_f	92	95	%
share of products sold half price	s_h	5	4	%
share of expired products	s_e	3	1	%
unsold item because of the sold out	u	1000	200	products/year

Figure 67. Market output table example

4.4.3 Results

Those interviewed thought that a 24 hour delivery would be the better delivery time. However, most of the interviewed thought it would also be impossible. Almost every person interviewed thought that freshness would also be a part of product pricing because the need would be better predictable, the amount of waste would decreased and sales would increase because there would not be so much need for fast sales because of fast ending shelf-life. One of those interviewed preferred the 48 hour delivery cycle if the 24 hour cycle would mean doubled deliveries and every received delivery needed work in the market. Several of the interviewed also hoped that synchronized orders from the markets were in need of improvement.

In the production plant 24 hour delivery is possible only if the production is divided into make to warehouse and make to order stages so that the first stage is already done before receiving any orders. Also the working hours would meet the changes and probably there would be more than one order delivery per day from the plant than. Because the production and deliveries take time decentralized production would improve the ability to deliver fast because production would be nearer to the customer.

5 CONCLUSIONS AND DISCUSSION

This chapter concludes the model construction and validation process, sustainability as a performance attribute and as part of strategic management is reviewed and a pre developed model for supply chain sustainable management is presented. Then the case study results about the effects of the logistic decisions to the sustainable performance are concluded.

5.1 Constructed model

This chapter concludes how the model introduced in this study supported supply chains in making more sustainable logistics decisions, how this study increased knowledge about sustainable supply chain management as a part of the sustainable use of natural sources in the long term including social, environmental and economic issues.

Also this chapter includes conclusions to how the use of the supply chain sustainable performance estimation model helped to set performance attributes and see the connections between performances of the different attributes and how this study improved sustainable development by accomplishing current SCM systems with sustainability issues and producing information on how sustainability related metrics should be taken into consideration in management of the food supply chain.

The concluded model chapter concludes how the model developed and how the validation process of model also pre developed the model and increased the body of the knowledge about sustainable supply chain management in the Finnish case food companies.

5.1.1 Sustainability as supply chains' performance attribute

The managers in the case companies had to include or exclude performance attributes to analysis and to the part of the decision making. The connections between sustainability performance attributes and metrics were easier to see because the metrics were side by side in Excel tools.

The need to handle sustainability issues as supply chain issues instead of corporate issues were pointed out in this research. This research suggests the supply chain responsibility figure which is based on Elkington's (1997) triple bottom line model of sustainability (Figure 68). The economic, environmental and social performance is examined from the point of view of the supply chain.

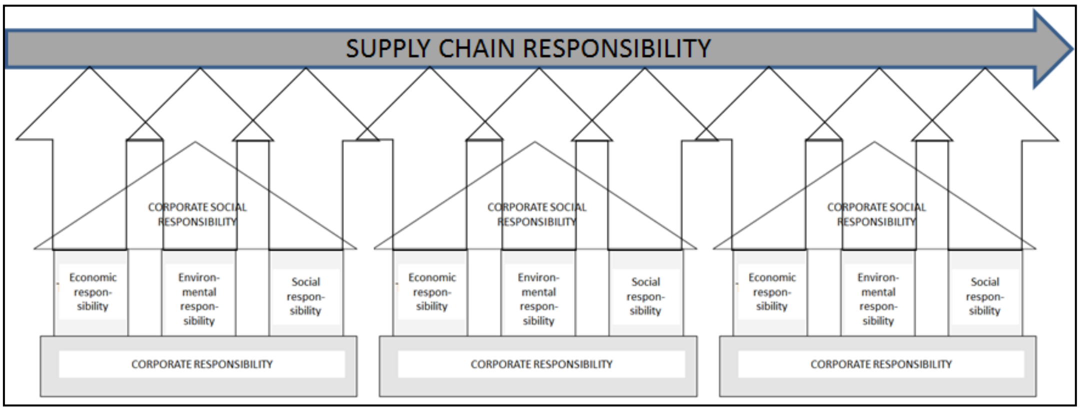


Figure 68. Supply chain responsibility

The goals of sustainable development of the supply chain are possible to achieve only by taking the goals beside strategic supply chain management. Independent management of supply chain and sustainability management systems are not sufficient enough.

Performance attributes and measuring belong to strategic management. Sustainability was used as performance attribute in this research. There is a need for sustainable development because of the need for sustainability in strategic management systems. Sustainability can be a competitive advantage in the supply chain. The supply chain sustainable performance diamond is shown in Figure 69 and it illustrates the theoretical way to describe how strategic supply chain goals can be handled as one of the supply chain performance attributes.

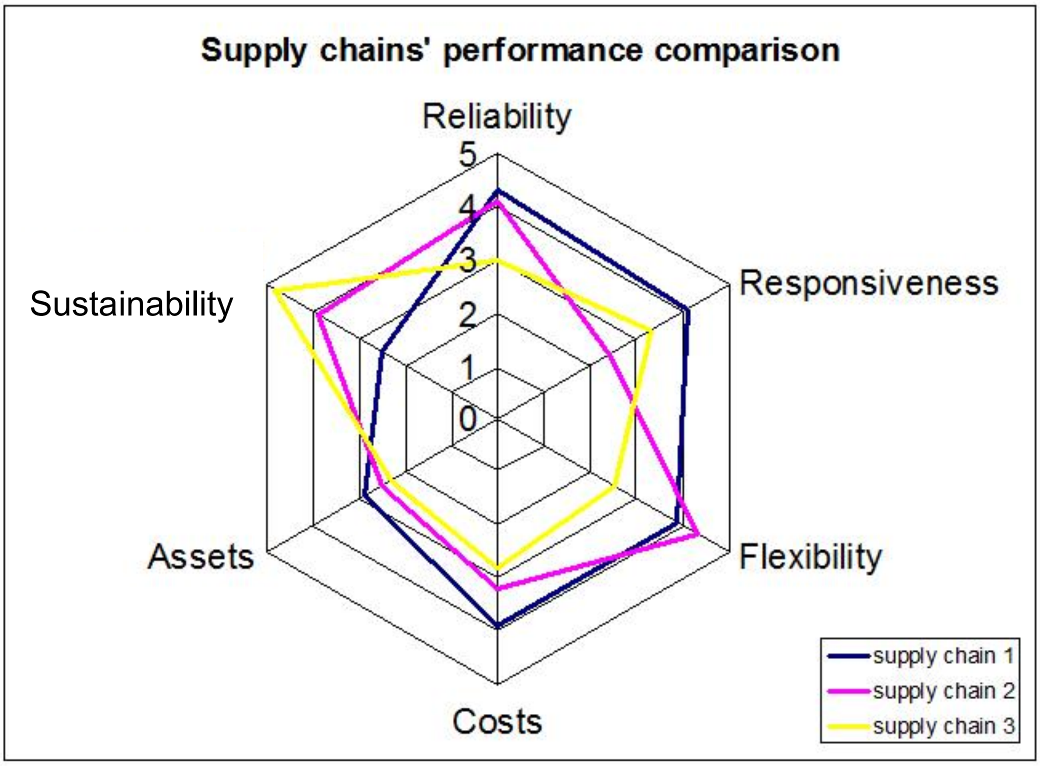


Figure 69. Supply chain performance comparison diamond

The supply chain sustainable performance diamond can be used when companies and supply chains are setting out their vision and mission and discussing their values.

The results of this study support, for example, Cooper et al.'s (1997) findings that each company in the supply chain directly or indirectly affects the supply chain performance. Now the environmental sustainability attribute and environmental metrics were placed beside the SCOR performance attributes (reliability, responsiveness, flexibility, costs and assets) and the metrics related to them, even if the environmental performance more likely affects the performance. This differs also from later developed SCOR models. More studies are needed to find out if the sustainability metrics should be inside the more traditional performance attributes. The green metrics are placed inside the current performance attributes for example in SCOR 9.0.

Seppänen et al. (2006) found that distance, loading capacity and transportation vehicle also impact the environmental effect of the transportation. Case A in this research showed that decisions considering loading capacities and integrating existing routes build up an essential part of supply chain sustainable performance. Supply chain management and logistical planning are needed. (Figure 70.)

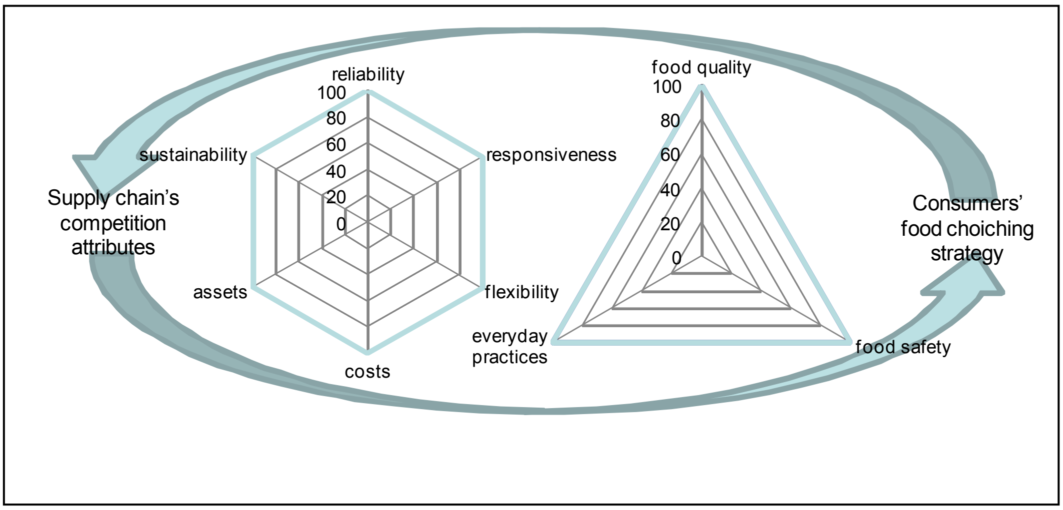


Figure 69. Connection between the competition strategy of the SC and consumers' food choice strategy

Performance is complex and dynamic term. At the same time some kinds of performance can improve while other kinds may get worse. It is a matter of future values as to how we set goals for the different performance attributes. It is possible only if we have the tools for it.

At the same time than model developed during this study has been developed and validated, several other researchers have published their models. For example a three-staged ecological green supplier management process developed by Bai, Sarkis and Wei (2011) may also help to get a broader corporate social responsibility and general sustainability perspective on the supply chain. Maybe food sector may also gain competitive advantage through strategic management of environmental challenges like Ho and Tsan-Ming (2012) suggest for fashion companies.

5.1.2 Model construction and validation

This study gave a new tool for SC management. It helped to see supply chain operations as a part of the sustainable use of natural sources in the long term. The use of the model gave supply chain view to the logistic decision making in all cases. The bigger picture helped management to see outside the own company.

The developed model included supply chains sustainability performance attributes and selected metrics for them. The case companies did not want to include all metrics to case analysis. However, excluding intentionally some metrics from analysis gave also information about sustainable decision making and made management to think the excluded issues. Lack of direction and legislation on environmental management makes it very difficult for organisations to know what they should measure and how to measure (Shaw, Grant & Mangan, 2010). Discussion in the companies during case based Excel tool construction processes helped companies to decide what to measure.

The cost and CO2 equivalent emissions rose up to the most important metrics. The case companies did not think the social performance issues, and other environmental performance metrics would not be among the most important issues in strategic logistic decisions and they were excluded from quantitative analysis. However the social issues were recognized in all companies. Also the other SCOR level 1 metrics were mainly excluded from quantitative analysis. However all metrics in the model were noticed at least in qualitative analysis.

These may be caused for example about the hard or wrong metrics in the model, difficulties to quantify many quantitative considered issues, focal companies mainly operates in Finland where social issues are generally thought be in well condition. Muthuri, Moon and Uwafiokun (2012) have researched the role of multinational corporations as obstacle to development but also as sources of solutions to some of the pressing social and environmental problems in developing countries. The circumstances in these countries are pretty much different from Finnish ones, and that is why the social issues may have different roles.

Hoffrén and Apajalahti (2009) found that sustainability and environmental things are not the issues for the Finnish medium sized companies. On the other hand in Ayuoso, Colomé and Roca's Spanish study (2013) small and medium companies can be effective in spreading the CSR requirements received from large companies through the supply chain.

The supply chain manager's decisions affect the supply chain´s sustainable performance. The supply chain's structural decisions, investment, production and supply and sourcing strategies have not only economic, but also social and environmental effects. Case studies have shown that the effects may be directed to one or several companies, or operations, for example in the studies made by Katajajuuri et al. (2008) strategic supply chain decisions have effects on performance in a shorter or longer timescale.

Number, capacity, efficiency, technology, throughput time and location of the production facilities and warehouse as well as the transportation methods compared to the market needs and raw material locations create the basics of sustainable performance.

The case companies were very interested in the carbon effect and costs related to strategic changes. Some parts of the SCOR based sustainable performance model were difficult to utilize and fit to their current management and strategic goals. The use of the model allows selecting which performance attributes and metrics supply chains companies use. The companies and supply chains that do not have sustainable performance management systems need simple tools to start. The first step for them to achieve sustainable supply chain management could be to start with a very simplified and rough model with only cost and carbon dioxide metrics. Shaw et al. (2010) said that measure must be comparable, robust, credible, valid and reliable and be applicable across all industries, sectors and countries. Developed model pointed out it possibilities to fill these criteria, but other industries, sectors and countries may need more attention for example social issues and ruminant and feeder production are not so important.

The results concerning the benefits of the supply chain sustainable performance evaluation model are encouraging. The use of the developed model helped to make strategic supply chain decision in a more sustainable way. It helped to set and implement more sustainable objectives and strategies and create and optimize sustainable supply chains. Additional to those benefits the use of the model in the case supply chain helped to foresee the effects of the estimated decisions and opened a discussion of the values of the companies in the supply chain.

The model helped management to estimate how ecological improvements in the supply chain affect the supply chain performance and vice versa. It helps to create future business strategies more ecologically and economically efficient. The model can be used as tool in supra-organizational supply chain development work. Use of the model also gave a bigger picture of the strategic decisions and the model complexity of the dependencies between the performance attributes.

Just as Wagner and Schaltegger (2003), for example, has suggested, so also this research supports the opinion that there is a relationship between environmental and social performance and economic success.

SCC have mentioned the benefits of using the SCOR model. According to the case studies the use of the SCOR based sustainable supply chain performance evaluation model helped the case companies achieve at least some of the benefits that SCC mentioned. Organizations could identification performance gaps and redesign and optimize supply chain networks and align supply chain team skills with strategic objectives.

Because the developed model is strategic and limited to the SCOR model´s first level it can be criticized as narrow. However, the number of strategic level metrics is argued and for the case companies it was the first step to develop their supply chain to be more sustainable competitive. The model may also help other food companies to take steps toward more sustainable and more compatible supply chains and to see amount of used energy, water, greenhouse gas (GHG) and to pay attention to social responsibilities like for example Pedersen (2009) suggest sustainability initiatives are.

Tools for sustainable supply chain management are needed.. The market test shows that the developed theoretical model can well be used in practical problem solving situations. Sustainable development is needed in supply chain strategic decision processes. According to the Beske (2012) investment in implementation of dynamic capabilities and SSCM practices may improve the agility of the overall supply chain and can lead to higher performance against the three dimensions of sustainability like.

Also companies need to carry out their company responsibility. Different sized companies in different industries need different ways to improve their sustainable performance. They need tools for setting sustainable goals and measuring their performance.

The model was developed before 2011 when WRI published a corporate value chain (scope 3) accounting and reporting standard. Then WRI (2011) wrote “until recently the companies have focused to emissions of their own operations but increasingly companies understand the need to account emissions along the value chain”.

The value chain accounting standard aims to make companies understand the impact of their value chain emissions and focus the company’s efforts on the greatest GHG reduction opportunities, and make more sustainable decisions about buying, selling, and producing. Scope 3 includes indirect upstream and downstream activities of the company such as purchased goods and services, capital goods, fuel and energy related activities, transportation and distribution, waste generated in operations, business travel, and employee commuting, leased assets, processing and use of sold products, end-life treatment of sold products, investments and franchises.

5.1.3 Concluded model

This section concludes and summarizes the developed food supply chain sustainable performance evaluation. The model divides the food supply chain into several parts and includes the most typical cost and greenhouse gas emission sources of the typical food chain. Also some uncertainty analysis is done with the simplified model.

Typical parts of the supply chain are crop farming, animal farming, food processing, order picking and sorting, market operations, and distribution. The most typical costs in the food supply chain consist of labor costs, material costs, fixed cost and transportation cost, fuel, warming, and energy costs. The most typical emissions from the food supply chain consist of ruminants, fertilizer, transportation and waste, as well as heating and water usage. (Figure 71.)

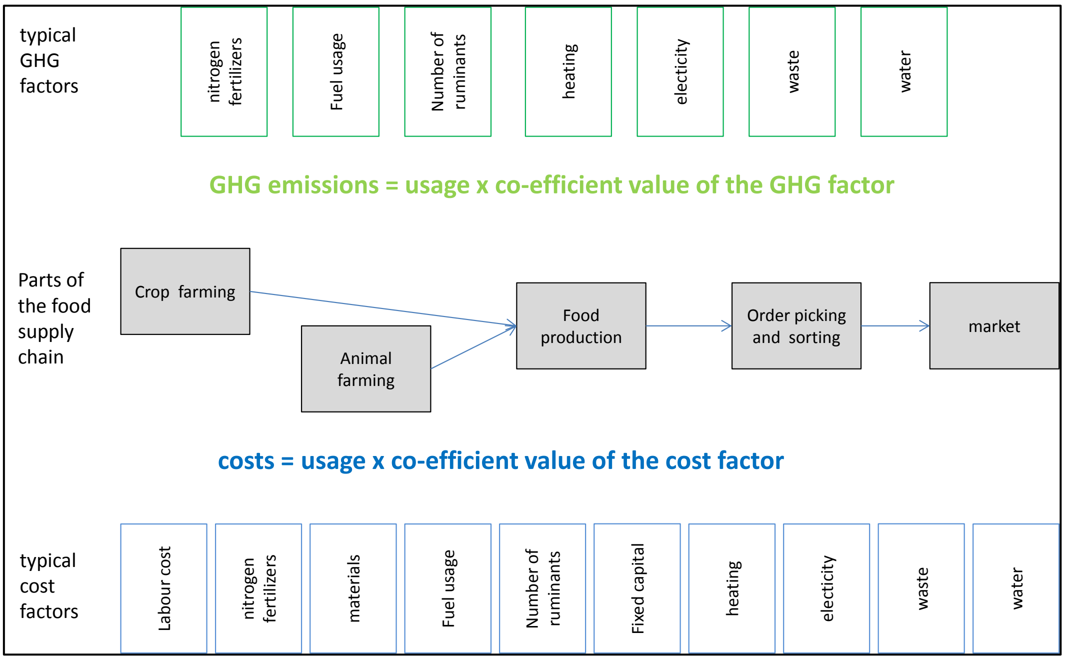
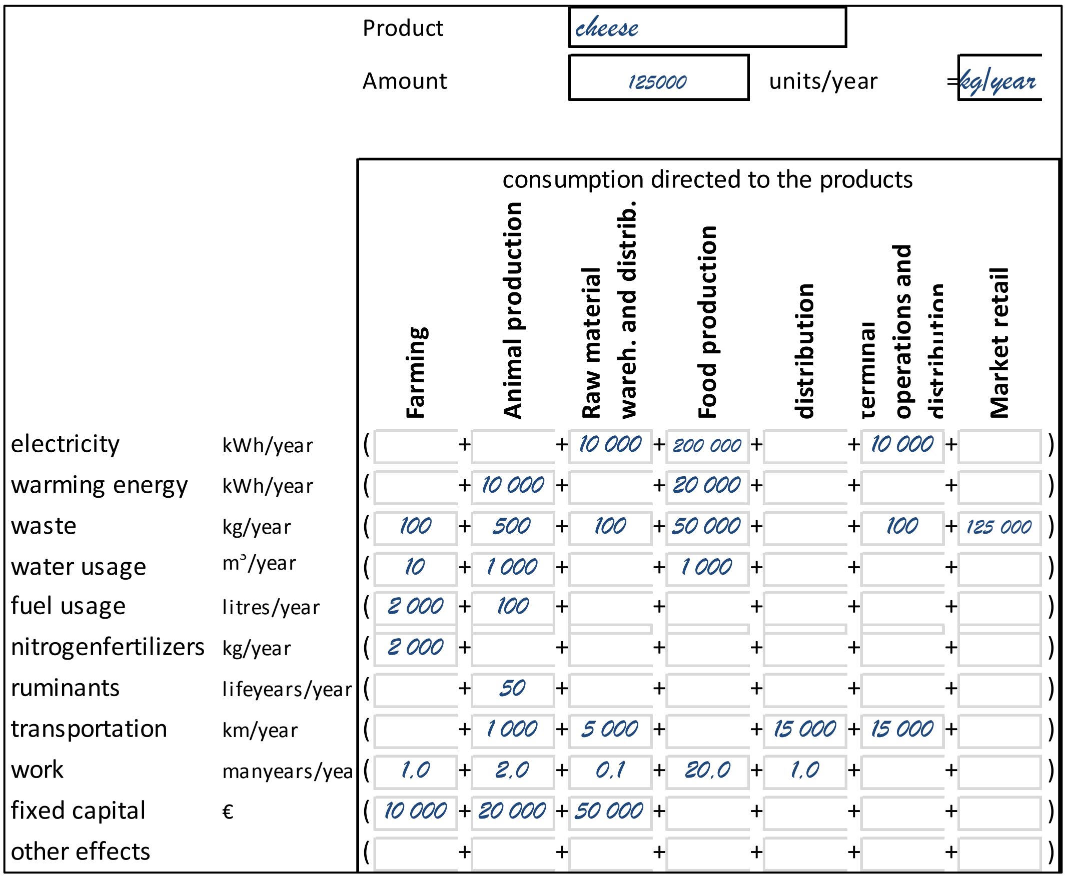


Figure 71. Typical food chain parts, cost and emission sources

The amount of chain emissions and cost sources are the results of multiplication of the usage of the cost or emission factors with the cost or emission co-efficient value. Most typical supply chain costs and GHG emissions have usage as a common divisor. Emissions and costs correlate if the co-efficient values and usage are constant.

The first step when using the simplified model is to identify the end product and supply chain processes and operators. The costs and emissions in the simplified model are based on usage. In the simplified model attention should be paid at least to electricity, heating, waste, fuel, nitrogen fertilizers, ruminant years, transportations, working hours, fixed capital and water usage. The usage should be allocated to the end product (Figure 72).



Product cheese

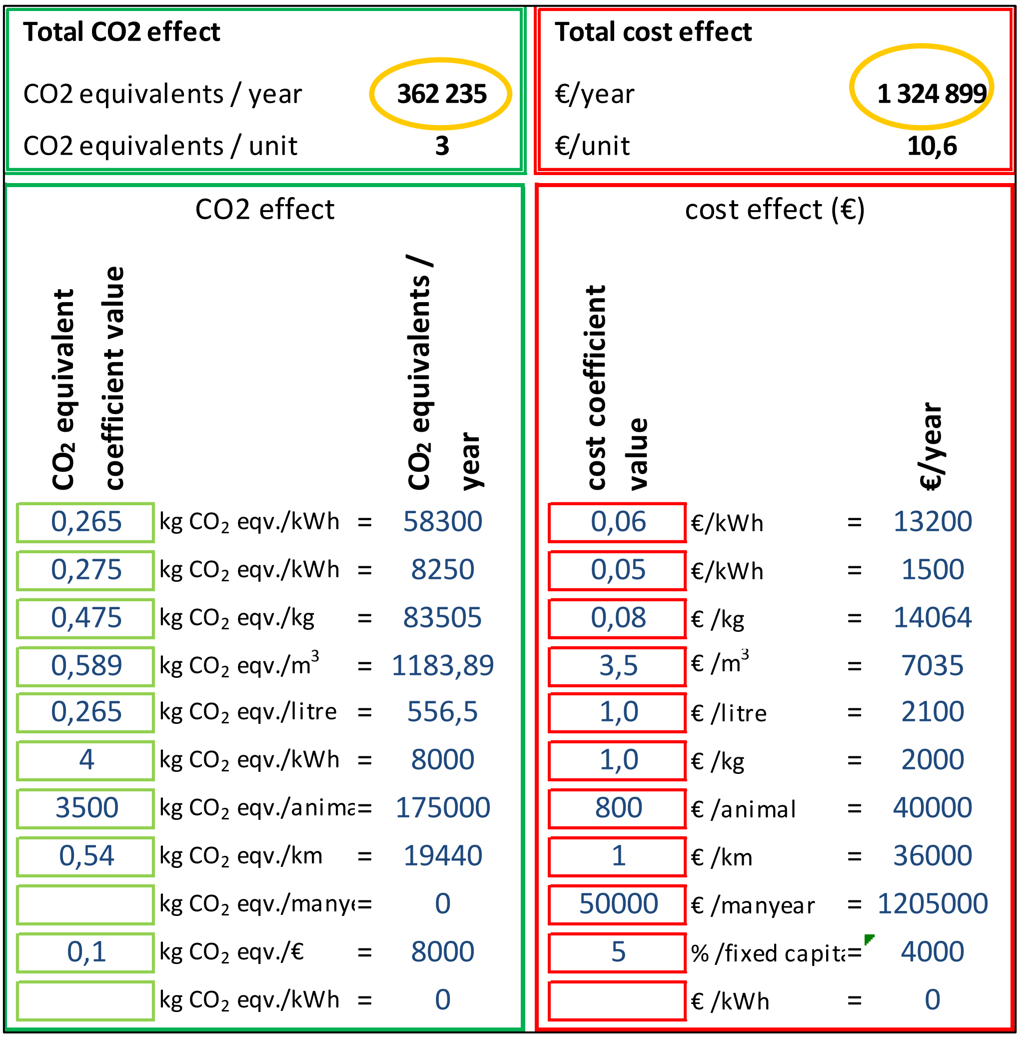
Amount 125000 units/year = kg/year

consumption directed to the products

		Farming	Animal production	Raw material wareh. and distrib.	Food production	distribution	terminal operations and distribution	Market retail
electricity	kWh/year			10 000	200 000		10 000	
warming energy	kWh/year		10 000		20 000			
waste	kg/year	100	500	100	50 000		100	125 000
water usage	m³/year	10	1 000		1 000			
fuel usage	litres/year	2 000	100					
nitrogenfertilizers	kg/year	2 000						
ruminants	lifeyears/year		50					
transportation	km/year		1 000	5 000		15 000	15 000	
work	manyears/yea	1,0	2,0	0,1	20,0	1,0		
fixed capital	€	10 000	20 000	50 000				
other effects								

Figure 72. Input table of the simplified model

The usage of the supply chain consists of the farming, animal production, raw material warehousing and distributing, food production, distribution, terminal operations and distribution, and market retail operations.



Total CO2 effect		**Total cost effect**	
CO2 equivalents / year	**362 235**	€/year	**1 324 899**
CO2 equivalents / unit	**3**	€/unit	**10,6**

CO2 effect				cost effect (€)			
CO_2 equivalent coefficient value			**CO_2 equivalents / year**	**cost coefficient value**			**€/year**
0,265	kg CO_2 eqv./kWh	=	58300	0,06	€/kWh	=	13200
0,275	kg CO_2 eqv./kWh	=	8250	0,05	€/kWh	=	1500
0,475	kg CO_2 eqv./kg	=	83505	0,08	€ /kg	=	14064
0,589	kg CO_2 eqv./m^3	=	1183,89	3,5	€ /m^3	=	7035
0,265	kg CO_2 eqv./litre	=	556,5	1,0	€ /litre	=	2100
4	kg CO_2 eqv./kWh	=	8000	1,0	€ /kg	=	2000
3500	kg CO_2 eqv./anima	=	175000	800	€ /animal	=	40000
0,54	kg CO_2 eqv./km	=	19440	1	€ /km	=	36000
	kg CO_2 eqv./many	=	0	50000	€ /manyear	=	1205000
0,1	kg CO_2 eqv./€	=	8000	5	% /fixed capita	=	4000
	kg CO_2 eqv./kWh	=	0		€ /kWh	=	0

Figure 73. Example of the output table of the simplified model

In the simplified model (Figure 73), there are two main outputs: CO_2 equivalent emissions kg/unit of product and costs €/unit of product. The CO_2 effect can be calculated by using CO_2 equivalent units. the CO_2 equivalent effect is calculated by multiplying the supply chain usage with CO_2 equivalent coefficient value.

The coefficient value of electricity and heating used in the example is based on the estimation given by Ikäheimo (2012) at the energy company Vantaan Energia. The waste is based on the report of Myllymaa et al. (2008). Fuel CO_2 eqv. coefficient value is based on *Energiatilasto* (2006). The annual CO_2 effect of nitrogen fertilizers and ruminants is based on Pipatti, Tuhkanen, Mälkiä and Pietilä (2000). The effect of transportation is based on VTT's database (2011), Lipasto: half load delivery car, maximum capacity 15 t. The total delivery (return) distance is divided into products.

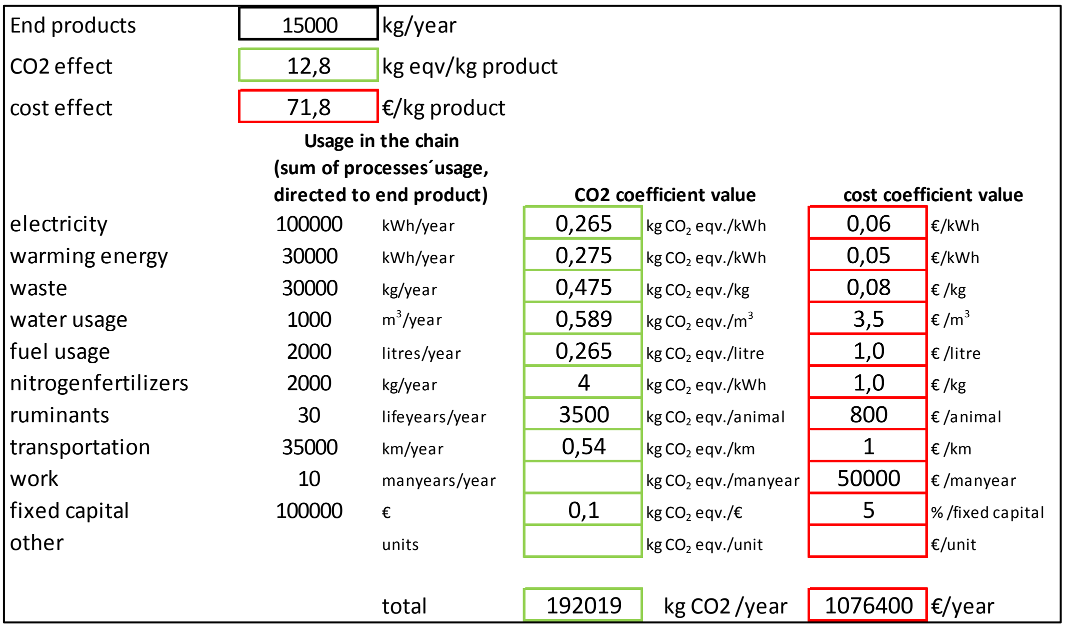
The electricity cost coefficient value is based on data from Energiamarkkinavirasto (2012), heating from Vattenfall (2012), waste costs from Myllymaa et al.'s report (2008), fuel from the Finnish Petroleum Federation (2012), nitrogen fertilizers from *Käytännön maamies* (2012). The cost of ruminant (feed) is based on data from Riepponen (2001): feeding costs 20% of the average total costs per animal (4000 €). Transportation costs are based on Kurkoline's (2012) fares on their website.

Fixed capital means building costs and these are based on Kurnitski (2012). He suggests the building carbon effect consists of building material and raw material production and the use stage causes energy usage, maintenance and disassembly effects. The carbon effect of building depends on the materials, so that in his study wood has the effect of 191 kg CO_2 / m^2 and concrete 268 kg CO_2 / m^2. If the building costs are 2000 €/m^2, then the carbon effect per build square meter is ca. 0.1 kg CO_2 / €. Yara (2010) informs that nitrogen fertilizers cause less than 4 kg CO_2 eqv. per used nitrogen fertilizer.

Usage and co-efficient value are often not constant and they depend a lot, for example, on infrastructural and political issues, the weather, delivery time and strategic decisions. If the usage affects the coefficient value then the correlation changes. The effect of the delivery time and transportation cost, load capacities, distances, and benefit allocation in a co-operation situation on the usage and co-efficient values are discussed in the next section.

5.1.3.1 Sensitivity analysis

This section introduces how changes in input values affect the outputs. In Figure 74 the input values are shown (usage of each main element of cost or CO_2 in the supply chain).



End products	15000	kg/year				
CO2 effect	12,8	kg eqv/kg product				
cost effect	71,8	€/kg product				
	Usage in the chain (sum of processes´usage, directed to end product)		**CO2 coefficient value**		**cost coefficient value**	
electricity	100000	kWh/year	0,265	kg CO_2 eqv./kWh	0,06	€/kWh
warming energy	30000	kWh/year	0,275	kg CO_2 eqv./kWh	0,05	€/kWh
waste	30000	kg/year	0,475	kg CO_2 eqv./kg	0,08	€ /kg
water usage	1000	m^3/year	0,589	kg CO_2 eqv./m^3	3,5	€ /m^3
fuel usage	2000	litres/year	0,265	kg CO_2 eqv./litre	1,0	€ /litre
nitrogenfertilizers	2000	kg/year	4	kg CO_2 eqv./kWh	1,0	€ /kg
ruminants	30	lifeyears/year	3500	kg CO_2 eqv./animal	800	€ /animal
transportation	35000	km/year	0,54	kg CO_2 eqv./km	1	€ /km
work	10	manyears/year		kg CO_2 eqv./manyear	50000	€ /manyear
fixed capital	100000	€	0,1	kg CO_2 eqv./€	5	% /fixed capital
other		units		kg CO_2 eqv./unit		€/unit
		total	192019	kg CO2 /year	1076400	€/year

Figure 74. Input values in the model

Every other input but the amount of end products has normal distributed uncertainty of +/- 10%. This means usage and coefficient values of the costs and emissions vary according to normal distribution +/- 10%.

In this kind of situation there is over 90% probability that the emissions of the chain are between 1.15 and 1.55 kg CO_2 eqv./product kg (Figure 75). The skewness of the deviation is 0.5 and mean emissions 1.3 kg CO_2 eqv./product kg.

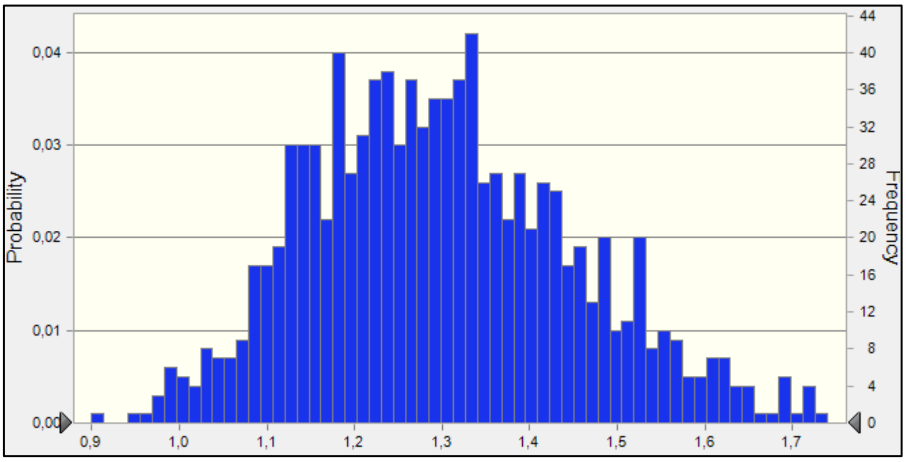


Figure 75. Probability and sensitivity of CO_2 emissions

The most sensitive input from the point of view of CO_2 equivalent emissions is the amount of end products (-72.4%) and ruminant life years (19.9%). The costs were most sensitive to the costs and coefficient value of fixed capital (35.0%;

13.0%), working costs (man years and cost per man year) (23.5%; 21.2%), usage of warming energy (- 1.3%) and amount of waste (1.1%). In this scenario there was over 90% probability that the unit costs of the product would varyfrom 6.2 to 8.7 €/ kg of the product.

5.1.3.2 Effect of delivery time to the markets

Delivery time has effects on the performance of the supply chain in many ways. Quicker delivery time is possible to reach by increasing the delivery cycle or quickening the delivery time "on the way". It affects, for example, the amount of waste, sold-out situations, delivery times, delivery cycles, market areas and demand forecasts. For this reason it has effects on the ecological and economic results because it affects costs and sold products.

In the case of doubling the ***delivery frequency*** the product has a longer shelf-life from the point of view of the end-users and markets because the product is available to customers earlier. The longer selling time decreases the amount of waste.

On the other hand, halving the delivery time enables double distance deliveries at the same time. Doubling the delivery distance means a four times bigger market area (from ca. 125 660 km^2 to 502 640 km^2) in theory (Figure 76).

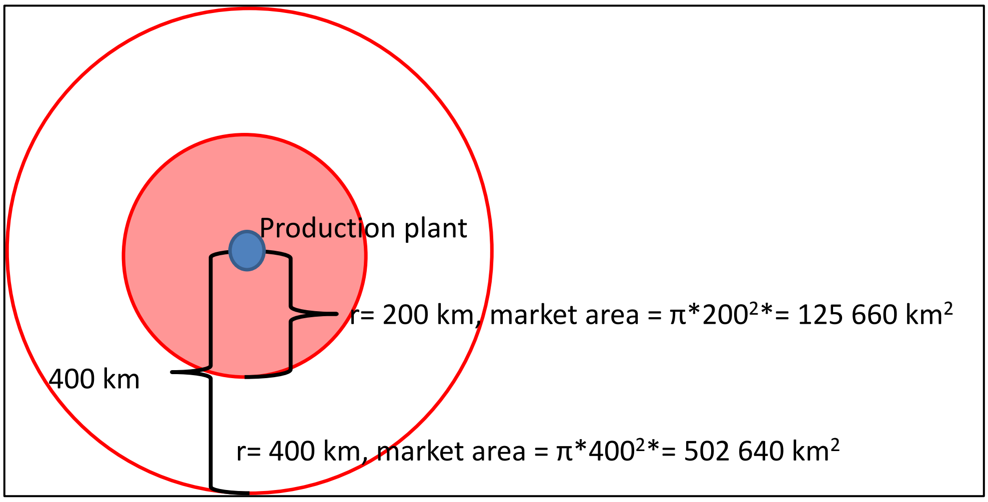


Figure 76. Market area when doubling delivery time

The delivery time of food may be an important factor in food sustainability. Freshness can also be a competitive advantage. Public institutions can use it, for example, as a purchasing criterion; for example, "bread has to baked not more than 4 hours before delivery to the customer's door".

If the markets stay constant, and the delivery time is halved, the supply chain sustainable performance would still meet the changes. Halving the delivery time can be the result of quicker deliveries because of higher speeds of the vehicles or quicker process or waiting times or increased delivery cycle. Those changes affect both costs and emissions, for example because of changed technologies. Quicker deliveries also increase the selling days which affect the amount of waste. That has an effect on costs and emissions. Quicker delivery time also improves the accuracy and predictability of the order sizes and decreases sold out situations.

In this scenario it is assumed that the product amount is 100 000 kg/year, the product shelf-life time is 14 days and mean delivery time is 2 days, when the amount of the waste is 10%. Then the delivery takes 14.3% of the product's shelf-life time and the product has 12 sales days left when the product arrives on the market.

It is also assumed that there is a negative correlation between ratio of delivery time and the product's shelf-life time compared to the amount of waste. If the amount of waste changes as much as the ratio between shelf-lifetime compared to the delivery time, then for example decreasing delivery time by 1 day means the sales days left when the product arrives on the market increase by 7,4% from 12 days to 13 days. At the same time it is assumed that the amount of waste decreases by 7.4% when it would otherwise be 9.3% (Figure 77).

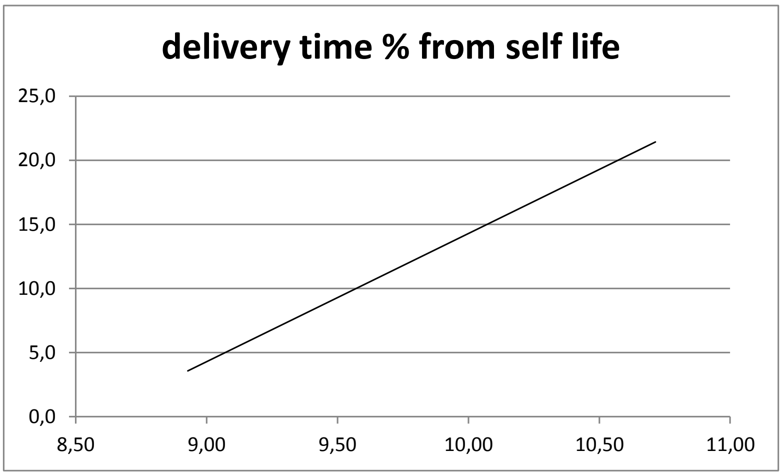


Figure 77. Share of delivery time of the shelf-life compared to share of waste

If the waste costs 10 €/kg and causes 0.475 g CO_2 eqv./kg waste, the greenhouse gas effect and costs depend on the delivery time linearly as shown in Figure 78.

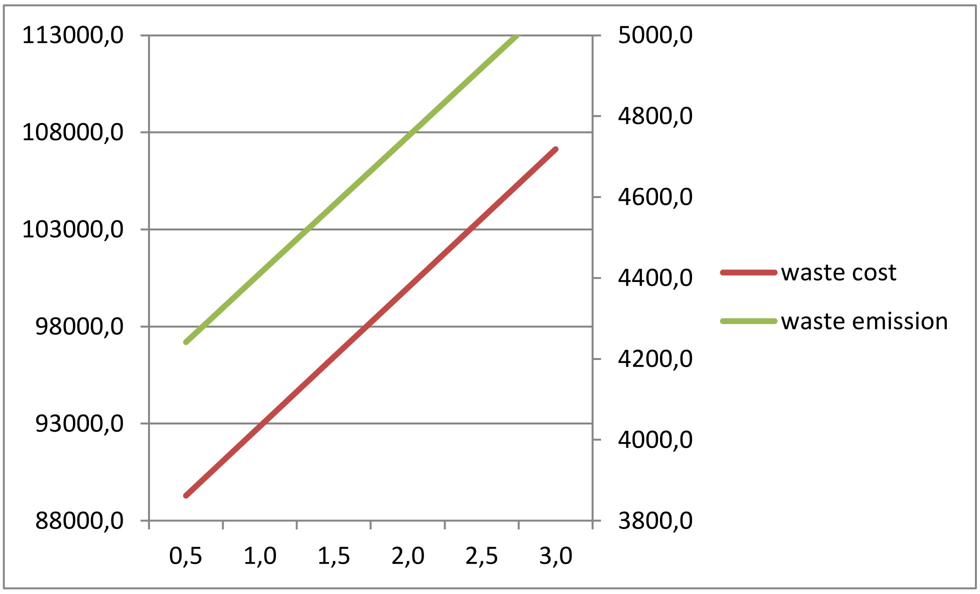


Figure 78. Waste costs and emission compared to delivery time

If the delivery time is halved because of faster vehicles, for example changing from van to train, it has effects on emissions and costs; for example, a train produces 9.3 g CO_2 eqv. per kilometer while a van emits 192 g CO_2 eqv. per kilometer.

This calculation is rough and needs more empirical studies and evidence, and it can be applied only for short shelf-life time products.

5.1.3.3 *Effect of the emission direction on costs and CO_2*

Figure 79 describes the direction problem of the transportation. In this research the whole route is calculated (A-A, A-B, B-B and B-A) and costs and emissions are directed to products in the relation of ton kilometers.

This section describes the effects of different direction principles. The CO_2 equivalent effects are divided into direct and indirect effects. Direct effects for company A consist of emissions in the route from plant A to A’s customer and for B from plant B to B’s customers (Figure 76).

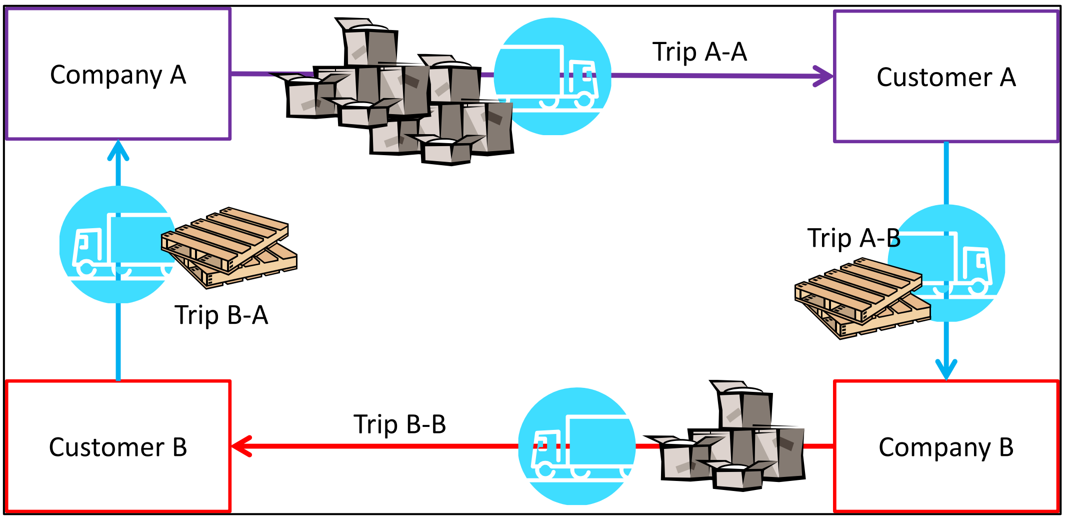
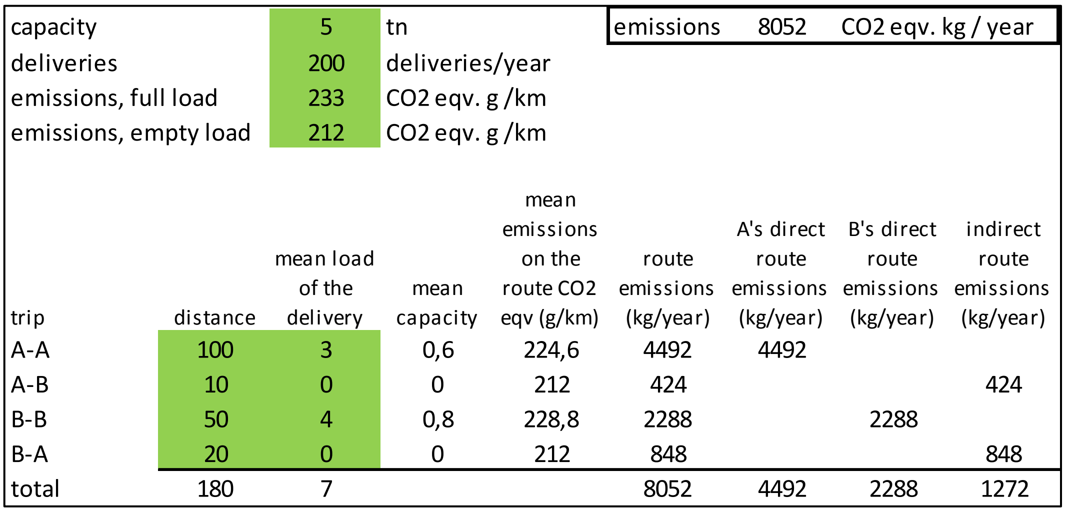


Figure 79. Example case of route emission direction problem

Indirect costs in these example calculations consist of the routes from A's customer to B's plant and from B's customer to A's plant. The indirect emissions are divided into A and B based on the products (kg/year), kilometers, and ton kilometers, or they can be divided for every company that have deliveries on the route.

If the capacity of the car is 5 tons and there are 200 routes / year the load capacity affects the emissions linearly. If the full load emissions are 233 and empty car emissions 212 CO_2 eqv. g/km (Lipasto, VTT, 2011) the load between 0 and 100% is between them 0.6; 0; 0.8; 0. The route emissions consist of A-A, A-B, B-B and B-A, and each is calculated as multiplying the number of deliveries/year (200), mean emissions of the route (224.6; 212; 228.8; 212 CO2 eqv. kg/km) and distance (100, 10, 50, 20 km). The direct emissions for A are in this case 4492 and for B 2288 kg CO_2 eqv./year and indirect 1272 kg CO_2 eqv./year, which means the yearly emissions of the whole route with these values are 8052 kg CO_2 equivalents (Figure 80).

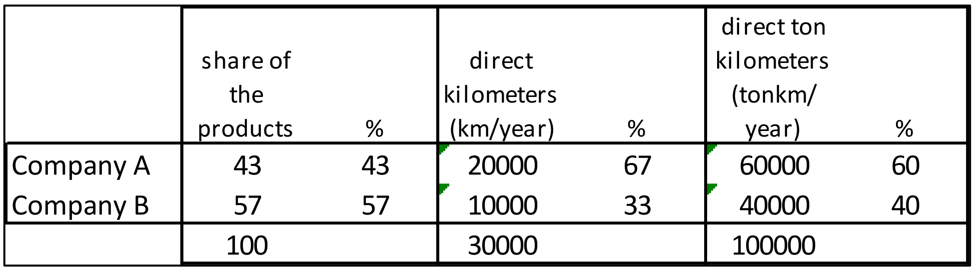


capacity	5	tn	emissions	8052	CO2 eqv. kg / year
deliveries	200	deliveries/year			
emissions, full load	233	CO2 eqv. g /km			
emissions, empty load	212	CO2 eqv. g /km			

trip	distance	mean load of the delivery	mean capacity	mean emissions on the route CO2 eqv (g/km)	route emissions (kg/year)	A's direct route emissions (kg/year)	B's direct route emissions (kg/year)	indirect route emissions (kg/year)
A-A	100	3	0,6	224,6	4492	4492		
A-B	10	0	0	212	424			424
B-B	50	4	0,8	228,8	2288		2288	
B-A	20	0	0	212	848			848
total	180	7			8052	4492	2288	1272

Figure 80. Route emission direction input table

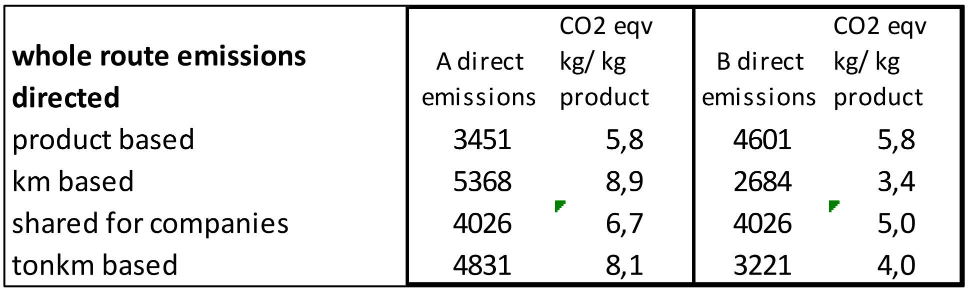
If the indirect emissions are divided based on A’s and B’s number of delivered products (kg/year) (43/57%), kilometers (km/year) (67 / 33%), and ton kilometers (ton kilometers/year) (60 / 40%) the results vary a lot (Figure 81).



	share of the products	%	direct kilometers (km/year)	%	direct ton kilometers (tonkm/ year)	%
Company A	43	43	20000	67	60000	60
Company B	57	57	10000	33	40000	40
	100		30000		100000	

Figure 81. Companies’ products, kilometers and ton kilometers

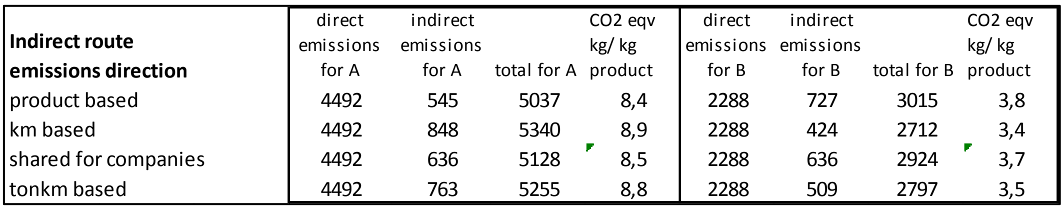
If the whole route emissions are directed to (Figure 82) company A and B’s products, A’s emissions per product vary from 5.8 to 8.9 kg CO_2 eqv/product kg and B’s from 3.4 to 5.8 kg CO_2 eqv/product kg.



whole route emissions directed	A direct emissions	CO2 eqv kg/ kg product	B direct emissions	CO2 eqv kg/ kg product
product based	3451	5,8	4601	5,8
km based	5368	8,9	2684	3,4
shared for companies	4026	6,7	4026	5,0
tonkm based	4831	8,1	3221	4,0

Figure 82. Direction of CO_2 eqv. emissions (whole route)

If the indirect emissions are divided into companies A and B in the same relation, the total emissions for A and B for one kilogram of product A varies from 8.4 to 8.9 and for product B from 3.4 to 3.8 kg CO_2 eqv./product kg (Figure 83).

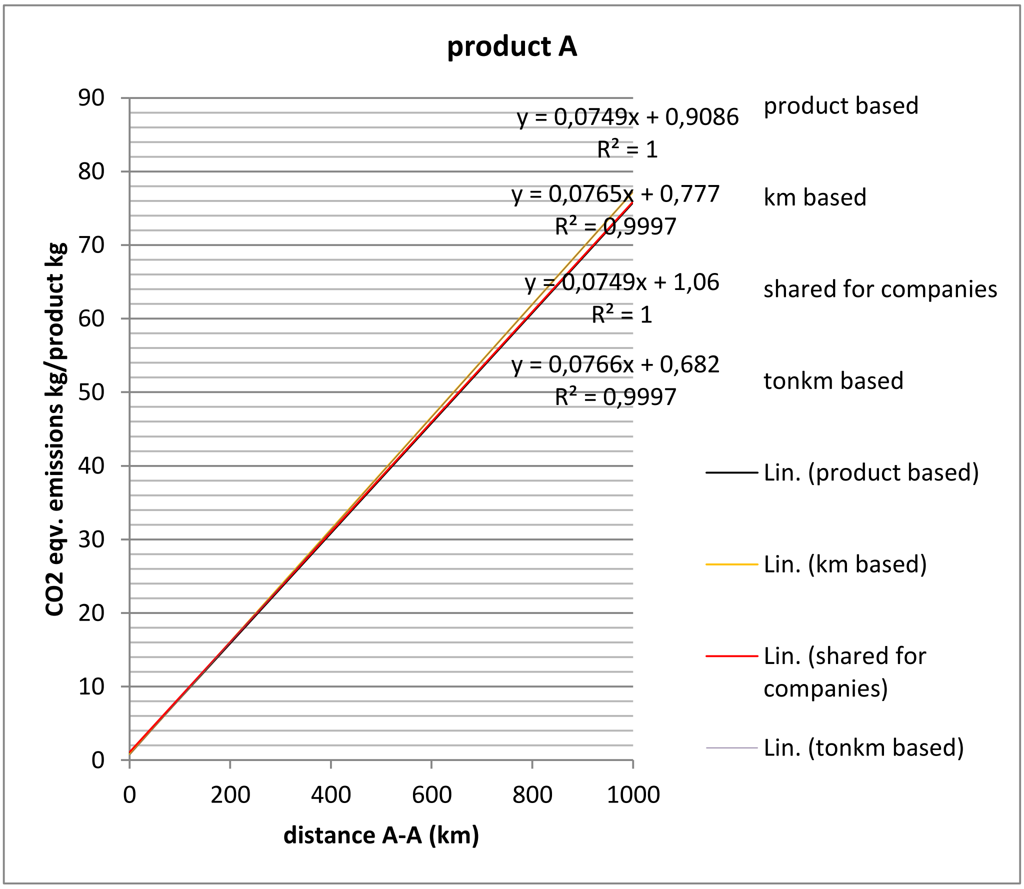


Indirect route emissions direction	direct emissions for A	indirect emissions for A	total for A	CO2 eqv kg/ kg product	direct emissions for B	indirect emissions for B	total for B	CO2 eqv kg/ kg product
product based	4492	545	5037	8,4	2288	727	3015	3,8
km based	4492	848	5340	8,9	2288	424	2712	3,4
shared for companies	4492	636	5128	8,5	2288	636	2924	3,7
tonkm based	4492	763	5255	8,8	2288	509	2797	3,5

Figure 83. Direction of indirect CO_2 eqv. emissions

Company A, which has longer distances, but smaller delivery capacity, would benefit from dividing all the route costs based on products. Company B that has smaller distance but bigger load capacity would benefit if it could divide its emissions based on kilometers.

If the distance A-A changes from 1 to 1000 kilometer per product, then A's product based emissions vary from 0.1 to 77 kg CO_2 eqv. per kilogram of the product and B's from 3.7 to 2.9 CO_2 eqv. per kilogram of the product (Figure 84). The route changes made by company A affect company B more if the emissions are directed to products based on kilometers or ton kilometers.


product A
CO2 eqv. emissions kg/product kg
distance A-A (km)
0
10
20
30
40
50
60
70
80
90
0
200
400
600
800
1000
y = 0,0749x + 0,9086
R² = 1
y = 0,0765x + 0,777
R² = 0,9997
y = 0,0749x + 1,06
R² = 1
y = 0,0766x + 0,682
R² = 0,9997
product based
km based
shared for companies
tonkm based
Lin. (product based)
Lin. (km based)
Lin. (shared for companies)
Lin. (tonkm based)

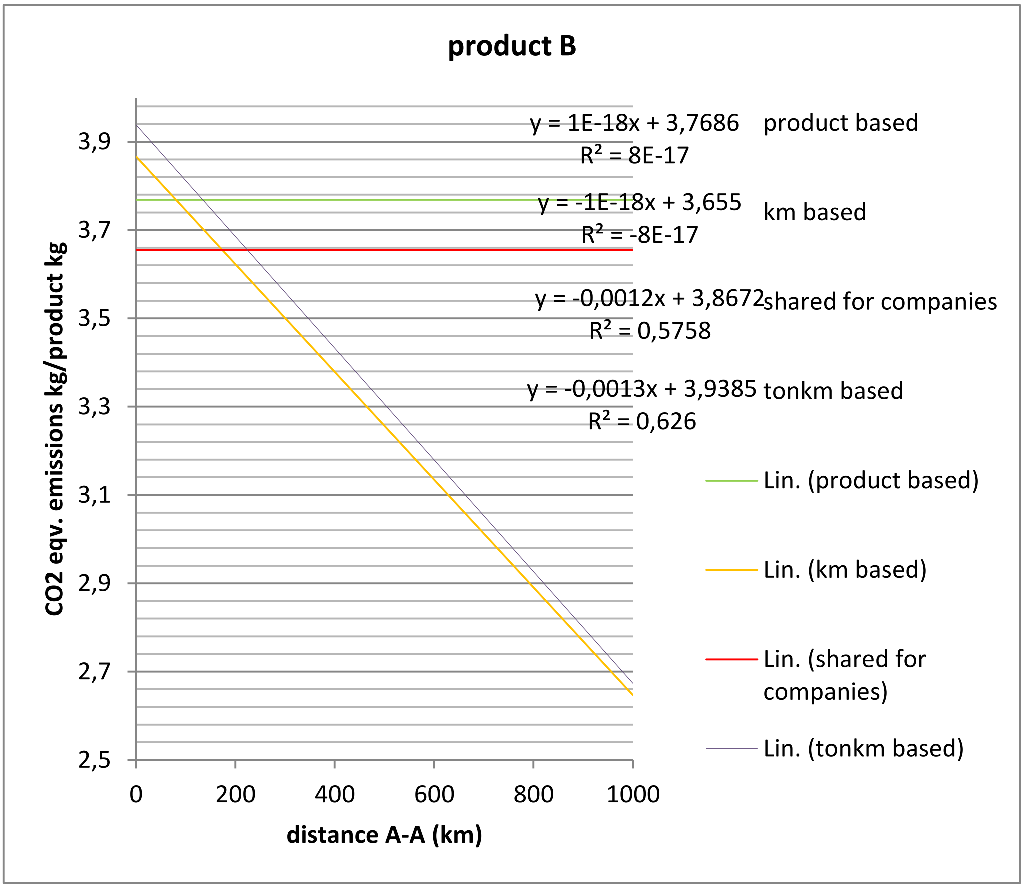


Figure 84. Effect of distance (A-A) on products' emissions by direction principles

If the mean load on the route varies between 0.5 tons and 5 tons (capacity 10% to 100%) the CO_2 effect per product A varies from 5.3 to 51 and for B from 3.3 to 4.3 kg CO_2 eqv/ product kg (Figures 85, 86 and 87).

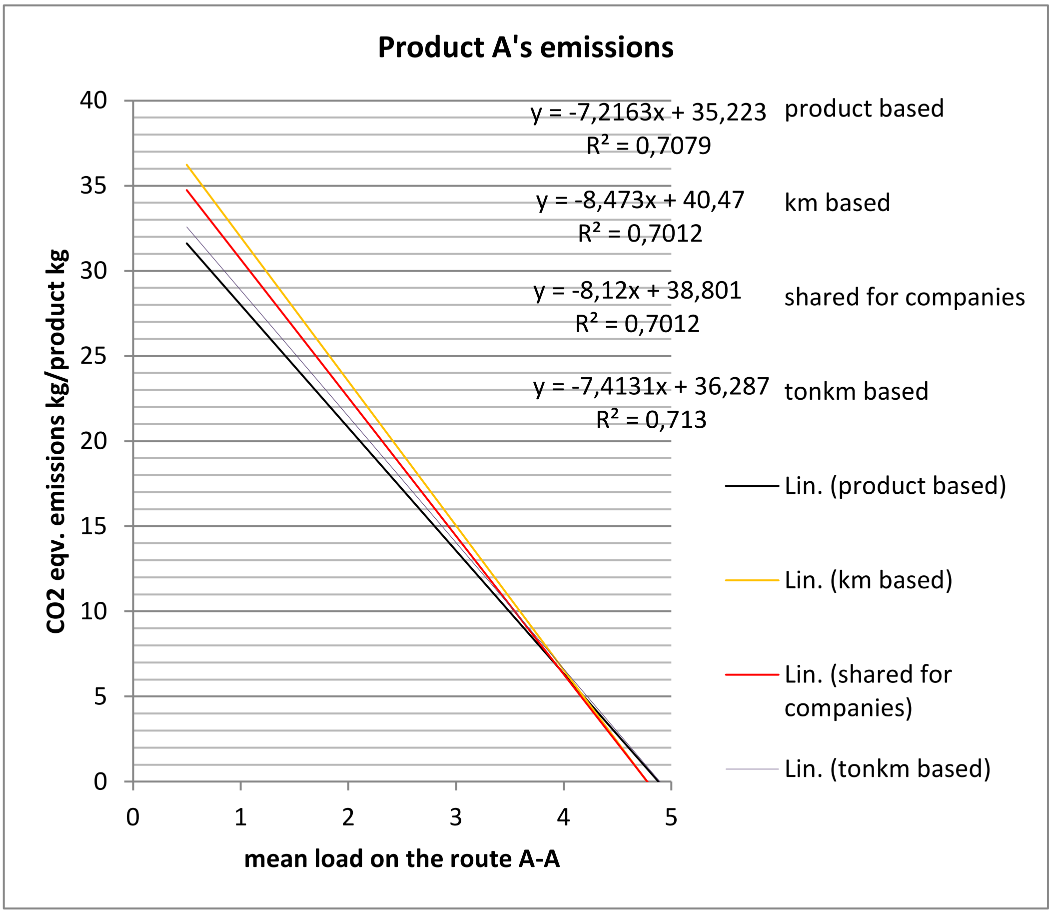


Figure 85. Effect of mean load in the route (A-A) to product A emissions

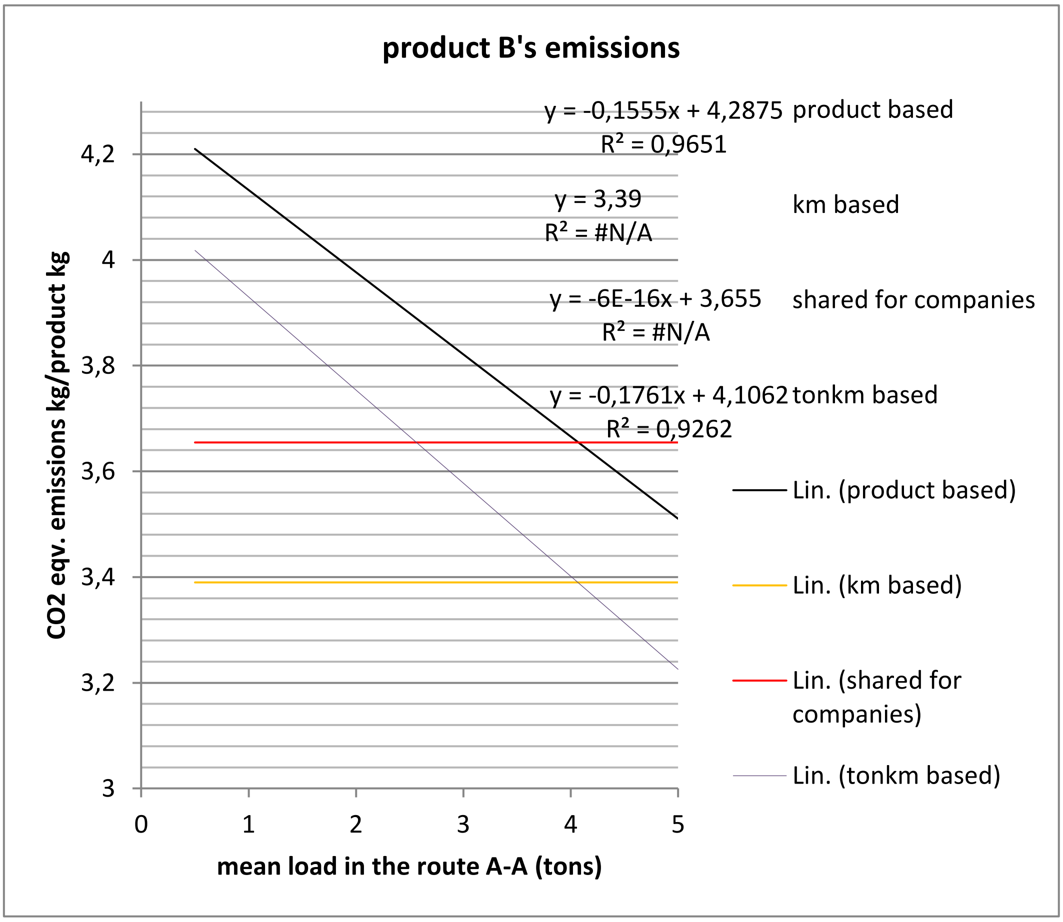


Figure 86. Effect of mean load on route (A-A) on product B emissions

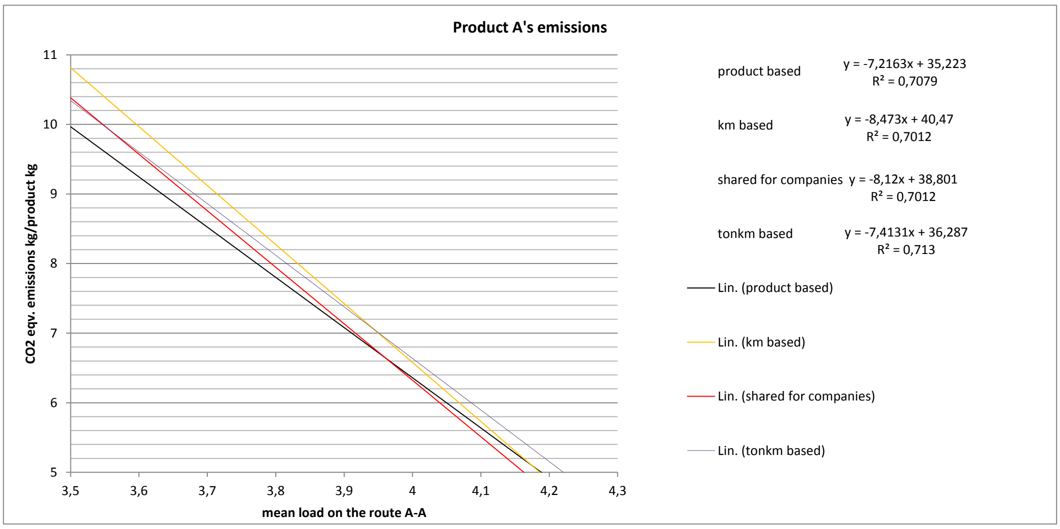


Figure 87. Effect of mean load on route (A-A) on product emissions: a detail of product A's emissions

Uncertainty of the input values was considered so that mean load is set to uniform distribution from 0.1 to 5 ton and on delivery distances a normal distribution of +/- 50% and number of annual deliveries from +/- 100%.

In that kind of situation deviation was skewed in every scenario, being more likely to be smaller than the mean values, which were 8.4 and 3.7; 8.9 & 3.4; 8.5 and 3.7; 8.8 and 3.5 kg CO_2 eqv./ kg of the end product. (Figure 88.)

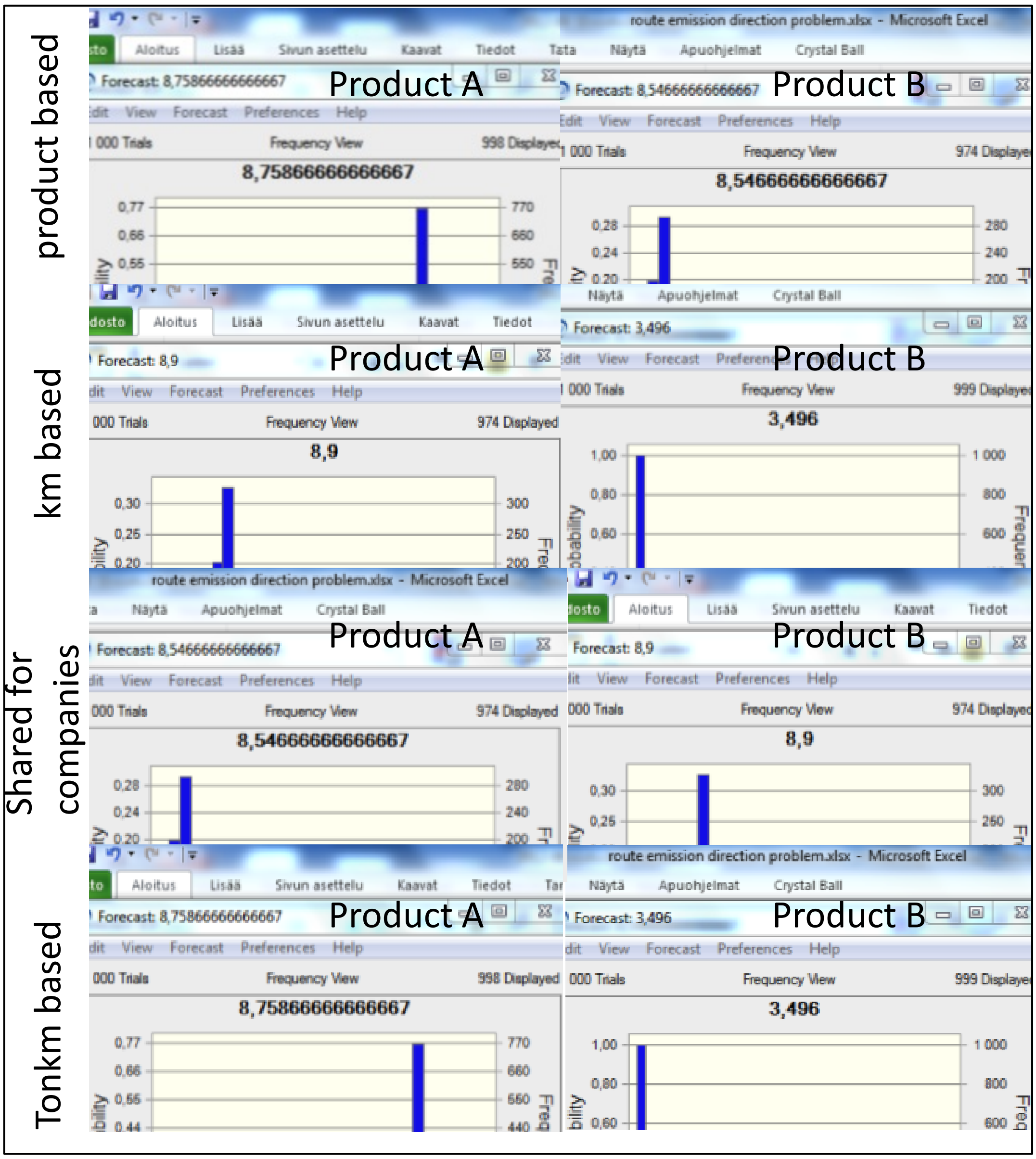


Figure 88. Effect of uncertainty on emission direction

Sensitivity analysis give for product A's most critical input values are mean load and distance A-A (-62 and 37.5; -63.3 and 36.3; -65.8 and 34; -60.9 and 36.6) and for B mean load and distance between B-B and (-61 and 37.6; -60.3 and 36.2; -71.5 and 25,9; -56.7 and 39.5).

5.1.4 Conclusions about the case studies

This chapter concludes how usable the model was in cased studies and *how well model gave answers how strategic supply chain decisions effected to the supply chain sustainable performance. This also concludes the case research questions:* Did the results of the case studies help to understand the role of logistic decisions in the supply chain´s sustainable performance?

Model gave information about effects of the strategic decisions in the supply chain.

This research introduced a SCOR-based method accomplished with few sustainability metrics. The introduced method was used in the case studies. The case studies gave encouraging results. The cases showed that the sustainable supply chain performance estimation method gives information which helps management to see a bigger picture of the supply chain performance and develop the supply chain toward a more sustainable future.

The case studies showed that the developed model is useful when making strategic logistical decisions. It helps to create a bigger picture of the supply chain´s sustainable performance. The developed sustainable food supply chain evaluation model was customized for each case in Excel. The Excel-tools allowed dynamic simulation of the different scenarios. Crystal Ball allowed use uncertainties and distributions in input values and the effects of input uncertainties were possible to see in output values as different probabilities.

The results were useful in every level of logistic strategy decision making process. The model proved to be useful in tactical/operative decision making in case A, and gave a bigger and wider perspective for strategic decision making in case B and case C.

5.1.5 Effects of logistic decisions on supply chain sustainable performance to cases

The usability of the model was tested with case studies. The purpose of the model was to find out how strategic logistical decisions would affect the supply chain´s sustainable performance. The results of the cases also increase the body of knowledge in the field of this research. The aim of the cases was to answer the following questions:

(Q1) What effects would there be on the supply chain sustainable performance if the disposable transportation crates were replaced with recyclable crates?
(Q2) What effects does the plant location decision have on supply chain sustainable performance?
(Q3) What is the effect of the delivery frequency on sustainable performance?

This section also discusses the research problems concerning measuring sustainable performance, the effects of logistical decisions on sustainable performance and suggests how information should be implemented in strategic planning of the SC.

The case study results show the usability of the sustainable food supply chain performance estimation model when making strategic supply chain decisions. The results show how it is possible to describe supply chain strategic decisions with changes of the performance attributes. The sustainability of the supply chain would improve in each case but also cost effectiveness would be achieved. Table 14 summaries the results of the case studies.

Table 14. Summary of case study results

	case A	case B	case C
Main changes between the scenarios	Box return process (washing), packing of the products, traceability	Investments, delivery process, order picking and sorting	Transportation efficiency, production strategy
Most sensitive inputs	Box washing location, box washing unit costs, system investment and operating costs, boxs' self-life	Distance between plant and terminal, investment costs, sorting costs	Distance and transportation costs and emissions
Main results	Carbon emissions, delivery reliability and cost improvements	Delivery time, emission and flexibility improvements	Delivery time, expired food (waste), sold out loss and sales predict improvements
Possibilities	Box return integration possibilities	Differentation possibilities between the two production plants, supplier policies	Possibilities to change production strategy from MTO to ATO. Order sorting efficiency

Some previous studies show that the carbon footprint may be quite concentrated among the supply chain processes and be very different with different food products (Katajajuuri et al., 2006). The same results can be seen in this case study. The effect of the logistical processes on the sustainable performance depends a lot on logistical infrastructure and strategic decisions.

In the first case the distances and crate washing service purchasing costs of the decided system affected the sustainable performance in many ways, especially costs and carbon equivalent emissions. Decisions about who organizes crate washing and where are essential. In the second case the increased costs were concentrated in the supply chain on the focal company because of the production investments. The location decision affected especially carbon equivalent emissions but also costs. Also Rodrique, Slack and Comtois (2001) suggest the hub-and-spoke is not environmentally friendly because it concentrates traffic at a relatively small number of terminals and also cause noise, air pollution and traffic congestion. Bosona et al. (2013) also found that the number of routes, visits, distance, time and emissions were.best in excising distribution center.

The same was seen also in the third case, but the increased transportation costs did not affect the carbon dioxide emissions so much. This was the result of the decreased amount of the waste which not only decreased carbon dioxide equivalent emissions but also costs. The changes in costs and carbon dioxide equivalent emissions were parallel.

Decisions on logistics affect the supply chain processes and supply chain performance. This study introduced three different types of logistic decisions and their effects on the supply chain´s sustainable performance. Table 15 shows an example of the results of the case studies. The most interesting metrics were costs and carbon dioxide equivalents. The costs and CO2 efficiency depend on how the return loads and capacity changes are used. Also Welford (2004) thinks probably most challenging in environmental management of logistics is need to think about reverse logistics and reverse of material flows.

The carbon efficiency of supply chains depends not only on the loading capacity but also the amount of waste which is related the speed and quality of the sorting and transportation processes. Information management systems and co-operation are useful when optimizing supply chain sustainable performance. It has to be kept in mind that the percentual changes are the estimated change of *those processes which are estimated to change* because of the logistical decisions. The change could also be compared to revenue or the supply chain or logistical costs.

Table 15. Cost and CO2 effects of the case studies

	case A	case B	case C
description	recyclable transportation box system compared to disposable transportation box system	two plants A and B compared to location one plant A	24 delivery cycle cycle compared to 48 hours delivery cycle
cost effect of decision %	-43 %	-20 %	75 %
CO_2 eqv. Effect of decision %	547 %	-51 %	100 %
critical inputs	box washing location and box integration possibility of box returning route	Voume of the production, investment costs of the plants, location and costs of plants	effects of delivery cycle to selling days and food waste, loading capacity utilization

In case A better economic performance lead to worse ecologic performance which is different for example from cases B and C. May researchers have found that better ecologic performance lead to better economic performance, for example Green et al. (2012), Rao and Holt (2005), King and Lenox (2001), El Saadany et al. (2011), and McKinnon (2010) who found that many of the GHG reduction yield financial benefit.

The cost efficiency of the transportation means usually the eco-efficiency of the transportation. However, many food products have short shelf life times. The carbon effect of the logistics depends a lot on the used type of the vehicle or fuel but also about road and load plans. In the food chain, the optimal point of logistical efficiency is affected also by product shelf-life related issues. Full loads are not necessarily reasonable, particularly if it happens at the cost of shortened selling days and increased amounts of waste due to product expiry.

Many studies have reported that there are a lot of defaults and variations between operations. For example, markets and distribution centers and sorting and picking operations may vary a lot. For this reason it is useful to know what are the most important factors affecting each part of the sustainable performance.

Route and load planning are crucial elements in sustainable logistical management. Supra-organizational co-operation in logistical management offers possibilities of developing sustainability and of seeing sustainability as shared interest. The importance of product return and integration in logistical sustainability is found also, for example, in Lee, Dong and Bian (2010). The results are equivalent to Britoa, Carboneb and Blanquartd (2008), who found that in fashion supply chains, for example, the optimization of flow management and flow consolidation by logistical integration, resource sharing solutions by clean transport modes and intermodal transport solutions improve the sustainability of supply chains. The results support, for example, Lockamy and McCormack's (2004) findings which prove that delivery process integration along the supply chain has a remarkable role in supply chain performance. Krause et al. (2012) said that company is no more sustainable than its supply chain and the results from the cases supported this.

The results of this research support, for example, Bäge's (1995) research that in striving to shorten supply chains may appear at first glance to be imminently desirable but must be considered within a wider context, namely the nature of the inputs and the location factors of the suppliers.

5.2 Sustainable food supply chains discussion

Food is an essential part of sustainable development. Food production and supporting policies, food assortments, pricing, consumer behaviour, nutritional recommendations, the world economy, trends and crises affect what we eat and how we plan our eating. Consumers' buying habits and appreciation of food have a big role in food sustainability and decisions in the supply chain create the framework.

Food supply chain sustainable management meets the special challenges because of the special nature of the products. There are almost 7 billion people in the world who eat every day. Compared to many other products not only the consumption frequency but also the need is high. Only a few decades ago many people produced a big part of their own food and the phenomenon of food from producer to food consumer is quite new. The number of operators in the food chain is also relatively big. The unit price of food is cheap, but the storing, transportation and preparing of food often need special equipment and are controlled by legislation. The shelf-life of a typical food product is limited and often very short.

Supply chains can be greened by reducing energy and virgin raw material usage and waste generation, and increasing product recovery options (El Saadany et al., 2011). McKinnon (2010) suggests that to reduce carbon emission, freight transport intensity, modal split, vehicle utilization, energy efficiency and the carbon intensity of the energy used in logistics are important. This research pointed out some kinds of logistics decisions which affect carbon emissions.

Partial optimization may decrease the food supply chain's sustainable performance. A bigger picture is needed when the focus is on supply chain sustainable performance. For example, if the goal is to minimize food production costs then the food should be produced in big batches in the best conditions with cheapest costs with cost-optimized fertilizers. There would be, for example, risks of losing food quality and production responsiveness. Carbon optimization of food production could lead to decreased production numbers. Food logistics cost optimization using full loaded energy efficient vehicles could lead to decreased quality and increased waste, and so on. Rodrigue, Slack and Comtois (2001) introduced four paradoxes of green logistics, namely costs, time or speed, reliability and warehousing. These paradoxes were met in the case studies. Food is a fragile product often with a short shelflife and large emissions from food waste are of great interest, because the speed of delivery seems to improve the carbon efficiency even if transportation efficiency decreases.

Agricultural products, places, amounts and processes should be optimized so that they are reasonable compared to the consumers' needs. The logistical operations should be time and cost optimized compared to the market needs and product characteristics. Market operations should be driven sustainably and the selection of goods and location of the markets should fit not only with competitors and customers and trends but also with the seasons.

Food pricing and nationally and internationally patronized systems are ways of directing food producing, delivering, marketing and purchasing strategies in a more sustainable direction. For example, doubling or halving the price of oil, seed or waste would have different effects on sustainability.

The waste amount optimization in every part of the supply chain provides an opportunity to improve sustainable performance of the supply chain. The faster the deliveries are the more there are days to use the products and the probability of selling the product is higher. Customers' awareness and skills and habits to plan and prepare menus and buy and use food are important. Customers can make more sustainable food choices if they have enough information and are able to use it. The use and development of packaging materials is a way to improve sustainability when packing sizes are customized enough for different customer needs. The package not only provides information but also protects the food from spoiling. On the other hand, after opening the package the risk of spoiling and producing waste increases. In addition to the many studies that point out the role of reducing packing waste, the effects of packing from the point of view of supply chain sustainable performance should be considered.

From the supply chain perspective, locally produced food provides possibilities of sustainability if the production and distribution and the consumers´ shopping trips are, for example, cost and energy efficient enough. On the other hand, efficient mass deliveries may be energy efficient even if the origin of the food is not near but the social, economic and environmental effects often are directed far away. Consumers can also organize purchasing in larger groups. Consumers should be able to plan a sustainable shopping frequency between generating food waste and frequent shopping trip driving.

Demand forecasting is important in supply chain management. The optimal balance between "sold out" and product expiring requires accurate and advanced systems but also responsibility towards suppliers.

Logistical efficiency can be improved, for example, with logistics planning (e.g. route optimization, scheduling and load planning, as many researchers have found and, for example, Interaction-report (Interaction, 2007) found the same things in the energy efficiency of the transportation. Route and load planning are crucial elements in sustainable food supply chains, especially in food logistics. The efficiency of load plans determine to a large extent how sustainable the deliveries are. Often well-organized co-operation would help to arrange deliveries and would save money, kilometres, emissions and time, but open-book calculating and often also compatible systems are required for it. Logistical co-operation at the terminal could offer possibilities for sustainability improvements also. logistical interaction along the supply chain requires relationships between the actors. The volume also has effects on sustainable performance.

Food development could proceed from sustainable development if it is possible to develop products successfully with longer shelf lifetimes, higher preservation temperature, and concentrated products. Then the supply chain would avoid delivering water compounds and the consumer could prepare the product by adding water. However, this should be reasonable from the supply chain viewpoint. Food producers could also improve the packaging materials, and change the packaging size (optimise the packaging size to reduce the waste from packages and contaminated content).

Energy sources and waste management can be improved in every part in the supply chain. The transport can be optimized from the sustainable viewpoint. Supply chain structure sustainable optimization also includes supplier selection, plant location decisions and selection decisions. The suppliers' locations and also contracts and strategies and management systems should be estimated when the sustainable supply chain is estimated. The supply chain should be able to share the advantages and losses, develop holistic thinking and supply chain responsibility. If social contradictions would be better noticed, probably environmental would lead more often to positive-sum games (Berger et al., 2001).

Food retailers have a lot of responsibility in terms of sustainable supply chains. Their food selection and pricing strategies are critical parts of food sustainability. The competition environment in Finland is very concentrated and increases this responsibility.

The agricultural sector aims to improve fertilizing efficiency and use methane as fuel and combine crop planning with animal farming. Rajaniemi et al. (2011) suggest that direct drilling and reduced tillage result in lower GHG emissions than conventional tillage. There are also possibilities to improve food chain sustainability by considering conventional and organic production. For example, in milk production Hörtenhuber, Lindenthal, Amon, Markut, Kirner and Zollitsch (2010) found that GHG emissions from milk varied from 0.90 kg CO_2 eqv./kg to 1.17 kg CO_2-eq for conventional milk production, while organic production on average emitted 11% less greenhouse gases (GHGs), the values ranging from 0.81 to 1.02 CO_2-eqv. per kg of milk. They emphasize complete life-cycle assessment in climate impact evaluation.

Consumers have responsibility, too. Huhtanen, Nousiainen and Nousiainen (2009) suggest that using one liter of milk every day compares with driving 1000 km annually, but fuel is typically from nonrenewable sources. On the other hand, different foods have different sustainable performance but also different consumption numbers and nutritional values and role in nutrition. Every consumer could ask him/herself: Do I need everything, everywhere and every time? Am I ready to change my habits for sustainable development? What food am I going to buy, and why, and am I going to use it?

Co-operation is needed in food supply chains. Many studies have pointed out that the bottleneck of local food from field to plate is logistics. This is the issue for many small companies in any industry, but especially for food companies because the food product usually has a short self-life and relatively high frequency of deliveries whilst the delivered amounts are low. The price and sustainability of the product gets higher the emptier the loads are.

5.3 Limitations and future research

Supply chain co-operation and logistic center models and comparative calculations about their sustainable performance are needed. New versions of the SCOR model have been published during this study. The sustainable food supply chain estimation model could also include a wider selection of metrics such as methane, human rights, fair play, etc., which were excluded from the strategic level metric bank. The newest SCOR model (10.0) is more sustainability oriented and it is potential to estimate and develop it also in food supply chains.

The comparisons and development work between already developed models and this study could be productive. For example, it would be very interesting to compare this study with WRI's recently published scope 3 value chain evaluating model and the study by Bai, Sarkis, Wei and Koh (2012) made up of evaluating ecologically sustainable performance measures for supply chain management

There is also a lot of potential to use supply chain performance attributes when setting out strategic missions and values. One way to set priorities is to use analytical hierarchy process (AHP) in the value setting. AHP also provides a tool to conclude and express the results of the supply chain evaluation and helps to categorize and order the attributes.

This study may encourage also developing a sustainable view for consumers for example in eco-labeling systems, which have potential as a fundamental component in the transition process towards eco-sustainability (Proto et al., 2007). It would also be interesting to find out if there are connections between the supply chain's competition strategy of the SC and consumers food choice strategy.

Sustainable supply chain performance development needs lot of attention in the future. Sensitivity analysis and paying attention to the most critical elements helps to develop the sustainability of supply chains.

5.4 Summary

This section summarizes the research questions, approach and achieved results in a theoretical context. The concept of sustainable supply chain performance was used and measured with the help of sustainable performance attributes and SCOR 8.0 based metrics. This research also suggested using the supply chain responsibility viewpoint instead of company responsibility viewpoint and introduced a model for food supply chain sustainable performance evaluation and three empirical case studies and their results.

The case studies showed that supply chain structural decisions have an effect on sustainable performance, and the developed model can be used when structural changes have to be estimated. The location can also optimized by using the model and the different sustainability attributes help to create a wider picture. The delivery cycle, as well as transportation crate system, affect not only costs and carbon dioxide emissions but also other areas of performance of the supply chain.

When the supply chain is cost efficient it also produces less greenhouse gas emissions than a less cost efficient supply chain. Costs and greenhouse gas emission emissions correlate in many situations because the usage of resources affects both costs and GHG emissions. In Rodrigue, Slack and Comtois (2001) the costs savings are usually output in a hub-and-spoke structure, but they were the least sustainable and least environmentally friendly. They define it because it concentrates traffic at a relatively small number of terminals and also causes noise, air pollution and traffic congestion. In most cases it is useful to aim to decrease the use of the energy, e.g. with fuel, electricity and water usage, but it also decreases factors behind the co-efficient factors such as ruminant keeping efficiency, energy efficiency, and fuel efficiency.

Sensitivity analysis showed that efficiency in producing end products with resources as well as efficiency in using vehicle load capacity are important from the supply chain sustainable performance viewpoint. If one company in the supply chain succeeds in improving its performance the effect ton the total supply chain performance may still be negative. The new tools and methods which aim to improve total supply chain performance and see over-organizational costs and benefits are useful in supply chain management. The performance is often understood quite narrowly. If the performance is seen as a conclusion of economic, ecological and social performance, then the performance is more sustainable. The model which evaluates supply chain performance in the wider context helps to set not only organizational but also supra-organizational supply chain visions, missions and goals which lead to more sustainable development.

Logistical decisions affect the supply chain´s sustainable performance, but there is a lack of empirical studies. Sustainable development requires information for the basis of making sustainable decisions. Sustainability should be considered as a performance attribute. Supply chain management is needed, not only for reducing costs, but also for sustainable development.

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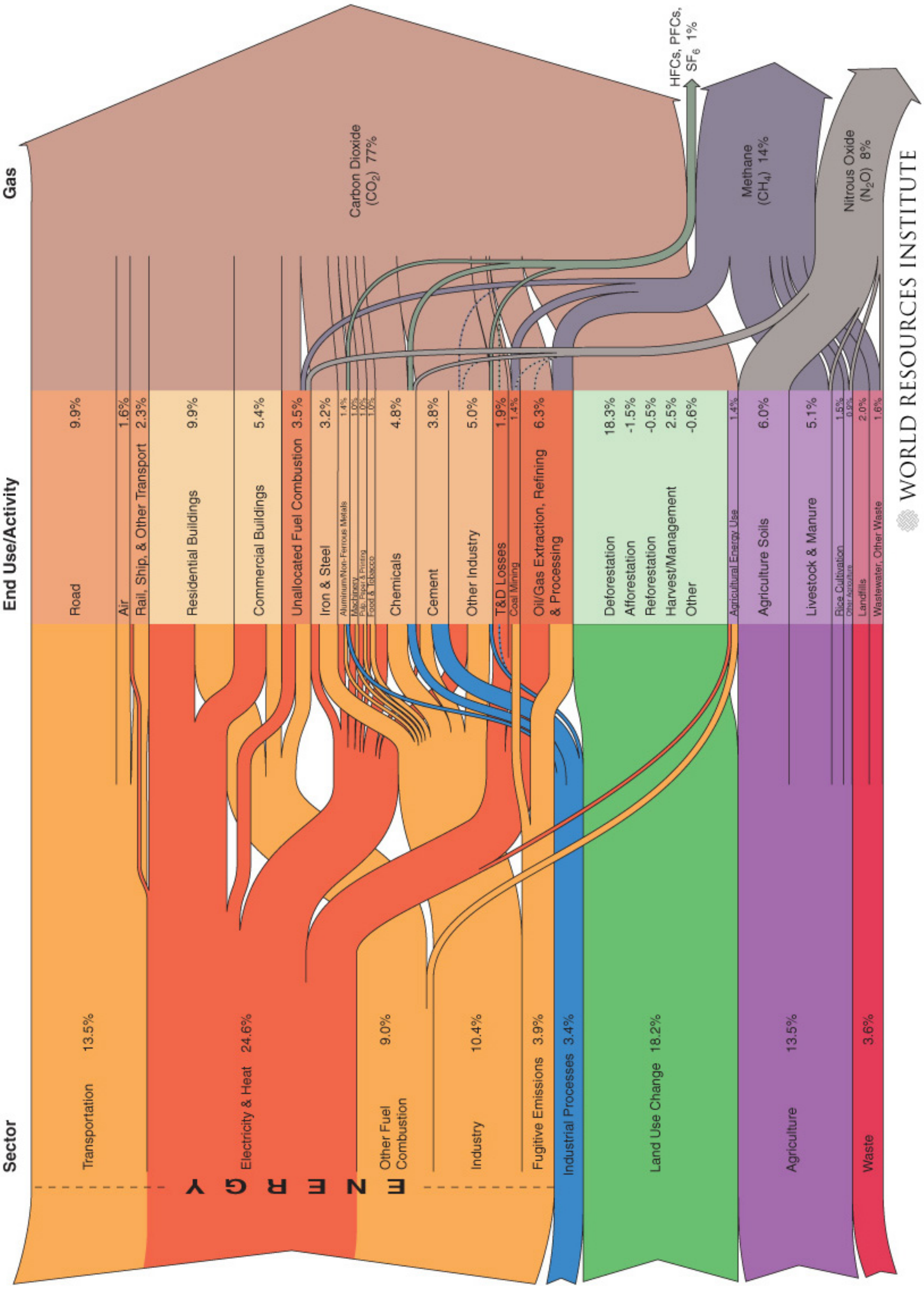
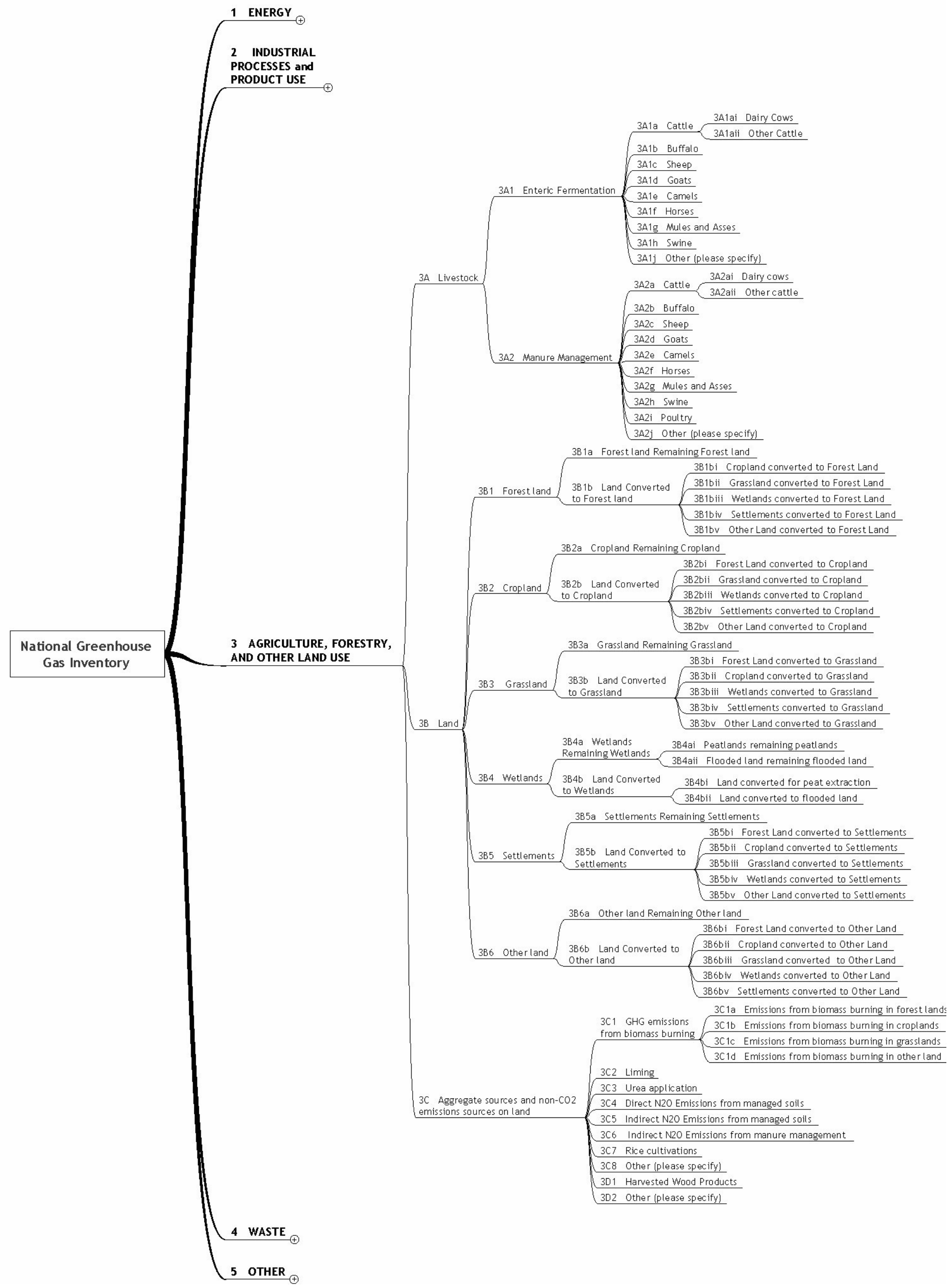
APPENDICES

APPENDIX 1



APPENDIX 2. Structure of AFOLU Reporting



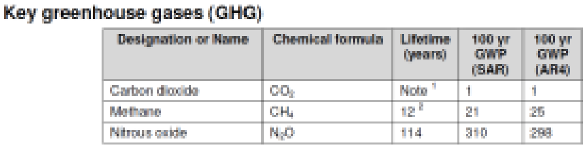
APPENDIX 3. Summary of the effects of the changes in the SC (example)

			supply chain													
			suppliers production	raw material warehousing	raw material transportation	raw material warehousing	production	storing	transportation	storing	transportation	retail	transportation to consumers	consumers warehousing	consumers production	supply chain
metrics	Perfect Order Fulfillment	%	+	+	-	+	-	+	+	-	+	0	-	0	-	0
	Order Fulfillment Cycle Time	days	0	-	0	-	0	0	-	0	-	0	+	+	+	-
	Upside Supply Chain Flexibility	days	0	+	+	+	-	0	+	+	+	0	0	-	0	0
	Upside Supply Chain Adaptability	%	0	0	-	0	0	0	0	-	0	0	0	-	0	+
	Downside Supply Chain Adaptability	%	0	0	-	0	-	0	0	-	0	+	0	0	0	0
	Supply Chain Management Costs	€	+	+	+	-	0	-	0	-	0	0	-	0	-	0
	Cost of Goods Sold	€	0	-	0	0	0	+	+	-	-	0	+	+	+	-
	Cash-to-Cash Cycle Time	days	0	-	0	-	0	+	-	0	0	0	0	-	0	0
	Return on Supply Chain Fixed Assets	%	-	0	0	0	0	+	-	0	-	0	0	-	0	+
	Return on Working Capital	%	0	-	0	0	-	0	-	0	0	-	0	-	0	-
	CO2-emissions	eqv.	+	+	-	-	0	+	+	-	0	+	+	+	-	-
	waste	kg	-	0	0	0	0	-	0	0	0	0	-	0	0	-
	energy use	MW	-	0	-	0	0	-	0	+	0	0	-	0	+	-

APPENDIX 4. Summary of the metrics used in the case studies

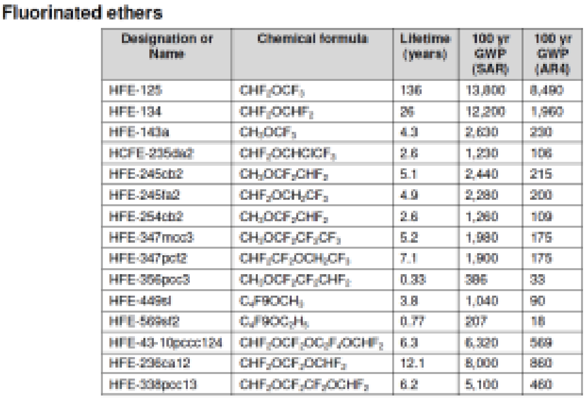
perfect order fullfillment	%	(Perfect Orders) / (Total Number of Orders) x 100%
order fullfillment cycle time	days	Order Fulfillment Cycle Time= (Sum Actual Cycle Times For All Orders Delivered) / (Total Number Of Orders Delivered)
upside supply chain flexibility	days	Total elapsed days between the occurrence of the unplanned event and the achievement of sustained plan, source, make, deliver and return performance. Note: Elapsed days are not necessarily the sum of days required for all activities as some may occur simultaneously. Upside Source Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in quantity of raw materials. Upside Make Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in production with the assumption of no raw material constraints. Upside Deliver Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in quantity delivered with the assumption of no other constraints. Upside Source Return Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in the return of raw materials to suppliers. Upside Deliver Return Flexibility: The number of days required to achieve an unplanned sustainable 20% increase in the return of finished goods from customers.
upside supply chain adabtibility	%	Adaptability measures are based on the actual number of returns compared to the maximum number of returns which can be achieved within 30 days. The weakest component determines the overall volume Note: The calculation of Supply Chain Adaptability requires the calculation to be the least quantity sustainable when considering Source, Make, Deliver and Return components. Upside Source Adaptability: The maximum sustainable percentage increase in raw material quantities that can be acquired/received in 30 days. Upside Make Adaptability: The maximum sustainable percentage increase in production that can be achieved in 30 days with the assumption of no raw material constraints. Upside Deliver Adaptability: The maximum sustainable percentage increase in quantities delivered that can be achieved in 30 days with the assumption of unconstrained finished good availability.Upside Source Return Adaptability: The maximum sustainable percentage increase in returns of raw materials to suppliers that can be achieved in 30 days with the assumption of unconstrained finished goods availability. Upside Deliver Return Adaptability: The maximum sustainable percentage increase in returns of finished goods from customers that can be achieved in 30 days.
downside supply chain adabtibility	%	Least quantity reduction sustainable when considering all components. Current elements needed to fully understand future requirements, to establish the volume delta that can be sustained based on the question “How much of a reduction in quantities sourced (expressed as a percentage) can the company sustain, given 30 days?”
supply chain management cost	€	order management costs + material acquisition costs + inventory carrying (Indirect Plan) costs + planning/finance costs + and information technology costs (Indirect Enable) costs
cost of goods sold	€	TSCMC = Sales – Profits – Cost to Serve (e.g., marketing, selling, administrative)
casg-to-cash cycle time	days	Cash-to-Cash Cycle Time = Inventory Days of Supply + Days Sales Outstanding – Days Payable Outstanding
return on supply chain fixed assets	%	Return on Supply Chain Fixed Assets = (Supply Chain Revenue – COGS – Supply Chain Management Costs) / Supply-Chain Fixed Assets
return on working capital	%	The excess of current assets over current liabilities, representing the funds available for financing business activities
carbondioxide emissions	eqv.	carbon dioxide emissions = (distance)*(emission per unit km/vehicle) * (share of the product under study of the load)
energy use	kW	energy use of the process * time to used to the process per unit
number of impacted countries	pcs.	Number of countries where 90% of the raw materials are sourced, where wastes are placed, products are stored or produced
waste	kg	amount of product per year * share of destroyed of lost goods

APPENDIX 5. GWP tables



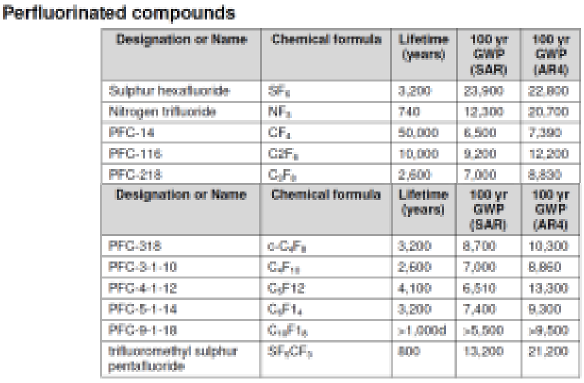
Key greenhouse gases (GHG)

Designation or Name	Chemical formula	Lifetime (years)	100 yr GWP (SAR)	100 yr GWP (AR4)
Carbon dioxide	CO_2	Note[1]	1	1
Methane	CH_4	12[2]	21	25
Nitrous oxide	N_2O	114	310	298



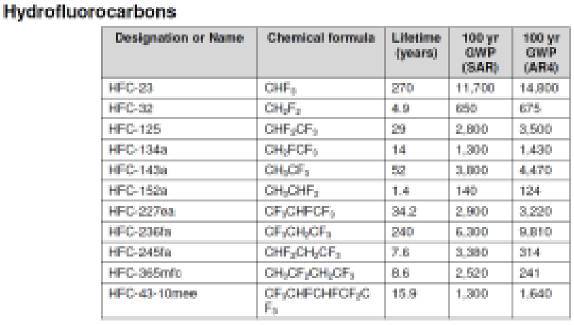
Fluorinated ethers

Designation or Name	Chemical formula	Lifetime (years)	100 yr GWP (SAR)	100 yr GWP (AR4)
HFE-125	CHF_2OCF_3	136	13,800	8,490
HFE-134	CHF_2OCHF_2	26	12,200	1,960
HFE-143a	CH_3OCF_3	4.3	2,630	230
HCFE-235da2	$CHF_2OCHClCF_3$	2.6	1,230	106
HFE-245cb2	$CH_3OCF_2CHF_2$	5.1	2,440	215
HFE-245fa2	$CHF_2OCH_2CF_3$	4.9	2,280	200
HFE-254cb2	$CH_3OCF_2CHF_2$	2.6	1,260	109
HFE-347mcc3	$CH_3OCF_2CF_2CF_3$	5.2	1,980	175
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	7.1	1,900	175
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	0.33	386	33
HFE-449sl	C_4F9OCH_3	3.8	1,040	90
HFE-569sf2	$C_4F9OC_2H_5$	0.77	207	18
HFE-43-10pccc124	$CHF_2OCF_2OC_2F_4OCHF_2$	6.3	6,320	569
HFE-236ca12	$CHF_2OCF_2OCHF_2$	12.1	8,000	860
HFE-338pcc13	$CHF_2OCF_2CF_2OCHF_2$	6.2	5,100	460



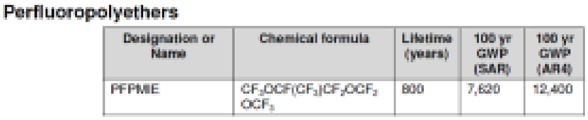
Perfluorinated compounds

Designation or Name	Chemical formula	Lifetime (years)	100 yr GWP (SAR)	100 yr GWP (AR4)
Sulphur hexafluoride	SF_6	3,200	23,900	22,800
Nitrogen trifluoride	NF_3	740	12,300	20,700
PFC-14	CF_4	50,000	6,500	7,390
PFC-116	$C2F_6$	10,000	9,200	12,200
PFC-218	C_3F_8	2,600	7,000	8,830
Designation or Name	**Chemical formula**	**Lifetime (years)**	**100 yr GWP (SAR)**	**100 yr GWP (AR4)**
PFC-318	$c\text{-}C_4F_8$	3,200	8,700	10,300
PFC-3-1-10	C_4F_{10}	2,600	7,000	8,860
PFC-4-1-12	C_5F12	4,100	6,510	13,300
PFC-5-1-14	C_6F1_4	3,200	7,400	9,300
PFC-9-1-18	$C_{10}F1_8$	>1,000d	>5,500	>9,500
trifluoromethyl sulphur pentafluoride	SF_5CF_3	800	13,200	21,200



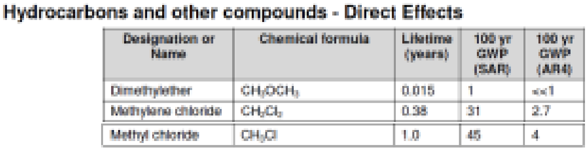
Hydrofluorocarbons

Designation or Name	Chemical formula	Lifetime (years)	100 yr GWP (SAR)	100 yr GWP (AR4)
HFC-23	CHF_3	270	11,700	14,800
HFC-32	CH_2F_2	4.9	650	675
HFC-125	CHF_2CF_3	29	2,800	3,500
HFC-134a	CH_2FCF_3	14	1,300	1,430
HFC-143a	CH_3CF_3	52	3,800	4,470
HFC-152a	CH_3CHF_2	1.4	140	124
HFC-227ea	CF_3CHFCF_3	34.2	2,900	3,220
HFC-236fa	$CF_3CH_2CF_3$	240	6,300	9,810
HFC-245fa	$CHF_2CH_2CF_3$	7.6	3,380	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	2,520	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	1,300	1,640



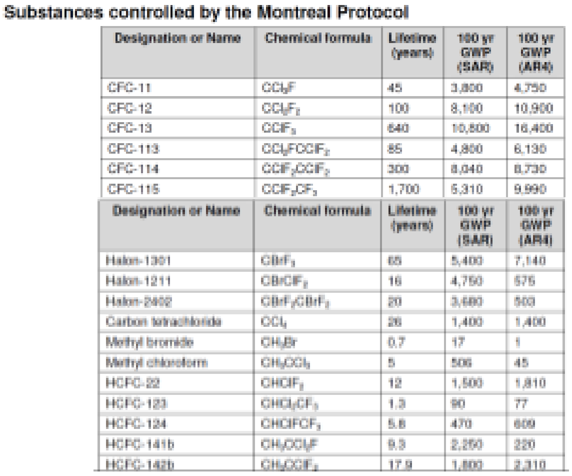
Perfluoropolyethers

Designation or Name	Chemical formula	Lifetime (years)	100 yr GWP (SAR)	100 yr GWP (AR4)
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	800	7,620	12,400



Hydrocarbons and other compounds - Direct Effects

Designation or Name	Chemical formula	Lifetime (years)	100 yr GWP (SAR)	100 yr GWP (AR4)
Dimethylether	CH_3OCH_3	0.015	1	<<1
Methylene chloride	CH_2Cl_2	0.38	31	2.7
Methyl chloride	CH_3Cl	1.0	45	4



Substances controlled by the Montreal Protocol

Designation or Name	Chemical formula	Lifetime (years)	100 yr GWP (SAR)	100 yr GWP (AR4)
CFC-11	CCl_3F	45	3,800	4,750
CFC-12	CCl_2F_2	100	8,100	10,900
CFC-13	$CClF_3$	640	10,800	16,400
CFC-113	CCl_2FCClF_2	85	4,800	6,130
CFC-114	$CClF_2CClF_2$	300	8,040	8,730
CFC-115	$CClF_2CF_3$	1,700	5,310	9,990
Designation or Name	**Chemical formula**	**Lifetime (years)**	**100 yr GWP (SAR)**	**100 yr GWP (AR4)**
Halon-1301	$CBrF_3$	65	5,400	7,140
Halon-1211	$CBrClF_2$	16	4,750	575
Halon-2402	$CBrF_2CBrF_2$	20	3,680	503
Carbon tetrachloride	CCl_4	26	1,400	1,400
Methyl bromide	CH_3Br	0.7	17	1
Methyl chloroform	CH_3CCl_3	5	506	45
HCFC-22	$CHClF_2$	12	1,500	1,810
HCFC-123	$CHCl_2CF_3$	1.3	90	77
HCFC-124	$CHClFCF_3$	5.8	470	609
HCFC-141b	CH_3CCl_2F	9.3	2,250	220
HCFC-142b	CH_3CClF_2	17.9	1,800	2,310

Source:

Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4), Working Group 1, Chapter 2, *Changes in Atmospheric Constituents and in Radiative Forcing*, Table 2.14, page 212, http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

In: Curt Hull, Manitoba Eco Network, www.climatechangeconnection.org

APPENDIX 6. Household waste emissions

Produced and avoided greenhouse gas emission caused by household wastes in 201

Waste Category	**tonnes CO_2-eqv.**	**kg CO_2-eqv. / inhabitant**	**%-share of Waste**
Chemical wastes	1,09	1	0 %
Health care wastes	0	0	0 %
Metals	-11,28	-10	3 %
Glass	-1,51	-1	3 %
Cardboard	-100	0	3 %
Paper	-40,91	-38	28 %
Rubber	50	0	1 %
Plastics	0	0	0 %
Wood	-6,01	-6	2 %
Discarded vehicles	0	0	0 %
Discarded electrical and electronic equipment	-5,27	-5	3 %
Animal and vegetal wastes	750	1	11 %
Mixed waste	57,31	53	47 %
Sorting residues	0	0	0 %
Sludges	0	0	0 %
Construction waste	0	0	0 %
Ashes and slags	0	0	0 %
Other mineral wastes	0	0	0 %
Other wastes	350	0	0 %
Total	-5,53	-5	100 %