A methodology and a mathematical model for reducing greenhouse gas emissions through the supply chain redesign

by

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A METHODOLOGY AND A MATHEMATICAL MODEL FOR REDUCING GREENHOUSE GAS EMISSIONS THROUGH THE SUPPLY CHAIN REDESIGN

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Abstract

This thesis introduces a methodology for helping companies to reduce their carbon footprint. The proposals include a guideline for Corporate Carbon Strategy and a mathematical model for designing a supply network where the net profit is maximized. Additionally, a set of initiatives is proposed for achieving carbon emission targets over time. The mathematical model was tested using three case studies. The first shows a network re-design in a Brazilian company due to tax benefits, whilst the second one came up with a new network design for reducing the product costs in a European-based company. Finally, the third case used a United States company to show the effect of the scope definition in the carbon strategy. For the three cases, the model put forward a set of green initiatives, such as energy management, cogeneration, multimodal or alternative fuels.

Keywords: supply chain design, carbon dioxide emissions, carbon strategy, Mixed-Integer Nonlinear Program, Green Supply Network Management, carbon footprint.

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Summary

Virtually the entire scientific, political, business, and social community is aware of the importance of climate change. Countries adhering to the Kyoto Protocol have taken up the challenge of reducing carbon emission, implementing national policies that include the introduction of carbon emissions trading programs, voluntary programs, taxes on carbon emissions and energy efficiency standards.

In this context, the business world must be able to generate a carbon reduction strategy to ensure long-term success, considering also that customers (and investors) are ever more interested in the well-being of the environment, and increasingly demand their suppliers to be eco-friendly.

This thesis has addressed the problem of designing (or redesigning) the supply chain to reduce carbon emission in an economically viable and, as far as possible, optimal way. The thesis addresses the problem by designing a complete and formalized methodology, which also includes a mathematical model to determine the best decisions to take.

The research begins, as usual, with a review of the basic terminology, standards and the scientific literature related to the topic. From the review of the literature, it has been concluded that, although there are authors who propose models related to the design of the supply chain including carbon reduction, there is a lack of formalized methodologies that can be applied to real cases.

The methodology consists of 4 stages: 1) The creation of a corporate carbon strategy; 2) The alignment with strategic financial planning; 3) The development of a mathematical model; and 4) The implementation and tracking.

In the first stage a six-step guide is developed to create a corporate carbon strategy. The steps are: 1) Determine the type of emission; 2) Boundaries definition; 3) Planning and performance information; 4) Identify carbon reduction opportunities; 5) Determine carbon reduction goals; 6) Participating in programs and carbon markets.

In the second stage, the corporate carbon strategy is evaluated from a financial point of view and integrated into the strategic planning. In the third stage, a Mixed Integer Linear Programming (MILP) model is proposed to obtain a plan for the supply chain redesign, so that: 1) the carbon reduction targets are achieved; 2) the strategic financial plan is taken into account; 3) all the real possibilities

are contemplated to redesign the supply chain; and 4) a solution is achieved to optimize the economic results of the company.

The carbon reduction methodology, including the mathematical model, has been applied to three case studies that are useful for adjusting some elements and for its validation. The first case study corresponds to a company that operates in the Home and Personal Care sector in Brazil, where the system of taxes is more complex than in other countries and illustrates how the mathematical model can be adapted to any context. The second case study deals with a multinational company which operates in the Foods sector in Spain and requires a redesign of the supply chain to improve its product cost. Finally, the third case used a company in the U.S. to show the effect of the scope definition on the carbon strategy.

In the three cases, the solution of the mathematical model maximizes the net profit, whilst the carbon reduction target is achieved. Therefore, the carbon reduction methodology is useful for achieving economic and environmental benefits, as well as providing benefits related to the improvement of the corporate image, strengthening of brands and avoiding possible carbon taxes risks.

In conclusion, the carbon reduction methodology proposed in this thesis, was developed to support companies that want to generate a competitive advantage and a sustainable development. In addition, it was designed to be flexible enough to adapt to the needs of each business and facilitate its execution in the business world.

Resumen

Prácticamente toda la comunidad científica, política, comercial y social es consciente de la importancia del desafío medio ambiental relacionado con las emisiones de Gases de Efecto Invernadero (GEI). Los países adheridos al Protocolo de Kioto han asumido el desafío de reducir los GEI, implementando políticas que incluyen programas de comercio de emisiones, programas voluntarios, impuestos sobre la emisión de GEI y normas sobre eficiencia energética.

En este contexto, el mundo empresarial debe ser capaz de generar una estrategia de reducción de GEI para garantizar el éxito a largo plazo, considerando además que los clientes están cada vez más interesados en el bienestar del medio ambiente.

Esta tesis ha abordado el problema de diseñar (o rediseñar) la cadena de suministro como vía para la reducción de GEI de una manera económicamente viable y, en la medida de lo posible, óptima. La tesis aborda la problemática diseñando una metodología completa y formalizada, que incluye también un modelo matemático para determinar las mejores decisiones a tomar.

De la revisión de la literatura, se ha concluido que, si bien existen autores que proponen modelos relacionados con el diseño de la cadena de suministro que incluyen la reducción de GEI, no existen trabajos que propongan una metodología completa y suficientemente formalizada que puedan ser aplicados a la realidad.

La metodología consta de 4 etapas que son: 1) La creación de una estrategia corporativa para la reducción de GEI; 2) La alineación con la planificación financiera estratégica; 3) El desarrollo de un modelo matemático; y 4) La implementación y seguimiento.

En la primera etapa se desarrolla una guía de seis pasos para crear una estrategia corporativa para la reducción de GEI, los pasos son: 1) Determinar el tipo de emisión; 2) Definir el alcance; 3) Establecer las bases de la medición; 4) Identificar oportunidades de reducción de GEI; 5) Establecer los objetivos; 6) Planificar la participación en programas de reducción de GEI.

En la segunda etapa, la estrategia corporativa antes propuesta, se evalúa desde un punto de vista financiero y se integra en la planificación estratégica. En la tercera etapa, se propone un modelo de Programación Lineal Entera Mixta para obtener un plan para el rediseño de la cadena de suministro, de modo que: 1) se logren los objetivos de reducción de GEI; 2) se tenga en cuenta el plan financiero

estratégico; 3) se contemplen todas las posibilidades reales para rediseñar la cadena de suministro; y 4) se optimicen los resultados económicos de la empresa.

La metodología, incluyendo el programa matemático se ha probado en tres casos de estudio. El primer caso de estudio corresponde a una multinacional del sector de productos de higiene del hogar y cuidado personal que opera en Brasil, donde el modelo matemático fue adaptado para integrar beneficios fiscales. El segundo caso trata de una multinacional del sector alimentario basada en España que requiere un rediseño de la cadena de suministro para mejorar el coste de producir. Finalmente, en el tercer caso se utiliza una empresa del sector del metal basada en EE. UU., para ilustrar la importancia de la definición de límites y responsabilidades corporativas.

En los tres casos de estudio, el modelo matemático maximiza el beneficio neto mientras alcanza el objetivo de reducción de GEI. Por lo tanto, la metodología es útil para conseguir beneficios económicos y medio ambientales, además de brindar beneficios relacionados con la mejora de la imagen corporativa, fortalecimiento de las marcas y el evitar posibles riesgos impositivos.

En conclusión, la metodología propuesta fue desarrollada para que su implementación pueda generar en las empresas una ventaja competitiva y un crecimiento fundamentado en la sostenibilidad ambiental; asimismo, fue diseñada para que sea lo suficientemente flexible y pueda adaptarse a las necesidades de cada negocio y facilitar su ejecución en el mundo empresarial.

CHAPTER 1

Introduction

Two hundred years ago, a scientist called Joseph Fourier carried out an experiment in order to understand the effects of incoming solar radiation. With this experiment, Fourier discovered that gases in the atmosphere could form a stable barrier, like the panes of glass (Fourier, 1827). The greenhouse effect is the process by which certain gases in the atmosphere retain much of the infrared radiation emitted by the Earth and return it to the Earth's surface, thereby heating it.

Greenhouse gas emissions (GHGs), as key contributors to global warming, have become a major concern for governmental bodies and the industrial sector in recent years. Upon the signing in 1997 of the Kyoto Protocol, 187 states (both developed and developing) have developed strict goals for their GHG emissions in the near future (Kyoto Protocol, 2007).

The Kyoto Protocol aims to reduce six types of greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). All these gases stop the heat from escaping into space, which is why they are called "greenhouse gases". In fact, there are a lot of terms which can be used in this field, i.e. "greenhouse gases", "CO_2", CO_2e" and "carbon" and their various meanings can get confusing.

The carbon dioxide equivalent (CO_2e) is the term for defining greenhouse gases in a common unit. Furthermore, in this thesis, the term 'carbon dioxide equivalent' is used as a synonym of greenhouse gases and the term 'carbon' – for instance "carbon strategy" or "carbon reduction" – includes the whole list of greenhouse gases. Nevertheless, in the references to previous publications, the authors' terms are used.

Virtually the entire scientific, political, business, and social community is aware of the significance of this environmental challenge. Governments are taking measures to reduce GHG emissions, implementing national policies that include the introduction of emissions trading programs, voluntary programs, carbon or energy taxes, and regulations/standards of energy efficiency (The Greenhouse Gas Protocol, 2004). In line with this, companies must be able to understand and manage their GHG risks if they are to ensure long-term success in a competitive business environment, and to be prepared for future national or regional climate policies.

The involvement of the scientific, political, business, and social communities in environmental issues is increasing steadily. Simultaneously, companies are changing their traditional way of viewing the supply chain. Indeed, (Corominas, 2013) suggests that the expression "Supply Chain" could be replaced by a more suitable expression, such as "Supply Network". In line with this new trend, many companies are going even further, including the green concept within their Supply Network and creating a new "Green Supply Network" (GSN), although the term "Supply Chain" and "Supply Chain Network" is still in use.

The concept Green Supply Network has recently appeared, to include the environmental factor in supply network design. Environmental factors in supply network design have become a focus of research in recent years. Studies have analysed the implications of different transportation types regarding GHG emissions (Pan, et al., 2013), as well as of energy-saving technology in both transportation and production.

The chapter is organized as follows: Section 1 defines the problem statement; Section 2 determines the thesis' objectives; Section 3 defines the scope; Section 4 describes the methodology used, and finally Section 5 highlights the main contributions of the thesis.

1.1 PROBLEM STATEMENT

Directly or indirectly, in the last decade many companies were faced with the need to include environmental concepts in their supply network and currently more and more companies are showing greater interest in including these concepts in their strategy. This new supply network philosophy, also called "Green Supply Network" (GSN), is the new trend that challenges companies to produce and grow, while respecting the environment and developing a more sustainable supply network.

Introducing the "green" concept into the supply network design is not at all simple, it often means taking decisions such as selecting the right supplier, choosing the appropriate transportation, deciding on plants or cross-docking locations, etc. Some of these decisions have an associated investment and need a proper cost/benefit analysis.

Currently, there are two approaches to quantifying and assessing the impact of a company's GHG emissions. The first approach is based on the life cycle of a product or service, where the objective is to determine the carbon footprint of a specific product or service. This approach could be useful for marketing purposes, because it gives the information of the total amount of carbon dioxide equivalent (CO_2e) emitted in producing the product portfolio of a company.

On the other hand, the organizational approach emphasizes the measurement of the impact of GHG emissions at an organizational level; in this context, the carbon footprint of an organization defines the climate impact (in terms of CO_2e emissions) of the organization under consideration.

Figure 1-1 shows an example of the four levels of a supply network where some CO_2e improvements at organizational level are identified. The opportunities for carbon emission reduction can be internal, in manufacturing and/or in the logistics operation, or it can be in the extended supply network, either in the suppliers or customers. Moreover, transportation is a transversal activity which is part of every stage of the network and has a lot of carbon reduction opportunities, related to the type of network, load, technology and fuel, etc., used.

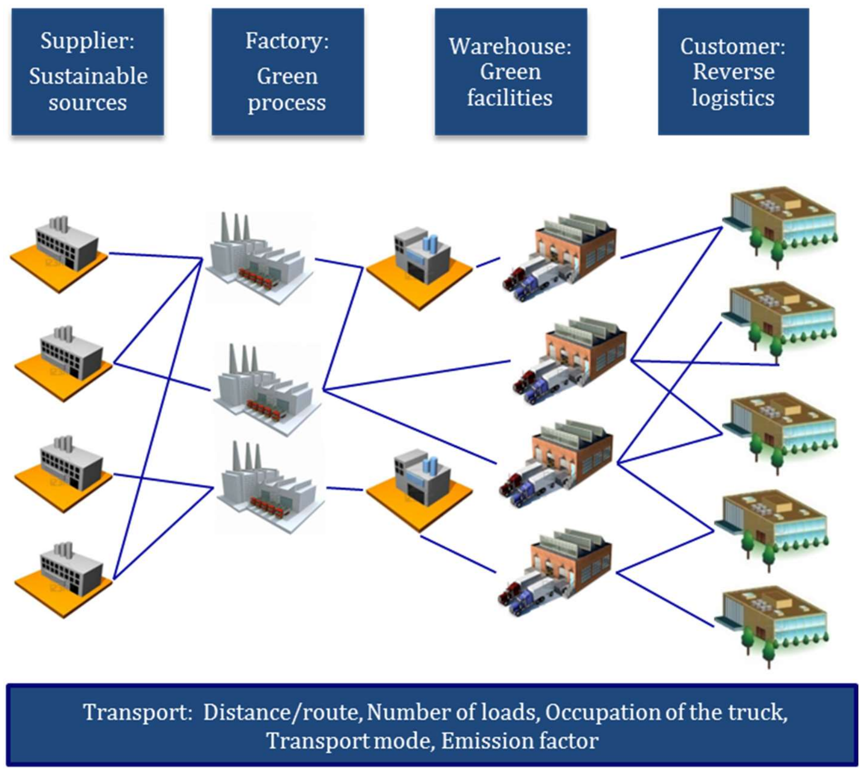


Figure 1-1 Main drivers for a green supply network.
Source: Own development

A supply network re-design is a decision that companies will need, eventually, to evaluate. Whether the secondary motive is to achieve more savings, reduce the product and distribution cost, improve service levels or increase incomes, the main goal is to improve the company's net profit. Externally, there are also some opportunities or threats to consider, for instance, developing a more environmentally friendly product can be an opportunity to generate a competitive advantage with consumers. On the other hand, as a consequence of changes in governmental regulations there is a risk of not establishing a Corporate Carbon Strategy, and the cost of doing nothing can be high.

Considering all the benefits of having a Corporate Carbon Strategy, more and more companies are starting to include it in the Corporate Social Responsibility (CSR). But, together with this initiative, some of the following questions have arisen:

- How to create a Corporate Carbon Strategy? And what kind of resources are needed?

- Are “green” decisions profitable?
- What is the impact of taking or not taking a green decision?
- What is the size of the investment needed for creating a Corporate Carbon Strategy?
- How to create a competitive advantage by developing a Corporate Carbon Strategy?
- What are the monetary and non-monetary benefits?

As soon as a company has outlined its Corporate Carbon Strategy, some strategies and targets are established and, normally, a second set of questions arises. Here are some examples:

- How to reach the carbon reduction targets?
- What kind of initiatives are needed?
- When should these initiatives be implemented?
- How to combine changes in the network and carbon reduction targets?

Certainly, the concept of climate change is generating actions at governmental level as well as changing consumers’ behaviour; therefore, companies need to adapt their strategy and use this trend to generate a competitive advantage. Consequently, there is a need to support companies and decision makers in this field.

Currently there is very good material such as PAS 2050 (BSI , 2011), GHG Protocol (WBCSD/WRI, 2004), CDP (CDP Organization, 2017), Carbon Trust (Carbon Trust, 2012), Defra (Defra & DECC, 2010), which provide some guidelines for concepts and initiatives. Nevertheless, there is still a lack of formalized procedures and tools for helping decision makers to develop a Corporate Carbon Strategy with specific plans for achieving targets. On the other hand, based on the concepts already established, Operation Research provides excellent tools to answer most of the questions presented above.

1.2 OBJECTIVES

1.2.1 MAIN OBJECTIVE

The main objective of this thesis is “To propose a carbon reduction methodology and an efficient tool for reducing CO_2e emissions through the supply chain redesign”.

1.2.2 SPECIFIC OBJECTIVES

1. Obj. 1. Develop a guide with the main drivers to reduce GHG emissions in the GSN.
2. Obj. 2. Identify opportunities to reduce carbon emissions in the supply network. It should be done by determining the main drivers to reduce GHG emissions and identifying the cost savings opportunities.

3. Obj. 3. Design a mathematical model to assist decision makers in companies by preparing strategies to achieve a greener supply network. The mathematical model should maximize the Net Profit and proposes a set of initiatives for achieving carbon emission over time.
4. Obj. 4. Assess the impact of emission reduction alternatives within the supply network through the analysis of possible scenarios.

1.3 SCOPE

The scope of this thesis considers the extended supply network, which means all the elements of the supply network, including suppliers. Therefore, the design of the supply network and carbon emission accounting includes the Distribution Network, Factories and Suppliers including all the associated transportation.

1.4 METHODOLOGY

In this section a general research strategy is described, outlining the way in which the thesis research is developed and classifying the methods to be used in it. The starting point of this research is the identification of opportunities, which includes a literature review to understand concept definitions, standards and opportunity areas.

The second relevant activity is the foundation of a Carbon Reduction Methodology, which includes the development of a Corporate Carbon Strategy and an optimization process where a mathematical model is proposed. Then the most dynamic step is presented; at this stage the model assessment is based on case studies. To understand the steps of the methodology and the connections between the steps, see Figure 1-2.

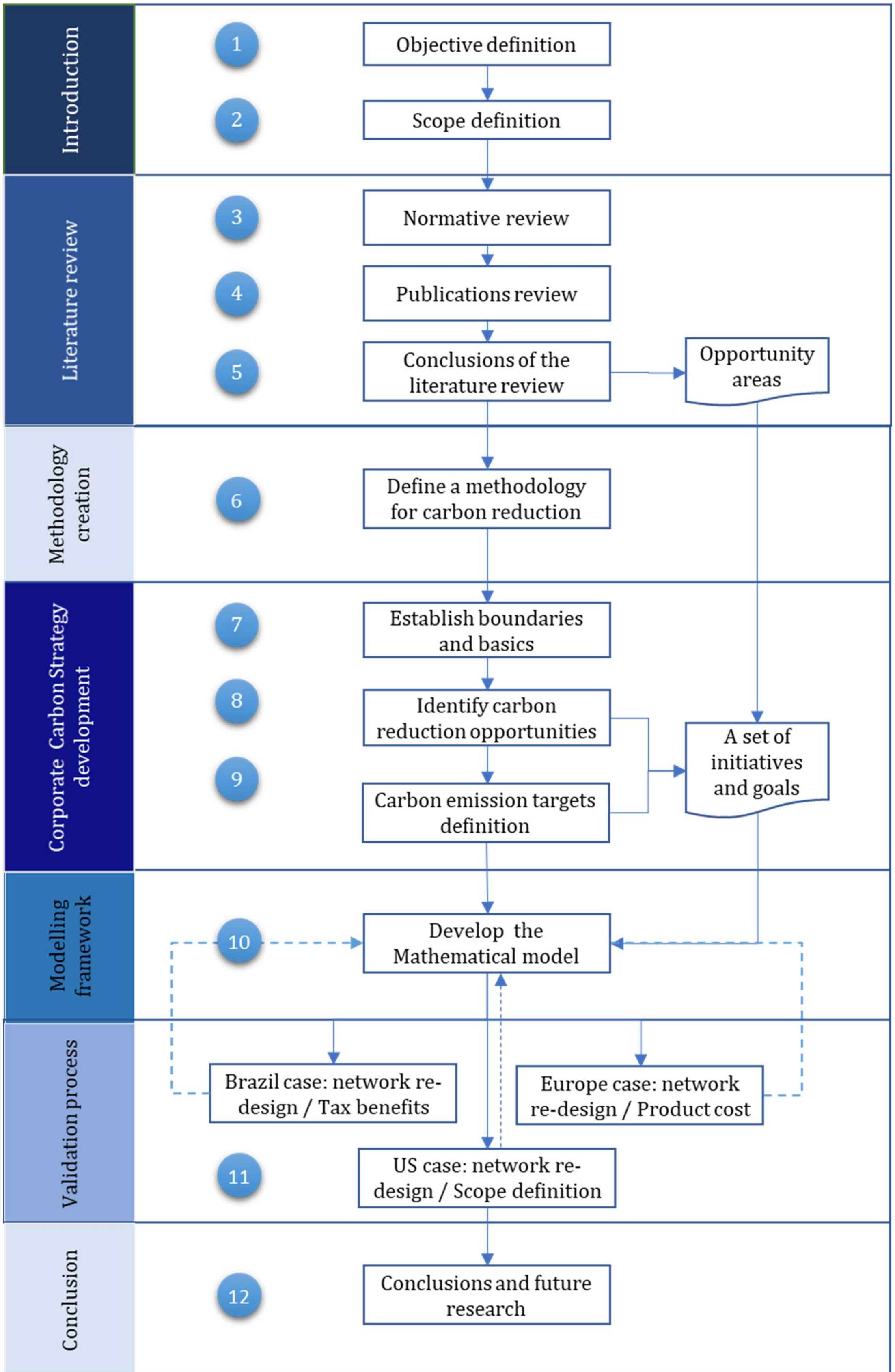


Figure 1-2 Research methodology procedure (own development)

1.4.1 Reviewing the literature

Many sectors have been trying to integrate sustainability aspects into the supply network since the beginning of the 1990s and literature review in this field goes back to those times. Much literature has been published in relation to measurements, standards and product life cycle analysis , seeking to identify opportunities to measure, manage and reduce GHG emissions.

The literature review is organized in four sections: first the basic terminology is explained; then the current standards and normative are highlighted; after that, 128 journal articles are reviewed and classified according to the green initiatives in the supply network, corporate carbon strategies and carbon emission markets. Finally, the research opportunities are highlighted.

1.4.2 The methodology creation

The intention at this stage is to propose a carbon reduction methodology for guiding companies on how to create a Corporate Carbon Strategy and how to integrate carbon reduction targets with the company's strategies and financial targets. This methodology contains guidelines, methods and a step by step process to transform a company into a more sustainable business.

1.4.3 Designing a Corporate Carbon Strategy

The objective of designing a Corporate Carbon Strategy is to define a clear and practical guideline for establishing the basis of the carbon reduction plan. This stage is the pre-requisite of the Mathematical Model phase, as the environmental inputs come from this preliminary stage.

The purpose of this stage is to help companies to establish the system boundary, the scope, and the carbon emission targets; prioritizing the main carbon emission initiatives in order to focus on the most important GHG emission-reducing agents and to achieve a greener supply network.

1.4.4 Designing a mathematical model

This section aims to provide an answer for the questions shown in the problem statement section, requiring an exhaustive search within a set of all potential solutions. The problem-solving method used in this thesis is a Mixed Integer Linear Programming (MILP). Conceptually, this method finds an optimal solution of mathematical programs with continuous and integer variables and linear functions in the objective function and the constraints.

1.4.5 VALIDATION PROCESS

The purpose of this section is to validate the carbon reduction methodology, highlighting the Corporate Carbon Strategy creation as well as the mathematical model testing. Three case studies were used to demonstrate the usefulness of this proposal.

The three cases are:

1. A multinational company operating in Brazil in the Home and Personal Care business

    - The impact of the tax benefits on the network design.
    - The implementation of double-deckers and ethanol fuel in logistics.
    - The use of cogeneration systems in manufacturing.
    - The procurement of more sustainable raw materials.
    - In this study case the flexibility of the mathematical model was proved.

2. A multinational company operating in Spain in the food business

    - The impact of changing a factory location because of lower labour costs.
    - The influence of the multimodal use and load fill in the carbon emission in transportation.
    - The use of biomass technology in manufacturing.

3. A multinational company operating in the United States in the metal sector

    - How the country's energy generation can influence a network decision.
    - How the scope definition can determine the carbon emission strategy.
    - The impact of using alternative fuels such as Compressed Natural Gas (CNG).

1.5 CONTRIBUTIONS OF THE THESIS

This thesis aims to support the decision-making process at strategic and tactical level. The main contributions are related with a proposal for a carbon reduction methodology based on:

a. The development of a carbon reduction strategy linked with the strategic financial process. Although the concepts to create a carbon reduction strategy already exist, the contribution of the thesis lies in the creation of a formalized methodology with a set of practical step by step processes.
b. The proposal of Mixed Integer Linear Programming (MILP) to maximise the companies' profit, along with a set of projects to reduce carbon emissions and achieve annual carbon targets.

c. Three case studies, with different locations, categories and setups, where the methodology, including the MILP model, is applied. These practical cases demonstrate the benefit of applying the methodology in a real scenario.

CHAPTER 2
State of the art

The purpose of this chapter is to review the basic concepts and literature related with supply networks, but more specifically the carbon emissions in the supply network and its environmental conditions. Figure 2-1 shows the structure of this literature review: first the basic terminology is defined in both supply network definition and the green supply network. Then, the existing standards and normatives in this field are reviewed.

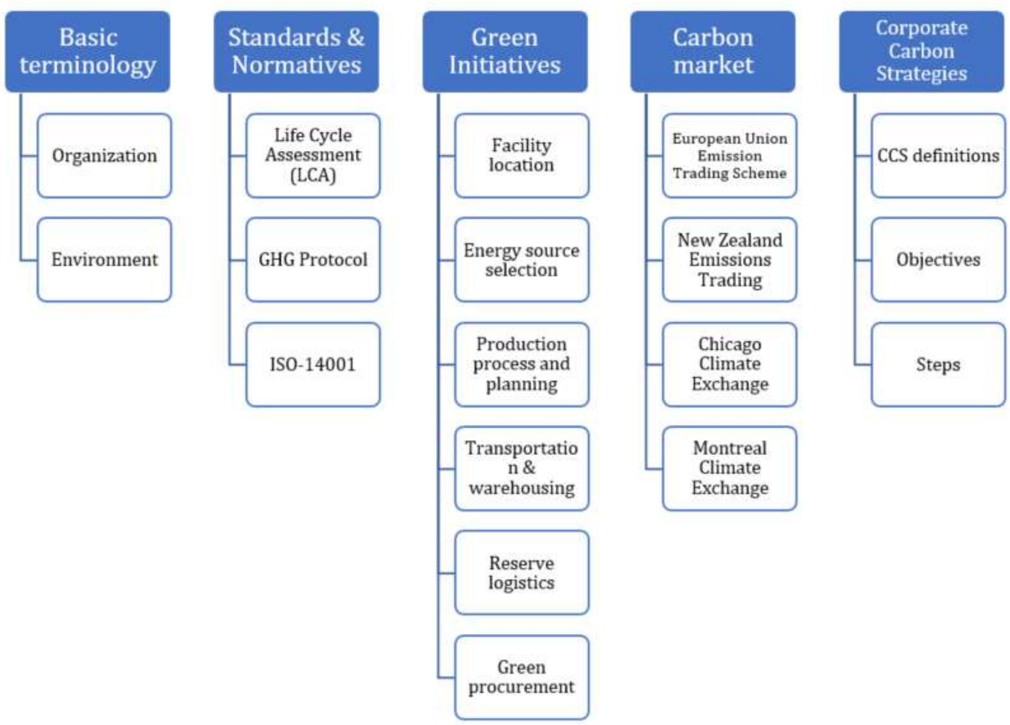


Figure 2-1 State of the art organization.
Source: Own development

The most relevant green initiatives are highlighted in a specific section, where the main contributions in recent decades are organized into six processes within the supply network. Finally, the integration of the carbon market in the supply network design, as well as a literature review related with the Corporate Carbon Strategies, is explained.

The chapter is organized as follows: Section 1 summarizes the basic terminology in this field; Section 2 describes available standards and normatives; Section 3 and 4 illustrate statistically where and how the research was focussed; Section 5 highlights carbon emission contributions within the supply chain, whilst Section 6 highlights the main contributions in the carbon market; Section 7 shows the relevant studies regarding corporate carbon strategy and finally Section 8 shows the conclusions and areas of opportunity.

2.1 BASIC TERMINOLOGY

Supply Chain is defined as a set of processes where different stakeholders (i.e. suppliers, factories, distributors and retailers) work together to convert raw materials into a final product ready to be delivered to customers (Damert, et al., 2017). Within the Supply Chain two main processes can be defined: (1) the Production Planning and Inventory Control Process, and (2) the Distribution Process, both working in a synchronized manner.

More than a physical flow, the supply chain encompasses all activities associated with the flow and transformation of goods from the raw materials stage (extraction), through to the end user, as well as the associated information flows. Material and information flow both up and down the supply chain. ***Supply Chain Management (SCM)*** "is the integration of these activities, through improved supply chain relationships, to achieve a sustainable competitive advantage'' (Handfield & Nichols Jr., 1999).

Since SCM covers the complete flow of goods it is often related with logistics. Indeed (Corominas, 2013) points out 'In early definitions, the term SCM was used, or perhaps misused, synonymously with traditional definitions of logistics management. However, the consensus today seems to be that SCM is somewhat more than logistics'. In this research, he has concluded that the expression 'supply chain' does not describe the reality and it is not accurate enough, since supply chains are a 'network of relationships within a firm and between interdependent organizations and business units'.

Thus, (Corominas, 2013) recommends making an effort to replace the expressions 'supply chain' and 'SCM' with the more suitable ones ***Supply Network (SN)*** and ***Supply Network Management (SNM)***, respectively. The vast majority of the authors mentioned in this literature use the 'supply chain' terminology, although in the last decade some contributions (Soylu, et al., 2006) (Ramudhin, et al., 2008) (Vujanovića, et al., 2014) have introduced 'Supply Network' terminology as a concept. However, the expression 'supply chain' is useful to practitioners/academics and this literature review keeps the original terminology used by the authors.

A supply network is traditionally designed based on the economic objectives (cost minimization, sales maximization) (Pinto-Varela, et al., 2011).However, as society's environmental concerns are increasing and every supply network forms part of the global society (Chaabane, et al., 2010), then a supply network based on the environmental objectives (carbon emissions, recycling performance, waste management and energy use), and the social performances (quality of life, noise, etc.) could also be evaluated.

Sustainable development is defined as a "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs" (WCED, 1987). Since a supply network has a strong link with society, an integrated approach which connects these three pillars (economic, environmental and social) is needed.

A ***Sustainable Supply Network (SSN)*** includes objectives related with sustainable economic, environmental and social development (Seuring & Müller, 2008). A supply network interacts with other stakeholders such as customers and suppliers, which are themselves another supply network. Therefore, a well implemented Sustainable Supply Network strategy will also impact on customer and suppliers, so all the stakeholders will contribute in creating an extended sustainable supply network.

Green Supply Network Management (GSNM) is a piece of the sustainable supply network where environmental thinking is integrated into supply network management (Srivastava, 2007). It includes supplier selection, product design, the manufacturing process, warehousing & transportation and end-of-life of the product.

The GSNM concept has been favoured in recent years due to the increasing momentum of climate change and its impacts on the earth (Genovese, et al., 2013). The main contributors to climate change are the anthropogenic greenhouse gases (GHG), as their atmospheric concentrations have grown markedly since pre-industrial times (Abdallah, et al., 2012).

The ***greenhouse gas*** (or GHG for short) is any gas in the atmosphere which absorbs and re-emits heat, keeping the atmosphere warmer than it would otherwise be (Brander, 2012). The GHG process occurs in the atmosphere as a natural process; nevertheless in recent years human activity has increased these levels, causing global warning and climate change.

A ***carbon footprint*** is the total greenhouse gas (GHG) emissions caused directly and indirectly by an individual, organization, event or product. A carbon footprint accounts for all six Kyoto GHG emissions: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (Kyoto Protocol, 2007).

Carbon dioxide equivalent (CO_2e) is the unit of measurement that permits different greenhouse gases to be compared in order to have the same unit of CO_2. CO_2e emissions are calculated by multiplying the emissions of each of the six greenhouse gases by its 100-year global warming potential (GWP).

There are two different schools of research into carbon footprints. The first approach, named ***product carbon footprint***, aims to calculate the CO_2e emissions arising from the life cycle of goods or services.

The carbon footprint in this context includes the CO_2e emissions resulting from the extraction and manufacturing of raw materials, right through to their use and final re-use, recycling or disposal.

The ***organizational carbon footprint***, is the other school of research, which aims to measure the GHG emissions from all the activities throughout the organization, including energy used in buildings, industrial processes and company vehicles. In this framework, a carbon footprint determines the climate impact (in terms of CO_2e emission) of the organization under consideration.

According to the research (Hertwich & Peters, 2009), the average per capita carbon footprint varies from 1 t CO_2e/year in African countries to ~30t CO_2e /year in Luxembourg and the United States. Based on 73 nations and 14 aggregate world regions, the authors have concluded that developing countries show more GHG consumption in categories related to food and services, while in rich countries it is connected with mobility and manufactured goods.

The Kyoto Protocol was signed in 1997 in response to climate change and it gained strength in 2005. Initially, the proposed targets were more aggressive for developed nations, due to their contribution since pre-industrial times. Until 2012 the reduction planned for 37 industrialized countries was 5% from 1990 levels until 2012 (Abdallah, et al., 2012), although a more ambitious international reduction agreement will be needed for the coming years. The Kyoto Protocol also proposed a set of legally binding conditions for the committing countries and introduced mechanisms in order to help countries to achieve targets and decrease costs.

The ***Emissions trading*** or carbon market is a system where the carbon dioxide can be tracked and traded as a commodity on the markets. This system is defined in article 17 and gives the countries which are exceeding their targets the opportunity to buy the excess capacity from the countries below the target.

Another way to help countries with greenhouse gas reduction commitments to reach their targets is defined in article 12 of the Kyoto Protocol. The ***Clean development mechanism (CDM)*** is the mechanism through which countries can invest in projects related with emission reduction in developing countries.

On the other hand, article 6 of the Kyoto Protocol introduced the ***Joint implementation (JI)***, which is the mechanism by means of which a country with an emission reduction commitment can invest in projects related to emission reduction in another developed country committed to their reduction.

At the end of this thesis there is a "Glossary of terms" section to help the reader to understand the related technical terms used in this thesis.

2.2 STANDARDS AND NORMATIVE

Establishing international standards for measuring environmental carbon emission impact is one of the methods that the business sector has found to reduce GHG emissions and measure environmental impact through emission inventories. Various tools and guides have been developed to help companies design effective strategies to reduce emissions. One of these tools is the Greenhouse Protocol (WBCSD/WRI, 2004) which allows for the measurement of direct and indirect GHG emissions from a corporate standpoint. Also at corporate level the Carbon Disclosure Project (CDP) helps global corporations to understand the impacts of climate change throughout the supply chain (CDP Organization, 2017).

Another regulatory tool is ISO 14064 (International Organization for Standardization, 2006) which is coherent and compatible with the GHG Protocol. In general terms, ISO 14064 identifies the "What" and the GHG Protocol the "How" and "Why". ISO 14064 is oriented toward audits, while the GHS protocol is oriented toward providing a set of options for reducing GHGs.

In line with this, there is another specification focus on the product rather than the company PAS 2050 (BSI , 2011), which provides a method for assessing the gas emission of products and services based on Life Cycle Assessment (LCA).

LCA, also called "Life Cycle Analysis" or "cradle-to-grave", is a useful methodology for evaluating the environmental impact associated with a product, process or activity. LCA methodology is based on four elements: goals and scope definition, inventory analysis, impact assessment and interpretation, all of which have the final objective of looking for opportunities for environmental improvements.

Companies interested in making environmental improvements to their supply network often use LCA to analyse environmental impacts within their processes (De Benedetto & Klemeš, 2009). LCA assesses the environmental impact throughout a product's life cycle and includes all stages within the supply network: from raw material extraction and processing to manufacturing, transport, distribution, consumption, reuse, recycling, and waste treatment (Alexander, et al., 2000). LCA is also used to assess possible investment alternatives related to environmental impact in cases related to raw material selection, suppliers and manufacturing processes (Freeman, et al., 1992).

Many publications use LCA for assessing and quantifying environmental impact within a supply network. This is the case of Pishvaee & Razmi (2012) and Tsai, et al., (2011) who look at the minimization of environmental impacts on supply network design, based on a LCA approach and traditional economic costs. In their articles, these authors propose a fuzzy, multi-objective mathematical model under conditions of uncertainty and use LCA to find a balance between positive economic balance and environmental impact.

De Benedetto & Klemeš (2009) propose a strategy, which they call "Environmental Performance Strategy Map", to support decision-making processes using the LCA approach. This combines environmental indicators (footprints) with the additional dimension of cost; additionally, they defined a Sustainable Environmental Performance Indicator as a single measure of the sustainability of a given option.

LCA methodology is described in a series of ISO documents (International Organization for Standardization, 2006). Globally, nearly 55,000 organizations are certified according to ISO-14001, which has the overall goal of continually improving organizations' environmental management (ISO 14001, 1996).

LCA is widely used by designers to assess the environmental performance but it needs a weighted interpretation. The "Eco–indicator 95" is an LCA weighting method that gives a final and quantitative rate; this methodology was used by Brentrup, et al., (2001) while an updated version, "Eco–indicator 99", was used by Contreras, et al. (2009), Santibañez-Aguilar, et al. (2014), and Graebig, et al. (2010), among others. Moreover, "Ecological Footprints" and "EcoPro" was used by Luo , et al. (2001). . All of these methodologies aim to be powerful tools for aggregating LCA results.

Additionally, regarding specific standards, the EN 16258 is an international methodology for calculating and declaring the energy consumption and GHG emissions of transport services (freight and passengers), which provides guidance on how emissions should be computed at product level.

2.3 RESEARCH METHODOLOGIES APPLIED

Three research methodologies were differentiated: (1) case study; (2) modelling papers and (3) literature reviews. Figure 2-2 shows the assignment of papers to the research methodologies.

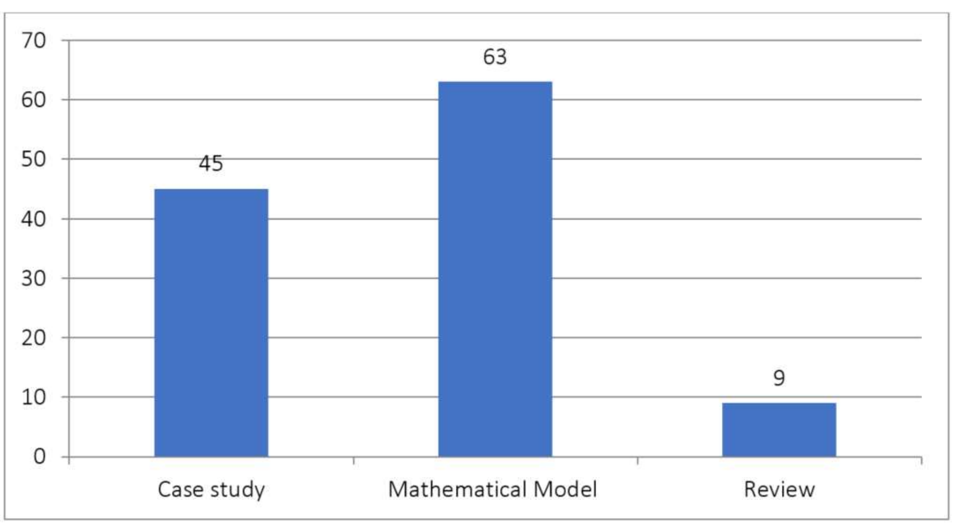


Figure 2-2 Research methodology employed.
Source: Own preparation based on literature review

1. ***Case study:*** According to Liping & Bin (2010) the top-3 sectors that contribute most to climate change are: Transportation Equipment, Metal Smelting and Pressing and Electricity, Steam Production and Supply. In terms of CO_2e emission density the top contributors include Coal Mining and Dressing, Non-metal Minerals Mining and Dressing, Petroleum, Coking and Nuclear Fuel Processing.

   Carbon trading is now a fact of life and the industry should get involved in defining carbon trading in order to advance and defend their interests (Johnson & Heinen, 2004), including penalties (Stranlund, 2007) and incentives (Kravanja , 2012).

   Incentives are also taken into account in building relationships with sustainable suppliers, as is illustrated in the case study presented by Seuring & Müller (2008) and Scholtens & Kleismann (2011). Other contributions such as Mitra & Datta (2014), Krause et al. (2009) and Kumar et al. (2016b) demonstrate that the suppliers' collaboration could have a positive impact.

   Reverse logistics is a key topic, especially for the automated sector, where the closed-loops are analysed (Duval & MacLean, 2007) (Schultmann, et al., 2006). A range of new green technologies are also illustrated by study cases, especially in the case of cogeneration systems (Bianchi & De Pascale, 2012) (Domenico, et al., 2005) and biomass (Yang & Chen, 2016). They also focus on different kinds of energies (Graebig, et al., 2010) (Hang, et al., 2013) or energy management (Ngai, et al., 2012).

   The applicability of different supply chain models has been tested in real industrial cases and different fields: in the telecommunication sector (White, et al., 2003) (Min & Melachrinoudis, 1999); the petrochemical industry (Johansson, et al., 2012);the aluminium sector (Ngai, et al., 2012);the automotive sector (DeCicco , 2013); the textile industry (Ferretti, et al., 2007) and food supply chains (Domenico, et al., 2005).
2. ***Modelling papers:*** different kinds of mathematical techniques are used by authors to include environmental aspects in the supply chain design. Mixed-integer linear programming is the most common, used by Chaabane, et al. (2010), Abdallah, et al. (2012) and Soyal, et al. (2014). Additionally, a Pareto frontier is used to observe the trade-off relationships between multiple objectives (Alexander, et al., 2000)(Bernier & Maréchal, 2012). Meanwhile, Guillén-Gosálbez & Grosssmann (2009), Fahimnia, et al. (2015) and Kaur & Singh (2017a) use a bi-criterion stochastic mixed-integer nonlinear program (MINLP). On the other hand, Frota, et al. (2008) show the advantages of using multi-objective programming (MOP) to design sustainable networks and Zhou, et al. (2000) propose a goal programming (GP) model to address a multi-objective problem with the integration of both relaxable and non-relaxable constraints .

   Regarding transport proposals Bektaş & Laporte (2011) and Kumar et al. (2016a) present a Pollution-Routing Problem (PRP) model, an extension of the classical Vehicle Routing Problem (VRP). Erdoğan & Miller-Hook (2012) deal with a Green Vehicle Routing Problem (G-VRP) and Schultmann, et al. (2006) use vehicle route planning for reverse logistics activities.

A Lagrangian heuristic based on the solution of the sub-problem is proposed by Elhedhli & Merrick (2012). Ravi (2012)has used the Multi-Attribute Global Inference of Quality (MAGIQ) technique and Min, et al. (2006) a genetic algorithm.

3. ***Literature review and survey:*** A complete literature review regarding sustainable supply chain management is offered by Seuring & Müller (2008) and Eskandarpour, et al. (2015). While Srivastava (2007) proposes a literature, review focussed more on green supply chain management and Pinto & Coves (2014) provide a review of the current trends in CO_2e emission reductions in supply network design.

   A critical review is presented by Freeman, et al. (1992), showing pollution prevention approaches to environmental improvement. Genovese, et al. (2013) present a survey in which they verify the penetration of environmental and green criteria for supplier selection in the corporate practice of the top 100 manufacturing companies.

2.4 DISTRIBUTION OVER TIME

Over the last two decades, environmental management has been increasingly network-integrated and this development has been accompanied by an increase in the literature on green supply networks. This section shows the most recent contributions in the field of GHG emission reduction in supply network design. Because the focus of the research, using mathematical models, is to integrate decisions to reduce GHG emission, much of the literature review centres on this approach. For a researched period (1992 - 2017), 128 papers were identified; see Figure 2-3.

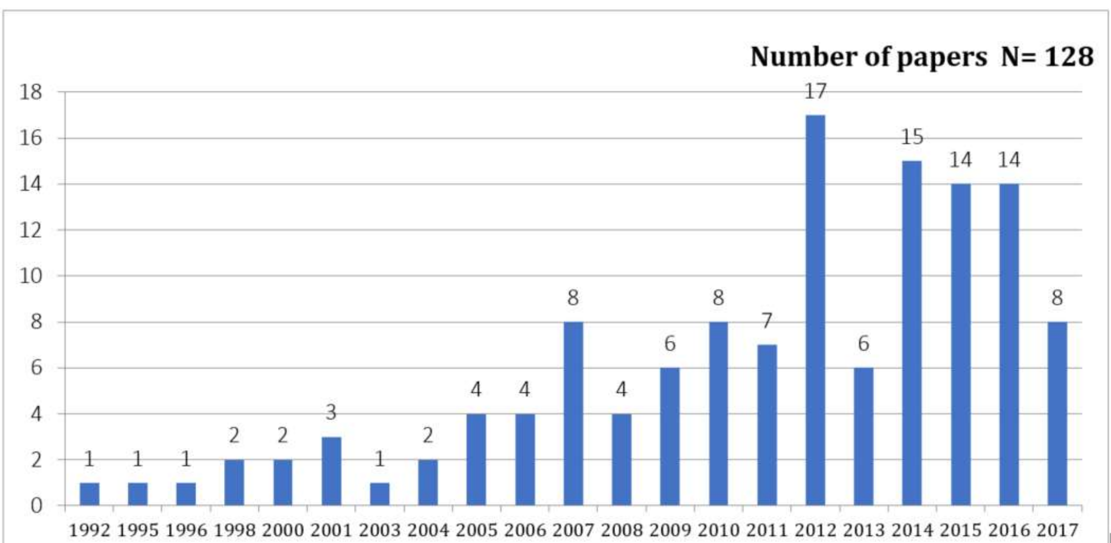


Figure 2-3 Publications per year throughout the period studied.
Source: Own preparation based on literature review

Due to the environmental field taking an increasingly important position at economic and social levels, over the past decade this has had some undeniably positive effects on research development. As Figure 2-3 shows, 57.6% (68 articles) of the papers reviewed for this thesis were published after 2012. In Figure 2-4, the pie chart shows the distribution of the literature review by category, where the greater share (32%) is related to topics concerning transportation, warehousing and the production process (12%).

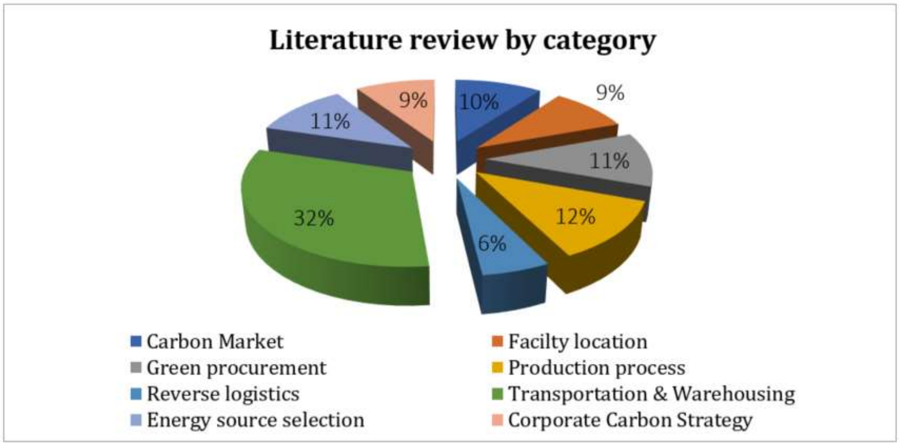


Figure 2-4 Publications organized by the integration of the CO_2e impact in the supply network.
Source: Own preparation based on literature review

In Table 2-1 publications are classified per the type of network supply design decision. Each publication is classified according to how the variables that reduce GHG emissions are integrated into the mathematical model and case studies.

Table 2-1 Publications by main contribution on green supply network.
Source: Own preparation based on literature review

Main contribution	Category	Author
Facility location	Mathematical model	Bojarski, et al. (2009), Guillén-Gosálbez & Grosssmann (2009), Min, et al.(2006), Pishvaee & Razmi (2012), Pinto-Varela, et al. (2011), Diabat & Al-Salem (2015), Rahmani & Mahoodian (2017),
	Case study	Jiang & Green (2017)
Green procurement	Mathematical model	Chaabane, et al. (2010), Hayami, et al. (2015), Ma, et al. (2016), Kaur & Singh (2017b), Kaur & Singh (2017a)
	Case study	Seuring & Müller (2008), Ferretti, et al. (2007), Scholtens & Kleismann (2011), Krause, et al. (2009), Mitra & Datta (2014), Plambeck (2012), Kumar, et al. (2016b)
Production process	Mathematical model	Boukherrouba, et al. (2015), Alexander, et al. (2000), Hugo & Pistikopoulos (2005), Mallidis, et al. (2012), Letmathe & Balakrishnan (2005), Luo, et al. (2001), Soylu, et al. (2006), Vujanovića, et al. (2014), Song, et al. (2017)
	Case study	Mani, et al. (2014), Klein, et al. (2016), Jin, et al. (2017)
Reverse logistics	Mathematical model	Hicks, et al. (2004)
	Case study	Duval & MacLean, (2007), Zhang, et al. (2014), Schultmann, et al. (2006)
Energy source selection	Mathematical model	Bernier & Maréchal, (2012), Bojić & Stojanovic (1998), Luo, et al. (2012), Muis, et al.(2010), Wang, et al. (2011)
	Case study	Bianchi & De Pascale (2012), Domenico, et al. (2005), Hang, et al. (2013), Johansson, et al. (2012), Ngai, et al. (2012), Graebig, et al. (2010), Yang & Chen (2016)
Transport & Warehousing	Mathematical model	Aksoy, et al. (2014), Fahimnia, et al. (2015), Bektaş & Laporte (2011), Erdoğan & Miller-Hook (2012), Jin, et al. (2014), Paksoy, et al. (2011), Pan, et al. (2013), Elhedhli & Merrick (2012), Santibañez-Aguilar, et al. (2014), Soyal, et al. (2014), Validi, et al. (2015), Van de Klundert & Otten (2010), Lagoudis & Shakri (2015, Fichtinger, et al. (2015), Liotta, et al. (2015), Abdallah, et al. (2013), Ameknassi, et al. (2016), Shen, et al. (2016), Yin & Chuang , (2016), Amir & Fallah (2016), Kumar, et al. (2016a), Suzuki (2016)
	Case study	Auvinena, et al. (2014), Rizet, et al. (2012), Günther, et al. (2015), Davydenko, et al. (2014), Mallidis, et al. (2012), Wu & Dunn (1995), Yu, et al. (2016), Ajanovic & Haas (2015), DeCicco (2013), Yu, et al. (2016), Chen, et al. (2016)
Carbon Market	Mathematical model	Abdallah, et al. (2012), Nagurney, et al. (2006), Ramudhin, et al.(2008), Sadegheih (2012), Tseng & Hung (2014), Comas & Tancrez (2015)
	Case study	Peace & Juliani (2009), Stranlund (2007), Johnson & Heinen (2004), Kravanja (2012), Gouldson Andy (2017)
Corporate carbon strategy	Case study	Damert, et al(2017), Busch, et al. (2012), Kolk & Levy (2001), Cadez & Czerny (2016), Yunus, et al. (2016), Lee Lam (2014), Okereke & Russel (2010), Jeswani, et al (2007), Montabon, et al.(2007)

2.5 GREEN INITIATIVES

During recent decades, many authors have presented their contributions proposing green initiatives for reducing the carbon emission in different areas of the supply network. In this section these contributions were organized by area.

The following paragraphs show the most relevant green initiatives to reduce carbon emission in a supply chain. This study is divided into six sections: 1) Facility location and capacity; 2) Energy source selection; 3) Production process and planning; 4) Transportation and warehousing; 5) Reverse logistics; and 6) Green procurement.

2.5.1 FACILITY LOCATION AND CAPACITY

Facility location is frequently linked with cost and profit, forming part of the classic supply network design for economic reasons and, lately, for sustainable reasons too. Due to the relationship between kilometres travelled and GHG emissions, the facility location has a direct ecological impact in terms of transportation. The environmental regulations of each place are also a factor.

The final objective of the network design is changing; currently both cost minimization and environmental impact are taken into account when designing the logistic network, "balancing *planet* and *profit*" (Frota, et al., 2008). Relocation decisions are part of the dynamic changes which include supplier and customer bases, distribution networks, corporate re-engineering, business climate and government legislation (Min & Melachrinoudis, 1999).

A mathematical programming-based methodology is proposed by Hugo & Pistikopoulos (2005) which includes two approaches. The strategic level shows a classical dynamic plant location, including a set of potential geographical sites and an optimal network of transportation. The operational level includes long-range capacity planning and an optimal plant expansion capacity.

On the other hand, Letmathe & Balakrishnan (2005), Chaabane, et al. (2010) and Abdallah, et al. (2012) introduce the size of productive plants and distribution centres. The location of pick-up and recycling centres was dealt with by Min, et al. (2006). A Genetic Algorithm (GA) was also proposed by Diabat & Al-Salem (2015) for the joint location-inventory problem, extending it to account for the reduction of carbon emissions.

Along the same lines, Guillén-Gosálbez & Grossmann (2010) and Pinto-Varela, et al. (2011) present a supply chain network design model to determine the supply chain configuration, along with the planning decisions that maximize the net current value and minimize the environmental impact. Wang, et al. (2011) and Bojarski, et al. (2009) include facility locations as variables within a multi-objective mathematical model to identify the trade–off between possible environmental damage and economic impact. A general overview is presented by Jiang & Green (2017) that evaluates the impact of geographic shifts in global supply chains on global greenhouse gas emissions. Recently, Rahmani & Mahoodian (2017) proposed a supply chain network design considering CO_2e emissions. Where strategic decisions are made in the design phase of the supply chain to invest in equipment with low emissions in factories, they demonstrate the importance of the pre-design phase carbon reduction strategy.

2.5.2 ENERGY SOURCES SELECTION

Despite the consensus on the importance and benefits of adopting sustainable practices throughout the entire value network, one of the major challenges continues to be the search for innovative technologies. Thus, the importance of generating long-term planning models to determine investment decisions relating to the optimal selection, installation, and expansion of process technologies (Hugo & Pistikopoulos, 2005).

Economic impact is often related to environmental impact. When dealing with investment in technology, the trade-off between total costs and environmental effects is especially important. Choosing the level of environmental protection is one of the variables to be decided in preparing the GSN design, and is related to the investment in process technology (Wang, et al., 2011).

A greater investment in technology leads to reduced CO_2e emissions; the initiatives can involve adopting solar absorption cooling and heating (SACH) systems (Hang, et al., 2013), ground-mounted photovoltaics (PV) and maize–biogas-electricity (Graebig, et al., 2010), in addition to cleaner processes, the purchase of equipment or the implementation of innovative technologies.

Along the same lines, Abdallah, et al. (2013) make an analysis of the PVs and conclude that it depends on the economic policies (incentives, subsidies, feed-in tariff), the efficiency of the PVs connected, and the quantity of incident solar radiation at the facility location. Furthermore, Yang & Chen (2016) conclude that wind power could substitute traditional fossil fuel-based power generation systems, due to having the 'lowest transformity of 4.49 × 104 sej/J, smaller environmental loading ratio of 5.84, and lower greenhouse gas emission intensity of 0.56 kg/kW'.

Modern technologies can be applied in manufacturing with cogeneration systems; as factories need electric and thermal energy simultaneously, Combined Heat and Power (CHP) can be an appropriate solution. Some authors (Bianchi & De Pascale, 2012) (Bojić & Stojanovic, 1998) (Johansson, et al., 2012) take the environmental benefit due to cogeneration into account. They assess the carbon reduction of emissions due to CHP operations, in comparison with the non-CHP operations of the same machine. Similarly, some studies (Domenico, et al., 2005) have demonstrated how it is possible to reduce both energy costs and CO_2e by using CHP systems.

Luo, et al. (2012) introduced fuel type, fuel composition, burning method and pollutant abatement technology into a MILP model for the operational planning of a steam power system. Additionally, Dodoo & Gustavsson (2013) compare different scenarios such as electric resistance heaters, bedrock heat pumps or cogeneration-based district heat, all with biomass-based energy supply.

Vujanovića, et al. (2014) present a multi-objective Mixed-Integer Linear Programming where renewable energy (biomass and other waste), is considered along with solar energy. They show that renewable-based energy production improves energy footprints, especially the electricity footprint, as well as carbon and nitrogen footprints; however, it depends very much on the regional characteristics, particularly the climatic conditions.

The biomass topic is also considered in the Klein, et al. (2016) paper, with the authors commenting that wood biomass involves non-renewable energy inputs, and thus possibly leads to environmental impacts. They evaluate different environmental impacts (GHG emissions, without biogenic CO2; non-renewable primary energy consumption; particulate matter) caused by the supply of forest biomass.

The multi-objective model developed by Wang, et al. (2011) introduces a new decision variable, “environmental protection level”. Technology selection depends on the environmental protection level set in the planning phase. Generally, a higher investment level is needed to achieve a greater protection level . Hugo & Pistikopoulos, (2005) also propose a multi-objective model in which potential plants may be selected using different types of technology. Their model is based on LCA principles, and presented as a support tool in sustainable investment planning.

The global industrial sector accounts for around 47% of energy-related carbon dioxide emissions (Moomaw, 1996) and its value is increasing rapidly. Thus, there is also a need for the authorities to develop new solutions. Along these lines, Muis, et al. (2010) propose a Mixed Integer Linear Programming (MILP) to meet the forecasted electricity demand, but at the same time minimize the cost of electricity generation and reduce CO_2e emissions by 50% from current CO_2e emission levels. This study suggests choosing from different kinds of renewable energy, which include: Pulverized Coal (PC), Integrated Gasification Combined Cycle (IGCC), Natural Gas Combined Cycle (NGCC), solar Photovoltaic (PV), nuclear and biomass from landfill gas, palm oil residues, wood processing residues, rice processing residues and municipal waste.

2.5.3 **Production process and planning**

Production operations contribute to increasing greenhouse gases in two main ways: a) through the energy source used, or b) by emissions related to the production process itself. The energy source used for production is the main factor in GHGs (Moomaw, 1996) which means that more efficient energy use, cleaner energy sources, and cleaner technological processes can significantly reduce GHGs.

At the strategic level, it is possible to pose the problem with a long-term planning horizon that includes the selection of the process technology and its expansion capacity (Hugo & Pistikopoulos, 2005) and develops a systematic focus to identify the synergy among the different energy generation systems (Soylu, et al., 2006). The Jin, et al. (2017) survey describes six themes for reducing the footprint impact, among them the energy efficiency assessment and control of mechanical manufacturing systems, low fossil-carbon process planning and production scheduling and sustainable innovation for product-service systems.

At the operational level, Ngai, et al. (2012) suggest that periodic pollutant emission limits should be introduced when the manufacturing plan is designed. Soylu, et al. (2006) propose a multi-period, discrete and continuous mixed integer linear programming model (MILP), which includes investment in energy generation systems within production planning. Letmathe & Balakrishnan (2005), Bojarski, et al. (2009) and Luo, et al. (2001) analyse the problem of CO_2e emissions caused by company production processes. and Bugg & Resch (2015) suggest significantly lower greenhouse gas (GHG) emissions can be achieved using large-volume production. Most of these papers present mathematical models that may be used in industry to determine optimal production levels and product mix in the presence of various environmental restrictions and typical production planning limitations.

The production planning is analysed by Boukherrouba, et al. (2015) where the economic, environmental and social performances are all coherently integrated into the model. Similarly, Nagurney, et al. (2006) propose homogeneous products in different manufacturing plants with distinct environmental emissions. On the other hand, Mallidis, et al. (2014) indicate that longer optimized replenishment cycles reduce a node's transportation costs and CO_2e emissions, but increase its inventory costs. Recently, Song, et al. (2017) studied the effects of carbon emission regulations on capacity expansion.

Around 40% of the primary energy use comes from the construction industry and Tsai, et al. (2011) explore the environmental impact in this sector. Using the LCA method they measure the CO_2e emission cost and use mathematical programming to determine the profit maximization of building projects. They conclude that the results depend on the energy intensive issues and impact on the profit of the construction company.

Since LCA is a useful methodology for quantifying the impact of industrial processes, authors (Alexander, et al., 2000) are using it to create environmental objectives, which include the transfer of mass or energy information. Thus, a multi-objective algorithm has been created, combining economic objectives with the LCA-based environmental objectives.

2.5.4 Transportation and warehousing

A supply chain network is described as a set of consecutive stages connected by communication and transportation links (Dotoli, et al., 2005). According to Hugo & Pistikopoulos (2005) and Lagoudis & Shakri (2015) the impact of transportation on the environment can be analysed in each supply network phase.

Distance travelled is directly linked with the CO_2e emitted, so there is a close connection between network optimization and emissions. Many models based on routing optimization (Validi, et al., 2015; Rodrigues Pereira Ramos, et al., 2014) have been developed to optimize transport costs and distance travelled. Nevertheless, the amount of carbon emissions produced by a vehicle also depends on load and speed, among other factors. These other factors are included in the Pollution – Routing Problem (PRP), which is an extension of VRP, where greenhouse gas emissions, fuel, travel times and their cost are included (Bektaş & Laporte, 2011).

According to DeCicco (2013) there are three elements which impact directly on the carbon emissions in transportation: reducing travel demand, improving vehicle efficiency and using alternatively (non-petroleum) fuelled vehicles. Meanwhile, Rizet, et al. (2010) suggest that the factors that influence the carbon efficiency are distance, retail type, area density and consumer behaviour.

Transportation modes (truck, rail, or waterway) are included in the redesign of the supply chains proposed by Jin, et al. (2014) and Liotta, et al. (2015).. Additionally, Pan, et al. (2013) propose an optimization model for freight consolidation in which CO_2e emissions are computed for two transport types (highway and railroad). Lee Lam (2014) and Rizet, et al. (2012) propose a sustainable maritime supply chain by taking customer requirements as the focus. Based on the benchmarking shown, maritime transport and the consumer leg seem to have high emissions, while logistics activities such as storage and road freight exhibit relatively low emissions.

Paksoy, et al. (2011) and Amir & Fallah (2016) analysed a closed-loop supply chain network using different modes of transport, each of which has its own emission rates and costs. Reis, et al. (2012) present a survey which analyses the advantages and disadvantages of combining rail transport with the other transport modes and Shen , et al. (2016) analyse transportation mode selection, with the consideration of vehicle capacity constraints (weight and volume).

Low utilization of freight trucks is one of the main causes of rising CO_2e emissions. The following authors (Van de Klundert & Otten (2010), Elhedhli & Merrick (2012) and Aksoy, et al. (2014)) have identified this as a key factor in reducing CO_2e emissions. One of the strategies proposed is to increase the capacity use by accepting additional through freight.

Also, Mallidis, et al. (2012) have introduced another important strategy to improve the loadfill and consequently reduce GHG emissions. They introduce decisions about using dedicated versus shared warehouses and transportation, as well as demonstrating that using shared warehouses transportation operations can reduce costs and improve the environmental impact of a company. This conclusion is supported by Fahimnia, et al. (2015), who conclude that to have a flexible supply chain is the greenest and most efficient alternative when compared to strictly centralized situations.

A Green Vehicle Routing Problem (G-VRP) is developed by Erdoğan & Miller-Hook (2012), who design a mixed integer linear program and two heuristics (the Modified Clarke - Wright Savings heuristic and the Density-Based Clustering Algorithm) for alternative fuel-powered vehicle fleets; they also studied the difficulties that exist as a result of limited vehicle driving range in conjunction with limited refuelling infrastructure.

Kumar , et al. (2016a) develop a VRP that simultaneously considers production and pollution routing problems with time windows, whilst Yin & Chuang, (2016) analyse vehicle routing problems but including a Cross-docking distribution perspective, using bee colony algorithm. Suzuki, (2016) comes up with a variant of the standard VRP, called the pollution routing problem (PRP), which minimizes the fuel burn or pollutant emissions of trucks.

Soyal, et al. (2014) include different transport environmental aspects, such as road structure, return hauls, product perishability, vehicle and fuel types, weight loads of vehicles and travelled distances in a Multiple Objective Linear Programming MOLP. Based on the application of the model in an international beef logistics chain, the authors have concluded that distance is the most relevant factor in terms of environmental impact, but bad infrastructure can also decrease the fuel efficiency, impacting negatively on the carbon emissions.

Vehicle fuel consumption plays a key role in the transport sector and directly affects GHG emissions. Wu & Dunn (1995) describe different alternative fuels (Emulsified Diesel, Biodiesel, Natural Gas, Propane, Ethanol-Diesel Mix) and, looking ahead, electric vehicles are also studied by Günther, et al. (2015) and Ajanovic & Haas (2015). These can significantly reduce vehicle emissions, with lower emission rates than diesel combustion. These alternative fuel solutions are have arisen on the assumption that global petroleum prices will continue to rise and accordingly Santibañez-Aguilar, et al. (2014) addresses the optimal design and planning of a bio-refinery supply chain to fulfil the expected ethanol and biodiesel needs.

Most of the environmental impact on distribution focusses on transport elements, but the impact of warehousing has received less attention. Fichtinger, et al. (2015) is one of the papers that contributes to this field, emphasizing the key effect of the inventory management decisions, such as supply lead times, reorder quantities, and storage equipment, on the carbon emissions in distribution.

In addition, Chen, et al. (2016) explores the optimal decisions in warehousing operation and technology investment under the cap-and-trade emissions policy; and Yu, et al. (2016) highlights the importance of the transport supplier selection in the sustainable supply chain network. Finally, Ameknassi, et al. (2016) consider the integration of logistics outsourcing decisions in order to achieve a green supply chain.

2.5.5 REVERSE LOGISTICS

Measuring the carbon emissions associated with waste is not an easy task. Zhang, et al. (2014) suggest measuring it with the treatment of the wastes (combustion, landfill and wastewater) from the production plants. For waste recycling and treatment, LCA is used to design models for identifying solid and liquid waste, as well as gas emissions in different production processes (Chaabane, et al., 2010). Models also analyse waste inside the supply network by analysing waste flow from the standpoint of accumulated costs (Hicks, et al., 2004).

In the paper industry, different options are taken into account to reduce emissions, for instance Counsell & Allwood (2007) consider that recycling reduces waste sent to landfills and reduces the energy demand of the paper-making process by re-using the fibres from waste paper.

The quantity of plastic in the automotive industrial sector has become an environmental problem in recent years. Although there is a benefit due to fuel efficiency and associated lower CO_2e emissions, the increase in plastics from end-of-life vehicles is generating a landfill capacity problem in some regions, such as North America.

Duval & MacLean (2007) propose a recycling network, which would reduce greenhouse gas emissions and energy, to solve this problem. However, they conclude that the post-consumer automotive plastics recycling network leads to an unprofitable proposition for a company. Schultmann, et al. (2006) propose a closed-loop supply chain in the automotive industry and Bazan, et al. (2015) study the impact of manufacturing and remanufacturing on the greenhouse gas emissions.

Ravi (2012) analyses end of life in the computer sector, where the main activities are recycling plastic and metal recovery. The survey proposes combining several types of recycling processes into an aggregate value representing the overall quality of recycling of each of the systems, while providing decision makers with an overall picture of the quality of the various recycling systems under evaluation.

2.5.6 GREEN PROCUREMENT

To minimize the environmental impact a company needs to work closely with its suppliers. Some authors are trying to include a green procurement concept, introducing to their models the option of choosing suppliers based on the trade-off between suppliers' emissions and the cost of their components (Abdallah, et al., 2012).

According to Krause, et al. (2009) the company's supply network cannot be more sustainable than its suppliers. Additionally, Genovese, et al., (2013) highlights the importance of supplier selection and Ma, et al. (2016) considers the relationship between supplier selection and carbon taxes. Based on Mitra & Datta (2014) and Sundarakan, et al. (2010) suppliers should implement an Environment Management System (EMS) and/or get ISO 14001 certified, to demonstrate their commitment to the environment and to facilitate their selection by the purchasing companies.

The automobile sector is studied in the paper proposed by Hayami, et al. (2015), concluding that encouraging suppliers who include sustainability policies can enhance competitive advantage and can include not only compliance with regulations and legislation but also cost savings. Also using an automobile case study Kumar , et al. (2016b) propose encouraging suppliers to go green and cut down their carbon emission or else "Pay Up" to comply with the emission norms.

The paper proposed by Kaur & Singh (2017a) suggests a MINLP (Mixed Integer Non- Linear Program) and MILP (Mixed Integer Linear Program) in which the environmentally sustainable procurement impact is analysed, including a variety of the real-time parameters from the buyer and supplier side, such as costs, capacities, lead-times and emissions. Along the same lines, Kaur & Singh (2017b) provide an optimal decision for low carbon procurement.

Alternative supply methods for raw materials are appearing, for instance Ferretti, et al., 2007 propose the possibility of receiving aluminium alloy from the supplier in liquid form, both to avoid transport pollution and to obtain a substantial benefit, because of the energy savings implicit in the method itself.

On the other hand, Seuring & Müller (2008) propose pressures and incentives for sustainable supply chain management and study the supplier management (particularly addressing issues at the supplier–buyer interface). Additionally, Plambeck (2012) suggests that manufacturers need to motivate suppliers by building strong relationships, with minimum purchase quantities at specified prices over a long period of time. Scholtens & Kleismann (2011) also suggest that several incentives can play a significant role.

2.6 CARBON MARKET

Article 17 of the Kyoto Protocol sets forth a new concept by allowing both countries and companies to optimize CO_2e emissions by establishing an "emissions trading" scheme. Under this scheme, companies can buy or sell CO_2e credits, and in doing so, meet their environmental goals. Some of them are trying to work within the already created carbon framework by applying voluntary commitments (Gouldson Andy, 2017).

Regardless of whether the company has set voluntary reduction goals or is subject to GHG emission caps, this scheme is based on assigning a quota of emission credits [1 credit= the right to emit one metric ton of carbon dioxide equivalent to (t CO_2e)], which each company must manage in the most efficient manner possible.

There are different carbon markets around the world (Johnson & Heinen, 2004), for instance the European Union Emission Trading Scheme (or EU ETS), the New Zealand Emissions Trading Scheme (NZ ETS), the Chicago Climate Exchange in the United States and the Montreal Climate Exchange in Canada.

The main objective of these markets is to create opportunities for investment in green technology development (Letmathe & Balakrishnan, 2005). In this kind of market, each company's emissions are verified at the end of each period. If real emissions are greater than the imposed emission quota, the difference may be compensated by purchasing credits on the market. If real emissions are less than those permitted the company may sell CO_2e credits on the market and earn profits (Chaabane, et al., 2010).

Managing CO_2e emissions through CO_2e credits is an interesting means of attaining environmental goals. Ramudhin, et al. (2008) are the first to include carbon market sensitive strategic planning in the supply chain network design. They suggest that the environmental impact can be measured by converting the CO_2e tonnage caused by supply network activities into CO_2e credits, according to the CO_2s to CO_2e price in the CO_2 market. Recently, some authors have linked the emission trading scheme with the sustainable supply chain design; Chaabane, et al. (2010) have used the life cycle assessment (LCA) principles and legislation capping GHG emissions to achieve sustainability objectives.

In a mathematical model, CO_2e emission credits may be managed by introducing an average expected cost per CO_2e credit into a company's economic objectives (Abdallah, et al., 2012). Similarly, Sadegheih, et al. (2011) propose a mixed integer programming and a genetic algorithm where carbon emission costs are included in the total costs of the supply chain. The model proposed allows scenarios, such as a change in carbon emission costs or penalties for over-emission, to be simulated. Comas & Tancrez (2015) propose a model for supply chain network design that studies carbon policies such as caps on supply chain carbon footprints, caps on market carbon footprints and carbon taxes.

The inclusion of the social costs of CO_2e emission in the supply chain design is well analysed in the paper proposed by Tseng & Hung (2014). In their results they suggest that legislation, which forces companies to bear the social costs of carbon dioxide emissions resulting from their economic activities, is an effective approach to reducing carbon dioxide emissions.

Ramudhin, et al. (2008) propose a mixed integer linear programming model for designing a green supply network which integrates decisions related to "carbon trading". The model allows companies to assess different strategies regarding supplier and subcontractor selection, product allocation, productive capacity utilization, and transport configuration in terms of their impact on GHG emissions. Abdallah, et al. (2012) presents an optimization model which seeks to minimize traditional costs and CO_2e emissions by introducing a new concept known as "green procurement", where companies can decide how to manage their CO_2e emissions within the CO_2e market.

Nevertheless, integrating external control mechanisms with sustainable supply chain management practices does have an impact, which is addressed by Stranlund (2007).. This survey has analysed the following initiatives : environmental regulations, take-back legislation, carbon taxes and emission trading. Additionally, Peace & Juliani (2009) show that a well-designed carbon market can encourage innovation and brings a cost reduction; while Kravanja (2012) discusses the advantages of incentives for sustainable development.

At governmental level, Nagurney, et al. (2006) develop a model and computational framework to help policy-makers determine the optimal carbon taxes applied to electric power plants, in the context of electric power supply chain (generation/distribution/consumption) networks. Three taxation schemes are described, the first model proposing a decentralized scheme where it is possible to determine the optimal tax for each electric power plant; the second policy assumes that the global emission limit is fixed and the third one proposes that the limit be a function of the tax.

2.7 CORPORATE CARBON STRATEGIES

So far, most management research has focused on carbon reduction and climate change mitigation, using different methodologies based on mathematical tools, research hypotheses or case studies. But the term corporate carbon strategy is defined by Damert, et al.(2017) as "a complex set of actions to reduce the impact of a firm's business activities on climate change and to gain competitive advantages over time".

For Busch, et al. (2012) a "carbon management strategy" is any effort by a company to reduce the impact on climate change, whilst Kolk & Levy (2001) argue that a "climate strategy" is based on the selection of various strategic carbon options. For Cadez & Czerny (2016) a "climate change mitigation strategy" is based on the application of the right carbon practices.

Yunus, et al. (2016) provide a more specific guide for a "carbon management strategy", proposing the inclusion of carbon measurement, reduction reporting, trading, risk, carbon reduction opportunities and an analysis of the carbon market place. But the term "corporate carbon strategy" is defined by Lee (2012) as a firm's choice of the scope and level of its carbon management.

Moreover, Okereke & Russel (2010) comment that a "corporate climate strategy" combines the possibility of achieving market gains while also keeping political influence. Creating a social-political strategy can also avoid future problems; for Jeswani, et al. (2007), a "business response to climate change" is basically the degree of proactivity that a company has in response to the climate change mitigation.

However, when a company aims to develop a "carbon management strategy" the major bottlenecks are the short-term mindset, especially when focused on profit maximization (Slawinski, et al., 2015). This approach is normally in conflict with a long-term strategy which includes carbon reduction. Therefore accommodating long-term carbon reduction strategy into the short-term goal is crucial for the success of the mitigation strategies. Indeed, the short and long-term connection is a prerequisite for any realistic assessment of carbon strategy effectiveness.

Damert, et al. (2017) recommend basing a corporate carbon strategy on three objectives: 1) carbon governance; 2) carbon reduction; and 3) carbon competitiveness. Their conclusion mentions the "talking before walking" argument as an explanation for the missing link between carbon governance and carbon reduction activities.

According to Montabon, et al. (2007) a key aspect of carbon reduction strategies is their effectiveness in delivering the desired long-term impacts ; this contribution is seconded by Mintzberg (2000), who concludes that a carbon reduction strategy is not mere words but words that must be translated into actions.

2.8 CONCLUSION OF STATE OF THE ART

In this section a literature review was made of supply network design, considering greenhouse gas emission impact. The research focussed on identifying applicable and explanatory organizational theories that have been utilized to expand understanding and knowledge of this research field.

After the Kyoto Protocol was signed in 1997 the climate change problem has received increasing attention in the academic and industrial world, with research in this field increasing significantly. On the other hand, many companies also use it as an opportunity to have a positive public image, due to consumers being more concerned about environmentally responsible production.

Based on this research several observations can be made. First, emergent standards and normatives have been created to support companies in homogenizing their GHG emission inventory and calculation. Secondly, most of the literature (81%) is focused on integrating carbon emissions into the supply chain; the carbon market is included in 10% of the papers reviewed and only 9% deals with developing corporate carbon strategies: see Figure 2-4. Third, articles related with green opportunities in the supply chain at tactical level include: transportation, production process, reverse logistics; and at a strategic level: energy sources selection, facility location green procurement and carbon market. The most relevant contribution in each area is shown in Figure 2-5.

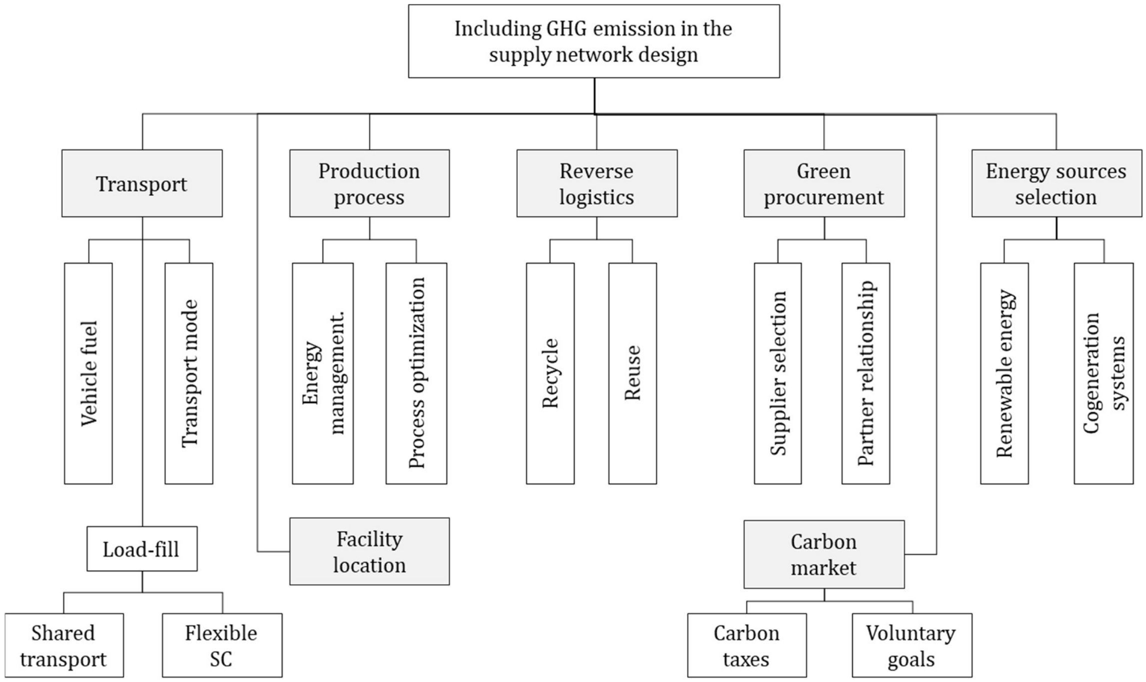


Figure 2-5 The most relevant initiatives to reduce GHG emission by category.
Source: Own preparation based on literature review

Fourth, authors propose different kinds of summarized mathematical models, where greenhouse emission is included: mixed-integer linear programming (MILP), multi-objective programming (MOP), mixed-integer nonlinear program (MINLP), goal programming (GP), heuristics and meta- heuristics. Much of the literature on applications has been applied to different sectors: aluminium, petrochemical, telecommunication, automotive and food industry.

Finally, the literature review shows a good contribution to green supply chain initiatives; however, a very limited amount of the existing literature covers the business strategy and climate change research of corporate GHG mitigation strategies and their impact on corporate carbon performance. There is a lack of mathematical models that allow decision makers to see a comprehensive GHG reduction plan, which would include a methodology for annual carbon reduction and the tactical and investment plans for this purpose.

CHAPTER 3

Carbon Reduction Methodology

Nowadays there are some guides and standards which have been developed to help companies to design effective strategies to reduce carbon emissions. One of these tools is the GHG Protocol (WBCSD/WRI, 2004) and another is ISO 14064 (International Organization for Standardization, 2006), which is coherent and compatible with the GHG Protocol.

In general, as mentioned in the literature review, there are two main schools of research in this field. The first one considers the LCA evaluation, focussed on calculating the footprint of a product or a service, whilst the second approach, normally based on GHG protocol, aims to quantify the carbon footprint of an organisation. Thus, the second approach is needed to create a carbon reduction methodology .

The standards and guidance already established are useful for helping to define some parts of the Corporate Carbon Strategy (CCS). For instance, GHG protocol is useful for defining reporting principles, determining boundaries and setting GHG targets, whilst CDP helps global corporations to understand the impacts of climate change throughout the supply chain.

Nevertheless, neither GHG Protocol nor CDP have a formalized guide to support companies in achieving the carbon reduction targets, using operation research tools to merge carbon emission decisions with corporate and financial decisions. Moreover, those guides are unable to answer some key questions such as; "How to design a CCS step by step?", "What kind of resources are needed?", "What kind of tools are useful for finding the best strategy?", "How to adapt the CCS to the business strategy and/or the supply network design?".

The Carbon Reduction Methodology proposed in this chapter offers a formalized guide for helping companies to achieve carbon reduction targets and financial benefits. Due to the nature of this guide an organizational level approach is taken, based on the GHG protocol. The methodology proposes a step by step guide, starting with the assessing and finishing with the tracking of results. The aim is to take advantage of the benefits of green growth and use it for marketing and attaining competitive advantage.

The rest of the chapter is organized as follows: Section 1 defines the aim and the scope of the Carbon Reduction Methodology; Section 2 establishes the intended user group; Section 3 discusses the assumptions; Section 4 develops the steps of the methodology and finally, Section 5 includes the main recommendations.

3.1 PURPOSE AND SCOPE

The aim of the Carbon Reduction Methodology is to put forward a clear guideline that companies can use to reduce their carbon emissions, achieve their carbon emission targets, as well as obtain attractive financial savings. Two key steps of the methodology are explained in detail in Chapter 4 (Designing a Corporate Carbon Strategy) and Chapter 5 (Modelling framework).

The Carbon Reduction Methodology covers the sustainability initiatives that aim to reduce a company's carbon footprint. It aims to be one of the pillars of the strategic financial plan of a company and strongly linked with it.

3.2 AUDIENCE

The intended user group of this methodology are the heads of the following departments: Strategic Finance and Planning, Regional Facilities Management, Strategic Facilities Management, Information Technology Services, Logistics and operation planning, Procurement Sustainability and Global Sustainability or Corporate Social Responsibility (CSR).

It is recommended that all the areas mentioned above understand the complete scope of this methodology. The Global Sustainability or Corporate Social Responsibility (CSR) area could lead the program, although the other areas should co-lead the whole initiative. Areas such as Regional Facilities Management and Strategic Facilities Management should be involved in the investment assessment and its corresponding carbon emission effect, whilst Strategic Finance and Planning can evaluate the financial impact. Procurement Sustainability should consider any links with suppliers and the Logistics and operation planning studies any network impact.

3.3 ASSUMPTIONS

The creation of this methodology assumes the following:

- The company works with a Strategic Financial Planning routine.
- The company has, or is willing to have, a Sustainability team or Corporate Social Responsibility (CSR) team.

3.4 THE STEPS OF THE CARBON REDUCTION METHODOLOGY

In Figure 3-1 four major steps are defined. The first is the creation of the Corporate Carbon Strategy, which will be explained in detail in Chapter 4. In this step the corporate carbon bases are defined. The second step is related with the long term strategic planning, normally linked with financial indicators. At this stage, the leadership team develops a plan considering future investments, capacity constraints, environmental indicators, potential savings and opportunities.

The third step of the methodology is the business optimization, which includes the development of a mathematical model where the supply chain is redesigned and the greenhouse gas emission is reduced. The outcome of this stage is the most relevant part of the methodology, because it suggests a complete plan of action to be implemented as a part of the company's strategy and carbon reduction roadmap. Chapter 5 explains it in more detail.

The last step is the implementation and tracking, this step is as important as the previous three. A proper project tracking will also provide the possibility of reviewing more alternatives and adjusting the plan for the middle – long term.

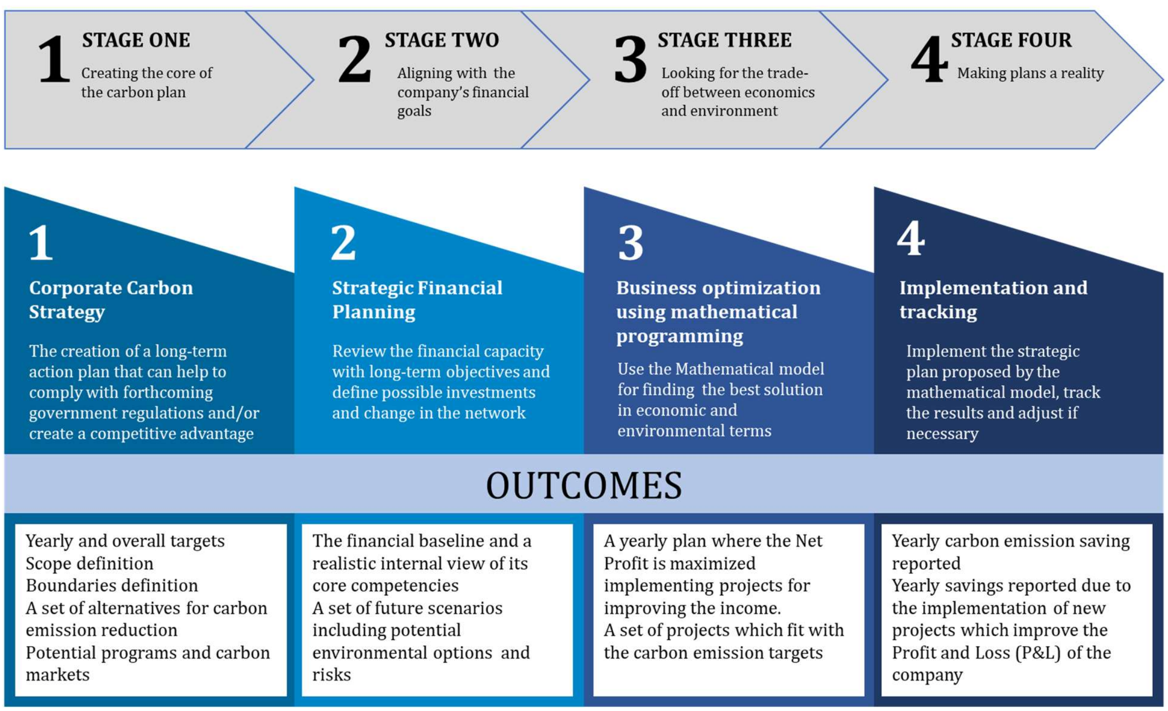


Figure 3-1 The four main stages in the Carbon Reduction Methodology.
Source: Own preparation

Figure 3-1 also summarizes the main objective of every step and briefly defines the expected outcomes of each. There is a well-made link between the steps; for instance, one of the most important outcomes of the Corporate Carbon Strategy is a set of alternatives for carbon reduction, which is used later in step two, where this set of alternatives is assessed from a financial point of view. In the third step, these alternatives are included in the mathematical model for finding a carbon reduction roadmap. The fourth step is explained in the next sections.

3.4.1 CORPORATE CARBON STRATEGY

The carbon reduction methodology starts with the creation of the corporate carbon strategy. The actions needed to complete this stage can be grouped around three major strategic objectives: 1) carbon baseline definition; 2) carbon reduction; and 3) carbon effectiveness. The carbon baseline is the starting point of the strategy, which includes establishing the type of emission, the data baseline and the boundaries.

The second objective is covered by two actions, the first of which is the identification of carbon reduction opportunities, defining what is to be done. The second action is the definition of carbon goals, which defines the strategy over time and represents the size of the challenge. The outcome of both actions should be reviewed as a part of the strategic business plan and both have an input in the strategic financial planning; see Figure 3-2.

Finally, the third objective consists in taking advantage of the corporate carbon strategy already created at that point. One of the most relevant activities would be to look for carbon programs and carbon markets in which the company could participate. The Corporate Carbon Strategy is explained in detail in Chapter 4.

3.4.2 STRATEGIC FINANCIAL PLANNING

The Strategic Financial Planning is usually the core of a company's long-term strategy, normally it is reviewed at the end of every year to determine the projects to be included in the next year's budget . The intention at this stage is not to explain a regular financial business process, due to the methodology assuming that there is one already well-established. The aim is to highlight the importance of integrating carbon reduction projects into the strategic financial review.

A strategic financial planning includes the following actions:

- *Establish the current situation:* Reviewing the yearly financial situation is a routine in every company, but from an environmental perspective, it should include the review of whether a corporate carbon strategy is in place or not. Some parameters to be analysed are the share market, sales volume and carbon tax impact (if applicable).
- *Define company's priorities:* The company should review the importance of applying a carbon reduction strategy and the impact of this decision. In this activity allocating a budget for carbon reduction projects is also important.

- *Identify risk and saving opportunities:* Every alternative where capital investment is needed should be evaluated. The first step would be to evaluate the project cost and the potential economic savings; if the project does not have savings, the carbon benefit could be converted using the market price for traded carbon. Then, as soon as the cost and the total saving are clear, the internal rate of return and the net present value should be calculated.
- *Develop the long-term objectives:* The carbon goals should be aligned with the long term financial objectives, in terms of the budget allocation of the future projects, as well as the expected long-term benefits of having a carbon reduction plan.
- *Develop a yearly financial projection:* The strategic financial planning is commonly done every 3 or 5 years and reviewed yearly. The yearly review helps to monitor the compliance of the planned projects and reviews the feasibility of implementing projects planned for the following year.

The strategic financial planning should provide the methodology with an approved list, in terms of the feasibility of the alternatives for carbon reduction. Besides, in this step the possible financial impact of the carbon tax (if applicable) should be analysed. Moreover, some financial parameters such as gross sales volume, cost of goods sold, expenses and gross profit should be ready at this point, in order to prepare the information for the next step.

3.4.3 BUSINESS OPTIMIZATION USING MATHEMATICAL PROGRAMMING

The previous steps converge at this point, in the development of a mathematical model. Mathematical optimization tools can provide more accurate results and, in this case, can offer a proper carbon reduction plan. This methodology proposes a Mixed-Integer Linear Program (MILP) mathematical model, which uses financial, logistics and environmental inputs.

This step includes a well-defined list of potential changes in the network and the associated costs, as well as a clear list of carbon reduction opportunities with the correspondent emission factors and costs and/or investments. As soon as the mathematical model is created, the running action depends on the number of variables and network characteristics. But, as soon as it is solved, it is strongly recommended to review the reliability of the output and make a sensitive analysis. Chapters 7, 8 and 9 include an example of a sensitive analysis for three case studies.

The MILP model proposed is general enough and aims to cover as much as possible the most relevant supply chain and environmental aspects of a firm. Nevertheless, sometimes the context of a country, sector or company needs a specific set of constraints and/or the objective function needs adjusting, so in these cases an adaptation of the model is required. For instance, Chapter 7 presents a case study of a multinational company operating in Brazil. Because the taxes in this country can affect the supply chain design, a set of constraints are added.

3.4.4 IMPLEMENTATION AND TRACKING

Once the previous steps have been completed, it is time to implement the projects planned and track the results. The sequence of the projects' implementation would be according to the plan, but it is necessary to track the performance against the target to check the monthly and yearly compliance. The GHG protocol (WBCSD/WRI, 2004) in Chapter 11, section 10, gives some guidelines for tracking and reporting the progress, these guidelines highlight the importance of two tasks:

- Track the performance against the target: Check the results periodically (weekly or monthly) and compare them in relation to the target. The company should develop a clear calculation process to report monthly and yearly results.
- Report progress in relation to the target: A general result against the target could be a good reference, but should also show the results by category (manufacturing, logistics, suppliers) against the target. In Chapter 4 section 4.5 of this thesis, there is a KPI suggested for reporting results. It is also important to report the absolute values and highlight any implemented internal project that affects the results.

Figure 3-2 shows the sequence of the activities of the four steps, including a brief description of the activity. The figure shows how the strategic financial planning and the corporate carbon strategy run in parallel but the carbon reduction opportunities and the carbon goals are reviewed and approved in the financial business plan.

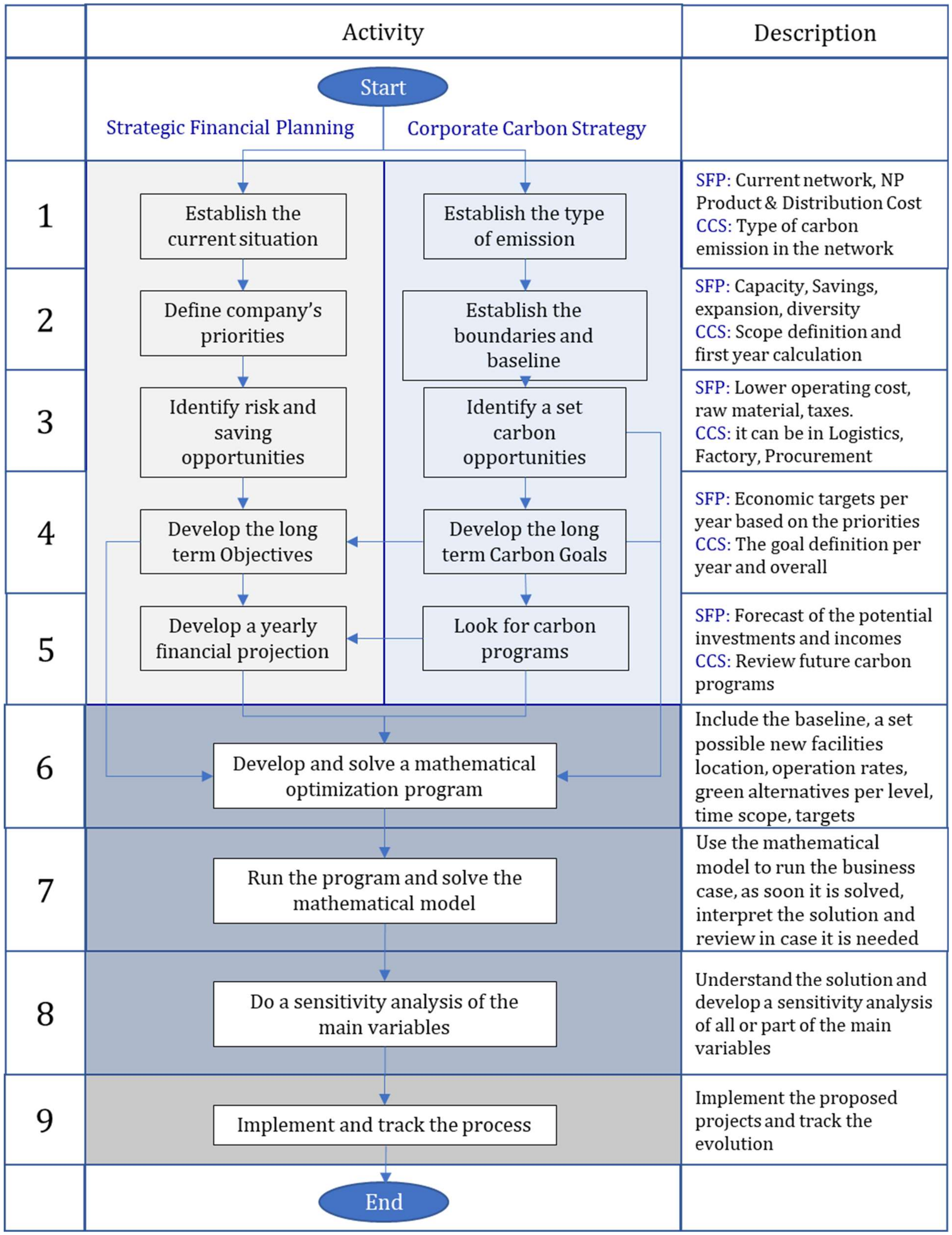


Figure 3-2 Sequence in detail of the steps.
Source: Own preparation

3.5 Recommendations

The success of this proposal is closely linked with the communication strategy. Especially in the development of the Corporate Carbon Strategy the operational and strategic areas should provide their best insights to the carbon reduction opportunities. Not using the experience of those areas can lead to the proposal following the wrong strategy.

In the implementation stage the communication strategy is even more important, the whole company should be committed to achieving the carbon reduction targets and visualizing how the company will reach it. Otherwise, the strategy will be a wonderful plan on paper and never a reality. It is highly recommended that the main actions for the following periods are communicated per area.

In case the strategy includes radical changes in the network with a high impact on the kilometres travelled and carbon emissions, the leadership team should communicate details of the plan over time to compensate for it. Besides, integrating carbon emission goals in the personal targets of the leadership team, as well the workers, can help to ensure the plan's success.

CHAPTER 4

Designing a Corporate Carbon Strategy

A corporate carbon strategy is defined as "a long-term action plan created to mitigate the climate change, through the implementation of carbon reduction alternatives, which help a firm to achieve market gains but also to comply with forthcoming government regulations". This definition combines different approaches of the authors mentioned in the literature review and is based on three important aspects: (1) it has a proactive strategic intention, (2) it uses carbon reduction alternatives to focus the results, 3) it has both social implications and the intention of benefitting business.

The corporate carbon strategy corresponds to the first step of Figure 3-1. This step includes establishing the type of emissions to be reduced, defining operational boundaries, planning and performance information, identifying emission – reduction opportunities, determining carbon reduction goals and deciding if the company can participate in voluntary GHG programs or carbon markets.

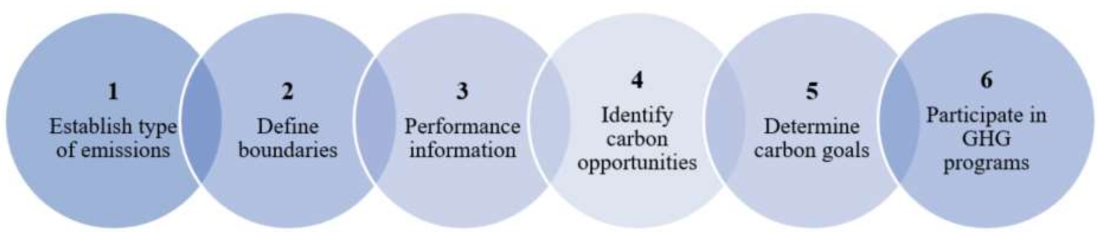


Figure 4-1 The most relevant initiatives to reduce GHG emission by category.
Source: Own development

The Corporate Carbon Strategy, summarized in Figure 4-1, is a practical proposal, which uses the Carbon Trust (Carbon Trust, 2012) and GHG Protocol (WBCSD/WRI, 2004) as a reference. The six steps proposed aim to give a clear and practical sequence for corporate carbon strategy creation.

Throughout this chapter the six steps are developed, most of the them clarifying concepts, scopes and/or indicators. Nevertheless, the fourth step is developed in detail due to its importance in the strategy creation. Thus, step four includes a set of alternatives for each part of the supply chain, including technical details, advantages or disadvantages and recommendations for implementation.

4.1 ESTABLISHING THE TYPE OF EMISSIONS

The carbon dioxide equivalent (CO_2e) is the single unit used to measure different greenhouse gases. Nevertheless, depending on the activity or products, a company will produce one or more than one greenhouse gasses. Therefore, as a first step towards managing a carbon strategy, the emissions linked with the company's activity must be identified and understood. The following definitions are made based on the United States Environmental Protection Agency (EPA, 2017).

- *Carbon dioxide (CO_2):* is the main greenhouse gas emitted by human activities. The combustion of fossil fuels to generate electricity is one of the main sources of CO_2 emission, although the use of coal will produce more CO_2 than oil or natural gas.
  The fossil fuels such as gasoline and diesel used for transportation are the other largest contributors. Additionally, several industrial processes produce chemical reactions generating CO_2 emission, even without involving combustion; for example, the production and consumption of mineral products such as cement, the production of metals such as iron and steel, and the production of chemicals.
- *Methane (CH_4):* in terms of climate change CH_4 is more than 25 times greater than CO_2 over a 100-year period. Around 60% of total CH_4 emissions are related to human activities. The main contributor is the natural gas industry, as every activity linked with production, processing, storage, transmission, and distribution of natural gas emits methane to the atmosphere.
  In the agriculture sector, an animal's digestive process produces large amounts of CH_4. These emissions are considered human-related because humans use these animals for food. Finally, the waste decomposing in landfills is the third source of methane.
- *Nitrous Oxide (N_2O):* able to live 298 years in the atmosphere, N_2O is normally emitted in the agriculture sector through the use of synthetic fertilizers. Nitrous Oxide is also emitted in the transport sector when fuel is burned, in the fertilizer industry or in the production of adipic acid, which is used to make fibers such as nylon and other synthetic products.
- *Fluorinated gases:* this category includes: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). It is the most powerful and longest lasting type of greenhouse gases, which comes only from human-related activities.
  The most important production of hydrofluorocarbons comes from their use as refrigerants (air conditioning systems in both vehicles and buildings), aerosol propellants, solvents, and fire retardants.
  Perfluorocarbons exist as a by-product of the aluminium industry and the manufacturing of semiconductors. Sulphur hexafluoride is also part of the manufacturing of semiconductors and magnesium processing, as a tracer gas for leak detection and is also used in electrical transmission equipment, including circuit breakers.

Every greenhouse gas (GHG) remains for a different length of time in the atmosphere and consequently has a different global warming potential (GWP). In order to calculate the CO_2e the GHG quantity should be multiplied by the global warming potential (GWP). For instance, 2 Kg of CH_4 represents 50 Kg CO_2e (2 CH_4 x 25 (GWP). "Appendix A: Global Warming Potential Values" includes a list of the global warming potential (GWP) values.

4.2 BOUNDARIES DEFINITION

According the GHG protocol there are two types of boundaries that a company has to define. The first one is the organizational boundary, which can be selected between an equity share approach and control approach. The second boundary is the operational one, which is generally divided into two categories: direct and indirect.

Establishing an organizational boundary from an equity share approach means that the carbon strategy is linked with the economic interests or extent of a company's rights to the risk and rewards accruing from an operation. Under the control approach, a company is totally responsible for the emissions from operations over which it has control.

Operational boundaries are important for delimitating the scope and identifying where reductions should take place. Direct emissions – Scope 1 – are from sources owned or controlled by the company (emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc). Indirect emissions are divided in two types: Scope 2 and Scope 3. Scope 2 accounts for GHG emissions from the generation of purchased electricity consumed by the company. Scope 3 accounts for other indirect emissions not covered in Scope 2, for example the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity and electricity-related activities.

Setting operational boundaries will help to improve transparency and manage the full spectrum of GHG risks and opportunities throughout the supply chain. For instance, if a company needs to decide where factories should be located, in terms of transportation emissions, the closest one will be selected. However, when the energy generation is included in the analysis, the energy used (wind, geothermal or nuclear) may be the first choice. For this reason, scope definition is so important, because depending upon what scope is defined and what is to be done with the results, the answers can be different.

4.3 PLANNING AND PERFORMANCE INFORMATION

Once the organizational and operational boundaries are defined, a company should start to measure its emissions reduction for determining the carbon emission baseline. At this stage a first estimation of the horizon plan should be determined. Performance information includes understanding the current performance evaluation and then planning the future emission forecasts and the capital expenditure planning. For this purpose, two performance metrics are identified:

- KPI 1: Absolute amount of carbon emitted as measured in "Kilograms of CO_2e" (Kg CO_2e). It gives information on a company's total CO_2e impact.
- KPI 2: Efficiency of carbon emissions as measured in "Kilograms of CO_2e per Kilograms sold" (Kg CO_2e/ Kg sold). It indicates the total amount of CO_2e to move one Kg of freight.

The efficiency of carbon emissions "Kilograms of CO_2 per Kilograms sold", also called carbon efficiency, would be an excellent base for establishing targets. Nevertheless, whatever the KPI used, it is highly recommended to use it as function of a business metric. Target emissions are performed transparently relative to past emissions, based on a fixed target or a rolling target base year.

4.4 IDENTIFYING CARBON REDUCTION OPPORTUNITIES

One of the most important steps in the Corporate Carbon Strategy is the identification of the potential improvements, which will help to achieve the carbon reduction targets. In this section, a collection of potential improvements is classified per category. Figure 4-2 summarized the "green" initiatives for carbon emission reduction.

Six major categories were identified, four of which are part of the main activities of the supply chain: 1) Transportation; 2) Warehousing; 3) Manufacturing and 4) Green procurement. Besides, the energy management is part of both the warehousing and manufacturing initiatives and it also has a strong relation with green procurement in areas associated with negotiations. Thus, due to the impact of the energy management on carbon emission throughout the supply chain, two extra categories were added, 5) Renewable energy and 6) Energy management.

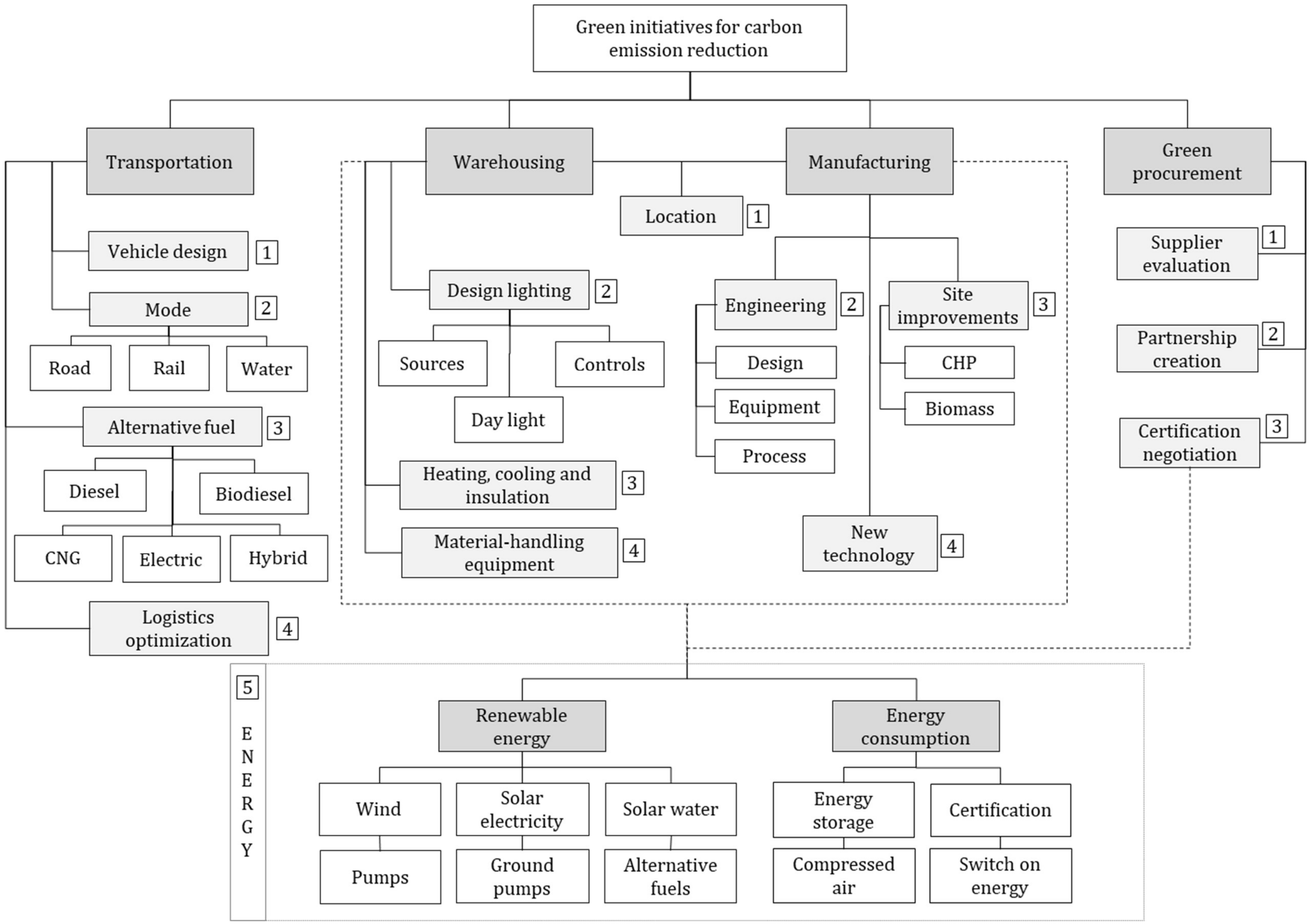


Figure 4-2 Summary of the green initiatives for carbon reduction.
Source: Own preparation

4.4.1 TRANSPORTATION

Logistics is an area brimming with opportunities for sustainability. Every transportation choice has an impact on sustainability and it is closely linked with transportation savings. For example, the type of fuel used determines how much emission will be produced; shifting from one transport mode to another can enhance sustainability; the truck design impacts on the truck's efficiency, carbon emissions and route design impacts on the total distance travelled and the carbon emission. The following sections explain four areas of opportunity in the transportation area, classified as: 1) Transportation modes; 2) Vehicle design; 3) Alternative fuel; and 4) Logistics optimization. This analysis was made based on Network for Transport and Environment (NTM), 2011.

4.4.1.1 TRANSPORTATION MODES

Every transportation mode has different kinds of features and restrictions which reflect advantages and disadvantages according to the particular situation of the operation, including costs, capacity and lead-times. Thus, the transport mode decision involves variables related to needs (urgent deliveries, type of materials to transport, distance, etc.) and possibilities (transport available, costs and resource access conditions, routes available, etc.).

According to the World Resources Institute (WRI, 2017) transportation represents 14.7% of the global carbon emission, the third position after industry (14,7%) and electricity & heat (24,9%). Additionally, road transport is responsible for emitting as much as all the other types of transport (10.5%). However, road transport is cheaper, it is a door to door service and adaptable to customer demands.

Rail transport can move a ton of freight more than 700 km on a single gallon of fuel, therefore producing fewer carbon emissions. Nevertheless, there are some disadvantages of rail transport, most of them related to the absence of enough infrastructure or service in some countries. It is only profitable in medium – long distance services and usually does not meet schedules, which can impact on the service level.

On the other hand, water transport is useful for long distances; it is cheap, has fewer restrictions on loading (liquid, bulk or containers) and as it is a large-scale transport , the carbon emission per ton is lower. Water transport could have some delays, which is why the recommendation is to consider having a security stock for any eventuality.

However, both for inland deliveries or short runs, the truck is currently the most common transport mode. The challenge is to look for a trade-off between business, economics and sustainability and to break down old mindsets about which mode is best. "Appendix B: Transportation assumptions" includes the transportation constraints and characterizes every transport mode.

4.4.1.2 Vehicle design

Improving the vehicle design has an economic, environmental and social impact on the road transport sector. Air resistance also plays an important role in fuel consumption. There are different kinds of aerodynamic devices, for instance: trailer side-skirts, plates which are mounted on the sides of trailers, side-skirts, wind deflectors, etc. All of them used with the same purpose, to allow air to flow more evenly around the vehicle, reducing drag, carbon emission and improving fuel efficiency.

The tire resistance can also affect aerodynamics and fuel consumption, as well as reducing the weave effect and accidents. An advance in tire design is the new super-single tire, which is wider than a normal tire and can replace two standard tires per wheel on a trailer. Its design provides high performance, improves the stability for heavy-duty tractor trailers and reduces carbon emission.

Another alternative in the design category is the double decker truck, which is a very good option for increasing the loadfill and reducing loads and carbon emissions. Nevertheless, the warehouses need to have the infrastructure for this type of operation.

4.4.1.3 Alternative fuel

If road transportation is the only real choice for short hauls, choosing the right power source can be important. Some fuel types are more sustainable than other, conventional fuels, such as fossil fuels (petroleum (oil), coal, and natural gas), as well as nuclear materials such as uranium and thorium and artificial radioisotope fuels that are made in nuclear reactors.

Alternative fuels, known as non-conventional or advanced fuels, are any material that can be used as fuel, this category includes biodiesel, bio alcohol (methanol, ethanol, butanol), chemically stored electricity (batteries and fuel cells), hydrogen, non-fossil methane, non-fossil natural gas, vegetable oil, propane, and other biomass sources. Table 4-1 summarizes the main types of fuels available on the market as well as the one recommended for every situation.

Table 4-1 Type of fuels.
Source: Network for Transport Measures (NTM)

Type	Level	Recommended distance/volume	Benefits
Fuel	Diesel	Medium - long distance trip High volume loads	Well known robust technology Infrastructure in place Low capital cost
	CNG /LPG	Short - long distance trip Low - high volume loads	Low operational cost Reduced CO_2e emission
	Biodiesel	Short - long distance trip Low - high volume loads	From 3% to 62% of CO_2e emission reduction per km
	Hybrid	Short - medium distance trip Low - medium volume loads Urban areas	Reduced cost of operation CO_2e emission reduction up to 25% per km for urban scenario
	Electric	Short distance trip Low volume loads Well known & scheduled route	Operational cost reduction up to 75% 100% CO_2 emission reduction during operation
Transport mode	Road	Short, Medium & long-distance trip	
	Rail	Short, Medium & long-distance trip	
	Water	Medium - long distance trip	
Vehicle design	Aerodynamic features	Medium - long distance trip >300 km	The way it interacts with the atmosphere while in motion plays a role in reducing fuel consumption. Approximately two-thirds of the fuel consumed by a commercial truck is related to its aerodynamics. When aerodynamics are improved, air flows more evenly around the tractor-trailer, reducing drag and improving fuel efficiency.

4.4.1.4 Logistics optimization

Implementing consolidation centers is a way to reduce supply chain traffic between suppliers, factories and warehouses, thus reducing carbon emission throughout the supply chain. Instead of many direct shipments between origins and destinations, the first movement of the goods is to the consolidation center. There, the goods are removed from the trailers, separated, consolidated with goods from other inbound loads, and shipped to the correct plant. Goods from many inbound loads are consolidated onto a single shipment that is sent to a single destination.

Route optimization is another logistics initiative, in this case optimization software can help the route planner to balance the use of consolidation centers, direct shipments, and consolidation at the pickup level to determine the best overall approach for reducing traffic and miles driven.

As a part of the logistics optimization it is important to define transportation boundaries, especially to limit the degrees of responsibility. Sustainability reporting protocols suggest that a business is responsible not only for its own emissions, but also for those of its suppliers and its customers. Although this is a bigger challenge, transportation choice and network design, are both essential in order to be sustainable. Either way, for both companies and third parties it is important to establish responsibilities regarding their supply and transport chains with the aim of eliminating the risk of duplicate accounting.

Figure 4-3 shows the different options regarding responsibility in transport logistics and overhead activity generated emissions. The most common scope used is outbound deliveries (scope B, C) which covers shipments from manufacturers to retailers; the extended supply network includes inbound deliveries (scope A) and a complete overview considers office and business trip emission (Scope D, E). For benchmarking reasons or for comparing changes over time it is essential to take into account the scope under evaluation.

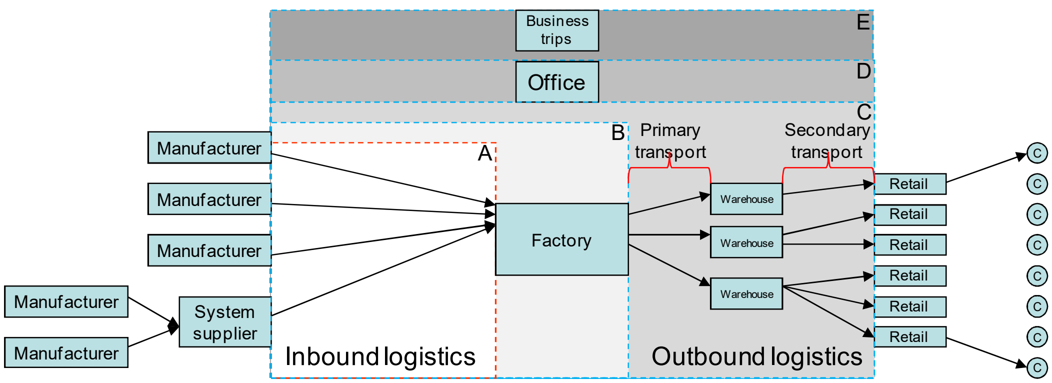


Figure 4-3 Outline of different shipper calculation boundaries with regard to their supply chains. Source: GHG Protocol

4.4.2 WAREHOUSING

Incorporating carbon initiatives into the warehouse provides the opportunity of a win-win proportion between economics and the environment. Building sustainable warehouses is a combination of: 1) choosing the right warehousing location; 2) the warehouse design; 3) the management of heating, cooling and insulation; and 4) the selection of the proper material-handling equipment. Moreover, all these initiatives can help to reduce operating costs and improve the warehouse performance.

The four initiatives related to carbon emission reduction in warehousing are mentioned in the following sections; all of them are based on Carbon Trust (2012).. Improvements related to energy management, which are also part of the warehousing initiatives, are described in sections 4.4.5. and 4.4.6 of this thesis.

4.4.2.1 WAREHOUSING LOCATION

The right location is linked to incentives, most of which offer an economic benefit in the case of company relocation, but in return the building needs to have an environmental compliance standard. Additionally, it should take into account green energy sources in the area and benefits related to this use.

Positioning the building at a site with ample available sunlight could reduce energy consumption. Natural light can provide light during the daytime and the Sun can be used for solar panels in order to offset daily energy and cut back operating costs.

4.4.2.2 WAREHOUSING DESIGN – LIGHTING

Providing good quality lighting is vital for the performance in the work place. Nevertheless, artificial lighting represents between 50 to 80% of the overall electricity consumption on site, therefore making lighting more efficient and more effective is a good opportunity to reduce carbon emission.

Alternatives for efficient illumination can be classified in three categories: 1) Light sources; 2) Lighting controls; and 3) Maximized usage of daylight. In "Appendix C: Warehousing design lights initiatives" there is a detailed explanation of these concepts and a set of carbon reduction initiatives regarding lighting in warehousing.

4.4.2.3 HEATING, COOLING, AND INSULATION

Energy consumption by heating can be as important as energy consumption by lighting in a warehouse. Therefore, the potential saving related to reduced heating costs can be significant Table 4-2 shows a list of heating opportunities for reducing carbon emission and energy consumption.

Table 4-2 Identifying heating opportunities.
Source: Carbon Trust

What to look for	What to look for Potential opportunities
Ensure optimal insulation	To minimize unintended heat loss, it is worth checking if all heating pipes are insulated properly to minimize unintended heat loss, especially in older warehouses.
Secure appropriate temperature levels	Thermostats systems are useful to secure the required temperature levels as well as prevent overheating/-cooling, additionally for specific areas the installation of rapid roll doors with sensors and/or air curtains can maintain the different temperature levels and reduce unintended airflows
Use appropriate heating equipment	For the area where people work, radiant heaters right above this area are a much better solution than ventilating heaters with a less precise heat distribution. Ventilators are the best solution only in the case with the objective is heating the full space.
Integrate solar walls in the heating system	Solar walls consist of specifically designed dark-colored solar collectors, which induct air into the collectors, heated by the sun and distributed by ventilators into the building. Solar walls reduce the energy demand for heating up to 50% per year.
Ensure equipment efficiency	Modern boilers reduce energy consumption up to 30%. An appropriate maintenance of existing boilers and heaters can ensure high-efficient operation. Additionally, old boiler replacement is also an appropriate method to reduce energy costs whilst securing reasonable payback periods.
Use adaptive ventilation and air-conditioning	Air quality sensors could ensure an appropriate level of temperature and air exchange. Another solution is to apply variable fan speeds and reduce air flow volume to around 50%. This has a potential to reduce around 87% of energy consumption and carbon emission from ventilation operation.

A basic assessment of a facility's heating and cooling systems and their energy-efficiency can be useful for evaluating the status and proposing an improvement. Moreover, a detailed assessment is needed to show how much exposure a facility has to the outer environment (windows, truck doors, doors for personnel to enter and leave). The status of the facility's walls should also be determined, meaning the kinds of materials and the types of roofing tiles used and how many days per year each system is in use.

4.4.2.4 MATERIAL-HANDLING EQUIPMENT

The material-handling equipment also has an impact on the total energy and the carbon emission. The total energy used will depend on the total amount of industrial equipment that a facility uses, as well as the type of equipment (forklift or pallet jacks); the type of energy (propane or electricity); the automatization level; and where they are operated (in some e-grid sub-regions, propane and electric power sources are roughly equal, and in others, i.e., the higher power grid regions, propane is will produce a lower level of carbon emissions). The carbon reduction opportunities related to material-handling equipment are linked with the energy management in the warehouse.

4.4.3 MANUFACTURING

Manufacturing, which accounts for about 80 percent of industrial energy consumption, also accounts for about 80 percent of industrial energy-related carbon emissions. Business growth presents a unique opportunity to deliver improvements by means of investment in new eco-efficient design and technology. Carbon projects can deliver both eco-efficiency and financial benefits. This provides fuel for growth and further opportunities for sustainability improvements, leading to a "Virtuous circle".

Adopting eco-efficiency manufacturing approaches enables both energy and carbon emissions to be reduced. Additionally, a carbon initiative is associated with cost avoidance, for example switching to renewable fuel in manufacturing also delivers cost savings compared with fossil fuel alternatives. Therefore, a carbon strategy in manufacturing is also good for business.

Figure 4-4 shows the carbon strategy in manufacturing based on four pillars, explained in detail in the following sections. Improvements related to energy management, which are also part of the manufacturing initiatives, are described in sections 4.4.5. and 4.4.6 of this thesis.

Figure 4-4 Manufacturing types projects for carbon reduction.
Source: Own preparation

4.4.3.1 Factory location

Following the same concept as the warehousing location, the factory location is one of the network initiatives that can affect the carbon emission, as the closer the facilities are to the customers the less carbon they emit. Considering that manufacturing activities generally consume a huge amount of energy, locating the factory in a region where renewable energies are available will have an impact on the carbon reduction strategy.

4.4.3.2 Engineering

New factories and new lines make a significant contribution to volume growth. Building Green Technology into the core engineering design of a new factory and line will bring long term benefits.

Much of the environmental footprint in a factory is associated with the production equipment; however, it is also important to get the design of the building right. Building certification schemes such as Leed (LEED, 2002) or Breeam (BREEAM, 2014) can also help when considering eco-efficient design.

From an engineering point of view, improvements in the production plan at strategic level, which includes large-volume production and optimal production levels, can improve the energy efficiency in the production process, reduce obsolescence and also the CO_2e from industrial waste.

4.4.3.3 Site improvements

Different kinds of manufacturing techniques may be directly adapted to eco-efficient versions, being able to determine the What, Where, How and When in terms of reducing carbon emissions. The focus in each site is to find a list of opportunities in terms of environmental performance and financial benefits. Nevertheless, all sites need to focus on the details in order to see a big improvement when multiplied by the total number factories. Small actions can be related to continuous improvement in eco-efficiency, for example preventing air leaks.

Other actions will be linked with capital investment; in this case projects should be selected according to a combination of eco-benefit and financial return. A change in site performance can be achieved through large capital projects. Two good examples are Combined Heat & Power plants or Biomass boiler utilization.

- **Combined Heat & Power**

  Typically, factories use Separated Heat and Power (SHP) to generate steam and buy electricity, but a good alternative might be the installation of a Combined Heat and Power (CHP) system. This combines the heat and power system, producing electric and thermal energy from one fuel source. Using CHP systems, a factory can improve its energy efficiency, reduce energy consumption, minimize operational costs and reduce the environmental impact.

- **Biomass boilers**

  Biomass combustion is well known as a carbon-free process, as the resulting CO_2e had been captured by the plants prior to combustion. Currently, coal power plants work with efficiencies up to 45%, being the most cost-effective power generation. In cogeneration mode the total efficiency may reach 85%-90%. Because of the feedstock availability, the biomass plants for combined heat & power (CHP) are normally of smaller size and lower electrical efficiency compared with coal plants.

  Integrated gasification combined cycles (IGCC) using black-liquor (a by-product from the pulp & paper industry) are already in use. Nevertheless, biomass integrated gasification in gas-turbine plants (BIG/GT) is not yet commercial. Anaerobic digestion to generate biogas is increasing in small, off-grid applications.

4.4.3.4 New Technologies

New technologies will play an important role in addressing these challenges and keeping companies on track for future targets. Nevertheless, some of these technologies are currently expensive – but as energy prices increase and technology prices reduce they become more attractive.

Emerging technologies that reduce carbon emissions in the atmosphere are being evaluated and piloted for potential global rollout. Carbon Capture Technology is a good example of the emerging technology; it is useful in recovering CO_2e from flue gases as a saleable by-product. This technology aims to remove carbon dioxide from the atmosphere or prevent it from reaching it. The Carbon

Capture Technology consists of separating the CO_2 emitted by industry and energy generation in the combustion processes, then transporting it to a geological storage site to isolate it from the atmosphere over the long term.

The chemical process of capturing CO_2 is energetically expensive and, probably, produces CO_2. This process only delays the release of CO_2, which cannot be stored indefinitely. However, this CO_2 could be used in multiple ways. According to IPCC (Intergovernmental Panel on Climate Change) (IPCC, 2011) this technology, if applied to a conventional modern power plant, could reduce CO_2 emissions by approximately 80-90% compared to a plant without Carbon Capture Technology. The IPCC estimates that the potential economy of Carbon Capture implementation could be from 10% to 55 % of total carbon mitigation up to 2100.

4.4.4 GREEN PROCUREMENT

Including CO_2e performance rates in the supplier's evaluation is the key for having a green procurement process. The role of the green procurement process is to support the evaluation, negotiation and selection of the suppliers and/services to support the company's carbon emission strategy. Some of the following criteria should be included in the supplier's evaluation and selection:

1. Type of energy used: energy consumption is included as part of the submission price, to create a direct stimulus for energy efficiency.
2. CO_2 performance certificates: The certificate obliges the tenderer to comply with a certain CO_2 reduction target for its method of execution and working processes.
3. The supplier location: Suppliers that are far from the company's activity will increase carbon emissions related to transportation.
4. Longevity of breeding stock: less replacement stock is needed overall, giving additional benefit in terms of wasted inputs.
5. Waste management methods: the supplier should demonstrate the methods used to reduce, replace and recycle these materials, and to reduce their carbon footprints.

In the specific case of the livestock farming sector, three GHGs should be reviewed: methane directly from cattle (as well as from manure), nitrous oxide (from fertiliser use and manure) and carbon dioxide (CO_2) from feed and fertiliser production. In this sector, the following aspects should be considered:

6. If the supplier has a program for reducing the use of artificial fertilisers.
7. If the supplier is reducing or avoiding ploughing of grassland – this reduces nitrous oxide emissions significantly.
8. If the supplier is optimising feed quality.

The supplier should provide the information of their products' carbon footprint. Otherwise the contractor should assess the carbon footprint according to the criteria mentioned above and include this assessment in the tender process. An assessment of the carbon footprint could be performed using a calculation tool; for instance, the 'Cool Farm Tool' (CFA, 2017).

4.4.5 Renewable energy source

Renewable energy refers to that energy that comes from waves, wind, the Sun and geothermal heat from the ground, or which can be produced from plant sources such as wood or crops grown specifically as a fuel. The first characteristic of this type of energy is that it occurs naturally and repeatedly in the environment and will not run out, unlike energy from fossil fuels. Consequently, using renewable energy sources guarantees that no net greenhouse gases are liberated and helps to mitigate the impact of climate change.

Moreover, using renewable energy sources can make financial sense for businesses. Commonly, energy sources are available locally or can be produced on-site (such as biomass). Thus, the use of renewable energy guarantees security of supply and can result in non-variable energy prices for businesses. Besides, at country level renewable energy is becoming more attractive from both an economic and a strategic viewpoint. Most countries have a huge demand for fossil fuels, thus governments are increasingly subject to fuel-price volatility and are more exposed to world market fluctuations.

Nevertheless, although renewable energy can offer significant environmental and economic benefits, the implementation of this kind of initiative should follow a proper order, according to how energy saving and 'green' energy measures should be prioritized. The energy hierarchy was conceived in 1998 as part of the Local Government Position Statement on Energy (Carbon Trust, 2012), and recommended the following sequence:

1. The priority for a business is to reduce energy consumption.
2. A business should use energy more efficiently.
3. After compliance with the two first steps it is necessary to consider switching to a renewable fuel source.
4. Any continuing use of fossil fuels should be clean and efficient.

Once a business decides to use any of the renewable energy technologies the next step is to select an appropriate one. At this stage it is important to consider that renewable energy projects can also take a long time to implement, due to the relatively immature nature of the market, but they can make both environmental and economic sense in the long term.

Four criteria should be considered for the correct selection of energy technology:

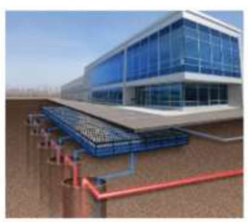
1. Understand the current usage: The starting point should be defined, considering points such as the energy quantity, the fluctuation of energy and the type of energy (electricity or heat).
2. The energy mix: This step helps a business to decide which renewable energy technology may be appropriate for them. For example, some renewables, such as wind and photovoltaics, just produce electricity. Others, such as solar water heating, just produce heat. Biomass, including anaerobic digestion, can provide both heat and electricity.
3. Review the limitations: In the case of the wind turbines, bear in mind that they will not provide electricity when it is not windy. On the other hand, if solar technology is selected, remember that it cannot be generated at night. For this reason, either a grid connection or a battery bank may be required to provide backup and power storage.
4. Develop a feasibility study: It should include the assessment of physical constraints, a cost-benefit analysis and a risk assessment to address the issues associated with switching to a renewable energy supply.

The renewable energy can be purchased, based on an agreement with the energy supplier, or can be part of an investment. It is important to understand what type of energy source is available on the energy market, along with the technology description, the site suitability and an estimate of the cost and payback period. Table 4-3 summarizes the renewable energy currently available on the market.

Nowadays, most efforts related to carbon emission reduction, are focused on R&D, according to Bill Gates in an interview with TheAtlantic.com platform (Atlantic, 2015). He explained that the current renewable energies were far from capable of covering the projected growth in energy consumption by 2030. He highlighted that "topics related with energy storage systems can be a good solution, for instance solar energy is still limited by the daily light, it only works better in regions where it is hot". Thus, looking ahead, energy storage systems are necessary.

Table 4-3 Type of energy source.
Source: (Carbon Trust, 2012)

Type of energy source			**Description**	**Site suitability**	**Cost and Payback Periods**
1	Wind Power		Wind energy is an alternative fuel where turbines produce electricity by capturing the natural power of the wind to drive a generator. Currently wind turbines are one of the cleanest sources of energy, although their installation is strongly dictated by many restrictions.	■ The wind speed determines the amount of energy produced. Therefore, to avoid peaks in the warehouses' energy, this energy is usually sold to the national grid. Otherwise the warehouse might not be covered or excess energy during windy periods can be indicated.	■ The economic feasibility of wind turbines depends on wind speed. ■ The greater the wind speed, the more electricity will be generated ■ The more electricity generated, the faster the investment will be paid back as a result.
2	Solar electricity (photovoltaics)		Photovoltaic panels (PV) convert solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. Power generation from solar PV has long been seen as a clean sustainable energy technology which draws upon the planet's most plentiful and widely distributed renewable energy source, the Sun.	■ The place where the PV system is installed should have a sufficient yearly amount of sunshine. ■ Especially in older warehouses, the roofs need to have the required bearing capacity for the panels. ■ PV will not meet the entire electricity needs of a business, but could provide a significant percentage.	■ The estimated payback time for a system varies significantly and depends on the circumstances. ■ The estimated life of a PV cell is around 25 years. ■ Maintenance costs for the cells are low and generally only involve cleaning the panels.
3	Solar water heating		Solar thermal or solar hot water systems is the conversion of sunlight into renewable energy, it works by absorbing energy from the sun and transferring it, using heat exchangers, to heat water.	■ Solar thermal Systems should ideally be roof-mounted and oriented to face between south-east and south-west. ■ Another good practice is to locate equipment (such as the heat exchangers) in the roof space close to the collectors.	■ Solar hot water heating is only truly economically viable in a business where there is a sufficiently high level of demand for hot water. ■ Generally, solar hot water is more economical in larger systems.

Type of energy source			Description	Site suitability	Cost and Payback Periods
4	Alternative fuels		There are a wide range of alternative fuels used to operate warehouses, they can be liquids (i.e. methanol, ethanol, biodiesel) or gasses (i.e. natural gas, biogas, hydrogen).	■ Some fuels such as biogas can be produced on-site but its production strongly depends on legislation and the availability of biodegradable waste.	■ For the biomass boiler's heating boiler, payback can be relatively short, although this varies. Additionally, it depends on the cost of fuel and the cost saving of the displaced fuel.
5	Fuel cells		Fuel cells consist of two parallel plates (one cell) arranged into stack (multiple cells). The stack produces electricity by electrochemical reaction with different kind of fuels. Fuel cells produce a high efficiency and zero carbon emission.	■ Plenty of warehouse applications can be run by fuel cells . ■ Forklifts run by hydrogen are now available on the market. ■ Their fueling takes only 5 minutes and low noise with clean operation make utilization more user friendly.	■ The cost of fuel cells is high now, around 80 Euros per kW plus cost of fueling systems, but fortunately it is decreasing year by year.
6	Air-source heat pumps		Air-source heat pumps (ASHPs) is a device which extracts heat from a source at low temperature and gives off this heat at a higher temperature. Such systems typically use an air-source collector, which is located outside the building. Heat pumps have a big potential for energy saving.	■ Installation of an ASHP requires planning permission. ■ ASHPs are a good alternative to GSHPs where lack of space is an issue. ■ The performance of an ASHP varies dramatically with the external air temperature.	■ The expected life of an ASHP is between 10 and 15 years. ■ The potential payback periods for ASHPs improve dramatically when the current boiler is due for replacement and installation of an ASHP is considered as part of this process.
7	Ground-source heat pumps		Ground-source heat pumps (GSHPs) take low-level heat which occurs naturally underground and convert it to high-grade heat by using an electrically-driven or gas-powered heat pump. The heat is collected through a series of underground pipes and can be used to provide space heating for a building.	■ The installation of GSHPs requires a large amount of civil engineering works. ■ The feasibility of doing this will depend on the geological conditions at the site.	■ The payback period is difficult to predict, it depends on how efficiently the system works. ■ A ground source heat pump can save you from €677 to €2,800 year

4.4.6 Energy consumption

Although a company uses renewable energies it does not mean that it is consuming less energy. Reducing energy consumption is an activity that should be done before thinking about the possibility of changing the type of energy used. In this section four initiatives for reducing energy consumption are listed: 1) Look for an energy performance certification; 2) Optimize the energy storage and charging process; 3) Ensure the efficiency provision of compressed air; and 4) switch on energy-saving mode.

4.4.6.1 Energy performance certification

Energy Performance Certificates (EPC) are obligatory nowadays for all kinds of buildings in some countries and can be a useful indicator, for instance in a warehouse's tenders. This certification is valuable in identifying the energy efficiency carbon footprint of the building, where rating 'A' stands for the highest efficiency and 'G' is the least efficient. Furthermore, it is also useful to obtain a recommendation report which describes the potential efficiency improvements. The example of an energy performance certificate is shown in Figure 4-5.

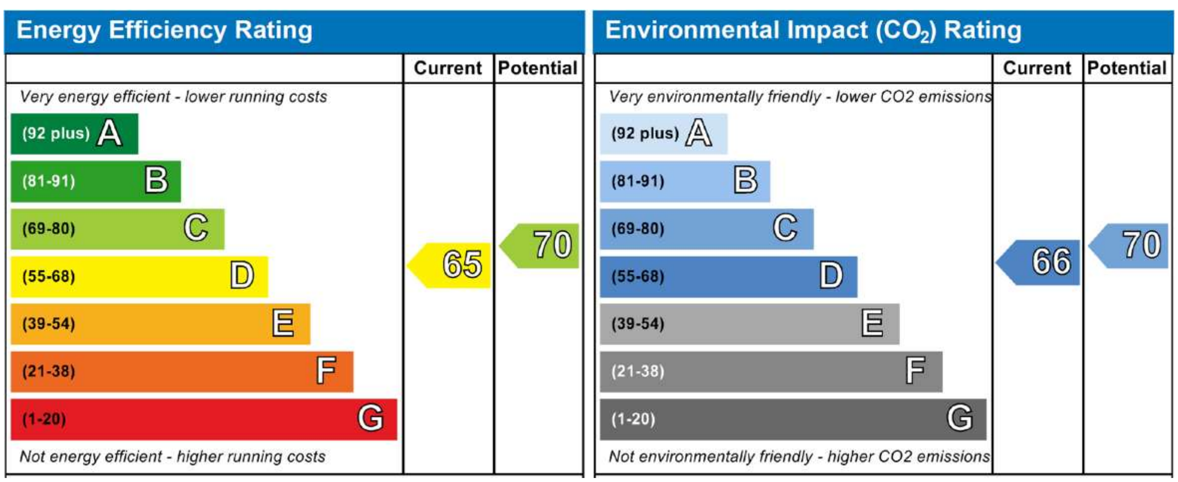


Figure 4-5 The Energy Performance of Buildings (Certificates and Inspections)
Source: England and Wales Regulations 2007 (S.I. 2007/991)

4.4.6.2 Optimal energy storage and charging process

Energy storage is a system particularly suitable for warehouses or factories with large numbers of electrical forklift trucks and stackers, which must be charged from time to time. Commonly, countries determine different types of electricity rates during the day, therefore is recommended to perform the charging process at off-peak times. Additionally, new charger models often consume significantly less energy than older chargers.

4.4.6.3 Ensure efficient compressed air supply

Compressed air is frequently used in warehouses for processes of rectifying or lifting pallets. The typical old compressors are fixed speed units, which are unable to deal appropriately with the varying demands for compressed air. This consequently leads to high energy consumption and operating costs. Variable speed compressors are a good alternative because they recognize the current pressure level in the system and reduce the energy accordingly.

4.4.6.4 Switch on energy-saving modes

Switch on energy-saving modes are especially important in automated warehouses, where there is a significant amount of energy-intensive equipment for pallet handling and identification. All equipment should be run only when necessary and then shut down at idle times. Timers are a good solution for ensuring that equipment is switched off after a certain period of idleness, while photo sensors help to recognize pallet movements and to steer the equipment accordingly.

4.5 Determining carbon goals

Establishing carbon emission targets helps to demonstrate the leadership's commitment and encourage staff throughout the organisation to reach real reductions in carbon emissions. Carbon emission targets should be aligned with existing corporative goals on a corporate level to ensure the strategy's success. Defining emission targets correctly will help to identify cost-effective reduction opportunities, risks and operational synergies. At this stage the horizon plan of the carbon reduction strategy should be confirmed and each year of the rolling plan should have a carbon emission target, with the last year having the final target for the planning horizon.

There are two different ways to determine carbon targets: absolute and efficiency of carbon base. The first is the total amount of carbon emission, measured in terms of kilograms or tonnes of CO_2e. The efficiency standpoint considers the total amount of carbon emission but as a ratio indicator, in which a business metric is included. It could be the connection between carbon emission and finished goods sold, the total sales volume or the turn over (see KPI1 and KP2, already established in section 4.3.).

4.6 Participating in Programs and Carbon Markets

After a corporate carbon strategy has been developed, corporations must continue to implement the strategy for years to come. The next step is to decide whether the company will publicly report emissions and/or will participate in voluntary programs. While participation in mandatory programs is required, participation in voluntary programs can increase the value of a corporate carbon strategy.

This requires an assessment of the governmental entities or voluntary program requirements, specifically related with accounting and/or reporting requirements that would be of concern. Additionally, a company should also consider whether it wishes to participate in GHG markets.

In order to increase the credibility of the strategy, companies should determine whether they wish to obtain third-party verification for their inventory. If a company is reporting its data to a public entity, the alignment with the stakeholders would be valued, therefore companies must have a cross check mechanism to ensure yearly reporting.

4.7 CONCLUSION

The basics for designing a Corporate Carbon Strategy have been identified in this chapter. The proposal has included the development of six steps including concepts, scopes and/or indicators. The first three steps help to clarify concepts and to define the baseline and scope. Then, as a part of the fourth, a set of carbon reduction opportunities were identified.

The carbon reduction opportunities section proposes a set of carbon reduction initiatives throughout the supply chain. The intention was to show the opportunities that a company can find per supply chain area, rather than being exhaustively detailed. Nevertheless, companies can use this list as good starting point for collecting carbon reduction initiatives.

The fifth step shows how to determine the company's targets, which is considered one of the most strategic decisions in the CCS creation. The carbon reduction target is to be attained over a long period, thus it needs the leadership's agreement and the commitment of the whole company. Finally, the last step shows how to use the company's achievements to take advantage of the results, and gives some instructions for using those results to participate in the Carbon Market and programs.

CHAPTER 5

Modelling framework

Following the carbon reduction methodology, the modelling framework is developed in this chapter. In a previous chapter the Corporate Carbon Strategy highlighted the potential alternatives for carbon reduction, and at this stage, a mathematical optimization tool is used to find the best strategy to maximize the benefit and minimize the carbon emission impact.

The mathematical model aims to design a supply network where the net profit is maximized and establish a set of initiatives for achieving carbon emission targets over time. The mixed integer lineal programming (MILP) model captures the list of potential carbon reduction alternatives already defined in the first step of the Carbon Reduction Methodology and reviewed at financial level as a part of the second step.

The MILP model proposes three pillars: The Planning and Networking Design, useful for organizing the network and supply chain activities; the Corporate Strategy Design, which incorporates the carbon approach to the model and the Economic Model Design which assesses the trade-off between the environmental and financial impacts.

This chapter is organized as follows: The first three sections define the three pillars explained in the paragraph above; section 4 describes the problem statement; section 5 introduces the mathematical formulation of the model and finally section 6 summarizes the main conclusions of this chapter.

5.1 PLANNING AND NETWORKING DESIGN

The design of the proposed supply chain design is to ensure that raw materials and components are distributed efficiently from their suppliers to manufacturing plants and warehouses, and to ensure that final products are delivered to customers. Strategically, an optimal network has the right number of warehouses and production plants in the right locations, customer demand points allocated to the right warehouses and warehouses allocated to the right plants.

The first relevant aspect for a network design is to determine the number of facilities and suppliers (nodes) and their corresponding location. The second aspect is to define the capability and capacity of those facilities, deciding which product will be made or stored in every facility and in what quantity.

Finally, the third aspect refers to the lanes or flows through which products move from facility to facility.

These three aspects are constantly interacting, intertwining and co-depending on each other. Figure 5-1 represents the link between these relevant decisions; for instance, facility location can impact on the operational planning in terms of lead-time and/or safety stock. Along the same lines, the factory's capacity determines the production volume, or the warehouse's capacity determines the inventory level; and the inventory level depends on the lead-time and the facility location.

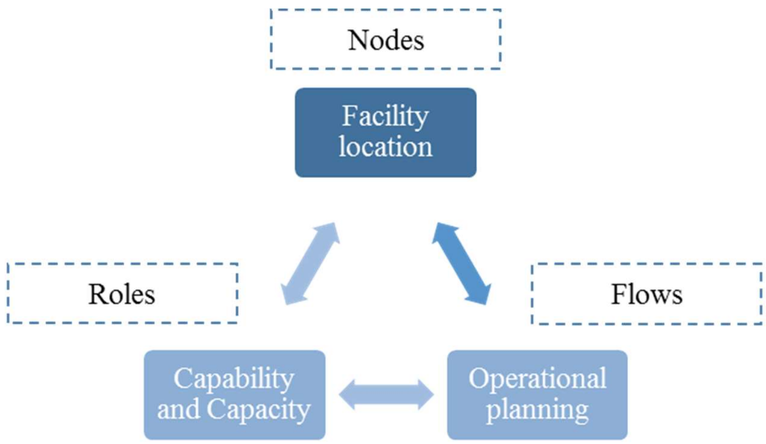


Figure 5-1 Main aspects in the Planning and Networking Design.
Source: Own preparation

In terms of facility location, the model should include the possibility of opening or re-locating certain facilities and selecting a location for these facilities from a set of placement options. The suppliers of raw materials should be chosen with the same criteria. Additionally, facility locations can be determined for tax benefits, trade concessions, capital subsidies, labour arbitrage and so on.

As a real component the flows are represented by the kilometre travelled, which should be minimized as a part of the optimization. The flow between warehouses and retailers is called "Secondary transport", the flow between factories and warehouse "Primary transport" and the flow between suppliers and factories "Inbound transport".

Finally, it is necessary to consider the capability and the capacity of the network components. The capability defines the product allocation, which means determining where to produce or store a product and in which quantity. The real capacity of the facilities is a constraint that limits the quantity of the product to be produced or stored.

5.2 CARBON STRATEGY DESIGN

Before doing a carbon strategy design and modelling, step 1 (Corporate Carbon Strategy) and step 2 (Strategic financial planning) should be implemented in order to integrate the carbon strategy correctly in the supply network design. The core of the link is related to the carbon reduction opportunities already identified at this stage. The carbon reduction alternatives are sorted according to their carbon emission impact and converted into environmental protection levels.

On the other hand, the carbon emission can be also converted into a monetary value using the carbon emission price under the Emission Trading System (ETS).

5.2.1 CARBON EMISSION FROM FACILITIES

The total carbon emission per facilities is related to the amount of energy used and depends on the level of environmental protection selected in every facility. Carbon emission factors will change, depending on the environmental protection linked with energy management. For this reason, the proposal is to classify levels of environmental protection into groups of projects, which can be organized depending on the level of investment and environmental effect.

As energy management is the main driver in facilities, where targets such as increasing energy efficiency, reducing energy consumption, minimizing operational costs and reducing environmental impact are constantly rated, the total amount of energy can be converted to CO_2e and can be assigned to every ton produced or stored, as carbon emission rate.

5.2.2 CARBON EMISSION FROM TRANSPORTATION

In the model, every echelon of the supply chain is associated with distance and carbon emission, as the carbon emission from transportation is a consequence of the distance, plus the transportation mode, vehicle design, type of fuel and loadfill level. The loadfill is an important parameter to take into account, because if the loadfill rate increases, fewer trips will be required. In this research, the impact of speed is not considered because the scope of the model covers the strategic and tactical level, whereas the speed impact is more relevant at operational level.

Using the same criteria, every improvement to the conventional transportation mode would be a new environmental protection level in transportation. For instance, hybrid vehicles, rail transport or aerodynamic vehicles are classified with a better carbon emission factor, thus emitting less carbon.

In the model, the transport between suppliers and factories is called 'Transport NK'; the primary transport between factories and warehouses is 'Transport KD' and the secondary transport between warehouses and retailers is called 'Transport DR'.

5.2.3 CARBON EMISSION FROM SUPPLIERS

Carbon emissions derived from raw materials are linked with the environmental protection level and depend on the type of supplier selected. The environmental aspects of suppliers depend on the sources, the quality and the environmental care at every stage of the raw material's process. It is possible to assume that raw materials with higher environmental protection will have a higher cost than supplies with less environmental protection, but it is not a general rule.

5.3 ECONOMIC MODEL DESIGN

The economic base of this proposal is the profit and loss statement (P&L), which is a summary of the financial performance of a business over time (usually monthly, quarterly or annually). A profit and loss statement, as the name indicates, summarizes the revenues, costs and expenses incurred during a specific period.

Each component influences the determination of net profit. The profit is represented by the gross sales volume (GVS), or revenues and losses including cost of goods sold (COGS) and expenses.

Gross Sales Volume is the total earned from ordinary business operations.

Cost of goods sold or cost of sales is the cost of merchandise sold during the period. It includes handling, direct labour, purchase price, distribution cost and other costs of converting materials into finished goods. COGS depend on the sales production volume; therefore, they vary directly according to sales and production.

Expenses are costs incurred for the purposes of earning income. They include items such as rent, wages, depreciation, etc.

Gross profit is the difference between Gross Sales Volume and Cost of Goods Sold. It reflects how efficiently labour and materials are used to produce goods. Net Profit (NP) is calculated by subtracting expenses from the gross profit, showing what the business has earned /lost in a given period of time, after both the cost of goods sold and operating expenses have been taken into account.

5.4 PROBLEM STATEMENT

A mathematical model for reducing the CO_2e emission throughout the supply chain redesign is a problem with two stages. On the one hand, a company should decide the supply chain design and on the other hand it should prepare a long-term strategy, including carbon reduction, in decision making. The network consists of a set of product types; a set of retailers; a set of distribution centers (DCs) of different throughput capacities; a set of potential plants of different production capacities and a set of candidate suppliers of raw materials.

The problem is to decide how to satisfy retailers' demand from the DCs, where and how much to produce, how to prepare the distribution plan and which suppliers chosen to deliver raw materials. The answer lies in guaranteeing that the total product distribution, facility location and carbon emissions costs are optimized. Additionally, a practical plan to reach carbon emission targets should be drawn up.

5.5 MODEL DEVELOPMENT

In this section, a Mixed-Integer Linear Program (MILP) mathematical model is proposed, which aims to develop a long-term strategy for the design and planning of a supply chain network, where a carbon strategy is included in the core of the business strategy. This proposal develops a robust generic formulation that provides a carbon strategy for long-term targets, whilst a profitable growth is developed.

The model takes the following assumptions:

- Retailers' demands are assumed to be deterministic.
- Factories and DCs have limited production and throughput capacities.
- The carbon emission is coming from:
    a. The movement of products from factories to DCs and from DCs to retailers, as well as the movement of raw materials from suppliers to the factories. The unit is CO_2e per Km transported.
    b. The energy consumption in facilities; both in the production process and in the warehousing process. The unit of measurement is CO_2e per ton produced and CO_2e per case stored.
    c. The raw materials of the suppliers, which is the carbon embedded in the raw material.
    d. For every year of the horizon plan there is a carbon emission target measured in terms of "Kg CO_2e/Kg sold".
- A list of alternatives for carbon reduction is given, and for each alternative the cost / investment and the associated carbon emission factor is known.
- The planning horizon is defined by the company and the model assumes that the alternatives cannot overlap, for example once a level of technology is reached it is not possible to go back.
- Every year of the horizon plan has its own carbon emission target. The model reaches the target yearly, proposing the implementation of carbon emission alternatives. The model considers that the global target should be reached in the last year of the horizon plan.
- The horizon plan is also useful for delimiting the scope of the strategy, which means that if the company wants to create a second part of the strategy a new study with a new horizon plan will have to be defined.

The goal is to determine:

- The facility location or relocation. It includes the possibility of closing a facility or commissioning another potential facility.
- The amount of product to be produced and the amount of product to be stored.
- The suppliers selected to provide raw material.

- The carbon emission impact associated with each supply chain node.
- A set of alternatives to reduce carbon emission and achieve the yearly carbon emission target.

The model is optimized based on the following decisions:

- The total supply chain benefit is optimized based on:
    a. The network configuration in terms of facility location, number of facilities, product allocation to factories and DCs.
    b. The choice of suppliers.
- The carbon emission is optimized based on the selection of the carbon emission alternatives over time:
    a. The transport configuration: transport mode, type of fuel, capacity and loadfill.
    b. The environmental level in factories and warehouses.
    c. The environmental impact of the raw materials.

  The carbon emission points mentioned above also impact on the optimization of the supply chain.

The model does not include:

- The crossdocking operation, thus the possibility of consolidating loads in a transfer point is not part of the supply chain.
- The repacker points are not included in the supply chain, nor the carbon emission from the waste generated in this process.
- Reverse logistics, including packaging recovery, customer returns and managing obsolete products are not part of the model.
- The carbon emission which is produced by the final customer, through the use of the products.
- The impact of speed on the carbon emissions related with transportation.

A non-linear optimization model is initially proposed. The non-linearity function serves, on the one hand, to calculate the final number of loads in the relationship between the quantity to be moved from initial node to the final node and the percentage of loadfill (both variables). On the other hand, there is the transport cost function (which is the product of transport rate which depends on the loadfill).

Although the proposal is a general model, every company can adapt this model to its own needs, meaning that more constraints can be added or even the objective function can be changed. In the customization of the model, for instance, the objective function can be to minimize the carbon emission considering a maximum budget, or to minimize the budget considering a carbon emission constraint. Chapter 7 shows an example of this type of customization.

5.5.1 NOMENCLATURE

Sets

P	Set of products
R	Set of raw materials
B	Set of retailers
S	Set of suppliers
K	Set of factories
W	Set of warehouses
F	Set of facilities, $K \cup W$
A	Set of pairs of connected nodes (suppliers and factories, factories and warehouses, warehouses and retailers)
M_i	Set of levels of environmental protection for facility i ($\forall i \in F$)
T	Set of types of transport
H	Number of periods in the planning and operational horizon

Parameters

D_{iph}	Demand of retailer i for product p in period h ($\forall p \in P$, $\forall i \in B$, h=1,...,H) [ton]
f_{rp}	Quantity of raw material r to produce one ton of product p ($\forall r \in R$, $\forall p \in P$) [ton]
fc_i	Capacity of the facility i ($\forall i \in F$) [ton]
tc_t	Capacity of transport unit in transport type t ($\forall t \in T$) [ton]
N_{ijt}	Number of options for the empty proportion and the transport rate (each empty proportion is associated with a transport rate) for transport type t between nodes i and j ($\forall (i,j) \in A$; $\forall t \in T$). The transport rate has been discretized for modelling (linearization) purposes.
Vlf_{ijtn}	Value of the empty proportion for the n option for transport type t between nodes i and j ($\forall (i,j) \in A$; $\forall t \in T$; n=1,..., N_{ijt})
Vtr_{ijtn}	Value of the transport rate of transport type t between nodes i and j for the n option ($\forall (i,j) \in A$; $\forall t \in T$; n=1,..., N_{ijt}) [euro/km]
p_p	Selling price of the product p ($\forall p \in P$) [euro/ton]
fa_{im}	Amortization cost for the facility i at a protection level m ($\forall i \in F$, $\forall m \in M_i$) [euro]
sc_{imh}	Setup cost (excluding investment) for facility i with a protection level m in period h ($\forall i \in F$, $\forall m \in M_i$, h=1,..., H) [euro]
cc_{imh}	Cost for closing a facility i under environmental protection level m in period h ($\forall i \in F$, $\forall m \in M_i$, h=1,...,H) [euro]
mc_{inmh}	Cost for modifying the protection level of facility i from n to m in period h ($\forall i \in F$, $\forall n,m \in M_i$ | $n \neq m$, h=2,...,H)

cs_{ir} Cost of raw material r supplied by i ($\forall i \in S$, $\forall r \in R$) [euro/ton]

c_{imp} Cost associated to each ton of product p manufactured/stored in a facility i under environmental protection level m ($\forall i \in F$, $\forall m \in M_i$, $\forall p \in P$). This cost may include, for example, labor costs, packaging & handling costs in factories and storing costs in warehouses.

d_{ijt} Distance between nodes i and j using transport type t ($\forall (i,j) \in A$; $\forall t \in T$) [km]

et_t CO_2e emission in transport type t ($\forall t \in T$) [kg CO_2e/km]

es_{ir} CO_2e emission from supplier i for the raw material r ($\forall i \in S$, $\forall r \in R$) [kg CO_2e/ton]

ef_{im} CO_2e emission into facility i with a protection level m ($\forall i \in F$; $\forall m \in Mi$) [kg CO_2e/ton]

γ_h Average expected cost of carbon credits in period h (h=1,...,H) [euro/ kg CO_2e]

α_h Actualization coefficient for period h (h=1,...,H)

φ_h Carbon target in period h (h=1,...,H) [kg CO_2e/ton sold]

Txr Income tax percentage in period h for products delivered from warehouse j ($\forall j \in W$; h=1,...,H)

M Large enough number (for modeling purposes)

Decision Variables

$v_{imh} \in \{0,1\}$1 *iff* facility i is running in period h under a a protection level m ($\forall i \in F$, $\forall m \in M_i$, h=1,...,H)

$y_{ijtnh} \in \{0,1\}$ 1 *iff* the n option for empty proportion for transport type t between nodes i and j is chosen in period h (i.e., $lf_h = Vlf_n$ and $tr_{th} = Vtr_{tn}$) ($\forall (i,j) \in A$; $\forall t \in T$; n=1,..., N_{ijt}; h=1,...,H)

x_{ijmtph} Quantity of product p shipped between nodes i and j in period h, being node i under environmental protection level m, in a transport type t ($\forall i \in F$, $\forall j$ | $(i,j) \in A$, $\forall m \in M_i$, $\forall t \in T$, $\forall p \in P$, h=1,...,H) [ton]

z_{ijtrh} Quantity of raw material r shipped between supplier i and factory j in period h in a transport type t ($\forall i \in S$, $\forall j \in K$ | $(i,j) \in A$, $\forall t \in T$, $\forall r \in R$, h=1,...,H) [ton]

Other Variables

$w_{inmh} \in \{0,1\}$ *Iff* facility i is running under protection level n in period h-1 and under protection level m in period h (i.e., the protection level has changed in period h) then this binary variable takes value 1 ($\forall i \in F$, $\forall n,m \in M_i$ | $n \neq m$, h=2,...,H)

SC_{imh} Cost for opening a facility i with a protection level m in period h ($\forall i \in F$, $\forall m \in M_i$, h=1,...H). [euro]

CC_{imh} Cost for closing a facility i under environmental level m in period h ($\forall i \in F$, $\forall m \in M_i$, h=1,...,H). [euro]

MC_{inmh} Cost for modifying the protection level of facility i from n to m in period h ($\forall i \in F$, $\forall n,m \in M_i$ | $n \neq m$, h=2,...,H). [euro]

L_{ijth} Number of trips shipped between nodes i and j by transport type t in the period h ($\forall (i,j) \in A$, $\forall t \in T$, h=1,...,H).

Lm_{ijt}	Minimum number of trips shipped between nodes *i* and *j* by transport type *t* in the period *h* (∀(*i,j*)∈*A*, ∀*t*∈*T*, *h*=1,...,*H*).
Tc_{ijt}	Transport cost between nodes *i* and *j* by transport type *t* in the period *h* (∀(*i,j*)∈*A*, ∀*t*∈*T*, *h*=1,...,*H*). [euro]
GSV_h	Gross sales volume in the period *h* (*h*=1,...,*H*). [euro]
$CO2_h$	Total quantity of CO_2e emission in the period *h* (*h*=1,...,*H*). [kg CO_2e]
$OpeC_h$	Operational cost in the period *h* (*h*=1,...,*H*). [euro]
$InTx_h$	Income tax in period *h* (*h*=1,...,*H*). [euro]
$NProf_h$	Profit in the period *h* (*h*=1,...,*H*). [euro]

5.5.2 MODEL FORMULATION

$$[MAX]z = \sum_{h=1}^{H} \alpha_h \cdot NProf_h \tag{1}$$

$$\sum_{i \in W} \sum_{m \in M_i} \sum_{t \in T} x_{ijmtph} = D_{jph} \qquad \forall j \in B;\ \forall p \in P;\ h = 1, \dots, H \tag{2}$$

$$\sum_{i|(i,j) \in A} \sum_{m \in M_i} \sum_{t \in T} x_{ijmtp} = \sum_{k|(j,k) \in A} \sum_{m \in M_j} \sum_{t \in T} x_{jkmtph} \qquad \forall j \in W;\ \forall p \in P;\ h = 1, \dots, H \tag{3}$$

$$\sum_{j|(i,j) \in A} \sum_{m \in M_i} \sum_{t \in T} \sum_{p \in P} x_{ijmtph} \leq fc_i \cdot \sum_{m \in M_i} v_{imh} \qquad \forall i \in F;\ h = 1, \dots, H \tag{4}$$

$$\sum_{m \in M_i} v_{imh} \leq 1 \qquad \forall i \in F;\ h = 1, \dots, H \tag{5}$$

$$w_{inmh} \geq v_{in,h-1} + v_{imh} - 1 \qquad \forall i \in F; \forall n, m \in M_i | n \neq m;\ h = 2, \dots, H \tag{6}$$

$$\sum_{j \in S|(j,i) \in A} \sum_{t \in T} z_{jitrh} = \sum_{k \in W|(i,j) \in A} \sum_{m \in M_i} \sum_{t \in T} \sum_{p \in P} f_{rp} \cdot x_{ikmtph} \qquad \forall i \in K;\ \forall r \in R;\ h = 1, \dots, H \tag{7}$$

$$Lm_{ijth} = \left(\sum_{p \in P} \sum_{m \in M_i} \frac{x_{ijmtph}}{tc_t} \right) \qquad \forall (i,j) \in A \backslash S;\ \forall t \in T;\ h = 1, \dots, H \tag{8}$$

$$Lm_{ijth} = \left(\sum_{r \in R} \frac{z_{ijtrh}}{tc_t} \right) \qquad \forall i \in S; \forall j | (i,j) \in A;\ \forall t \in T;\ h = 1, \dots, H \tag{9}$$

$$L_{ijth} \geq Lm_{ijth} \cdot \left(1 + Vlf_{ijtn}\right) - M \cdot \left(1 - y_{ijtn}\ \right) \qquad \forall (i,j) \in A;\ \forall t \in T;\ h = 1, \dots, H; n = 1, \dots, N \tag{10}$$

$$\sum_{n=1}^{N} y_{ijtnh} = 1 \qquad \forall (i,j) \in A;\ \forall t \in T;\ h = 1, \dots, H \tag{11}$$

Carbon constraint

$$CO2_h = \sum_{i\in F}\sum_{j|(i,j)\in A}\sum_{m\in M_i}\sum_{t\in T}\sum_{p\in P} ef_{im}\cdot x_{ijmtph} + \sum_{i\in S}\sum_{j|(i,j)\in A}\sum_{t\in T}\sum_{r\in R} es_{ir}\cdot z_{ijtr} + \sum_{(i,j)\in A}\sum_{t\in T} et_t\cdot d_{ijt}\cdot L_{ijth} \qquad h = 1,\dots,H \quad (12)$$

$$\frac{CO2_h}{\sum_{i\in B}\sum_{p\in P} D_{ip}} \le \varphi_h \qquad h = 1,\dots,H \quad (13)$$

Financial constraint

$$GSV_h = \sum_{j\in B}\sum_{p\in P} p_p\cdot D_{jp} \qquad h = 1,\dots,H \ (14)$$

$$Tc_{ijth} \le Vtr_{ijtn}\cdot d_{ijt}\cdot L_{ijth} + M\cdot\left(1 - y_{ijtn}\right) \quad \forall (i,j)\in A;\ \forall t\in T; h = 1,\dots,H;\ n = 1,\dots,N_{ijt}\ (15a)$$

$$Tc_{ijth} \ge Vtr_{ijtn}\cdot d_{ijt}\cdot L_{ijth} - M\cdot\left(1 - y_{ijtnh}\right) \quad \forall (i,j)\in A;\ \forall t\in T; h = 1,\dots,H;\ n = 1,\dots,N_{ijt}(15b)$$

$$MC_{ih} = \sum_{n\in M_i}\sum_{m\in M_i|m\ne n} mc_{nmh}\cdot w_{inmh} \qquad \forall i\in F;\ h = 1,\dots,H\ (16)$$

$$SC_{imh} \ge sc_{im}\cdot\left(v_{imh} - \sum_{m\in M_i} v_{im,h-1}\right) \qquad \forall i\in F; \forall m\in M_i;\ h = 2,\dots,H\ (17)$$

$$CC_{imh} \ge cc_{imh}\cdot\left(v_{im,h-1} - \sum_{m\in M_i} v_{im}\right) \qquad \forall i\in F; \forall m\in M_i;\ h = 2,\dots,H\ (18)$$

$$OpeC_h = \sum_{i\in S}\sum_{j\in K|(i,j)\in A}\sum_{r\in R}\sum_{t\in T} cs_{ir}\cdot z_{ijtrh} + \sum_{i\in F}\sum_{j|(i,j)\in A}\sum_{m\in M_i}\sum_{t\in T}\sum_{p\in P} x_{ijmtph}\cdot c_{imp} + \sum_{i\in F}\sum_{m\in M_i}(CC_{imh} + SC_{imh}) + \sum_{i\in F} MC_{ih} + \sum_{i\in F}\sum_{m\in M_i} fa_{im}\cdot v_{imh} + \sum_{(i,j)\in A}\sum_{t\in T} Tc_{ijth} \qquad h = 1,\dots,H \quad (19)$$

$$InTx_h = GSV_h\cdot Txr \qquad h = 1,\dots,H(20)$$

$$Nprof_h = GSV_h - OpeC_h - CO2_h\cdot\gamma_h - InTx_h \qquad h = 1,\dots,H\ (21)$$

5.5.3 Planning and Networking Modelling

Constraint (2) makes sure that the demand of each retailer in each period is satisfied by the open warehouse, while constraint (3) is the flow conservation constraint. Constraint (4) is related to the production planning; it states that the total processing requirement of all products handled in each facility should not exceed the capacity. Constraint (5) ensures that the maximum facility is open per period. Constraint (6) validates that the protection level cannot be reduced. Purchasing requirements are defined in constraint (7), where all the raw materials needed are assigned to the corresponding suppliers. Constraint (8) and (9) compute the number of loads for goods and raw material flows. Loads are affected by the empty factor Vlf, which is a key variable in determining the transportation efficiency. Thus, the higher the empty factor, the greater the number of loads required.

Constraint (10) represents the number of loads including the empty factor. This is not a linear constraint; thus, it cannot be linearized by sections. To linearize it the constraint (11) was added, then the variable Vlf can take values from a list (this does not avoid taking a wide range of values).

5.5.4 Carbon Modelling

Constraint (12) measures the absolute value of the total CO_2e emissions in all the supply chain. The first part is the total CO_2e emission in all facilities. Since carbon emissions in facilities are closely related to energy consumption, the set of levels of environmental protection M are associated with energy management and determine the factor emission. The second part is the CO_2e emission for suppliers and depends on the chosen supplier and the emission factor associated with the raw material. The last part represents the transportation carbon emission, which takes into account the emission factor associated with type of transport (transport mode, alternative fuel, new technologies, etc.). Finally, constraint (13) allows planning carbon reduction targets in terms of carbon efficiency.

5.5.5 Economic Modelling

Gross sales volume is defined in constraint (14) while constraints (15a) and (15b) define the transport cost which depends on the transport rate, in turn depending on the truck's load fill. Constraint (16) describes the cost of modifying the technology in facilities. Constraint (17) defines the cost associated with setting up a new facility, whilst constraint (18) describes the cost associated with closing a facility. Constraint (19) represents the total operational cost for each period, including procurement cost, facility operating cost (labour costs, packaging & handling costs in factories and storing costs in warehouses), distribution cost, facility depreciation and cost to open, close and modify facilities. Finally, constraint (20) outlines the income tax per period.

Net profit by period is defined in constraint (21), which is the gross sales volume less operational cost, income tax and carbon emissions cost associated with carbon trading.

The objective function (1) maximizes the total net profit (21).

5.6 CONCLUSION

In this chapter, a Mixed-Integer Linear Program (MILP) is proposed, integrating a Planning and Networking, Carbon Strategy and Economic model design in a unique model. The total carbon in terms of absolute value per category and the carbon efficiency is included as two restrictions. The carbon efficiency restriction (13), depends on the targets that the company has established over time.

In every link and node of the supply network there are initiatives for carbon reduction, starting from the As Is scenario until the most carbon efficient alternative. To evaluate every initiative the solution of the model looks for the trade-off between carbon and cost and assigns carbon initiatives over time for achieving targets yearly.

The following chapters contain three case studies to test the model; the first case is based on a company that operates in Brazil, the second company works in Spain and the third one operates in the United States market. In every case the model, despite its complexity, is solved in a manageable time.

CHAPTER 6

An introduction to the methodology validation

6.1 INTRODUCTION

The aim of this chapter is to introduce and contextualize the methodology validation. The validation process aims to confirm and provide objective evidence that the methodology proposed in this thesis is clear and useful enough for creating a carbon reduction strategy. This validation consists of the following four steps: 1) The selection of the companies; 2) The understanding of the context (internal and external); 3) The methodology application and 4) The experimentation with software and the analysis of the results and revision of the methodology.

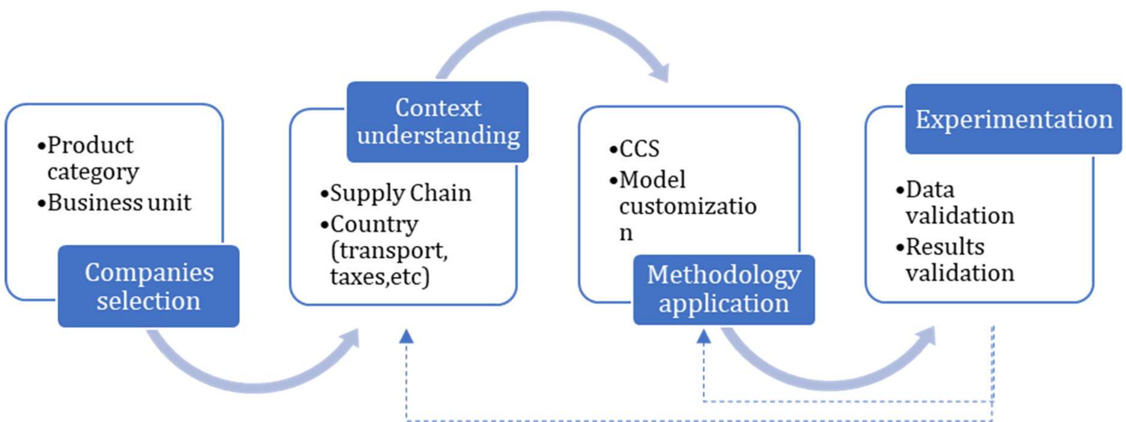


Figure 6-1. Steps of the validation process.
Source: Own development

Figure 6-1 shows the validation process, starting with the company selection where concepts such as the size of the company, product category or the business units are considered. As soon as the company is selected the work context should be understood, both at company and country level, then the CCS methodology is applied and the general model is adapted as needed. Finally, the model is tested with optimization software and the results are validated. The next sections include a description and explanation of these steps.

6.2 THE SELECTION OF THE COMPANIES

Three case studies are developed, using multinational company data. The first one operates in Brazil in the Home Care and Personal Care (HPC) business. In the second case study, the company works in Spain with Food products; and in the third one the company works in the metal sector for the United States market. Although the names of the companies are confidential, the following sections provide a summary of them, as well as the context of the countries where they operate.

6.2.1 THE FIRST CASE STUDY

The company's portfolio is dominated by deodorants and detergent brands, being one of the global leaders in both categories and with a very good position in haircare and surface cleaning. The multinational company is well-established in most Western markets, and has a remarkable presence in developing markets such as Brazil. As with many other global companies, the existing business is the consequence of many years of cooperation between the separate operating units.

The product category selected was Home Care and Personal Care (HPC). According to the company's 2016 annual report, the Personal Care sector had a global turnover of around €20 billion in 2016 and is the largest category, accounting for more than 45% of operating profit. The company is one of the big three global players in this category, reporting a sales growth of 4.2% in the same year. On the other hand, Home Care has reported more than €9 billion globally in 2016. Around 80% of sales in the Home Care category are generated in emerging markets such as Latin-America.

6.2.2 THE SECOND CASE STUDY

The company generated more than €10 billion globally in 2016 and is one of the five biggest food companies in the world. Nowadays, part of the company's strategy is based on accelerating growth in emerging markets and renovating the portfolio to address changing consumer habits. Focussing on the second priority, the company has brands working to create sustainable business, understanding how important this topic is for consumers.

Moreover, in Europe consumers are constantly looking for healthier options, consequently the company has been working in recent years to create organic and '100% natural' brands, giving the consumers trust and transparency along with new taste experiences. Although the sector is generally going through a difficult stage, the company had a sales growth of 2.1% in 2016, according to its annual report.

6.2.3 THE THIRD CASE STUDY

The company used for the third case study is a company specializing in lightweight metal engineering and manufacturing, with its headquarters in the United States. The core business of the firm is the manufacturing and distribution of products which include aluminum, titanium, and nickel, and are used worldwide in aerospace, automotive, construction and industrial applications.

The company revenue reported a profit of $0.1 billion in the last year. The operations consist of three worldwide reportable segments: Global Rolled Products, Engineered Products and Solutions, and Transportation and Construction Solutions. The business case will be based on the Construction Solutions category.

The company has been helping to advance innovation in building design for well over a century. The technologies that the company offers serve a greater purpose, the products of this category are useful for high-thermal performance, protection against hurricanes and natural disasters and for helping the architectural design to protect the internal components and structures.

6.3 THE UNDERSTANDING OF THE CONTEXT

In understanding the context regarding the company, several aspects must be considered. These include the company's targets, the company strategy for the horizon plan, the product category strategy (new launches, technology used, etc.) and the company environmental policy. A deeper understanding of the supply chain includes the network, production process, distribution methods and practices, suppliers, the most relevant financial data and financial targets. Additionally, possible risks and issues have been identified.

Even though the three case studies use global manufacturing companies, which means operating globally, every case study is focussed on the customer demand in some specific countries, thus it is important to understand the selected country's context. An understanding of the context regarding the country focusses mainly on industry and the economic situation, also providing a background of the environmental situation which includes the trends and current strategies. The analysis includes an explanation of the freight transport network, as well as the strengths and opportunities that each country has in this field.

6.4 THE METHODOLOGY APPLICATION

For every case study the Carbon Reduction Methodology is applied, which includes the Corporate Carbon Strategy, the Strategic Financial Planning and the Business optimization. In the optimization part, case studies 2 and 3 have used the general mathematical model proposed in this thesis. For case study 1 the model was adapted according to the needs of the country and the companies' supply chain; it was useful for showing that the model can be customized when needed. Finally, for each case study there are some recommendations for implementation and tracking.

6.5 THE EXPERIMENTATION WITH SOFTWARE

In the validation step the optimization software package used was IBM ILOG CPLEX Optimization Studio in Version 12.6.0.0. This software was utilized for solving the mathematical model of the three case studies. The corresponding chapters (Chapters 7, 8 and 9) explain the number of variables, as well the resolution time, in detail. Finally, the outcome of the software is shown and validated for every case.

Due to the application and validation of the three case studies some elements of the methodology were revised and refined.

6.6 CONCLUSION

This chapter has given a context and introduction to the following chapters, in each section the four steps of the validation process have been illustrated. The three companies selected for the three case studies were introduced along with some relevant information. Then an explanation of the topics considered in understanding the context at company and country level is given.

The Corporate Reduction Methodology is tested in every case study. The next Chapter, with a case study of a multinational company operating in Brazil in the Home and Personal Care business, is used to illustrate how the Corporate Reduction Methodology is implemented by adapting the general model to the company and country needs.

CHAPTER 7

Case Study I: A multinational company operating in Brazil in the Home and Personal Care business

7.1 INTRODUCTION

This is a case study based on a global manufacturing company located in Brazil; the selected categories for the study are Home and Personal Care. The customers are distributed in two main groups, one in the Northeast (NE) with 30% of the customer demand and another with 70% in the Southeast (SE) area. The retailers are located in strategic cities such as Sao Paulo, Minas Gerais, Rio de Janeiro, Parana and Rio Grande do Sur in the SE, and Bahia and Pernambuco in the NE.

For supplying the customers' demand the company has five warehouses, located in Rio Grande do Sul, Sao Paulo, Minas Gerais, Bahia and Pernambuco. There is also a factory located in Pernambuco, which produces goods in this category. For a detailed understanding please see Figure 7-1 below.

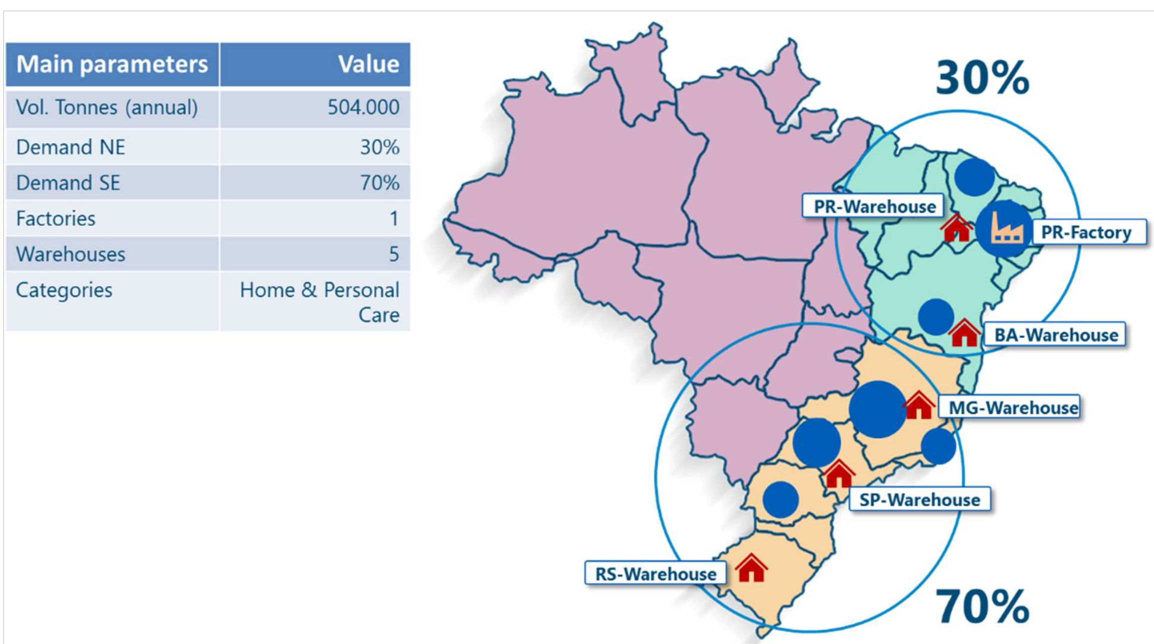


Figure 7-1 Brazil Network and main parameters, As Is Situation.
Source: Own preparation

7.1.1 THE COMPANY'S PROFILE IN BRAZIL

According to the annual report, the company in Brazil has a turnover of more than €1.2 billion and has more than 80% of the market share in the Home Care category, which is the category with the most growth potential. Most specifically, the company has an historical presence in detergents and because of the socio-economic context in the country, it still has the possibility to continue growing with the capture of new customers.

Low-income consumers in northwest Brazil are a large and specific customer segment to be captured. Brazil is a country where 28% are low-income consumers, where clothes in the northwest are frequently washed using public areas or rivers. Due to this socio-economic situation, the low-income segment is a target for the company, especially in the northeast of the country.

Home Care category represents 45% of the business, whilst Personal Care makes up the other 55%. Personal Care (PC) is a well-established category in the country and it is quite strong in brands such as skin cleaning, hair, oral and skin care. The PC category has a solid marketing strategy based on the constant launch of innovations.

The company enjoys a very good reputation and is very well-recognized in Brazil. In 2003 Forbes Magazine recognized the company as "One of the three most admired companies in Brazil", and in 2005 Carta Capital Magazine named the company as "The most admired company in Home Care and Personal Care categories". Moreover, the company has a strong social commitment , hence in 2004 the Guia Exame de Boa Ciudadania Corporativa mentioned the company as "One of the ten best examples of corporate social responsibility (CSR) companies in Brazil".

7.1.2 THE COUNTRY CONTEXT

Brazil is, in terms on geographic size and population, the fifth largest country in the world. In addition, in recent decades, it was ranked within the ten largest consumer markets in the world, due to its booming economic growth. Nevertheless, Brazil is a tough environment, not only because of the recent economic and political upheaval but because even in a stable situation Brazil has a complex distribution system.

The challenge for a successful supply network design in Brazil is basically founded on the country's geographic expanse, with rich states located in the Southeast area and poor states located in the rest of the country. On the other hand, the tax policy is complex and high when compared with the logistics cost, thus companies normally include taxes as a part of the key factors in their decision making.

7.1.2.1 CARBON EMISSION CONTEXT IN BRAZIL

In terms of carbon emission, Brazil is one of the group of 10 countries that produce around 70 percent of global GHG emissions. However, it is also the first major developing country to have clear targets in its commitment to reduce carbon emission. The country aims to cut its emission by 37% between 2005 and 2025 by reducing deforestation and boosting the share of renewable sources in its energy mix (Ministry of the Environment, 2015).

However, the country has already reported significant achievements in past decades, especially focused on the deforestation in the Amazon. Nonetheless, there is still a long way to go to achieve the 1.5bn tones by 2025. According to the World Bank the CO_2 emissions, in terms of metric tons per capita, have increased gradually in recent years; see Figure 7-2.

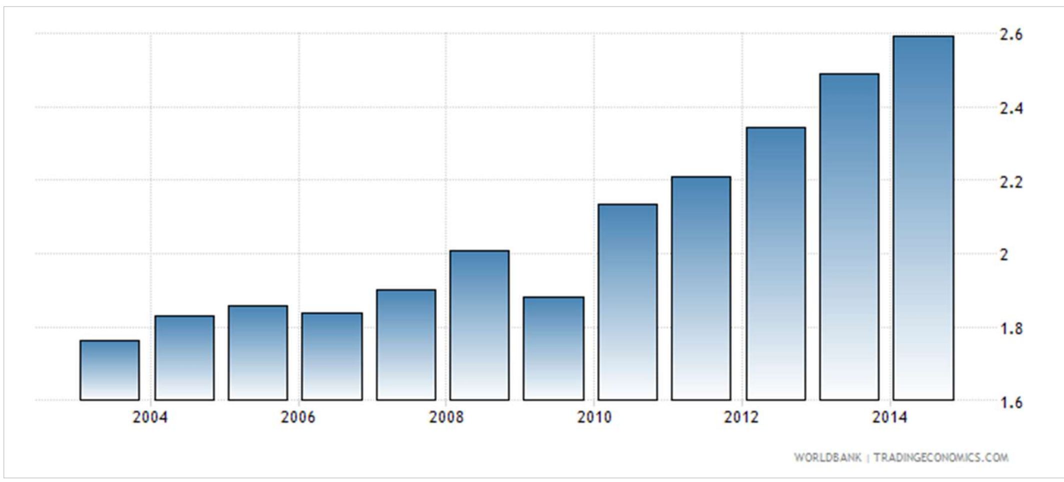


Figure 7-2 Brazil - CO_2 emissions (metric tons per capita).
Source World Bank

According to Brazil's leaders, by 2030 Brazil is planning to use the country's large dams to generate 66% of its electricity from hydropower. Currently the country is working together with the US to double its non-hydropower renewable sources to 20% by 2030. Regarding other renewable sources, they want to increase other energy sources such as wind, solar and biomass by 23%.

7.1.2.2 THE TRANSPORT SYSTEM IN BRAZIL

The road transport in Brazil accounts for about 64% of cargo whilst the railroads, that are planning to expand their network, represent 33%. For efficient use, the waterways network (given the rich and extensive hydrography), requires dams and locks, and the short sea shipping routes need to be reformulated from ships to ports.

The intermodal transport is mainly used by the grain, sugar and automotive sector. The combination of road and rail has attracted the main trading, due to the lower costs. Nevertheless, the use of rail transport is still limited to high volumes, which limits its usefulness for medium and small companies.

Thus, by presenting lower costs, the intermodal transport becomes an important transportation alternative. Nevertheless, in order to increase the use of intermodal transport investments are needed; bottlenecks caused by the difficulty of access to transhipment points, disused railroads and pipeline shortages combine to threaten this opportunity to operate at lower costs.

During PAC 1 (Programa de Aceleração do Crescimento), R $ 65 billion was designed for logistics projects and, for PAC 2, R $ 104.5 billion was destined for transportation axis projects. The private initiative has invested in intermodal terminals as well as new transhipment points to facilitate the use of intermodal transport (Secretaria Nacional de Habitação, 2017). In the first half of 2015, the PIL – (Programa de Investimentos em Logística) was launched, involving investments in highways (R $ 17 billion), railways (R $ 99 billion) and in ports (R $ 54 billion).

The use of alternative transport in Brazil frequently involves a major lead time and it can be associated with an extra inventory cost. Thus, in the short and medium term the use of intermodal transport modes could be recommended for the primary and/or inbound transport, but considering the available routes and the associated cost. Moreover, in road transport Brazil has a well-established biofuel industry with low production costs. This means that Brazilian bioethanol is cost competitive with petrol and diesel.

7.1.2.3 The tax structure in Brazil

Brazil has a complex tax structure where the movements of goods between states can generate an advantage. The 26 Brazilian states have their own taxes and can represent 26 countries in one. For example, a company in Minas Gerais shipping its product to São Paulo would pay about 12% in ICMS (Operações Relativas à Circulação de Mercadorias e Serviços de Transporte Interestadual de Intermunicipal e de Comunicações). If the destination state was Bahia, the tax would be only 7%.

There are at least 16 types of taxes in Brazil, but for a better understanding this case study will include four of them and they will be divided into Non-recoverable and recoverable.

Non-recoverable taxes are indirect taxes that are included in the price of the goods or services. In this category, Brazil has the following taxes:

- **COFINS** is the abbreviation for *Contribuição Social para o Financiamento da Seguridade Social* and is a tax for Social Security Financing. This is a tax for companies based on added value. The value depends on the company profile.
- **IPI** is the terms used for *Imposto sobre Produtos Industrializados* and it applies to companies who modify products industrially for consumption or use. The rate is based on the products NCM code (Nomenclatura Comum do Mercosul).
- **PIS** is the terminology used for *Contribuição para os Programas de Integração Social*. This tax aims to collect funds for Social Integration Programs, and is based on gross revenue earned.

The characteristic of the recoverable taxes is that they can be claimed as credit against the taxes that are payable by the tax payer; in this category Brazil has the ICMS. The ICMS works by making a balance between credits and debits and creating significant incentives that should be considered in supply network design. A proposal for a Brazil supply network design without ICM tax considerations can lead to the wrong decisions being taken, with lost cost savings opportunities.

The optimization model for Brazil includes the ICMS tax, which is the tax on operations related to the circulation of goods and the provision of interstate and interregional transportation and communication services, also known as the tax on circulation of goods and services (ICMS). The ICMS values depend on the value-added tax, the base state and the origin, destination and product category. A table with standard values is shown in Table D- 9 in Appendix D.

Some states where the company has facilities have special benefits in the ICMS, as in the cases of Minas Gerais and Pernambuco.

- **Minas Gerais:** The incentive granted by the Government of the state of Minas Gerais (MG) is the application of a fixed ICMS rate as a tax burden on all outflows to establishments within the MG state, combined with the non-use of ICMS credits for Materials and services.
  All deliveries to out-of-state facilities or Customers have a 9% Tax Incentive (ICMS 12% - 3% Tributary Load).
- **Pernambuco:** The incentive granted by the Government of the state of Pernambuco is composed of 5% of the value of deliveries outside the North East (Book Value outside NE x 5%).

7.2 WHY IS THE COMPANY INTERESTED IN A CARBON REDUCTION PLAN?

The company has two important challenges for the medium and long term, one of which is related to the tax benefits and their impact on the network and the second one regards the sustainability targets that they are already committed to.

- Both carbon goals and the increase of profits are important for the company; they know that a new network configuration can affect the carbon targets, therefore they have decided to optimize their network and at the same time develop plans to either mitigate the impact and/or help to reach the target, which is -20% in the Kg CO_2e per Kg sold until 2023.
- The Brazilian government has already committed to strong carbon reduction targets. Thus, the company wants to be aligned with this strategy in order to be prepared in case a new sustainable tax appears in the future.
- Brazilian consumers increasingly value companies with corporate social responsibility, which is why the company is evaluating the use of a carbon reduction plan as a good marketing strategy, while generating a competitive advantage by doing so.

7.3 To Be Situation

The company aims to have the best strategy for a supply network re-design by means of a holistic approach, where taxes, transfer prices, regulation changes, etc. are included. At the same time, they are starting with a carbon reduction strategy where the target is to reduce the carbon rate by more than 20% until 2023. Therefore the proposal should include a carbon strategy with concrete actions for achieving the carbon targets.

7.4 Methodology implementation

The proposed methodology is validated by using the information of the consumer goods company located in Brazil. The methodology starts with the creation of the corporate carbon strategy and the strategic financial planning, both running in parallel. Although the company already has a carbon reduction target and some fundamentals in place, the methodology is running since the beginning, using the existing information. Once the two first steps have been established, the business optimization is made, using the generic mathematical model proposed in chapter 5, but developing some constraints to include the tax implications.

The information included in the corporate carbon strategy and the strategic financial planning is provided by the company; and the strategy resulting from the mathematical model is the business proposal of the methodology to the company. The implementation phase shows the progress in the implementation, with some advice given for that step.

7.4.1 Corporate carbon strategy and Strategic financial planning

The corporate carbon strategy starts with a definition of the type of emission associated. The manufacturing process of these products essentially consists in combining and mixing the raw materials in appropriate proportions to obtain the desired product. Therefore, in the manufacturing process boilers and plastics for detergents and aluminum for deodorants are the most relevant greenhouse gas emitters.

In stage two of the CCS the scope is defined and the finance team validated the information. The ownership perspective is the scope selected but it includes suppliers and excludes corporate offices. Then, the data baseline is defined. The 2017 forecast is the base year and the carbon emission equivalent for this year is 1,905,120 CO_2e tones, with an efficiency of 3.8 Kg CO_2e/Kg sold.

The goals are defined in the fourth stage of the CCS, in this case the carbon emission target is a reduction of 20% in terms of carbon efficiency. This target should be achieved in 7 years. At this stage, the finance team, as a part of the strategic finance planning, confirms the values and approved sales volumes for years involved. Table 7-1 summarizes the steps 1, 2, 3 and 4 of the CCS implementation for this case study.

Table 7-1 Steps 1,2,3,4 of the Carbon strategy and Strategic Financial Planning. Case Study I.
Source: Own preparation

	Step of the CCS	Corporate Carbon Strategy	Strategic Financial Planning
1.	Type of emission	Carbon dioxide (CO_2) Methane (CH_4) Nitrous oxide (N_2O) and Perfluorocarbon (PFC)	
2.	Scope definition	Ownership perspective Including Suppliers Excluding Corporate Offices	Finance confirm the scope in terms of ownership
3.	Carbon emission baseline	Year: 2017 forecast KPI1: 1,905,120 CO_2e tons KPI2: 3.8 Kg CO_2e/Kg sold	Sales: 504,000 tons forecast 2017
4.	Carbon reduction goals	Plan: 7 years 3% reduction per year. Year1: 3.84; Year2: 3.39; Year3: 3.29; Year4: 3.19; Year5: 3.09; Year6: 3.01; Year7: 2.91 KPI2: At least 20% reduction in terms of Kg CO_2e/Kg sold	Sales: 890,286 tons forecast 2023

The alternatives are explored in step 5, with Table 7-2 summing up the set selected by group. The criteria used for the carbon alternatives' selection were based on three factors: (1) cost of the alternative, (2) carbon emission impact in terms of CO_2e tonnes and (3) marketing effect.

Table 7-2 Step 5: Alternatives selected. Case study I

Level	Manufacturing	Warehousing	Transportation		Supplier
			DR	KD - NK	
1	Do nothing	Do nothing	Articulated truck	Articulated truck	Brazil
2	Coal-fuelled CHP	LED lights	Dual vehicle	Water-Road	Germany
3	Biomass	Institutional Tuning	Ethanol		China
4		Daylight Solatube			

The alternatives related with supply chain design in manufacturing are: 1) Keep the Pernambuco factory; 2) Open a new factory in Sao Paulo and/or 3) Open a new factory in Minas Gerais. The warehousing alternatives are: 1) Work with the existing warehouses; 2) Close one or more of the existing warehouses.

The manufacturing alternatives selected include:

- Alternative 1: SHP systems in the Pernambuco Factory.
- Alternative 2: CHP system for the existing or new factory.

- Alternative 3: Biomass for the existing or new factory.

The warehousing alternatives are:

- Alternative 1: Current warehouse with incandescent lights.
- Alternative 2: Change current lights to LED lights.
- Alternative 3: Institutional Tuning.
- Alternative 4: Daylight Solatube.

The transportation alternatives for the secondary transport between the Distribution Center and Retailers:

- Alternative 1: Use the conventional 17tn Articulated truck.
- Alternative 2: Use Hybrid 17tn vehicles.
- Alternative 3: Use Ethanol 17tn truck.

The transportation alternatives for the primary transport between Factories - Distribution Centers and Supplier and Factories (See Appendix D for available routes):

- Alternative 1: Use the conventional 33tn Articulated truck.
- Alternative 2: Use the intermodal Water-Road. (The only alternative for Raw material transport).

The options for buying raw materials are concentrated in three alternatives. In this case every alternative is a supplier located in a different country.

- Alternative 1: Supplier located in Brazil.
- Alternative 2: Supplier located in Germany.
- Alternative 3: Supplier located in China.

7.4.2 BUSINESS OPTIMIZATION USING MATHEMATICAL PROGRAMMING

The third step of the carbon reduction methodology recommends the development of a mathematical model. In order to integrate taxes into the supply chain design, in this case study, the equation (14) is replaced by constraint (23), the equation (20) is replaced by constraint (26) and the equations (24) and (25) are included in the model.

$$GSV_{ijph} = \sum_{m \in M_i} \sum_{t \in T} x_{ijmtph} \cdot p_p \qquad \forall (i,j) \in A;\ \ \forall p \in P\ ;h = 1, \dots, H \tag{23}$$

$$Tx\_O_{ij} = \sum_{p \in P} GSV_{ijph} \cdot ICM\_O_{ji} \qquad \forall (i,j) \in A;\ \ h = 1, \dots, H \tag{24}$$

$$Tx\_I_{kjh} = \sum_{m \in M_i} \sum_{p \in P} \sum_{t \in T} x_{ijmtph} \cdot Pc_p \cdot ICM\_I_{kj} \qquad \forall (k,j) \in A; \quad h = 1, \dots, H (25)$$

$$Tx_h = \sum_{j \in W} \sum_{i \in B} Tx\_O_{ij} \; - \sum_{k \in K} \sum_{j \in W} Tx\_I_{kjh} \qquad h = 1, \dots, H (26)$$

Constraint (23) changes the presentation form of equation (14) to present the GSV as a function of the origin and the destination, which is needed for the creation of the next constraint (24). Constraint (24) represents the tax on the output of the finished product from the warehouse to factories, whilst (25) shows the tax on the movement of goods from the factory to the DC. Constraint (26) expresses the difference between input and output. The model was run on a computer with a processor Core i7 2.59 GHz and16 GB of RAM using IBM ILOG CPLEX Optimization Studio in the Version: 12.6.0.0.; it has 92,416 variables, 17,480 constraints and is solved in 12 minutes.

In the following sections the results of the model are explained, beginning with an explanation of the re-designed supply chain as well as the economic impact of the proposal. Secondly, the proposed model for the carbon reduction roadmap is explained, including details of the set of projects that are part of the reduction plan.

7.4.2.1 The Supply network proposal

According to the solution of the model several changes in the network are proposed, one of which is the reduction in the number of warehouses from five to two. The main warehouse will be in Minas Gerais (the rich area) and the other one will be in Pernambuco (the poor area); see Figure 7-3. The MG-Warehouse will supply the highest volume, whilst the PE-Warehouse will support the customer demand of the NE area.

Minas Gerais is one of the most attractive states in terms of tax benefits, consequently the model suggests consolidating the main operation in this area. The warehouses located in Sao Paulo, Bahia and Rio Grande do Sul should be closed and the volume must be transferred to the MG- and PR-Warehouses, Figure 7-3. Although the tax benefit would be significant due to the network re-design, the cost of closing facilities needs to be considered, as well as the impact of the decision on relationships with the trade unions.

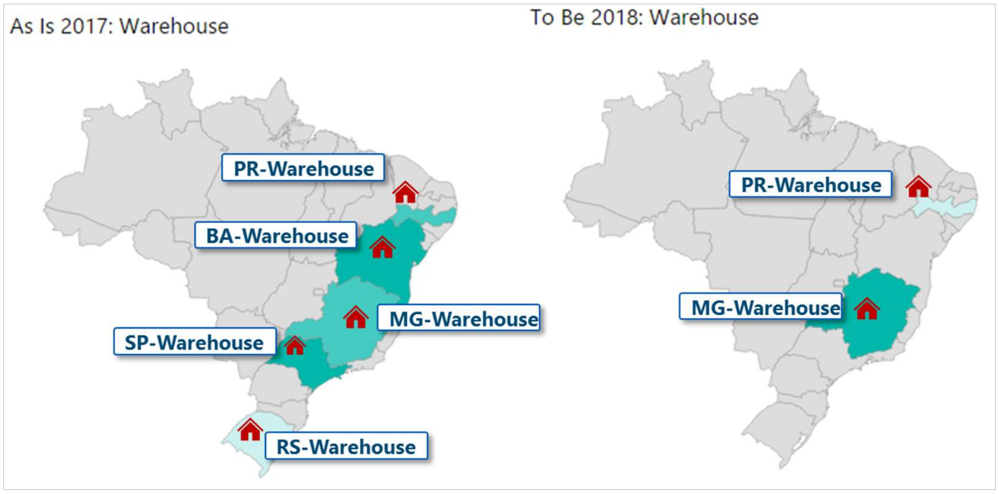


Figure 7-3 The new supply network design. Warehouse locations.
Source: own preparation

The second proposal is the commissioning of a new factory, based in Minas Gerais. This decision is associated with the concentration of operations in this area and with the percentage of customer demand in the area. Furthermore, the model suggests keeping the Pernambuco Factory in the Northeast of Brazil. See Figure 7-4.

Figure 7-4 The new supply network design. Factory locations.
Source: own preparation

The model optimization proposes a new business model where the net profit increases by 25% in the first year and 53% overall; see Figure 7-5. At the same time, the carbon emission in terms of Kg CO_2e per Kg sold would be reduced by 23% until 2023.

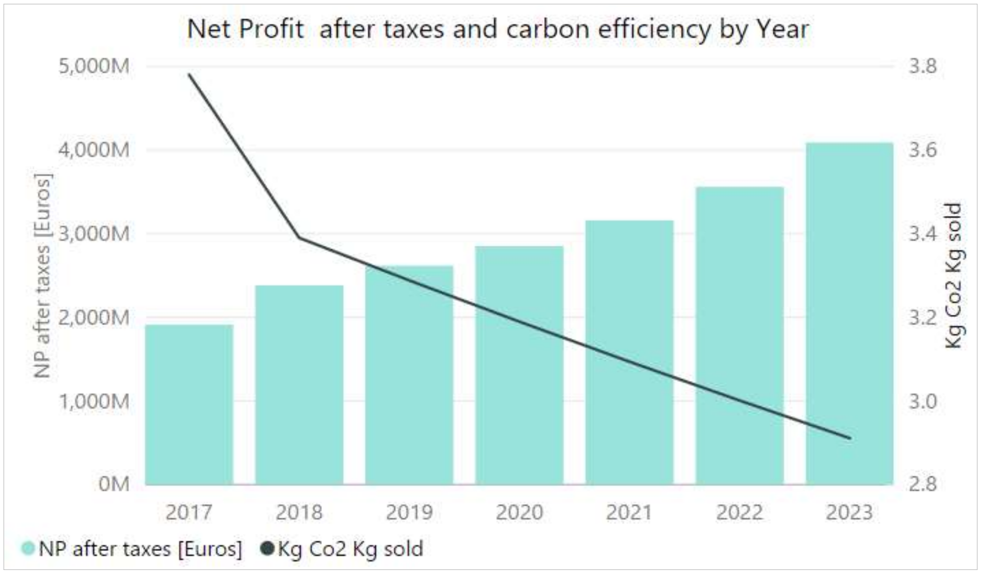


Figure 7-5 Evolution of the Net Profit and Carbon efficiency.
Source: Own preparation

The tax benefit is one of the key drivers that determine and promote a new network design. As the Figure 7-6 shows, there is a significant reduction of the recoverable taxes (ICMS), due to the new stock allocation. The company reduces the ICMS tax in the first year by 85%, which represents a saving of around 215 million euros in the first year.

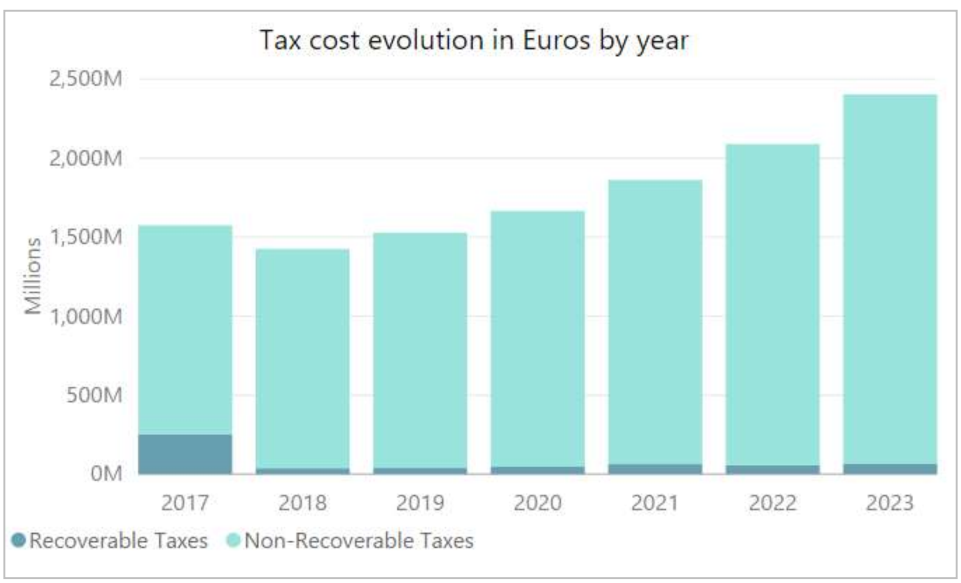


Figure 7-6 Tax cost evolution in Million €.
Source: Own preparation

The investment needed for concentrating the stock in just two warehouses and the commissioning of a new factory does not exceed 40 million euros, which means that the payback of the investment is in less than one year. Beyond the tax benefits, the proposed solution is also good in terms of network configuration; as Figure 7-7 shows there is also a remarkable saving in the transport cost.

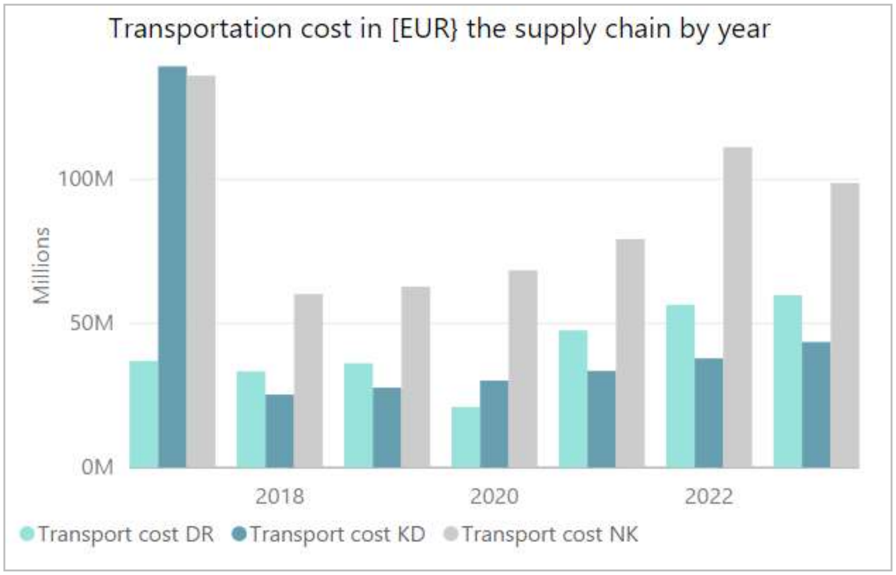


Figure 7-7 Evolution of the transportation cost.
Source: Own preparation

The transportation cost would be reduced by 62% in the first year, achieving a saving of around 193 million euros, therefore reducing the distribution cost by 28%. Savings in both transportation and recoverable taxes impact on the overall benefits, giving the company a competitive advantage.

7.4.2.2 The carbon reduction roadmap

This section shows the carbon reduction roadmap for this study case. The purpose of this plan is to explain the specific actions needed per year and the impact of this set of actions on the yearly and overall targets. The horizon plan was determined as 7 years, the model has selected several carbon reduction alternatives for every year in order to reach the annual carbon target. Figure 7-8 shows the fulfilment of the yearly target in the horizon plan.

The company has determined a carbon emission baseline of 3.78 Kg CO_2e per Kg sold and would reach 2.91 in 2023, improving this key performance indicator by 23%. See Figure 7-8 and Table 7-3.

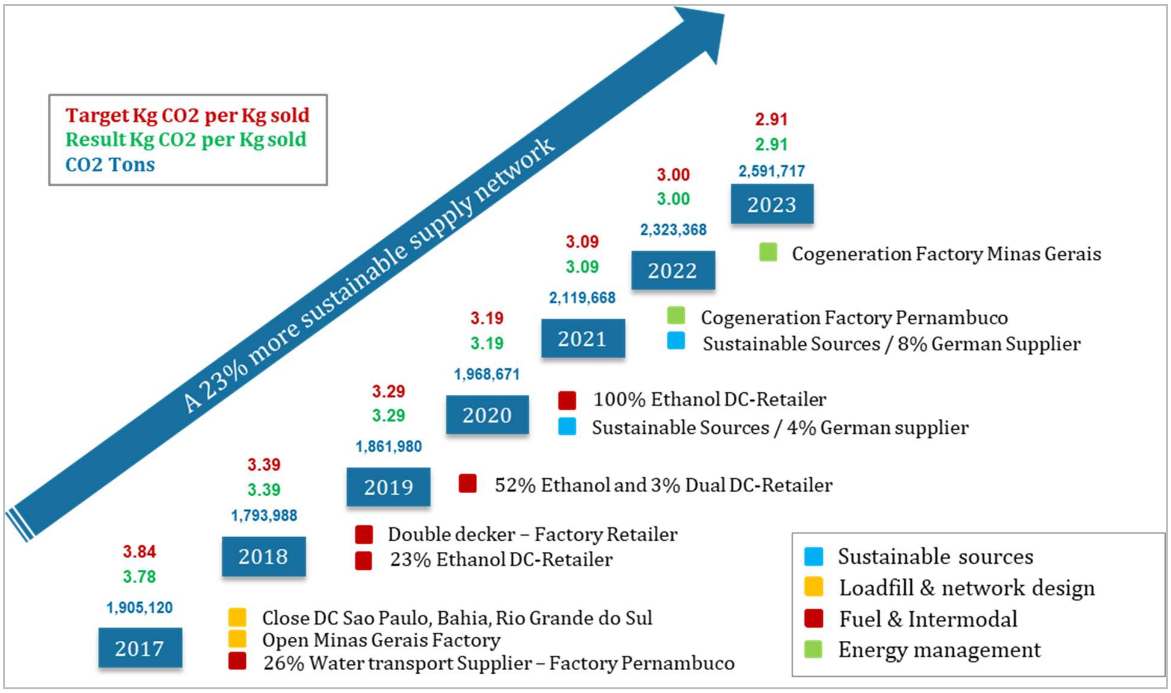


Figure 7-8 Carbon Reduction Roadmap: Brazil Case Study.
Source: Own preparation

Table 7-3 Carbon Reduction Plan 1 - 7 Year: Brazil Case.
Source: Own preparation

Carbon Reduction Plan 1 - 7 Year

Year	Sales volume	Emission	KPI2	Total CO2 saving identified
FY	tons sold	tonnes sold	kgCO2/Kg sold	tonnes CO2
2017	504,000	1,935,360	3.84	
2018	529,200	1,793,988	3.39	**(238,140)**
2019	566,244	1,861,980	3.29	**(57,587)**
2020	617,206	1,968,672	3.19	**(60,887)**
2021	685,099	2,119,669	3.09	**(65,557)**
2022	774,161	2,323,369	3.00	**(71,857)**
2023	890,286	2,591,718	2.91	**(80,156)**

				CO2 reductions allocation					
Year	Project / Action	Area	Project description	Factory energy	Intermodal	WH energy	Network design	Technology / fuels	Sustainable Source
2018	Network redesign	Overall	Close 3 DCs: Sao Paulo, Bahia, Rio Grande do Sul and				- 226,233		
2018	Maritime transport	Logistics	Maritime mode - Inbound transport		- 11,907				
2019	Double decker	Logistics	Double decker – Factory Retailer					- 14,785	
2019	Ethanol Program	Logistics	23% Ethanol					- 42,802	
2020	Ethanol Program	Logistics	52% Ethanol and 3% Dual DC-Retailer					- 60,887	
2021	Procurement Sustainability	Procurement	Raw Materials from Sustainable Sources 4%						- 7,325
2021	Ethanol Program	Logistics	Ethanol DC-Retailer 100%					- 58,232	
2022	Procurement Sustainability	Procurement	Raw Materials from Sustainable Sources 8%						- 14,371
2022	Cogeneration	Manufacturing	Cogeneration Pernambuco Factory	- 57,485					
2023	Cogeneration	Manufacturing	Cogeneration Minas Gerais Factory	- 80,156					

The strategy is mainly based on a logistics strategy that represents 72% of the total carbon reduction, which includes changes in the network and the use of alternative fuels and innovative technologies to improve the truck loadfill. The second pillar of the plan is the energy management in both factories, which represents 29% of the carbon emission reduction. In the following paragraphs, these projects will be explained in more detail.

With regard to the solution of the model two relevant projects related to manufacturing are proposed, the first one planned for 2022 in Pernambuco and the second one in 2023 in the Minas Gerais factory. Both factories are planning to use cogeneration systems. The cogeneration project will generate a carbon saving of 57,485 tonnes in 2022 and 80,156 tonnes in 2023; the impact of implementing these alternatives is shown in Figure 7-9.

The technology proposed is the industrial design of a gas turbine-steam turbine combined-cycle plant, also called combined heat and power (CHP); with electrical efficiencies approaching 60% (NCV), it can reach overall system efficiencies (electricity and useful thermal energy) of 80%. This technology was selected because gas turbines are one of the cleanest means of generating electricity, reducing both CO_2e and NOx.

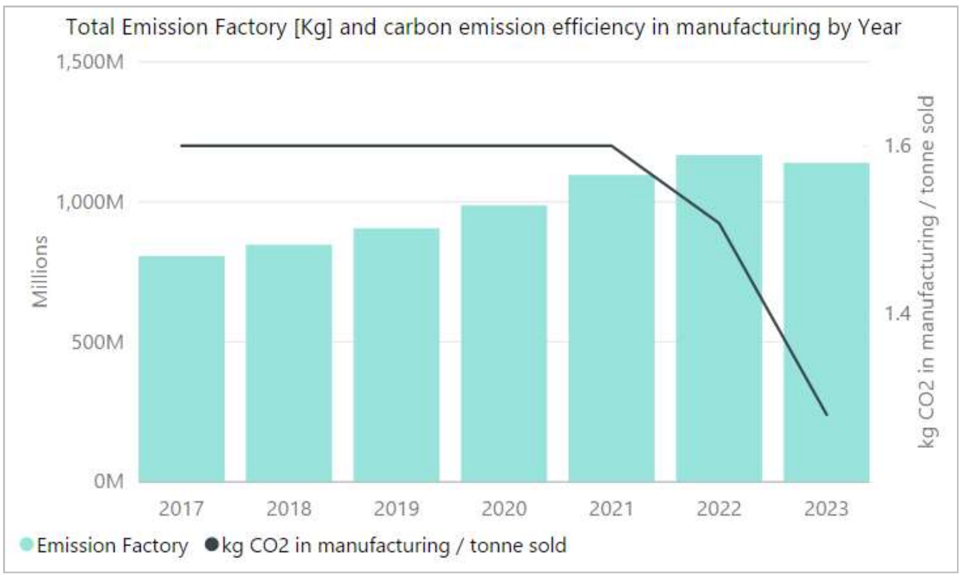


Figure 7-9 Evolution of carbon reduction in manufacturing.
Source: Own preparation

In 2020 and 2021, the strategy involves the procurement team procuring chemical products from a supplier based in Germany. There are three potential suppliers for this specific raw material, one based in Brazil, the other in China and the third one in Germany. However, the technology and the energy used by the German supplier is more environmentally friendly, even including the distance needed for its transportation.

Therefore, in 2021 4% of the raw material will be procured from this supplier and 8% in 2022, for an overall reduction of 21,696 CO_2e tonnes, see Figure 7-10.

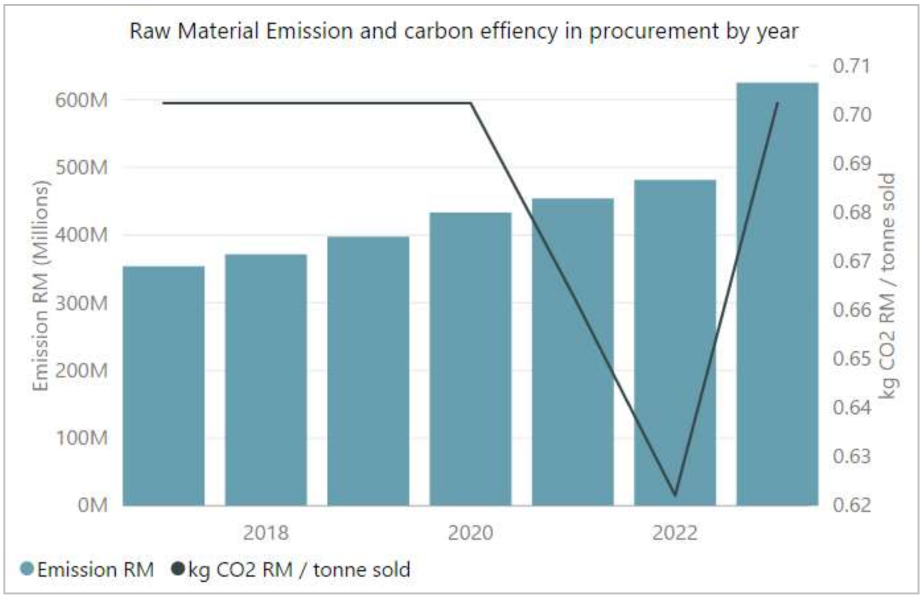


Figure 7-10 Evolution of carbon reduction in the procurement process.
Source: Own preparation

The transportation strategy is one of the most important means for achieving the goals. In just the first year there is a 37% reduction of carbon emission due to the new network configuration; the following years include the use of alternative fuels in the secondary transport, different transport modes and new technologies in the primary and inbound transport.

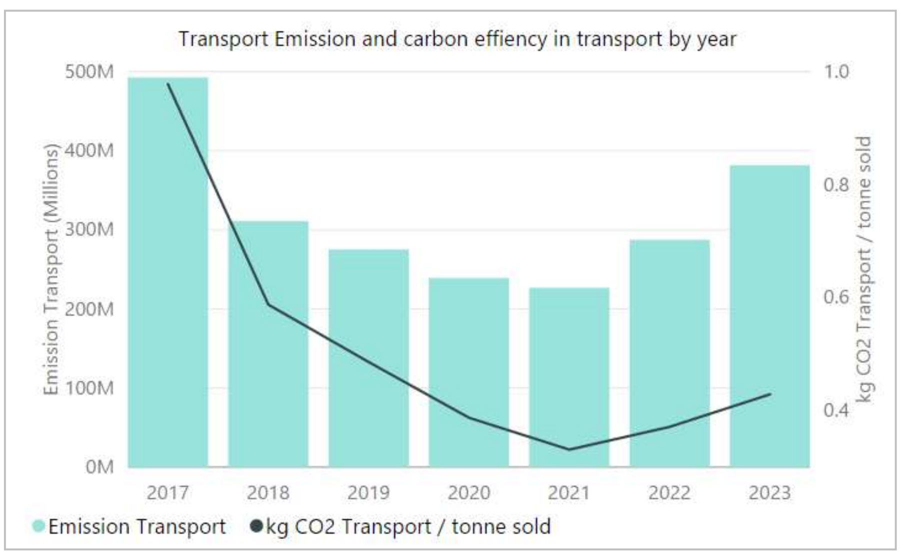


Figure 7-11 Evolution of carbon reduction in transportation.
Source: Own preparation

There is an outstanding evolution of the Kg CO_2e in transport per Kg CO_2e, according to Figure 7-11 it would be reduced by 56% until 2023, as a result of the set of projects explained below.

The first element which impacts on carbon effiency in the transportantion sector is the reduction of 40% in kilometers travelled, 78% in the primary transport, 61% in the inbound transport and 10% in the secondary transport; see Figure 7-12. This also has an impact on the tranportation cost; see Figure 7-7.

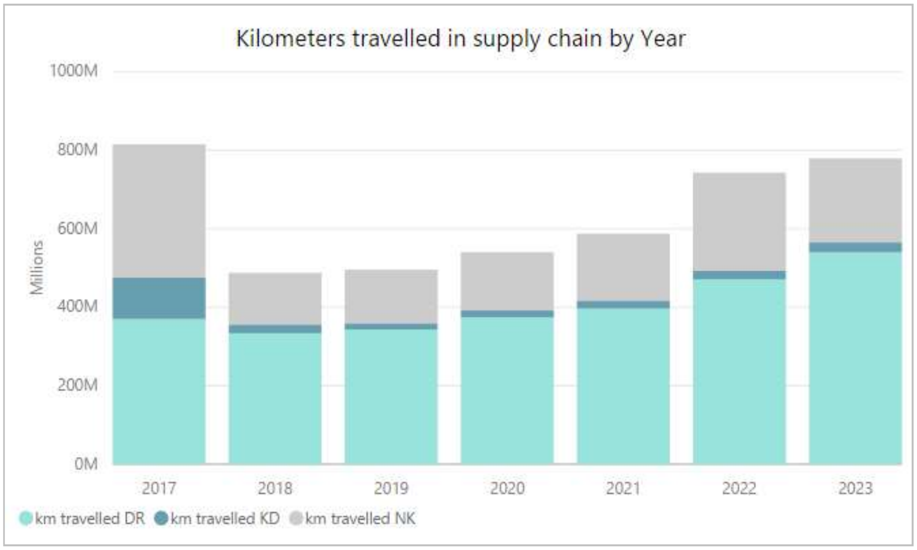


Figure 7-12 Kilometres travelled by category transport.
Source: Own preparation

Undeniably, the re-design of the network impacts positively on the transport cost, the kilometres travelled and consequently the carbon emission, at least in the first year, see Figure 7-13. The supply chain re-design in 2017 is visible in the three transport categories. The secondary transport has a reduction yearly until 2022, whilst the primary transport reduce the carbon emission only until the third year.

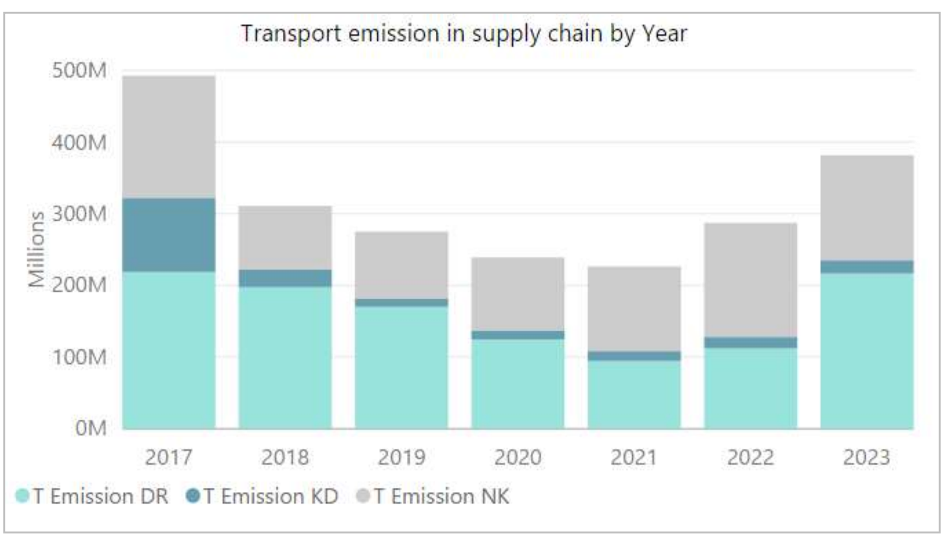


Figure 7-13 Carbon emission by category transport.
Source: Own preparation

The secondary transport would use 5% dual trucks (methane gas and diesel) in 2020 and 2023. Additionally, Brazil is using ethanol produced from sugar cane as motor fuel, which is why the proposal is to start with this kind of fuel in 2019.

Ethanol is an attractive alternative fuel because it is a bio-based renewable. Nevertheless, a complete infrastructure needs to be established. Thus, the proposal is to have gradual growth, 23% in 2019 and 52% in 2020, 100% in 2021 and 2022 and 59% in 2023; see Figure 7-14.

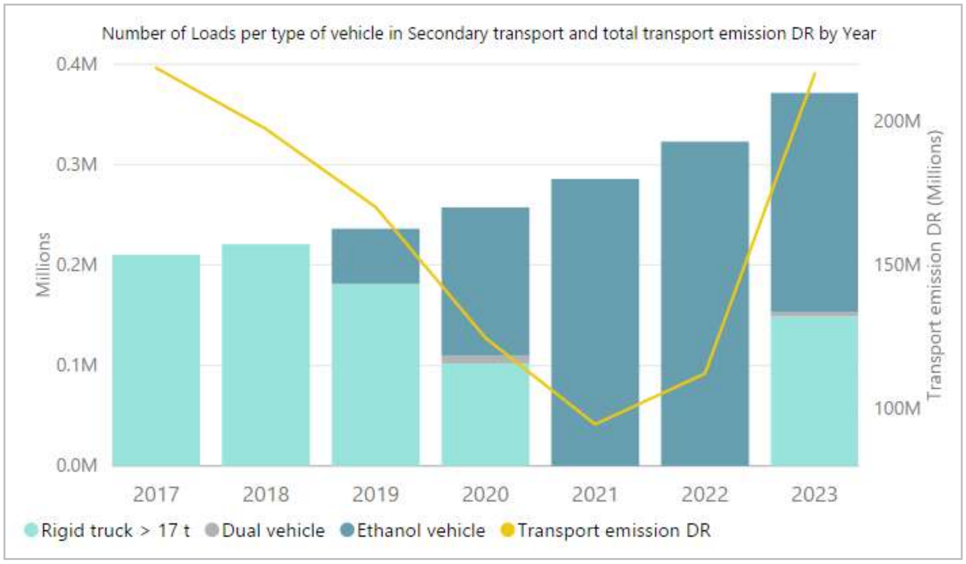


Figure 7-14 Type of fuel in the secondary transport.
Source: Own preparation

The strategy in the primary transport is based on the utilization of double-decker trucks, which should reduce 29% of the loads and 53% of the carbon emissions in transportation between 2018 and 2019, also improving the primary transport performance (Kg CO_2 in primary transportation per load) by 33.5%, see Figure 7-15.

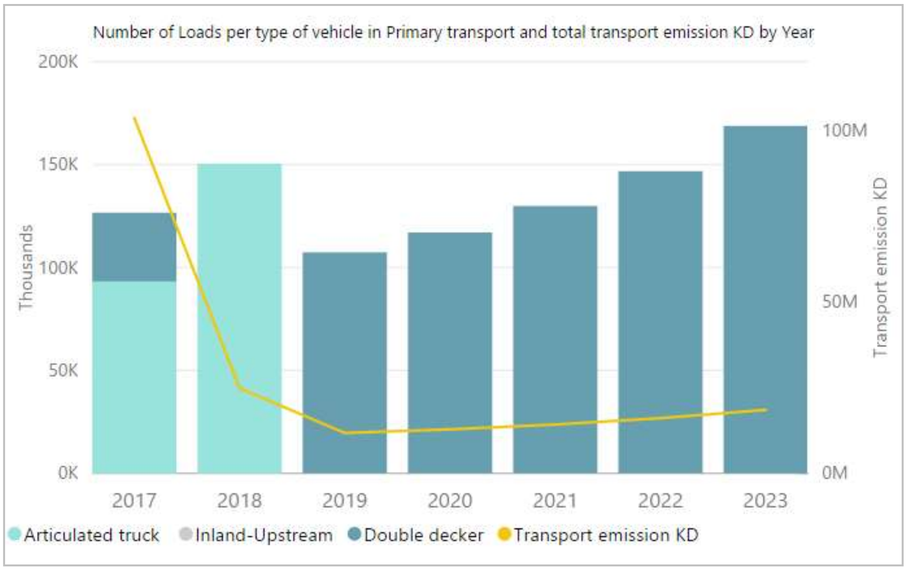


Figure 7-15 Type of transport mode in the primary transport.
Source: Own preparation

7.4.2.3 THE IMPACT OF THE CARBON PLAN IN THE CARBON PERFORMANCE

Figure 7-16 shows, per category, the relation between the total carbon emission and the carbon emission performance in terms of Kg CO_2e per Kg sold. The carbon emission performance rate is the best way to determine an activity's efficiency and it is useful for understanding the progress. In the initial situation, the worst rate is the carbon emission in manufacturing (1.6 Kg CO_2/Kg sold), with the second worst being the carbon emission in transportation (0.98 Kg CO_2/Kg sold).

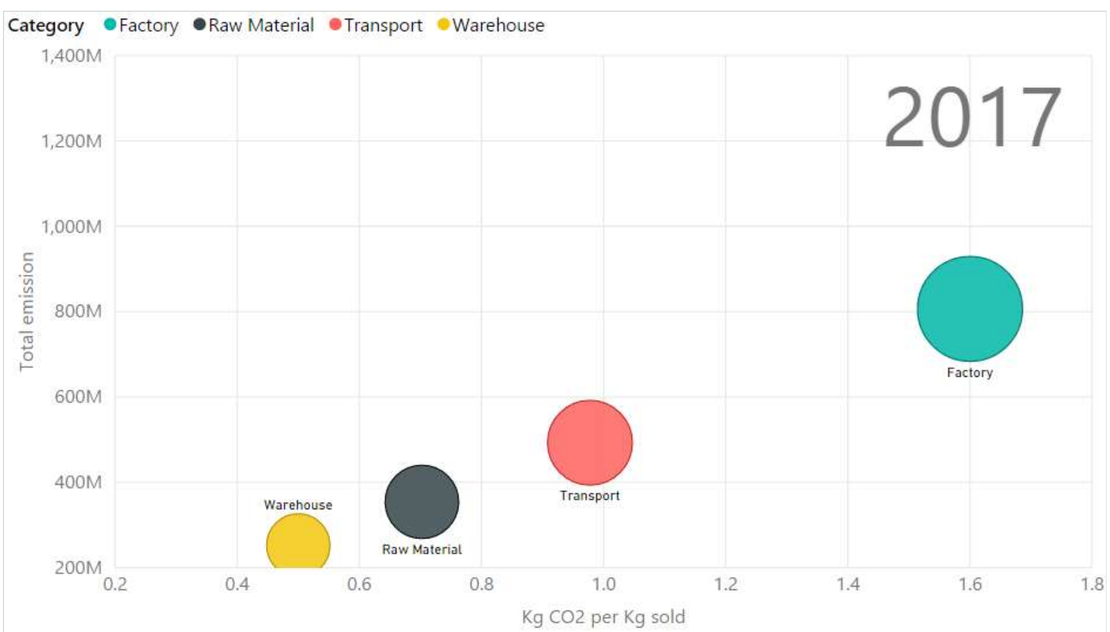


Figure 7-16 Initial situation of the Kg CO_2e per Kg sold rate.
Source: Own preparation

Because of the implementation of the plan there is a significant improvement regarding the relation of carbon emission vs carbon emission performance in manufacturing, transportation and procurement. The most remarkable case is the transportation rate, which improves both carbon emission by 23% and performance by 56% (Kg CO_2/Kg sold: 0.98in 2017 vs 0.42 in 2023). See Figure 7-17.

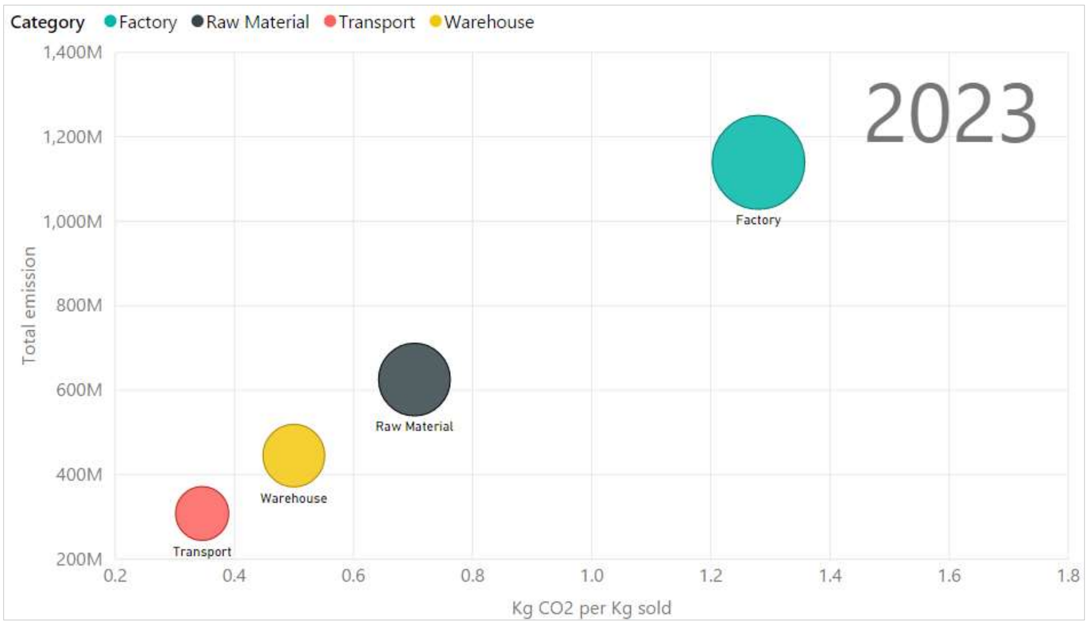


Figure 7-17 Final situation of the Kg CO_2e per Kg sold rate.
Source: Own preparation

Another important improvement is the carbon emisson performance in manufacturing, which would be reduced by 20% (Kg CO_2/Kg sold: 1.6 in 2017 vs 1.28 in 2023). All of them are the pillars of the carbon reduction plan, improving its results in its categories and contributing to reach 23% of the reduction by 2023.

7.4.3 SENSITIVITY ANALYSIS OF THE TAXATION

Evidently, including taxes and tax benefits in the network design and aligning it with the P&L, together with carbon emission programs, will bring overall benefits. However, tax benefits are often volatile and depend on governmental decisions.

On the other hand, a new network design normally comprises future strategic moves such as mergers, acquisitions and supply chain capacity planning, all of which are linked with investments. Consequently, it is important to perform a sensitivity analysis of the taxation. Four scenarios are explained in Figure 7-18, all of them related with the recoverable tax variation, which is a key driver that determines, somehow, the network configuration.

The first scenario is the one raised in this case study, where both Minas Gerais and Pernambuco state have tax benefits; based on this input the solution of the model is to open a new factory in Minas Gerais and keep one warehouse in Pernambuco and another in Minas Gerais. The result shows that this is the most convenient scenario in terms of tax savings.

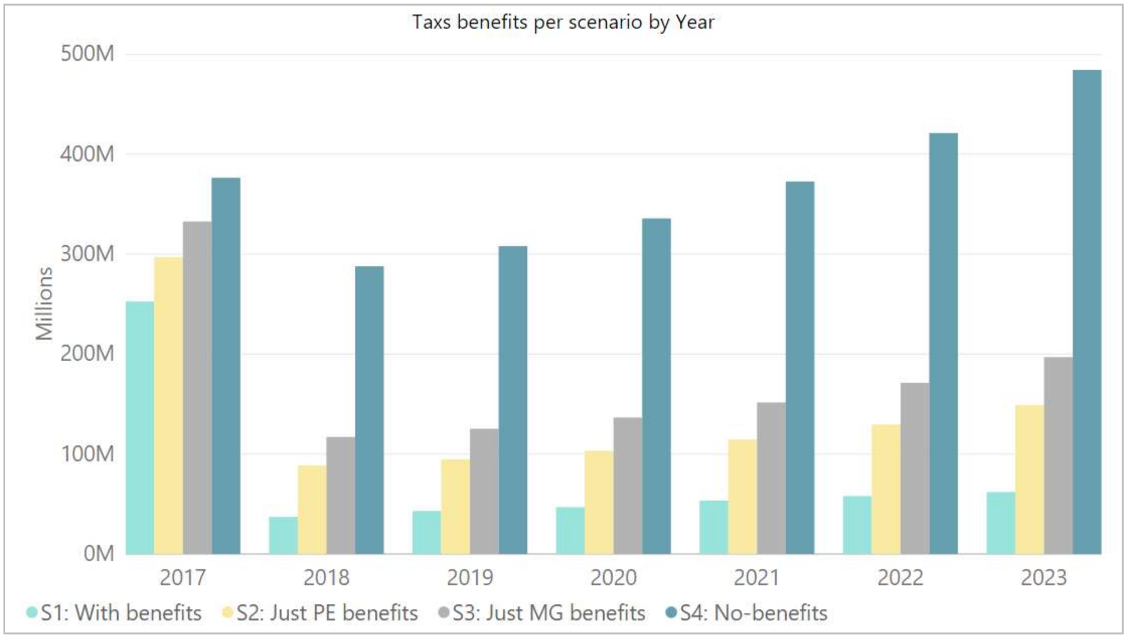


Figure 7-18 Tax benefits under different scenarios.
Source: Own preparation

The second scenario includes only the Pernambuco state benefits; the input still proposed the same network organization as the first scenario. However, it proposes allocating more volume to the Pernambuco warehouse and factory and clearly this solution proposes fewer savings in recoverable tax. The third scenario just considers the benefits of the Minas Gerais state; this new information changes the solution of the model by proposing to locate all the facilities in the south of the country, see Figure 7-19.

Figure 7-19 Change in the network due to the ICMS rate.
Source: Own preparation

The fourth scenario is the ICMS tax without benefits, in this case the solution of the model again proposes the facility allocation shown in Figure 7-19, selecting this area due to major customer demand being located here.

The carbon strategy also depends on the scenario; for instance scenario two is stronger in the manufacturing strategy in order to compensate for the increase of 38% in the kilometres travelled; on the other hand, scenarios three and four concentrate the volume in the southern area where the customer demand is highest, therefore both scenarios are stronger in the transport strategy, see Table 7-4 and Table 7-5.

Table 7-4 Kg CO_2e per Kg sold per category and scenario.
Source: Own preparation

Year	kg CO_2e Factory/ Kg sold			kg CO_2e Transport / Kg sold				kg CO_2e RM / Kg sold		
	S1	**S2**	**S3/S4**	**S1**	**S2**	**S3**	**S4**	**S1**	**S2**	**S3/S4**
2017	1.60	1.60	1.60	0.98	1.03	1.03	1.02	0.70	0.70	0.70
2018	1.60	1.60	1.60	0.33	0.59	0.42	0.39	0.66	0.70	0.70
2019	1.60	1.47	1.60	0.39	0.52	0.42	0.42	0.70	0.70	0.70
2020	1.60	1.47	1.60	0.59	0.61	0.39	0.42	0.70	0.70	0.70
2021	1.60	1.41	1.60	0.49	0.48	0.29	0.29	0.70	0.70	0.70
2022	1.51	1.28	1.54	0.37	0.50	0.26	0.26	0.62	0.63	0.70
2023	1.28	1.28	1.34	0.43	0.52	0.36	0.36	0.70	0.70	0.70
Total	**10.79**	**10.11**	**10.88**	**3.57**	**4.24**	**3.17**	**3.17**	**4.80**	**4.85**	**4.92**

Table 7-5 Kilometres (000) travelled per scenario.
Source: Own preparation

Year	S1	S2	S3	S4
2017	815,482	821,457	827,385	819,135
2018	587,584	696,669	326,748	372,308
2019	540,230	745,436	349,621	349,621
2020	487,568	812,525	372,308	326,748
2021	495,624	901,903	413,262	413,262
2022	742,675	1,019,150	466,986	466,986
2023	779,252	1,226,929	537,033	537,033
Total	**4,448,415**	**6,224,070**	**3,293,342**	**3,285,092**

The aim of having tax incentives in the north of Brazil is to generate movement in this area, which is why the model originally proposes keeping a warehouse in Pernambuco. Nevertheless, if this tax benefit disappeared the facilities would be located in the south and this would involve a stronger strategy in the transportation sector.

7.4.4 IMPLEMENTATION AND TRACKING

The implementation of the carbon reduction methodology is in progress; it has validated the supply chain re-design and includes the corporate carbon emission strategy and the financial planning . The solution of the model is viable, reasonable and aligned with the company's perspective.

Recommendations for the implementation and tracking:

- Tax benefits and agreements should be reviewed yearly, as they can be volatile and can change depending on the government.
- The use of ethanol should be analysed in detail because it depends on the number of service stations available. It is highly recommended to review this proposal periodically.

7.5 CONCLUSIONS

- A successful supply network should consider the benefit of local agreements in order to improve competitiveness and to avoid the risk of missing out on potential savings. Besides, it should ensure a proper balance between supply chain costs and tax obligations.
- For this Brazilian company, a new network organization is proposed, with only two warehouses needed in the rich area (Minas Gerais) and another in the poor area (Pernambuco). Besides, another factory should be opened in Minas Gerais.
- The solution of the model leads to a new business model where the net profit increases by 53% due to tax benefits and improves its carbon efficiency by 23% up to 2023.
- The carbon reduction plan is mainly based on the implementation of cogeneration systems in manufacturing, the use of multimodal, double-decker and alternative fuels in logistics and the green procurement process.

- Finally, a sensibility study was performed to ascertain the impact of the tax benefits in the supply network design. Four scenarios were explained, all of them related with the recoverable tax variation, which is a key driver that determines, somehow, the network configuration.
- The sensibility study has demonstrated how governmental decisions can affect the supply chain design and can change the final decisions affecting both cost and carbon emission. The supply chain proposed can change in the event of the tax benefits in the north of Brazil disappearing; the facilities would be located in the south and this would involve a stronger strategy in the transportation sector.
- If countries such as Brazil or India, where the taxes are significant, do not include and/or do not react fast enough to add these regulations, they might in the long run have serious financial and operational consequences.

CHAPTER 8

Case study II: A multinational company operating in Spain in the food business

8.1 INTRODUCTION

This second case study illustrates the importance of the intermodal transport in the carbon strategy and it is made using a European network. The company under review is a global manufacturing company which commercializes food products and the customer demand is based in Spain. The company works with a set of retailers located in the most relevant geographic zones: Madrid, Barcelona, Pamplona, Bilbao, Sevilla, Zaragoza and Logroño.

During recent decades, the company has been using three Distribution Centers, in Montornès, Segovia and Vigo, for supplying the customer demand, as well as a factory located in Mussolente, (Vicenza, Italy) that produces the products of this category for the countries of southern Europe; see Figure 8-1. The raw materials are sent from suppliers mainly based in Brazil, Russia and Ukraine.

Figure 8-1 European network design, As Is Situation.
Source: Own preparation

8.1.1 THE COMPANY'S PROFILE IN SPAIN

The last accounts balance (2016 fiscal year) presented by the company shows a Social Capital of more than € 40 million and has a sales rank of more than € 200 million in the Foods category. The company has more than 30 years' presence in Spain, but in recent years the economic crisis has had a significant impact on the sales volume.

The company is one of the leaders in the market in brands such as mayonnaise, margarines and soups in a country where "white brands" have a strong presence in this sector. Nevertheless, the company is betting on innovation to keep its position and increase the sales volume. In 2016, the company ranked as one of the first five in the Radar innovation ranking, carried out each year by Kantar World panel. Some of its launches were nominated as the 10 innovations with the greatest power to attract customers in their first year on sale.

Recently, the company has received the Equality Award in Business, awarded by the Spanish Ministry of Health, Social Services and Equality. It is a recognition of excellence that is given to companies that apply policies of equality in the workplace and offer the same opportunities to men and women. Regarding the environmental aspect, the company has clear targets for 2020, for instance sustainably-grown agricultural raw materials, such as the vegetables in Food brands. This is especially important for climate change mitigation or to halve the waste associated with the disposal of the products.

The company is well-known for its circular economy management, which aims to reduce the entry of materials and the production of virgin waste. The firm undertakes to reduce the impact of its products after consumption, for instance, nowadays it is possible to give a second chance to 70% of the plastic generated by the company's products and one of its objectives is to have all of its plastic containers recyclable by 2025.

Even in middle of the economic crisis in Spain, the firm has a strong social and environmental commitment, both characteristics forming part of the marketing strategy and the company's philosophy.

8.1.2 THE COUNTRY CONTEXT

Spain has suffered a long and intense recession, triggered by an international crisis that hit part of the world financial system. Almost a decade after the crisis began, Spain has reported four consecutive years of Gross domestic product (GDP) growth. Nevertheless, although Spain's decline has stopped, the consumer goods industry still has not fully recovered.

The latest crisis has significantly impacted the consumer goods sector in Spain. According to an investigation by Boston Consulting Group in 2017, the market is almost stagnant with an annual increase of 2.5%. This value is due to the results of small and medium companies, since the big ones have only increased by 1.3%.

As a consequence of the economic crisis the "white brands" are well established in the market and are strong competitors in the Consumer Goods sector, both in Spain and Europe. On the other hand, consumers are looking for new taste experiences and healthier options. Thus, companies should strive to find a space by modernizing their portfolios, launching new organic and '100% natural' products and innovating in new strategies to reduce cost and increase productivity.

Besides, the logistics strategy in Europe is also changing. The large increases in the scale of consumption in Europe during the recent decades, combined with the extension of the Union to Central and Eastern European countries, is opening opportunities for reducing operational costs, especially those related to labour. It is also leading to the possibility of redesigning their networks.

Under this context, an efficient transport system is an essential prerequisite for the companies' competitiveness, and striking a balance between socio-economic and environmental sustainability will provide a real challenge.

8.1.2.1 Carbon emission context in Spain

The Spanish Strategy of Climate Change and Clean Energy was put into place in 2007 and is expected to run until 2020. However, the economic crisis provided a huge challenge to carbon emissions reduction and sustaining growth in the renewable energy sector. Nevertheless, both policies are already in place, which demonstrates the commitment of the country to climate change mitigation.

According to the Observatorio de la Sostenibilidad in 2016, the carbon emission in Spain was reduced by 3.1% compared to the previous year. But in the previous years, carbon emissions rose by 0.5% in 2014 and in 2015 soared to 3.2%. Figure 8-2 shows the evolution of the GHG emission since 1990 with a significant reduction from 2007 until 2013.

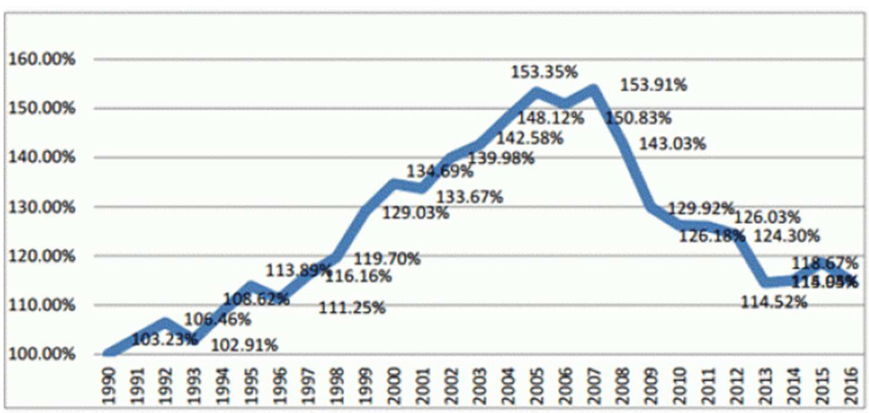


Figure 8-2 Estimation of GHG emissions in percentage until 2016 indexed to 1990.
Source: Observatorio de la Sostenibilidad del Gabinete de Historia Natural

According to the European Commission Government, Spain is producing more CO_2e emissions than 1990 (the reference year of the Kyoto Protocol). In 1990 the carbon emission reported was 285.9 million tonnes of CO_2 equivalent, whilst in 2016 the carbon emission would be 328.7 million tonnes. In the last year, this increase was associated with an increase of 23.9% in coal burning.

In order to comply with the Kyoto Protocol, between 2008 and 2012 Spain had to spend more than € 800 million on rights to compensate for excesses. Most of the European countries are in a positive dynamic and they emit less and less CO_2e; nevertheless, in Spain the glimpses of economic recovery have halted the progress of the previous decade.

Looking forward, the Observatorio de la Sostenibilidad recommends "a transition towards sustainability" following the recommendations of the OECD and the ONU. According to this entity, the government should boost renewable energy and change the energy matrix, currently based on coal and fossil fuels. Moreover, the Observatorio de la Sostenibilidad highlights that the government should work together with companies to create a low carbon economy that in the medium and long term will be competitive, innovative and sustainable.

8.1.2.2 The transport system in Spain

Three transport modes are used to move goods in Spain: road, rail and water. The most commonly used freight transport within the peninsula is road transport. In 2016 the authorized heavy vehicles for the transport of goods performed 182 million transport operations, transporting 1,286 million tons and generating 217 billion tons-km, with the average distance per trip being 112 km, (Ministerio de Fomento, Gobierno de España, 2017).

Within Spanish logistics, intermodal transport is the most critical aspect of transportation. The improvement of intermodality is a general indicator of the services level and contributes to the improvement of the whole supply chain. For companies, the use of intermodal solutions is linked with social responsibility, which will be more demanding every day.

According to the Plan Estratégico de Infraestructuras y Transporte (PEIT), Spain has the geographic characteristics to be an international logistic platform. As Figure 8-3 shows, the Mediterranean is starting to have a very important position, especially in global logistics and international trade, because it can play a dual role: acting as a point of entry and exit in the logistics between Asia and Europe and as a link between Asia and America (way porting strategy).

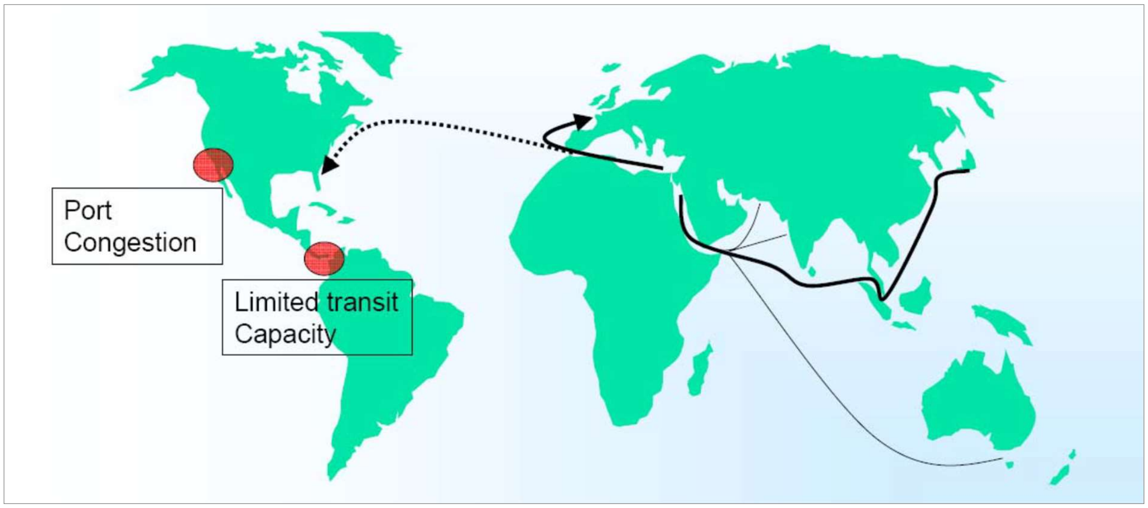


Figure 8-3 A new route through the Mediterranean.
Source: Drewry Shipping Consultants

However, a good strategy is needed to make use of the opportunities that Spain presents. This strategy should be based on the improvement of rail transport, the use of intermodal water-rail transport, an increase in intermodal water-road transport and support for the transition from road transport to intermodality.

Spain has an extensive network of ports throughout its geography, as well as various shipping lines. Spain is the third power of the European Union in the transport of goods by port and the number eleven worldwide. According to the Ministerio de Fomento, Maritime transport represents 74% of the import and export of goods in the country. In this activity, the main ports in 2017 were, on the Mediterranean coast, the ports of Algeciras, Valencia and Barcelona along with the ports of Bilbao and of Las Palmas on the Atlantic coast.

On the other hand, a rail strategy connected with the rest of Europe is crucial for the success of the strategy proposed in the PEIT. One of the biggest challenges in this area is the change of track gauge and the use of the Mediterranean and Atlantic axes, since they are also included in the first proposal for a European rail network.

Furthermore, several steps would be necessary to improve the rail freight: 1) infrastructure; 2) promoting the liberalization of the rail market; 3) implementing a management by corridors dedicated to goods; 4) planning, executing and managing the logistics activities with the operators; 5) modernizing the operation and management of the terminals; 6) helping small users to extend the market of the train and 7) changing the rail freight image (Ministerio de Fomento, Gobierno de España, 2016).

Most of the freight transport in the peninsular area is performed by road transport. But the use of intermodal rail-road would also be an option. Figure 8-4 shows the main corridors that the PEIT 2020 proposes, but this option should be analyzed carefully. On the primary routes the rail-road could work but the associated inventory cost, due to the extra lead-time needed when compared with road transport, should be taken into account. It is not yet recommended on the secondary routes, because of the customer's strict delivery time window .

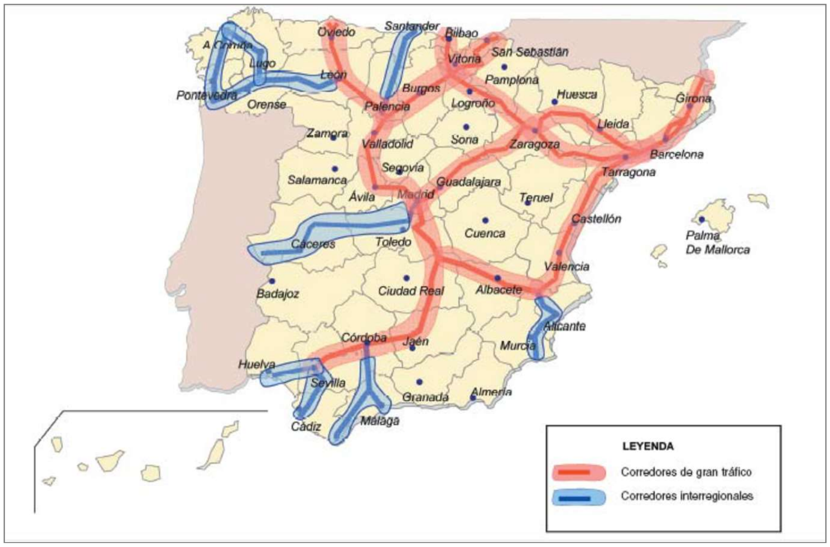


Figure 8-4 Main corridors in the rail transport.
Source: PEIT 2020

In conclusion, in the case study shown in Chapter 8 rail transport is not an alternative for the secondary routes. The secondary transport uses road transport, changing the size and vehicle fuel; the primary transport has two alternatives (road and water-road) and raw material transport uses just the intermodal water-road due to the geographic characteristics.

8.2 WHY IS THE COMPANY INTERESTED IN A CARBON REDUCTION PLAN?

The company has a strong commitment to sustainable growth, in reality it means to carry out the changes needed to reduce the product cost while at the same time reducing the carbon emission impact.

- The company is aware of the impact that a new supply network design can have on the carbon emission targets, for this reason they need a complete plan to mitigate the possible negative impacts.
- The company has decided to adopt a rate of €30 per tonne of CO_2 equivalent emission as the internal carbon price. This rate should be included in the capital assessment and be part of the cash flow analysis. Applying this rate, the company is ensuring that the carbon impact is part of any in-house decision-making.

8.3 TO BE SITUATION

The company is having some trouble with the product cost of the foods category, which is the main reason why the company is assessing the possibility of re-designing the supply network; the changes under review are as follows:

- Close the current Italian factory and open a new one based either in Poland or Portugal. If the factory is in Lisbon (Portugal) the manufacturing cost would be 77% of the current cost and will be closer to the market. If the factory is based in Katowice (Poland) the distance will increase but the manufacturing cost would be 53% of the existing cost.
- They are also reviewing the number of Distribution Centers in order to reduce them, if possible, but they do not know what the optimal number of DCs is and where they should be located.
- At the same time, the company is starting a carbon reduction plan where they aim to reduce at least 30% of the carbon emission by 2024.

8.4 METHODOLOGY IMPLEMENTATION

The methodology here proposed is proved by using the food company data in Spain. First, the pillar of the strategy is defined in the corporate carbon strategy and validated in the strategic financial step. At this point, the methodology proposes to organize the information given by the company, following the steps of the methodology to create the bases of the carbon strategy. Secondly, the methodology uses the data provided to propose a carbon reduction plan in order to achieve the carbon reduction targets.

8.4.1 CORPORATE CARBON STRATEGY AND STRATEGIC FINANCIAL PLANNING

The processes associated with the production are normally drying, distilling or fermentation and the associated emissions can come from these processes or from the combustion in the boilers of the cooking process. The greenhouse gases associated with this production process are mainly carbon emission (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFCs).

At this point, as a part of the strategic financial planning the carbon tax equivalent is estimated at €57 million, using a carbon rate of 30 Euros per CO_2e tonne, although this standard value is far from the last value reported by the EU Emissions Trading System (EU ETS).

As a part of the second step, the company decides to include the suppliers in the carbon strategy and defines the scope as an "ownership perspective including suppliers". Then the baseline is demarcated with 2017 as the first year, a carbon emission forecast of 1,908, 408 CO_2e tonnes and a carbon efficiency of 5.7 Kg CO_2e/Kg sold. Next the carbon goals are established, defining them as 30% of carbon reduction efficiency in terms of Kg CO_2e/Kg sold, and should be reached by 2023. Table 8-1 summarizes the first four steps of the methodology implementation of this study case.

Table 8-1 Steps 1,2,3,4 of the Carbon strategy and Strategic Financial Planning. Case Study II.
Source: Own preparation

	Step of the CCS	Corporate Carbon Strategy	Strategic Financial Planning
1.	Type of emission	Carbon emission (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and Hydrofluorocarbons (HFCs)	Carbon tax equivalent: 57M€
2.	Scope definition	Ownership perspective Including Suppliers Excluding Corporate Offices	Finance confirm the scope in terms of ownership
3.	Carbon emission baseline	Year: 2017 forecast KPI1: 1.908.480 CO_2e tons KPI2: 5.7 Kg CO_2e/Kg sold	Sales: 336.000 tons forecast 2017
4.	Carbon reduction goals	Plan: 7 years 6% reduction per year. Year1: 5.68; Year2: 5.4; Year3: 5.08; Year4: 4.77; Year5: 4.49; Year6: 4.22; Year7: 3.96 KPI2: 30% reduction in terms of Kg CO_2e/Kg sold	Sales: 593.524 tons forecast 2023

Following the methodology, the next step would be the selection of the alternatives. Table 8-2 shows the set of alternatives by group; the company's criteria for selecting these alternatives were: 1) Feasible alternatives aligned with governmental projects; 2) Alternatives with more carbon impact; 3) Alignment with the marketing strategy.

Table 8-2 Step 5: Alternatives selected. Case study II

Level	Manufacturing	Warehousing	Transportation		Supplier
			DR	KD - NK	
1	Do nothing	Do nothing	Articulated truck	Articulated truck	Brazil
2	CHP (40% Biomass, 60% Coal)	Daylight Solatube	Dual vehicle	Rail-Road	Russia
3	CHP (100% Biomass)	Solar Power	CNG	Water-Road	Ukraine
4		Green certification			

Additionally, the company is considering a supply chain re-design. The options for factory relocation are 1) Keep the factory in Italy; 2) Open a new factory in Portugal and 3) Open a new factory in Poland. Moreover, there is also a proposal to change the warehouses of the network, the options being: 1) Work with the three existing warehouses located in Segovia, Montornès and Vigo; 2) Keep just two warehouses and 3) Work just with one warehouse.

The manufacturing alternatives selected include:

- Alternative 1: Light Fuel Oil with Grid electricity in the current factory in Italy.

- Alternative 2: CHP (40% Biomass, 60% Coal) for the selected factory.
- Alternative 3: CHP (100% Biomass) for the selected factory.

The warehousing alternatives are:

- Alternative 1: Current warehouses with conventional light with LEDs.
- Alternative 2: Daylight Solatube for the selected warehouses.
- Alternative 3: Solar Energy for the selected warehouses.
- Alternative 4: Green energy for the selected warehouses.

The transportation alternatives for the secondary transport between the Distribution Center and Retailers are:

- Alternative 1: Use the conventional 17tn Articulated truck.
- Alternative 2: Use 17tn Hybrid trucks.
- Alternative 3: Use 17tn CNG trucks.

The transportation alternatives for the primary transport between Factories - Distribution Centers and Supplier and Factories (See Appendix E for available routes) are as follows:

- Alternative 1: Use the conventional 33tn Articulated truck.
- Alternative 3: Use the intermodal Rail-Road. Not available for inbound transport.
- Alternative 2: Use the intermodal Water-Road.

There are three alternatives for buying raw materials. In this case each alternative is a supplier located in different countries.

- Alternative 1: Supplier located in Brazil.
- Alternative 2: Supplier located in Russia.
- Alternative 3: Supplier located in Ukraine.

8.4.2 BUSINESS OPTIMIZATION USING MATHEMATICAL PROGRAMMING

In the third step of the carbon reduction methodology, the mathematical model developed in chapter 5 is used without modifications, using the data provided by the company selected for this second case study. The model was run on a computer with a processor Core i7 2.59 GHz and 16 GB of RAM using IBM ILOG CPLEX Optimization Studio in the Version 12.6.0.0.; it has 53,734 variables, 9,250 constraints and is solved in 21 minutes.

In the following paragraphs, the results of the model are explained. First there is an explanation of the new supply network proposed and its economic and environmental implications. Next the carbon reduction roadmap is explained, together with the alternatives selected as a part of the strategy.

Finally, an analysis is made of the impact of the carbon reduction plan on the carbon yearly performance.

8.4.2.1 The Supply network proposal

The solution of the model proposes a new supply network design, where the factory located in Vicenza (Italy) is closed and a new factory in Katowice (Poland) is commissioned. Moreover, the warehouse in Vigo is closed, with demand being supplied through the current warehouses located in Montornès and Segovia, as shown in Figure 8-5.

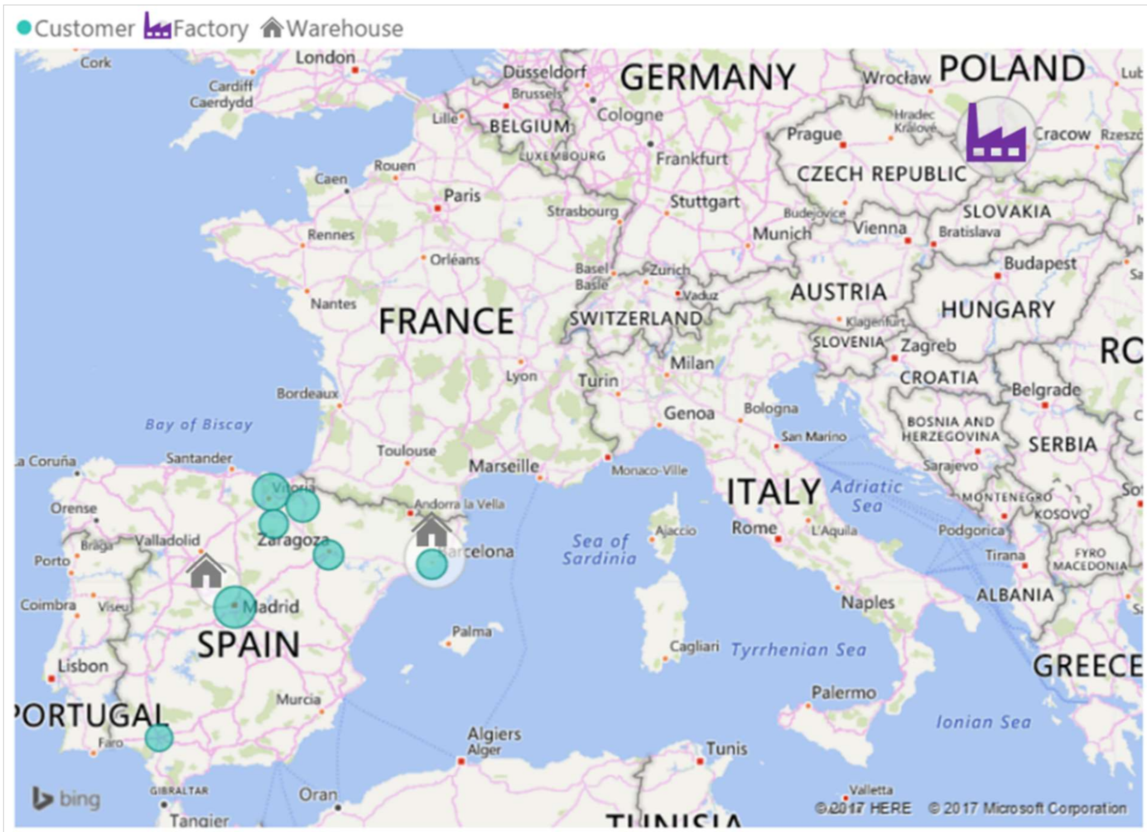


Figure 8-5 The new supply network design.
Source: own preparation

Figure 8-6 shows how both distribution centers will supply the customer demand. The Montornès DC will supply the demand in the northern area and the DC in Segovia will supply mainly the demand in Madrid and Sevilla.

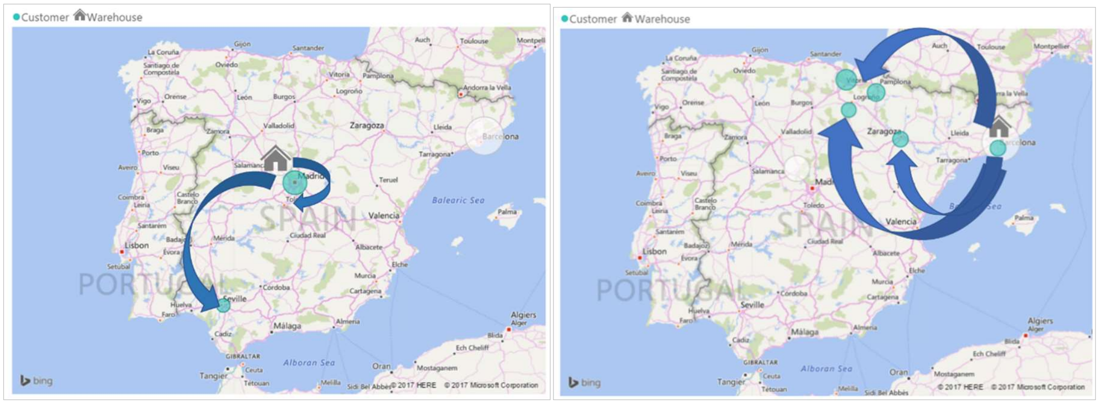


Figure 8-6 The supply from the Distribution Centers to the Retailers.
Source: Own preparation

The model delivers a solution where the net profit after taxes is increased by 74% in the first-year due to the new supply network configuration; this change also impacts on the results of the following years. In 2023 the demand forecast increases 1.76 times, whereas the net profit forecast increases by 2.77. Besides, the model meets the obligation of reducing the carbon emission impact by 30% in terms of carbon efficiency [Kg CO_2e per Kg sold]. Figure 8-7 shows the evolution of the Net Profit and Carbon efficiency and net profit.

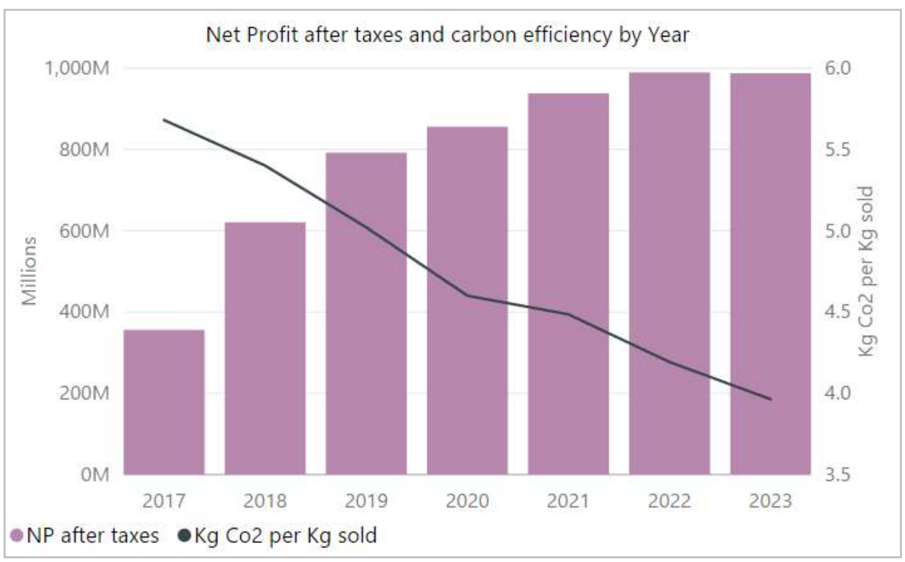


Figure 8-7 Evolution of the Net Profit after taxes.
Source: Own preparation

Due to the factory relocation the manufacturing cost is reduced by 44% in the first year and consequently the product cost was reduced by 22%. Figure 8-8 shows the evolution of the manufacturing cost versus the product cost. In the graph it can be seen how the product cost is reduced abruptly in 2018, whilst the manufacturing cost increases progressively in the following years.

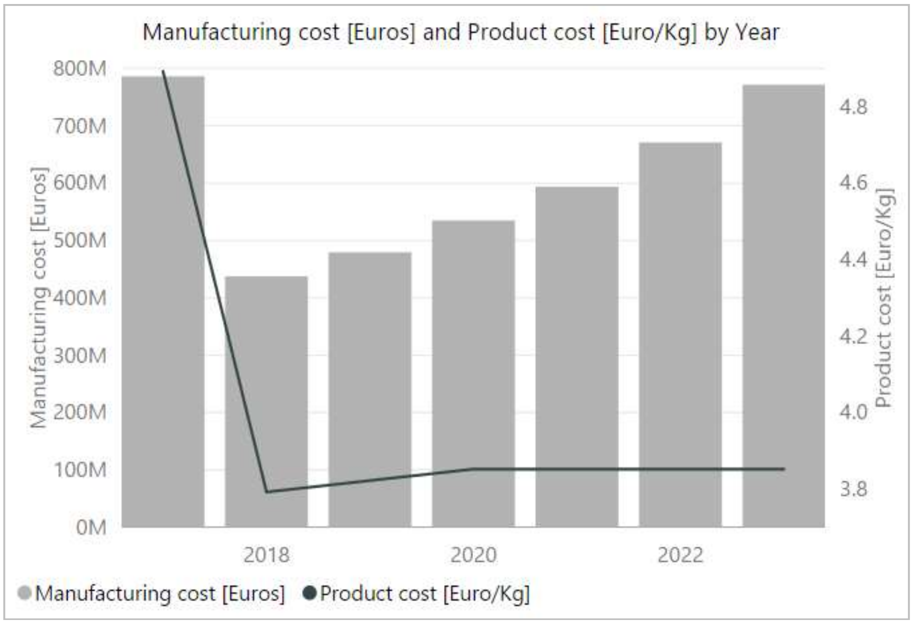


Figure 8-8 Evolution of the Manufacturing cost and the product cost.
Source: Own preparation

Although the factory relocation impacts significantly on the product cost, it increases the delivery cost, due to the increase in kilometres travelled in the primary transport. Figure 8-9 shows a comparison of both scenarios on the Italy factory – DC (the baseline) and the Poland factory – DC (the proposal) routes; the primary transportation cost increases overall by 23% due to the increase in the kilometres travelled.

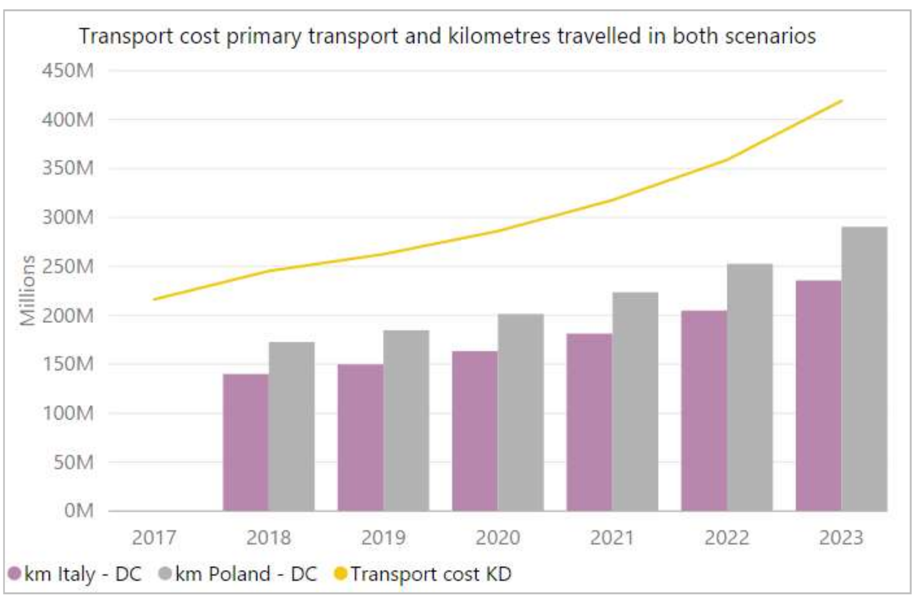


Figure 8-9 Transport cost primary transport and kilometres travelled in both scenarios.
Source: Own preparation

The carbon reduction plan starts with a 2017 baseline of 5.68 [Kg CO_2e/Kg sold] and proposes a gradual reduction over 7 years. The carbon rate in 2023 is 3.96 Kg CO_2e/Kg, reaching the target of 30% in seven years. See Figure 8-10.

Figure 8-10 Evolution of the carbon efficiency.
Source: Own preparation

8.4.2.2 THE CARBON REDUCTION ROAD MAP

The carbon reduction roadmap was based on a horizon plan which was determined as 7 years, with an overall target of 30%. The model has selected a set of carbon reduction alternatives for every year in order to reach the annual carbon target.

The proposed initiatives are related to network design, energy management in both manufacturing and warehousing, alternative fuels and multimodal in the logistics sector. These initiatives aim to achieve targets yearly and reach the main goal in 2023, see Figure 8-11.

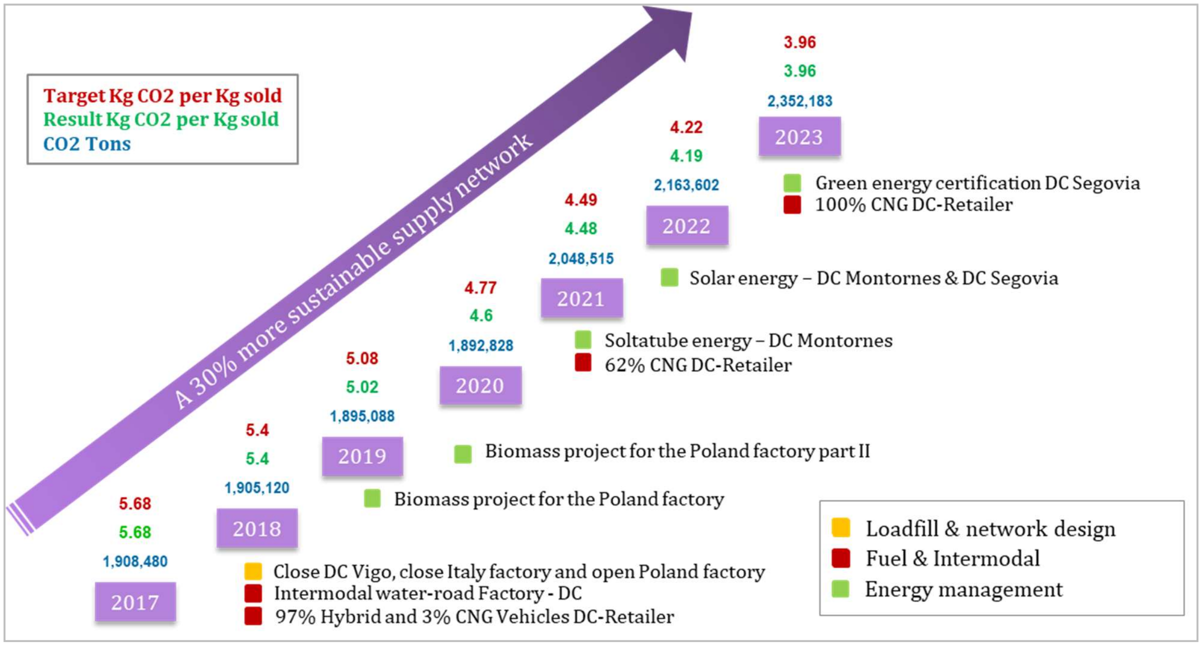


Figure 8-11 Carbon reduction roadmap: Europe case.
Source: Own preparation

Table 8-3 shows the total carbon saving per year and where the carbon emission savings are located. The plan proposes a total reduction of 754,696 CO_2e tonnes until 2023, with the manufacturing projects being the highest contributors (42%) and energy management in warehouses (39%) in second position.

Table 8-3 Carbon Reduction Plan 1 - 7 Year: Europe Case.
Source: Own preparation

Carbon Reduction Plan 1 - 7 Year

Year	Sales volume	Emission	KPI2	Total CO2 saving identified
FY	tons.sold	tonnes.sold	kgCO2/Kg sold	tonnes CO2
2017	336,000	1,908,480	5.68	
2018	352,800	1,905,120	5.40	(98,784)
2019	377,496	1,895,088	5.02	(143,390)
2020	411,471	1,892,829	4.60	(172,818)
2021	456,732	2,048,515	4.49	(52,525)
2022	516,108	2,163,603	4.19	(151,219)
2023	593,524	2,352,183	3.96	(135,960)

			CO2 reductions allocation					
Year	Area	Project description	Factory energy	Intermodal	WH energy	Network design	Technology / fuels	Sources
2018	Overall	Close DC Vigo, Italy factory and open Poland				- 48,940		
2018	Logistics	Intermodal water-road Factory - DC		- 37,653				
2018	Logistics	97% Hybrid and 3% CNG Vehicles DC-					- 12,191	
2019	Manufacturing	Biomass energy - part I	- 143,390					
2020	Manufacturing	Biomass energy - part II	- 172,818					
2021	Warehousing	Solatube energy - DC Montornes			- 47,801			
2021	Logistics	62% CNG DC-Retailer					- 4,724	
2022	Warehousing	Solar energy – DC Montornes & Segovia			- 151,219			
2023	Logistics	100% CNG DC-Retailer					- 42,082	
2023	Warehousing	Green energy certification DC Segovia			- 93,878			
			- 316,208	- 37,653	- 292,898	- 48,940	- 58,997	-

For 2019 and 2020, the sustainable sources of biomass represent a significant opportunity to increase the use of renewable energy in manufacturing. CHP - 40% Biomass and 60% Coal- saves 14% of the carbon emission in 2019; the second part of the CHP project – 100% Biomass - saves 18% more in 2020. The proposal consists in implementing biomass boilers which are fed with waste wood from the furniture industry and old pallets. However, the factory should only use sustainable biomass from genuine "end of life" sources that do not compete with food crops. See the impact of this project on the carbon manufacturing performance in Figure 8-12.

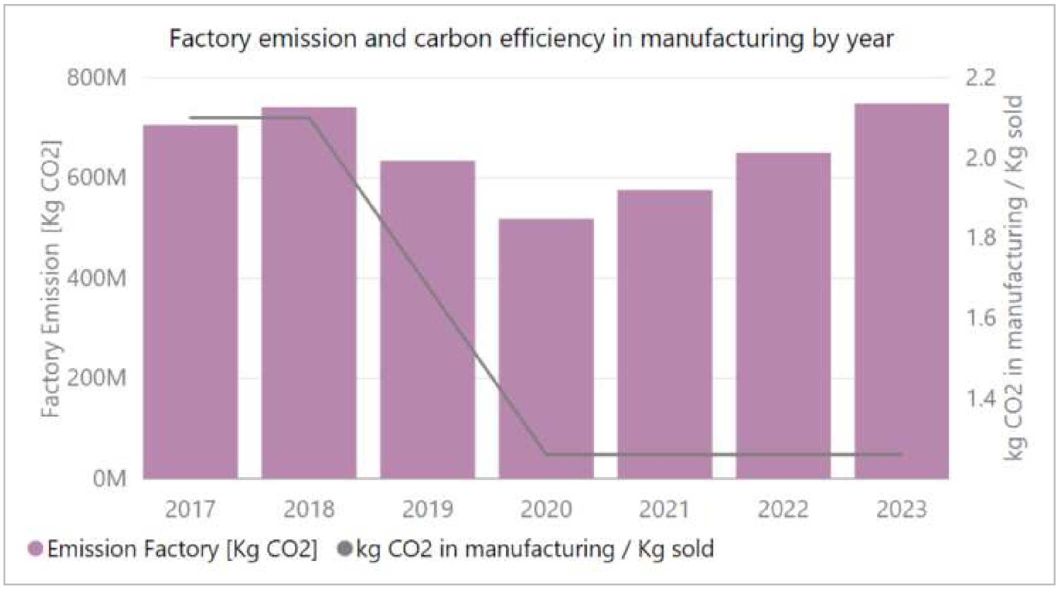


Figure 8-12 Evolution of manufacturing carbon emission and efficiency.
Source: Own preparation

For the period between 2021 and 2023 the warehouse carbon emission strategy is based on the following projects:

- **Solatube energy 2021:** In the Montornès DC nearly 900 Solatube systems would be installed to provide daylight for around 150,000 square meters.
- **Solar energy 2022:** A solar energy system would be installed in both distribution centers, Montornès and Segovia . The system consists of 4,000W solar panels mounted on the warehouse rooftop. This system will power 62 20W LED lights . The system has the capacity to support all the electrical requirements and would reduce the carbon emission by 38% in each Distribution Center.
- **Green energy certification 2023:** The Segovia DC is in negotiations with the energy supplier, the forecast for 2023 is to buy all the energy from renewable sources. It will transform the Segovia DC into a zero-emission distribution center and will reduce the carbon emission in warehouses by more than 36% .

The impact of this implementation is shown in Figure 8-13. Between 2017 and 2023 there is a 52% reduction of CO_2e tonnes and 73% in terms of Kg CO_2e in Warehouses per Kg sold.

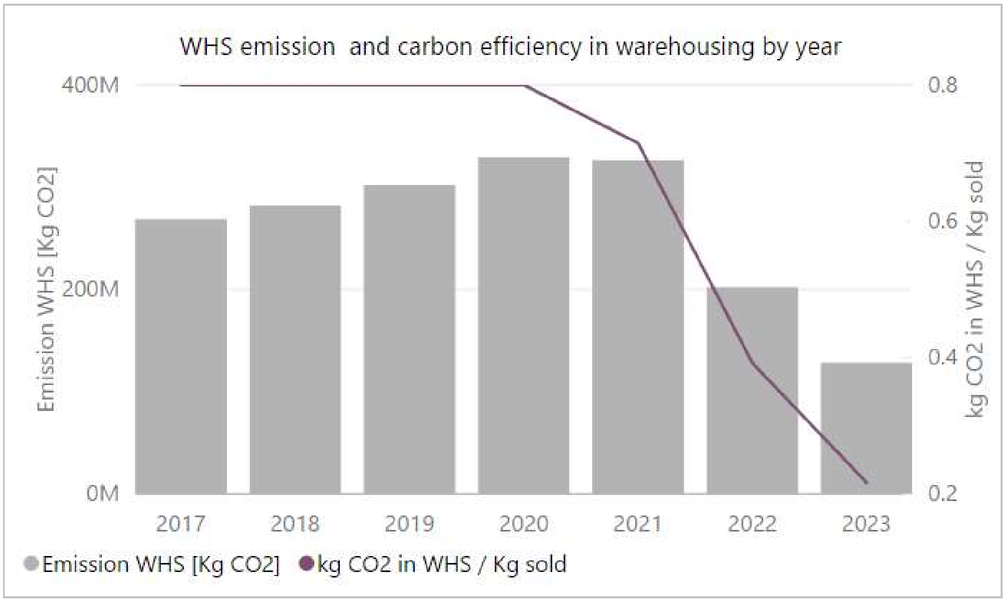


Figure 8-13 Evolution of warehousing carbon emission and efficiency.
Source: Own preparation

The logistics strategy is based on the intermodal utilization and alternative fuels, representing an overall 96,650 CO_2 tonnes; see Table 8-3. All these initiatives produce a reduction of 56% in the average amount of carbon Kg emitted in moving 1,000 Kg of freight a distance of 1 Km; this is a good indicator for understanding the carbon emission efficiency in eliminating the effect of the volume variations; see Figure 8-14.

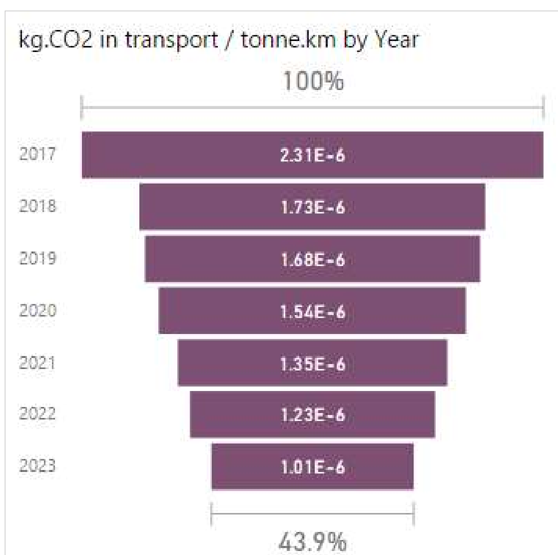


Figure 8-14 Evolution of the Kg CO_2e per tonne km.
Source: Own preparation

Another relevant indicator that evaluates the transport performance is the Kg CO_2 per Km travelled; as Figure 8-15 shows, the overall result of this indicator (which includes inbound transport, primary and secondary transport) has a very good progress, reducing Kg CO_2 per Km by 23% until 2023.

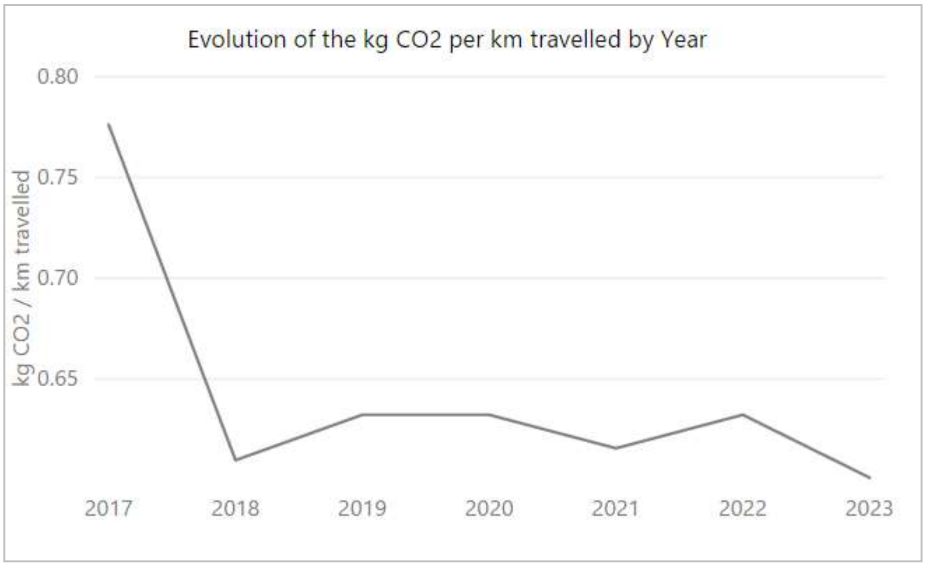


Figure 8-15 Evolution of the kg CO_2e per km travelled.
Source: Own preparation

Table 8-4 shows the transport indicators trend, all of which demonstrate a significant year by year improvement. The secondary transport shows a substantial change starting in 2018 and decreases even more in later years, with something similar occurring in primary transport. Both behaviours are related to alternative fuel and intermodal utilization.

Table 8-4 Transport indicators.
Source: Own preparation

Year	kg CO_2e/ km travelled	Kg CO_2e Transport / load	Kg CO_2e Transport / Kg sold	Kg CO_2e transport DR/Kg sold	Kg CO_2e transport KD/Kg sold
2017	0.776	1306	1.368	0.201	0.540
2018	0.610	1039	1.088	0.157	0.407
2019	0.632	1077	1.128	0.197	0.407
2020	0.632	1077	1.128	0.197	0.407
2021	0.616	1049	1.098	0.167	0.408
2022	0.632	1077	1.128	0.197	0.407
2023	0.601	1026	1.074	0.134	0.417

The secondary transport strategy recommends that 97% vehicles in 2018 should be Hybrid , which is a good plan considering that the electric and hybrid market has great potential for growth and will be one of the key tranport strategies in Europe.

Implementation of the CNG vehicles, starting in 2021, is fully aligned with the European Commission (Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014, on the deployment of alternative fuels infrastructure) which aims to have CNG stations in densely populated areas by 2020 and an energy price equivalent to gasoline; to facilitate comparison, see Figure 8-16.

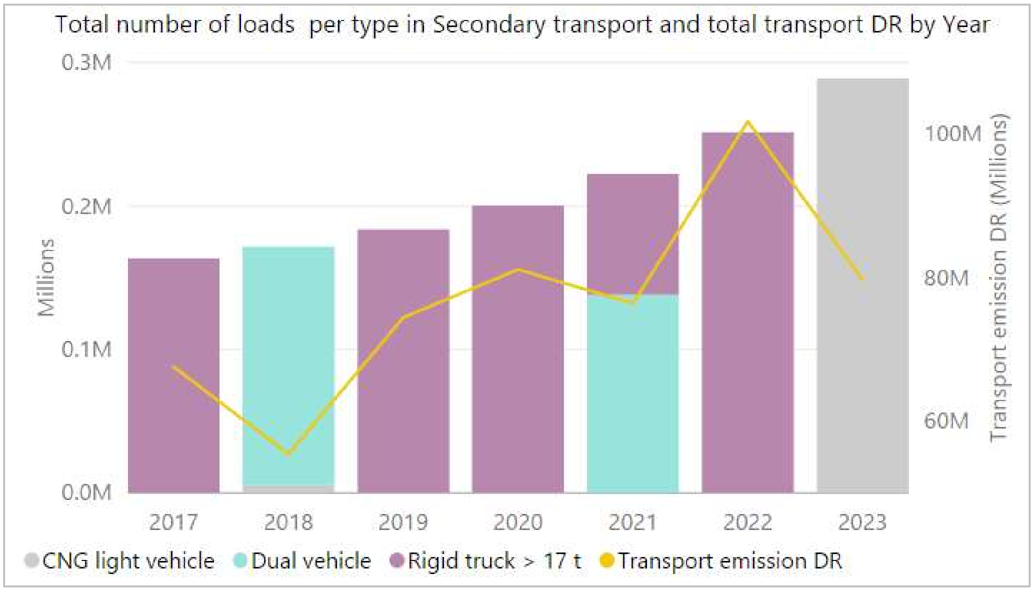


Figure 8-16 Different vehicles used in the secondary transport and transport emission.
Source: Own preparation

The primary transport strategy would change in 2018, along with the network redesign, see Figure 8-17. The route selected for this purpose would be Katowice factory – Port of Genova – Port of Barcelona - Montornès DC; a total of 1,588 km, with 42% of the transport by water. Katowice factory – Segovia DC would follow the same route, then using road transport between Port of Barcelona – Segovia DC; a total of 2,206 km, with 30% of the transport by water.

This initiative would save 34% of the carbon emission per load. Nevertheless, even if water transport seems to be the best ecological decision it can change depending on key parameters like the distance and the type of ship; this is explained in detail in the section below.

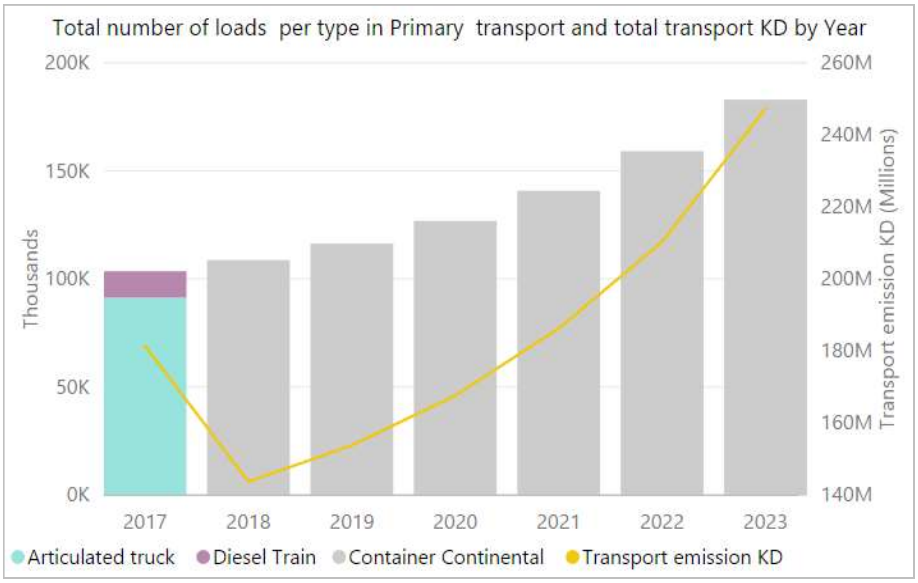


Figure 8-17 Intermodal used in the primary transport.
Source: Own preparation

8.4.2.3 THE IMPACT OF THE CARBON PLAN ON THE CARBON PERFORMANCE

Table 8-5 shows what the results will be in terms of efficiencies in the four main areas of the company. There are outstanding results in the manufacturing carbon emission performance, reducing the carbon impact by 40% until 2023.

Table 8-5 Evolution of the carbon emission and key indicators.
Source: Own preparation

	Manufacturing		Warehousing		Transportation		Procurement	
Year	**Emission Factory [Tonnes CO2]**	**kg CO2 in manufacturing / Kg sold**	**Emission WHS [Tonnes CO2]**	**kg CO2 in WHS / Kg sold**	**Emission Transport [Tonnes CO2]**	**kg CO2 Transport / Kg sold**	**Emission RM [Tonnes CO2]**	**kg CO2 RM / Kg sold**
2017	705,600	2.1	268,800	0.8	459,564	1.4	474,516	1.4
2018	740,880	2.1	282,240	0.8	383,758	1.1	498,242	1.4
2019	634,193	1.7	301,997	0.8	425,779	1.1	533,119	1.4
2020	518,453	1.3	329,177	0.8	464,100	1.1	581,099	1.4
2021	575,483	1.3	326,368	0.7	501,643	1.1	645,020	1.4
2022	650,296	1.3	202,314	0.4	582,120	1.1	728,873	1.4
2023	747,840	1.3	128,603	0.2	637,536	1.1	838,204	1.4

The evolution of carbon emission in the warehousing sector is also remarkable, as it would reduce efficiency by 73% until 2023. What is more, the carbon emission in terms of tonnes would be reduced by 52%. Along the same lines, the improvements in transportation are notable, reducing the carbon efficency by 21%.

Figure 8-18 shows the baseline in terms of the carbon performance for four categories. Meanwhile, Figure 8-19 shows how these indicators will look in 2023, in order to compare the results of these indicators in the event of roadmap implementation.

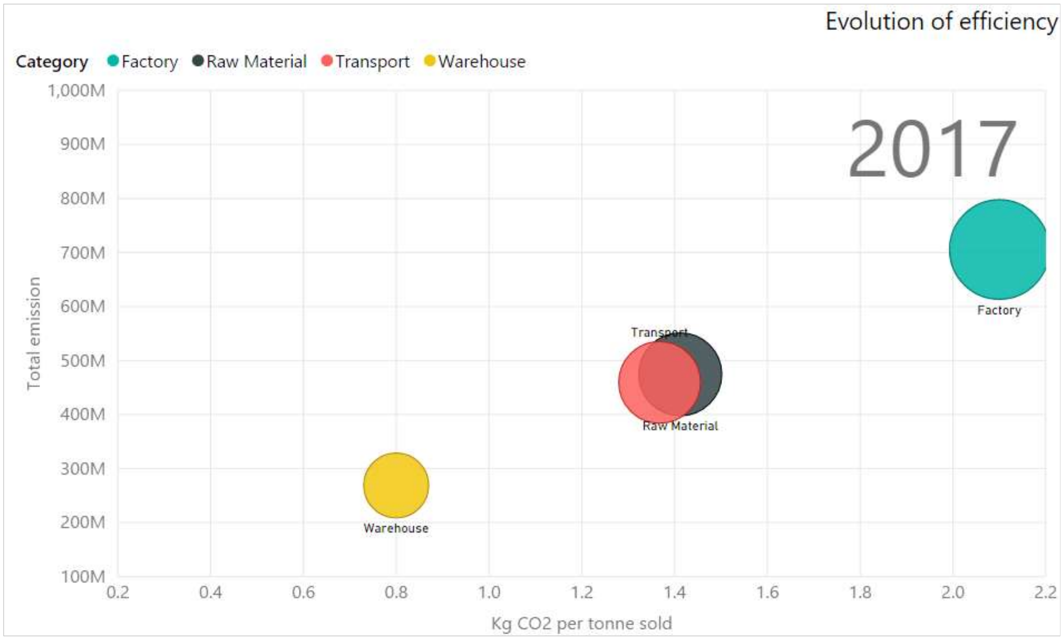


Figure 8-18 Initial situation of the carbon performance per category.
Source: Own preparation

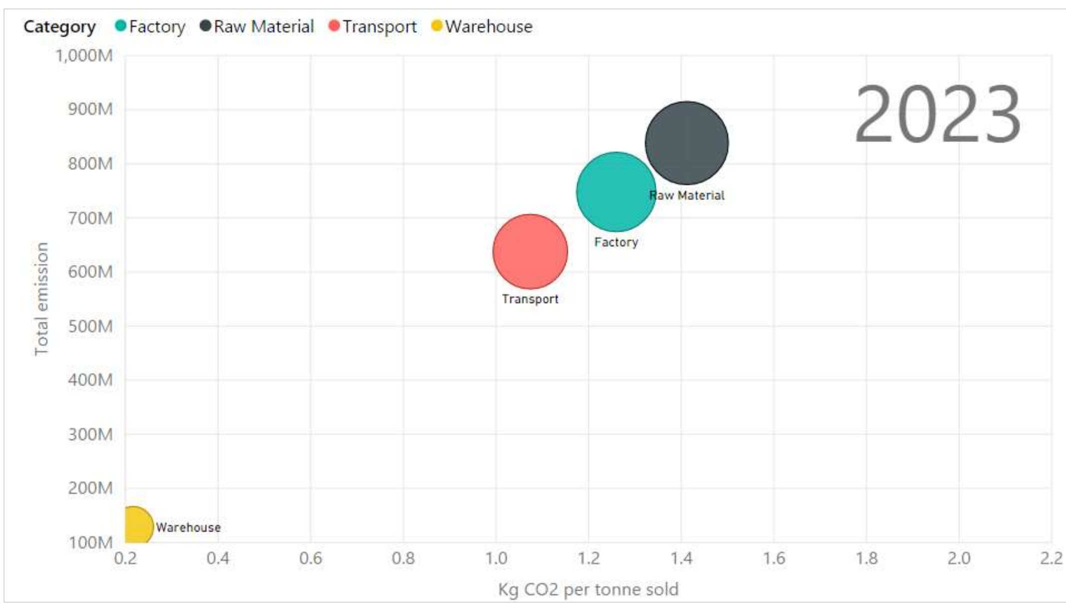


Figure 8-19 Carbon performance per category in the latest year of the plan.
Source: Own preparation

8.4.3 SENSITIVITY ANALYSIS OF THE LOGISTICS CASE

Sustainability in Logistics is commonly related with intermodal transportation and usually water or rail transport is associated with lower carbon emission. The sensitivity analysis explained in this section aims to use the results of this case study to evaluate whether this assumption is correct or not.

The total carbon emission depends on key drivers such as distance, number of loads, loadfill and the emission factor. The emission factor also depends on the type of transport (road, water, rail), the fuel technology (diesel, CNG, electric, hybrid, etc.) and the loadfill. It means that it is important to assess each driver for every case; an overall assessment is needed, not only for the distance or the emission factor.

The solution of the model proposes network changes in 2018, where the factory located in Mussolente (Italy) is closed and a new factory in Katowice (Poland) is commissioned For the primary transport three options were evaluated; 1) road transport mode using a > 33t/Diesel Articulated truck with a total carbon emission of 2,026 Kg CO_2e/load at 2,006 km; 2) rail-road transport mode with 1,631 Kg CO_2e/load at 2,920 km and 3) intermodal water-road with emission of 980 Kg CO_2e/load at 1,588 km, and see Table 8-6.

Table 8-6 Three options for the route Katowice Factory - Montornès DC.
Source: Own preparation

Option	Origin	Destination	Distance [Km]	Total Distance [Km]	Transport mode	%	Emission factor [Kg CO2/ Km]	Average Emission factor [Kg CO2/ Km]	Total emission [Kg CO2]
#1	Katowice	Montornes	2006	2006	Road	100%	1.01	1.01	2026
#2	Katowice	Montornes	2336	2920	Rail	80%	0.45	0.56	1631
		Terminals*	584		Road	20%	1.01		
#3	Katowice	Genova	889	1588	Road	56%	1.01	0.69	1089
	Genova	Barcelona	663		Water	42%	0.27		
	Barcelona	Montornes	36		Road	2%	1.01		

The solution of the model chooses the third option (Katowice Factory – Genova Port – Barcelona Port – Montornès DC) which is the most appropriate in terms of total carbon emission per load. Nonetheless, looking at the average emission factor itself, the most convenient would be the second option (rail-road).

The selected option uses water transportation for just 42% of the route; in order to increase the water percentage another option (#4) can be assessed, which would be Katowice Factory – Gdansk Port – Barcelona Port – Montornès DC. This new route uses 82% of water transport, has a better emission factor (0.4 Kg CO_2e/Km) and covers 5,647 km; nevertheless, due to the total distance this option (#4), produces 2,281 Kg CO_2e per trip, which is even worse than the road transport mode (#1) with 2,026 Kg CO_2e per trip. See Table 8-7 and Figure 8-20.

Table 8-7 The best option comparing other intermodal routes.
Source: Own preparation

Option	Origin	Destination	Distance [Km]	Total Distance [Km]	Transport mode	%	Emission factor [Kg CO2/ Km]	Average Emission factor [Kg CO2/ Km]	Total emission [Kg CO2]
#1	Katowice	Montornes	2006	2006	Road	100%	1.01	1.01	2026
	Katowice	Genova	889		Road	56%	1.01		
#3	Genova	Barcelona	663	1588	Water	42%	0.27	0.69	1089
	Barcelona	Montornes	36		Road	2%	1.01		
	Katowice	Gdansk	1001		Road	18%	1.01		
#4	Gdansk	Barcelona	4610	5647	Water	82%	0.27	0.40	2281
	Barcelona	Montornes	36		Road	1%	1.01		

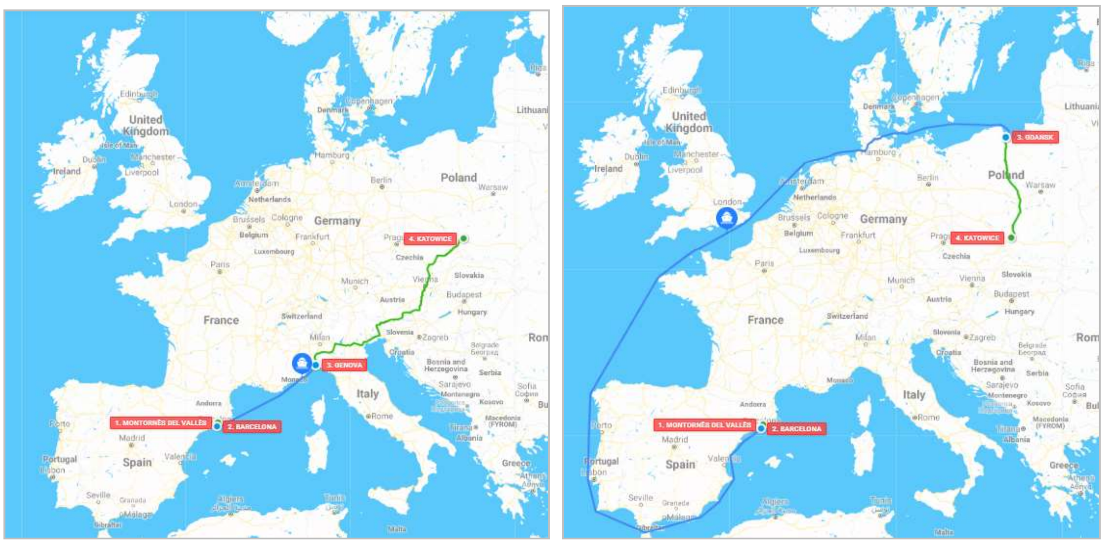


Figure 8-20 Comparison of two water transport routes.
Source: Own preparation

Therefore, the carbon emission depends on the combination of several factors and needs to be analysed case by case. This means that the most appropriate transport mode in some situations i.e. Katowice Factory – Genova Port – Barcelona Port – Montornès DC, can be the worst in others, e.g. Katowice Factory – Gdansk Port – Barcelona Port – Montornès DC.

In Figure 8-21 the distance impact on carbon emission is illustrated by means of a comparison of road transport with other transport modes. Diesel trains emit less carbon emission than road transport, but if the distance using diesel trains exceeds 83% of Km travelled, then the road transport emits less. Additionally, if the road vehicles were Hybrid the inflection point would be 46%. The same occurs with the water mode; if the distance increases 198%, the road transport becomes more sustainable.

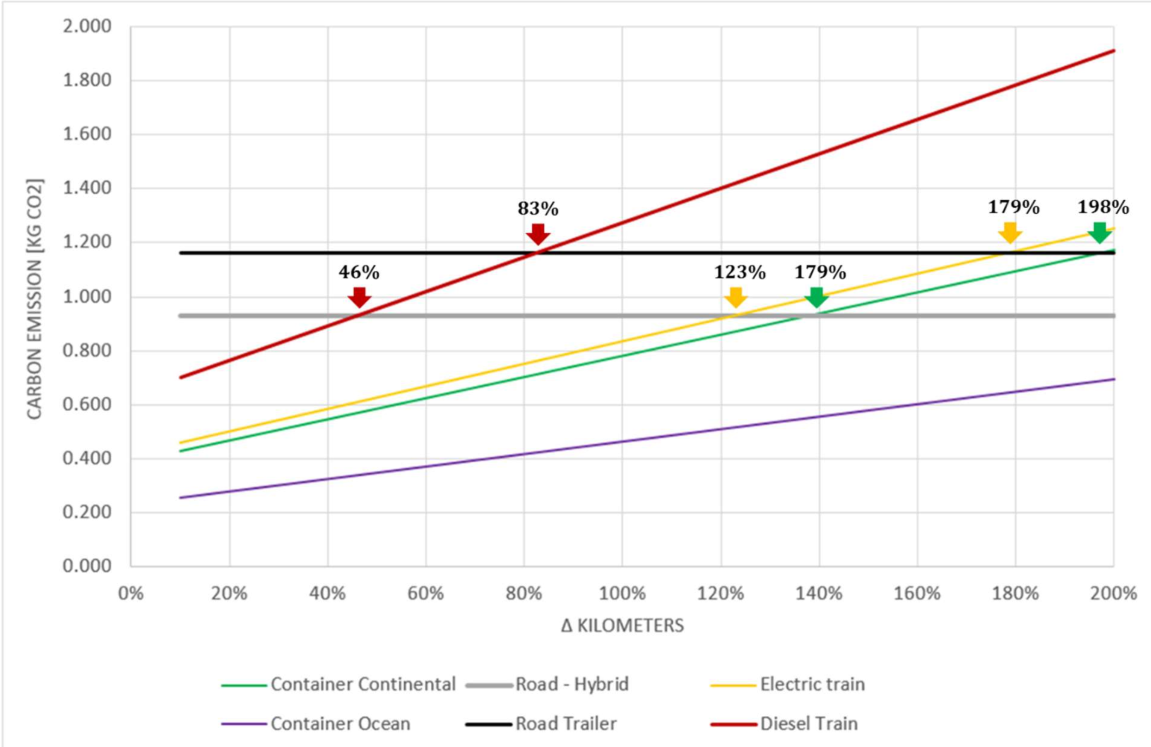


Figure 8-21 Impact of distance on the carbon emission.
Source: Own preparation

Intermodal rail or water have fewer carbon emission factors, but distance is directly proportional to the emission amount and, in some cases, is even more important than the transport mode. Another key driver to consider is the truck loadfill; in Figure 8-22, the carbon emission is analysed according to truck loadfill, the analysis being made for 100 loads.

The first important thing to mention regarding the loadfill impact is the overall effect on the number of loads; for instance, if the company needs to transport 2,200 tonnes at 100% loadfill it will need 100 loads, but if the loadfill level is 80% it will need 120 loads to transport the same product quantity.

The loadfill on the Katowice Factory – Montornès DC route is 70% and consequently the best transport mode, from a carbon emission perspective, would be the intermodal water-road. If the loadfill is lower the best option would be the train. Therefore the routing decisions depend on the changes in loadfill.

Figure 8-22 illustrates the impact of the loadfill on the total carbon emission. The route from Katowice Factory to Montornès DC is analysed considering differences in terms of distance, transport mode and type of fuel. Figure 8-22 shows the total carbon emission for the five scenarios; when the loadfill is low, road transport is the least efficient transport mode; the next is road using hybrid fuel, and the third is a route using water intermodal transport. The train is the most efficient. A special case is shown by the green line, using water transport over very long distances.

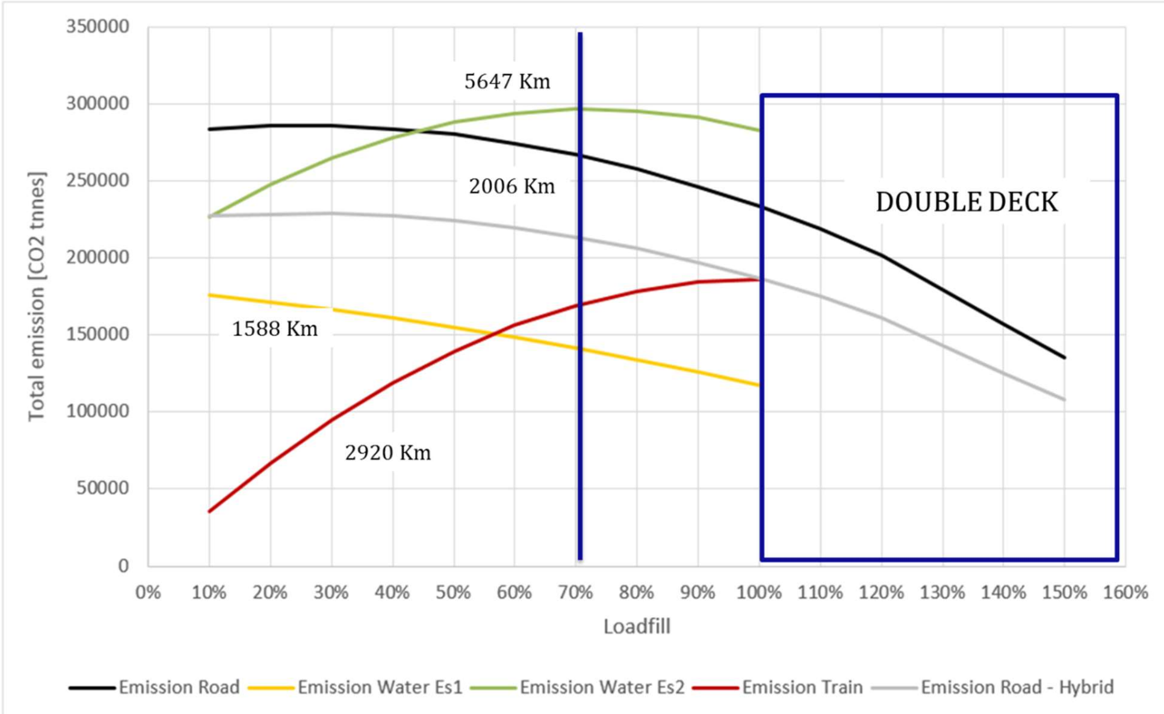


Figure 8-22 Carbon emission depends on the loadfill, fuel technology and double deck.
Source: Own preparation

Using the same example, the least efficient at 70% loadfill is the long distance water transport (green line). This shows that water transport is a good option but if it is considerably longer than road, it stops being efficient. At this level water is more efficient than train (in the shorter distance scenario).

Moreover, the double-decker truck can also be another viable option for reducing the number of trucks on the road and, consequently, carbon emission. The use of double decker trucks could be more sustainable than using intermodal train-road; even more so if the trucks use alternative fuels such as Hybrid (Electric – Diesel). The impact of double decker trucks is shown in the right section of Figure 8-22. For the sample route, if the loadfill level in the double-decker truck is around 140% it is better than using intermodal train; if the road transport uses both double deck and hybrid fuel, this alternative is even better than intermodal water.

8.4.4 Implementation and tracking

The implementation of the carbon reduction methodology has completed the first two steps: the corporate carbon strategy and the strategic financial planning. The company uses the methodology to choose the alternatives that are to be part of the strategy; introduction of the supply chain redesign has already been approved and the implementation is under evaluation.

Recommendations for the implementation and tracking:

- At the moment of choosing the transport mode it is important to consider all of the potential options according to their distance. Also, some other potential routes, like the Mediterranean Corridor, should be considered when forecasting the future.
- Before deciding on a biomass boiler, the factory should always ask three questions: "Do we need a boiler?", "Where do we need heat?" and "How much heat do we need?". Some technologies such as solar PV, solar thermal and geothermal can also be an appropriate solution.
- When using the Biomass combustion process it is important to ensure the supply of raw materials.

8.5 CONCLUSIONS

- The model comes up with a new design which allows the company to have a sustainable growth, doubling its net profit, whilst the carbon emission impact is reduced by 30%.
- The proposed network design, helps the company to reduce its product cost. The solution of the model is to move the Italian factory to Poland, and reduce the number of warehouses from three to two.
- To achieve the carbon emission targets, the solution of the model proposes a plan based on the use of multimodal (water and rail), alternative fuels (CNG and hybrid vehicles), Biomass in manufacturing and projects for improving energy consumption in warehouses.
- The current idea that 'water and rail transport is greener' is challenged in the sensitivity analysis. The study shows that some parameters, such as distance and/or loadfill, can be even more important than changes in the transport mode.

CHAPTER 9

Case Study III: A multinational company operating in the United States in the metal sector

9.1 INTRODUCTION

This is a case study that illustrates the scope effects and how they may have a significant impact on the total carbon emission. The scope definition is a key part of the carbon reduction strategy and reflects what the company is trying to do with the results. The case study proposed here may lead to different scenarios where the scope is analysed.

Since the scope's definition determines what the companies are trying to do, different scenarios can be envisaged. For instance, if only the transportation between Distribution Centers and Retailers is considered, both distance and the agreements with the 3PLs will be key factors.

If the scope is extended to the factories, the energy management can be even more important than the transportation aspect. Again, the agreements with the factory, e.g. joint venture agreements, would be significant. Furthermore, if the scope includes raw materials, the supplier's location would be important; it would also be essential to know if the supplier works according to sustainable policies.

The following case study is based on a global manufacturing company in the metallurgical sector. The company has a set of retailers located in the United States, which is the principal market; these retailers are physically based in Texas, Virginia, Florida, Colorado, New York, Chicago and California; see Figure 9-1.

Figure 9-1 Customer distribution within the country.
Source: Own preparation

Nowadays, the company has a factory in Michigan (United States) and they concentrate the network distribution in a unique Distribution Center (DC) which is located in California; see the map of Figure 9-2 for a better understanding of the current situation. For transportation, this manufacturing company uses third-party providers to move goods through the network, using a combination of rail and truck for movements between the factory and the DC.

Figure 9-2 Supply Network. Current situation.
Source: Own preparation

The Michigan factory has a group of suppliers that service the factories, but the most relevant are located in China, Turkey and Ukraine. The flows between the suppliers and the Michigan factory use water transportation and the company tries to avoid air transport for any flow. From the Michigan factory to local points in the United States they use a 3PL that handles all the deliverables.

9.1.1 THE COMPANY'S PROFILE IN THE UNITED STATES

The company is one of the most important companies in the sector, with several years of presence in United States. Besides, it is a leader in Research and Development, running several Research and Development Centers in the United States, where it has an extensive intellectual and physical resource for innovation.

The company has agreements with major retailers to provide showrooms where they can market their products to end consumers. This is where they can jointly create some promotions with their retailers. The strategy has been very successful and many of their retail sales come from these specialty retail locations, where they have much more co-management of the market.

A very extensive safety program is part of the firm's continuous improvement and it is one of the safest companies in the world, despite the aluminum industry's inherent risks. Regarding the business sector, the Political Economy Research Institute ranks the company as one of the 20 companies with the highest GHG emissions in the United States in this sector.

Nevertheless, the company set out the respective targets in the "2020 Framework for Sustainability", which includes creating new and sustainable solutions, supporting the regions in which the company operates, implementing new technologies for reducing carbon emissions in the manufacturing stage (using modern coating technology) and verifying the sustainability of its products with the emphasis on recyclability.

9.1.2 THE COUNTRY CONTEXT

Nowadays the United States enjoys stable economy and it is, according to the International Monetary Fund (IMF), one of the world's largest economies by nominal GDP as well as the most influential financial market. As reported by the World Bank, the United States' GDP grew by an average of 1.7% from 2000 to 2014 and Industry represents 19.4% of the country's GDP .

According to the Institute for Supply Management the manufacturing sector in the United States contributes more than $ 2 trillion to the economy and the industry is expanding, meaning there is an increase in output. The aluminum industry produced around 1.7 million metric tons of primary aluminum in 2014. In the same year, the United States was the world's 6th largest producer of primary aluminum.

9.1.2.1 CARBON EMISSION CONTEXT IN UNITED STATES

The U.S. Environmental Protection Agency (EPA) has confirmed that the total greenhouse gas emissions in the U.S. have increased by 7.4% from 1990 to 2014. Figure 9-3 illustrates the GHG evolution in absolute values. Carbon dioxide represents 80.9% of the total amount, whilst CH_4 is 10.6%, N_2O is 5.9% and HFCs, PFCs, SF_6 and NF_3 is 2.6%.

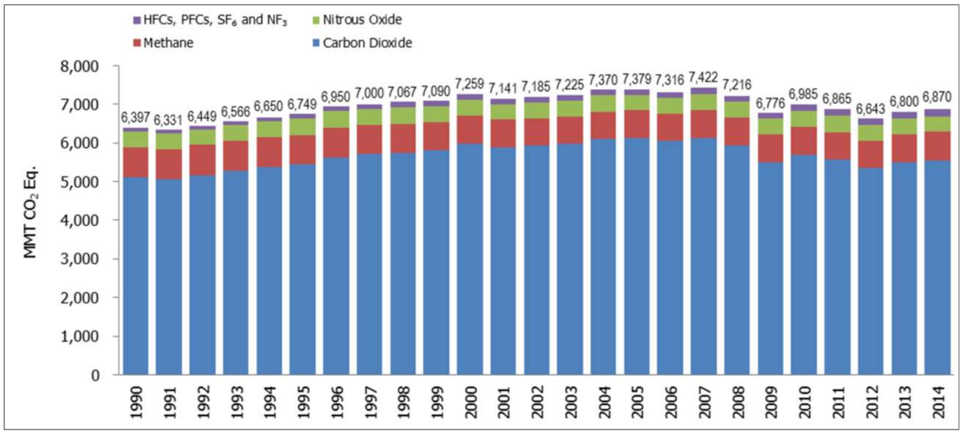


Figure 9-3 U.S. Greenhouse Gas emission by Gas (MMT CO2 Eq.).
Source: U.S. Environmental Protection Agency

A remarkable result in recent years is the reduction of Perfluorocarbon emissions from aluminum production, which has decreased by 88.2% (18.9 MMT CO_2e) from 1990 to 2014. This reduction is due both to reductions in domestic aluminum production and to actions taken by aluminum smelting companies to reduce the frequency and duration of anode impacts.

The commitment to the Kyoto protocol goals has been a very controversial topic in the United States in recent years. Whilst the George W. Bush administration decided not to support the Kyoto Protocol polices, the Obama administration, together with various state, local and regional bodies, has tried to adopt some Kyoto Protocol targets. Nonetheless, the Donald Trump administration has confirmed that United States is going to quit the Paris climate agreement.

However, some states such as California have voted to extend laws to cut carbon emissions by 2030. Indeed, California's legislators have taken this decision after the Trump administration communicated its position regarding the Paris climate change accord. The aim of California is to cut greenhouse gases by 40% from 1990 levels by 2030. Despite the central administration's position regarding the Kyoto agreements, California is one of the leading states in mitigating climate change.

9.1.2.2 THE TRANSPORT SYSTEM IN THE UNITED STATES

In the United States most cargo is carried by trucks (60%), followed by pipelines (18%), rail (10%), ship (8%), and air (0.01%). In terms of ton-miles (freight tonnage multiplied by distance traveled), the road transport represents 40.24% (2011 estimates by the Bureau of Transportation Statistics) whilst rail transport represents 26.13%; the difference in percentage is due to the extreme efficiency of trains.

The road transportation carried out by trucks, semi-trucks, box trucks or dump trucks is responsible for most of the freight movement over land, and is essential for the manufacturing, construction and warehousing industry. On the other hand, the transportation sector is responsible for two-thirds of the United States' oil consumption. In order to reduce this impact, the US government has been implementing several policies to promote the use of biofuels, for example the production of dual-fuel vehicles and the sale of E85 ethanol fuel.

Rail transport is widely used in the United States; according to the Association of American Railroads the railway system is the world's busiest and it is one of the main axes of logistics movement in the country. Figure 9-4 shows the freight flows by transport mode; the highway flows in red, the railroad in green and the waterway flows in blue.

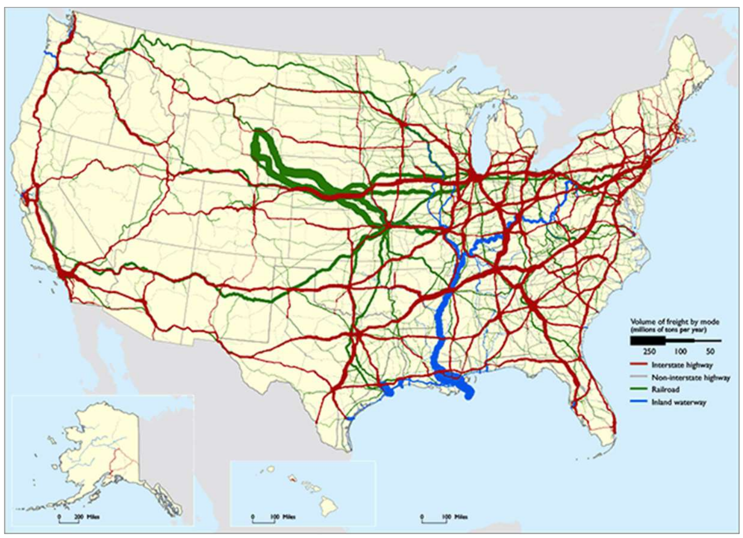


Figure 9-4 Freight Flows by Highway, Railroad, and Waterway: 2011.
Source: Highways: U.S. Department of Transportation, Rail: Based on Surface Transportation Board, Annual Carload Waybill; Inland Waterways: U.S. Army Corps of Engineers, Institute for Water Resources

The most important seaports in the United States are New York City on the east coast, Los Angeles on the west coast and New Orleans and Houston on the Gulf coast. The water transport in the United States is also used for internal movements, which use shipping channels via the Great Lakes Waterway, the Saint Lawrence Seaway and the Mississippi River System. Water transportation is widely used for internal cargo transport; 41,009 Km are navigable in the United States, and 47% of that total is used in commerce.

9.2 WHY IS THE COMPANY INTERESTED IN A CARBON REDUCTION PLAN?

The company under review wants to have a carbon reduction plan for three reasons:

- The competitors have started reporting emissions in the Carbon Disclosure Project. So, the company feels some threat from their competitors.
- This company was trying to promote itself as being more environmentally responsible and they are also publically traded. They also felt under pressure because they were attracting attention from the media and questions from customers. The company is evaluating the possibility of participating in some voluntary reduction programs. As the company has facilities in California, they would like to participate in a voluntary program there.

9.3 TO BE SITUATION

The company is evaluating the possibility of changing the current network design. They want to consider the following points:

- Most of the most important raw materials come from suppliers located in Shanghai, which is why the company is reviewing the possibility of opening another factory in China or in the Pacific Islands.
- Another option under review, is to open another factory based in Germany, due to the technology needed for the manufacturing. The Germany factory would be a joint venture with a German company, where the U.S company would own 50 percent of those assets in Germany.
- In order to be closer to the retailers, they are also looking into the possibility of opening another two Distribution Centers, one in Georgia and the other in Texas.
- Regarding sustainability, the impact of the travel distances should be evaluated, as well as the type of energy used by country. For instance, in the Pacific Islands these factories are mostly powered by wind and geothermal power; in Europe, mostly by a combination of nuclear power and wind energy; and in the United States mostly by fossil fuel, coal and other less renewable sources.

9.4 METHODOLOGY IMPLEMENTATION

The carbon reduction methodology is applied for the company under review. The methodology starts with the creation of the corporate carbon strategy and the alignment with the financial planning strategy. Application of both steps is explained in the first section. Then, the proposed model is validated using the information of case study III.

The information for the corporate carbon strategy and the strategic financial planning was provided by the company, including the set of alternatives for carbon reduction. In this case the methodology helps the company, by giving instructions of the steps needed. On the other hand, the business optimization section is the proposal of the methodology in terms of strategy.

9.4.1 CORPORATE CARBON STRATEGY AND STRATEGIC FINANCIAL PLANNING

Following the carbon reduction methodology, the corporate carbon strategy is applied to the metallurgical company. In the first step, the company defines the type of greenhouse gases that the company emits as a part of its process; in this case the aluminium process involves mainly CO_2 and PFCs. Next the scope is defined from an ownership perspective, including suppliers and excluding corporate offices.

The third step defines 2018 as the baseline year and estimates 4,619,467 CO_2e tonnes and an efficiency of 11.5 Kg CO_2e/Kg sold in this first year. The collecting data process beyond the scope of this explanation. The plan has an estimated duration of 7 years and a carbon target of 30% in terms of carbon efficiency.

As a part of the strategic financial planning the carbon tax equivalent, which is 50M€, is estimated for the baseline year. This is an important step in giving the leadership team a financial perspective of the environmental impact. At this stage some financial data, such as the scope definition, are validated and the sales forecast is provided. Table 9-1 summarizes the steps explained above.

Table 9-1 Steps 1,2,3,4 of the Carbon strategy and Strategic Financial Planning.
Case Study III. Source: Own preparation

	Step of the CCS	Corporate Carbon Strategy	Strategic Financial Planning
1.	Type of emission	Mainly Carbon dioxide (CO_2) and Perfluorocarbon (PFC)	Carbon tax equivalent: 50M€
2.	Scope definition	Ownership perspective Including Suppliers Excluding Corporate Offices	Finance confirm the scope in terms of ownership
3.	Carbon emission baseline	Year: 2018 forecast KPI1: 4,619,467 CO_2 tons KPI2: 11.5 Kg CO_2e/Kg sold	Sales: 400,000 tons forecast 2018
4.	Carbon reduction goals	Plan: 7 years Year1: 12; Year2: 11.04; Year3: 9.94; Year4: 9.34; Year5: 8.78; Year6: 8.25; Year7: 7.76 KPI2: 30% reduction in terms of Kg CO_2e/Kg sold	Sales: 706,575 tons forecast 2024

An exploration of the alternatives is made in step 5, with Table 9-2 summing up the set selected by group. The criteria used for the carbon alternatives selection were based on three factors: (1) cost of the alternative, (2) carbon emission impact in terms of CO_2 tonnes and (3) marketing effect.

Table 9-2 Step 5: Alternatives selected. Case study III

Level	Manufacturing	Warehousing	Transportation		Supplier
			DR	KD - NK	
1	Do nothing	Do nothing	Articulated truck	Articulated truck	China
2	CHP system	Daylight Harvesting	Dual vehicle	Rail-Road	Turkey
3	Biomass	Personal Tuning	CNG	Water-Road	Ukraine
4		Daylight Solatube			

In addition to the carbon reduction alternatives shown in Table 9-2, the company is also considering the supply design alternatives explained in the previous section. Briefly, the supply design alternatives in manufacturing are: 1) keep the U.S. factory; 2) keep the U.S. factory and commission a new one in Japan and/or 3) keep the U.S. factory and commission a new factory in Germany. The warehousing alternatives are: 1) work with the existing warehouse located in California; 2) add a new warehouse in Georgia and/or 3) add a new warehouse in Texas.

The manufacturing alternatives selected include:

- Alternative 1: SHP systems in the U.S. factory – coal energy. In the event of commissioning the factory in Germany or Japan: SHP system in the Germany factory – wind energy; the SHP system in the Japan factory – a combination of nuclear power and wind energy.
- Alternative 2: CHP system for all the proposed factories.
- Alternative 3: Biomass for all the proposed factories.

The warehousing alternatives are:

- Alternative 1: Current warehouse in California with conventional light with LEDs.
- Alternative 2: Daylight Harvesting for all the proposed warehouses.
- Alternative 3: Personal Tuning for all the proposed warehouses.
- Alternative 4: Daylight Solatube for all the proposed warehouses.

The transportation alternatives for the secondary transport between Distribution Center and Retailers are:

- Alternative 1: Use the conventional 33tn articulated truck.
- Alternative 2: Use Hybrid 33tn vehicles.
- Alternative 3: Use CNG 33tn trucks.

The transportation alternatives for the primary transport between Factories - Distribution Centers and Supplier and Factories (see Appendix F for available routes) are:

- Alternative 1: Use the conventional 33tn articulated truck. Not available for inbound transport.
- Alternative 2: Use the intermodal Rail-Road. Not available for inbound transport.
- Alternative 3: Use the intermodal Water-Road.

The alternatives for buying raw materials are limited to three options. In this case every alternative is a supplier located in a different country.

- Alternative 1: Supplier located in China.
- Alternative 2: Supplier located in Turkey.
- Alternative 3: Supplier located in Ukraine.

9.4.2 BUSINESS OPTIMIZATION USING MATHEMATICAL PROGRAMMING

The generic mathematical model proposed in chapter 5 is used at this stage. The alternatives listed in the previous section, as well as the data shown in Appendix F, were the input of the model. The model was run on a computer with a processor Core i7 2.59 GHz and16 GB of RAM using IBM ILOG CPLEX Optimization Studio in Version 12.6.0.0.; it has 53,912 variables; 9,412 constraints and it is solved in 7 minutes.

In the following sections, the results of the model optimization are shown. First, the proposed supply network is described, highlighting the economic savings and the carbon emission impact. Next the carbon reduction roadmap is explained, as well as giving details of the selected alternatives.

9.4.2.1 THE SUPPLY NETWORK PROPOSAL

According to the solution of the model, the Net Profit (NP) after taxes is maximized and increases by 86% with respect to the base year. Figure 9-5 shows how both financial parameters (Net Profit and Gross Profit) are simultaneously increased until 2020; starting in 2021 the Net profit increases even more with respect to the Gross Profit, which demonstrates the impact of the optimization.

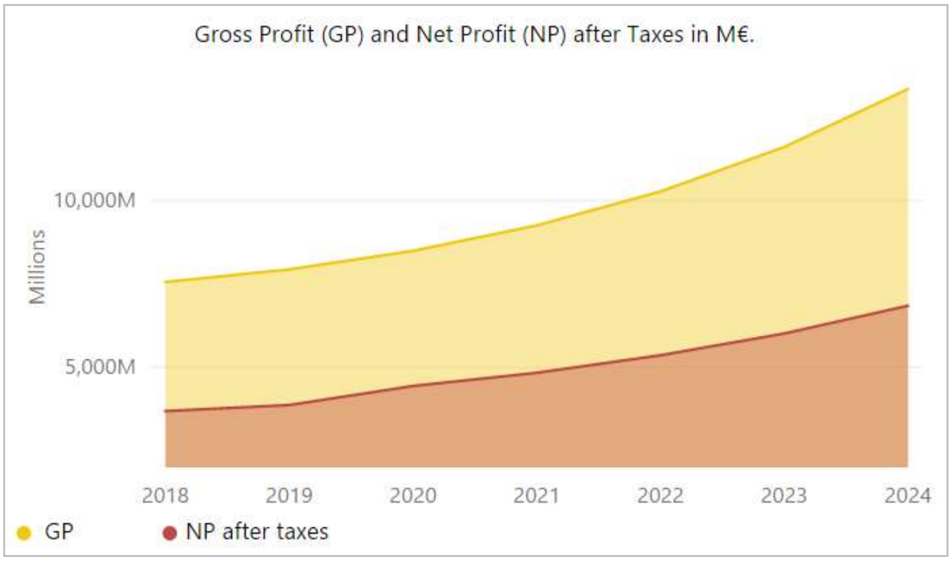


Figure 9-5 Gross Profit (GP) and Net Profit (NP) after Taxes in M€.
Source: Own preparation

Figure 9-6 shows the sales volume and the carbon reduction efficiency forecast until 2024. The figure shows how the reduction efficiency decreases yearly, whilst the sales volume increases. The rate of Kg CO_2e per Kg sold decreases by 13% in the first year, due to the supply network re-design, then between 2020 and 2024 there is a progressive and constant decrease. Both Figure 9-5 and Figure 9-6 demonstrate the compliance of the two main requirements of the model (economic and environmental).

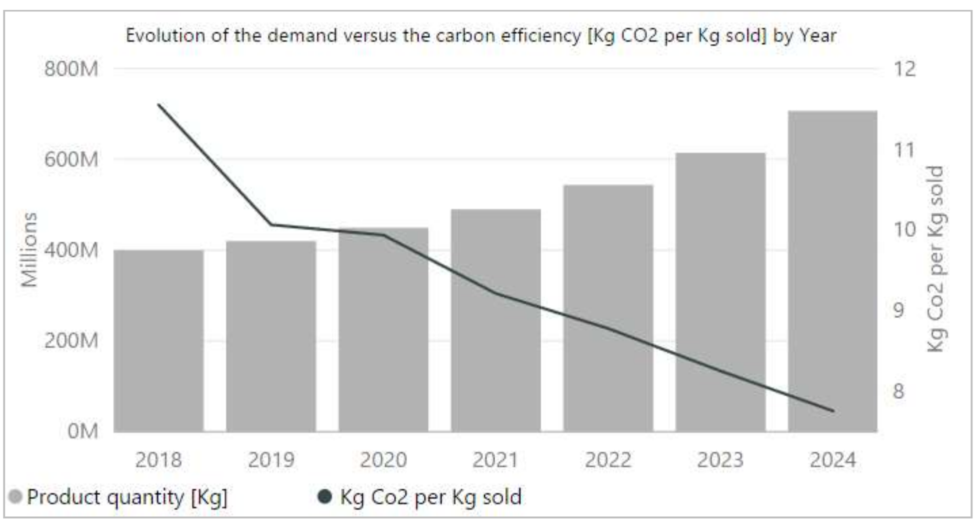


Figure 9-6 Evolution of the demand versus the carbon efficiency [Kg CO_2 per Kg sold].
Source: Own preparation

The solution proposed by the model to achieve these results is to open two Distribution Centers, one in Georgia and another one in Texas, which brings the company closer to customer demand and will also avoid problems with the lead-time. On the other hand, there is a proposal for commissioning a new factory based in Germany. Figure 9-7 shows the new supply network proposed.

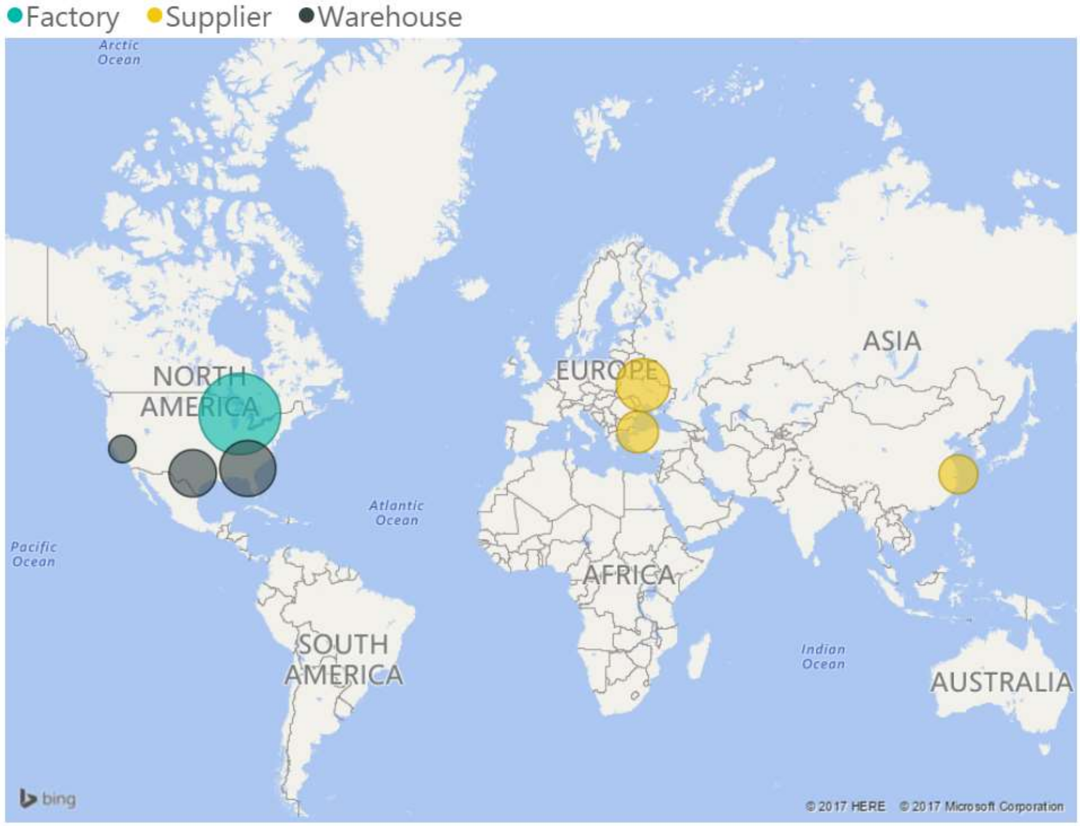


Figure 9-7 The supply network proposal.
Source: Own preparation

The following two figures show the evolution of the costs. The transportation costs associated with the operation (warehousing and manufacturing), as well as the raw material costs, are increasing gradually as a result of sales volume. Nevertheless, the transport cost DR, which represents the transportation cost between distribution centers and retailers, is reduced significantly due to the two new warehouses being closer to the customer demand. Along the same lines, the transportation cost between the factory and warehouses is reduced because of the changes in the network.

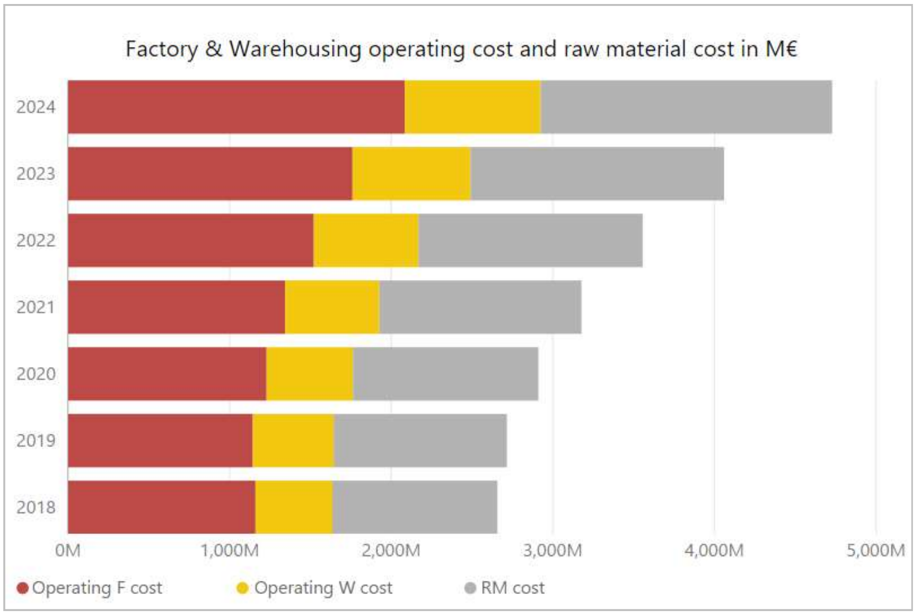


Figure 9-8 Factory & Warehousing operating cost and raw material cost in M€.
Source: Own preparation

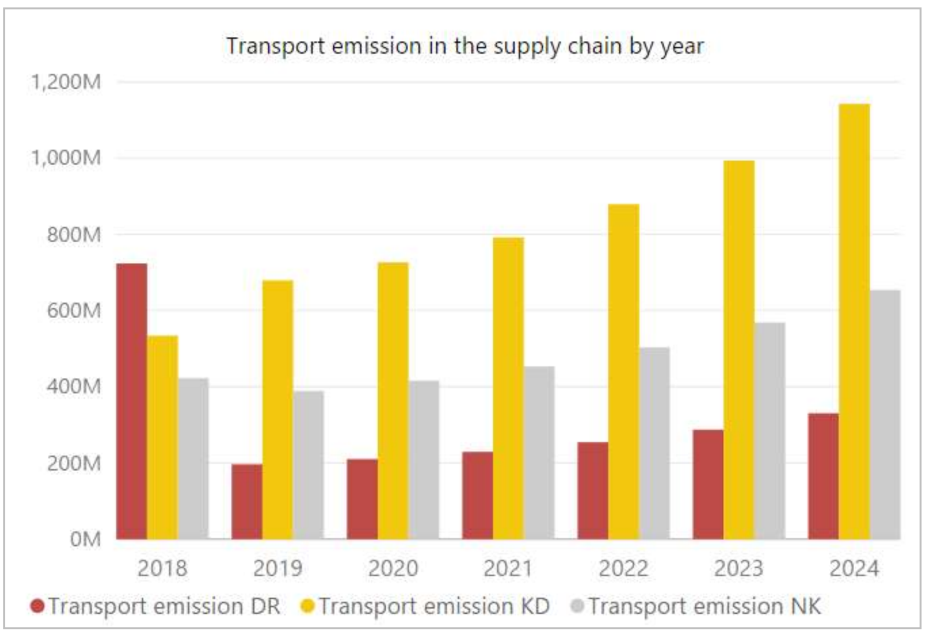


Figure 9-9 Transport emission in the supply chain by year.
Source: Own preparation

The carbon reduction plan proposed here includes an improvement of 32.8% in the carbon efficiency (Kg CO_2e per Kg sold) until 2024, see Figure 9-10. One of the biggest decisions that impact on the result is the commissioning of a new factory in Germany in 2019. At an environmental level the model chose the new factory in Germany due to the type of energy resources used in that region and also because it is convenient at an economic level.

As Figure 9-10 shows, the Kg CO_2e per Kg sold rate starts in 2018 at 11.55 and 7 years later this rate is 7.76. This reduction is significant, considering that the forecast sales volume increases by 77% in the same period.

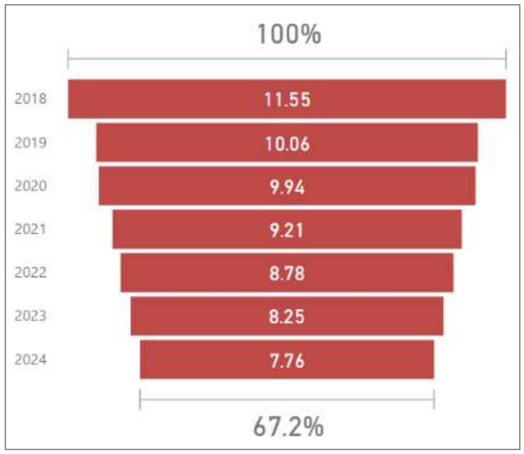


Figure 9-10 Carbon efficiency (Kg CO_2e per Kg sold) until 2024.
Source: Own preparation

9.4.2.2 THE CARBON REDUCTION ROAD MAP

In this section the carbon reduction plan for the company is shown, and it includes a complete list of actions for every year; see Figure 9-11 and Table 9-3. For the horizon plan, the model has selected several carbon reduction alternatives each year in order to reach the annual carbon target; Figure 9-11 shows the fulfilment of the yearly target in the horizon plan.

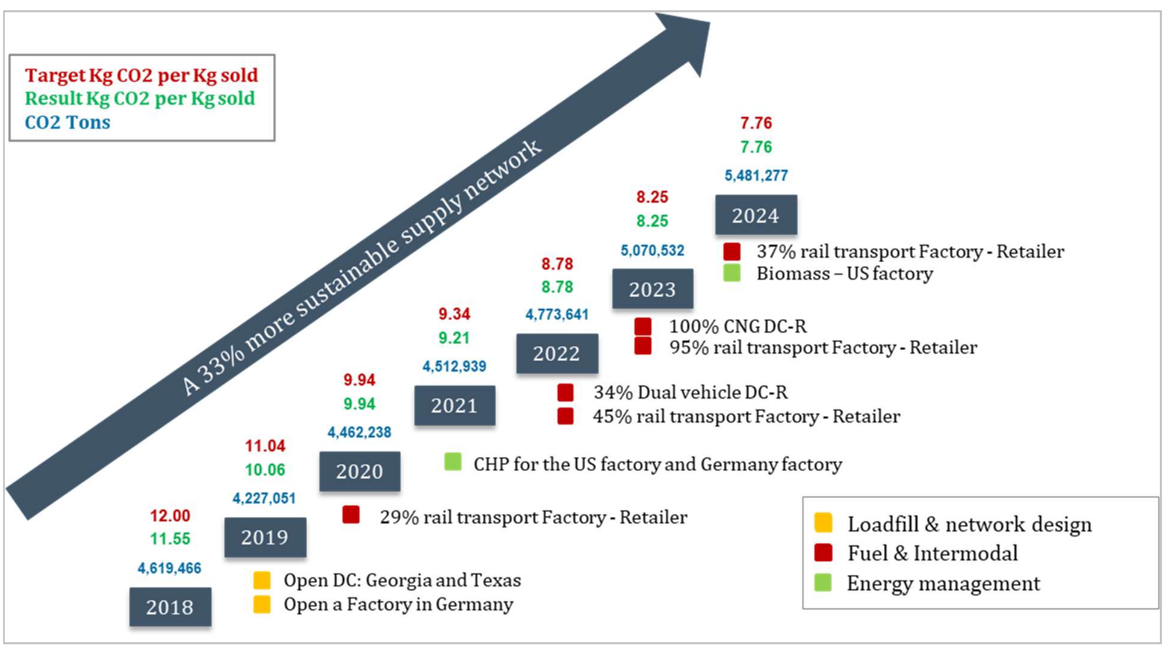


Figure 9-11 Carbon Reduction Roadmap: Case Study III.
Source: Own preparation

Table 9-3 Carbon Reduction Plan 1 - 7 Year: Case study III.
Source: Own preparation

Carbon Reduction Plan 1 - 7 Year

Year	Sales volume	Emission	KPI2	Total CO2 saving identified
FY	tons.sold	tonnes.sold	kgCO2/Kg sold	tonnes CO2
2018	400,000	4,619,467	11.55	
2019	420,000	4,227,051	10.06	**(623,389)**
2020	449,400	4,465,238	9.94	**(57,706)**
2021	489,846	4,512,939	9.21	**(354,171)**
2022	543,729	4,773,642	8.78	**(235,721)**
2023	614,414	5,070,562	8.25	**(323,653)**
2024	706,576	5,481,278	7.76	**(349,869)**

				CO2 reductions allocation					
Year	Project / Action	Area	Project description	Factory energy	Intermodal	WH energy	Network design	Technology / fuels	Sustainable Source
2019	Network re-design	Overall	Open 2 DCs and Open a Factory				- 623,389		
2020	Rail transport	Logistics	29% rail Factroy - Retail		- 57,706				
2021	Cogenaration	Manufacturing	German Factoy and US Factory	- 354,171					
2022	Dual Program	Logistics	34% Dual vehicle DC-Retailer					- 129,646	
2022	Rail transport	Logistics	45% rail Factroy - Retail		- 106,074				
2023	CNG Program	Logistics	100% CNG DC-Retailer					- 203,901	
2023	Rail transport	Logistics	95% rail Factory - Retail		- 119,752				
2024	Cogenaration	Manufacturing	Biomass Germany	- 349,869					

Figure 9-11 shows the key alternatives that need to be implemented to achieve the carbon targets. The strategy is based on the supply redesign in 2019, the implementation of energy management projects in factories, the use of alternative fuels and alternative transport modes. Table 9-3 illustrates the carbon emission impact of each alternative.

Two major projects are part of the carbon emission reduction strategy in the manufacturing area; one of them is associated with the network design and the other with improvements in the current factory in Michigan (U.S.). Below is a description of both:

- ***CHP for both factories in Germany:*** As part of the network re-design, the solution of the model recommends commissioning a new factory in 2020; this decision is proposed because some operations, from an environmental and carbon footprint perspective, are better in Europe than in the United States.
  Nevertheless, there is still room for improvement, and the results of the model recommend the implementation of CHP in both factories in 2021. This improvement will represent a 20% (2021 versus 2020) carbon reduction in the manufacturing process. Under this condition the factory in Germany would combine biomethane with its existing renewable energy, and consequently it would be closer to achieving the Zero Carbon challenge.
  In the case of the United States, it would be a Coal-fuelled CHP. The reality in the U.S. is that coal is less expensive and more abundant than most other energy options, although coal-fired factories are the least recommended in terms of carbon emission.
- ***Biomass for the U.S. factory:*** The proposal for the U.S. factory is to implement the current CHP but with 50% Biomass, 50% Coal. The aim of a Biomass project is to convert the waste from their own operations into energy. This kind of technology works through an anaerobic digester – a type of plant that processes biodegradable waste and turns it into fuel.

This plan is based on the possibility of making some agreements with a renewable energy company, which will provide a certified supply of biomethane (also known as biogas) to power the site's heating. Due to the implementation of this project, in 2024 the company would reduce the manufacturing carbon emission by 59% with respect to the previous year.

Figure 9-12 shows how the previous projects impact on the carbon emission performance (kg CO_2 per Kg told), starting in 2019 with the commissioning of the German factory, the implementation the CHP project in both factories in 2021 and the improvement of the U.S. factory in 2024.

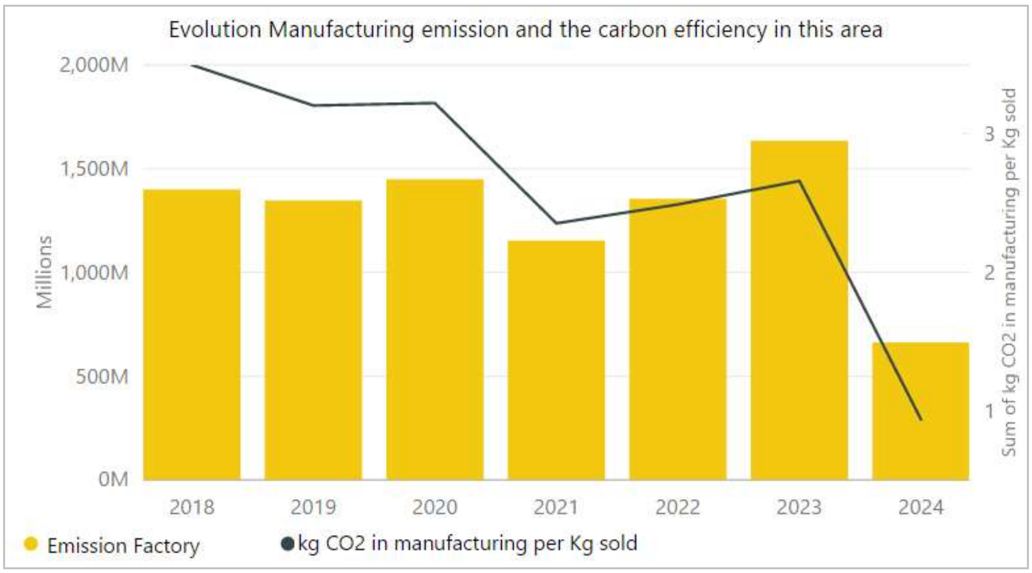


Figure 9-12 Evolution Manufacturing emission and the carbon efficiency in this area.
Source: Own preparation

The implementation of transportation projects also has a significant carbon impact, especially between 2018 - 2019, in both secondary transport (35%) and primary transport (45%). As Figure 9-13 shows, this reduction is mainly a consequence of the network re-design, which has an impact on the kilometres travelled, reporting 31% less in primary transport and 45% in secondary transport.

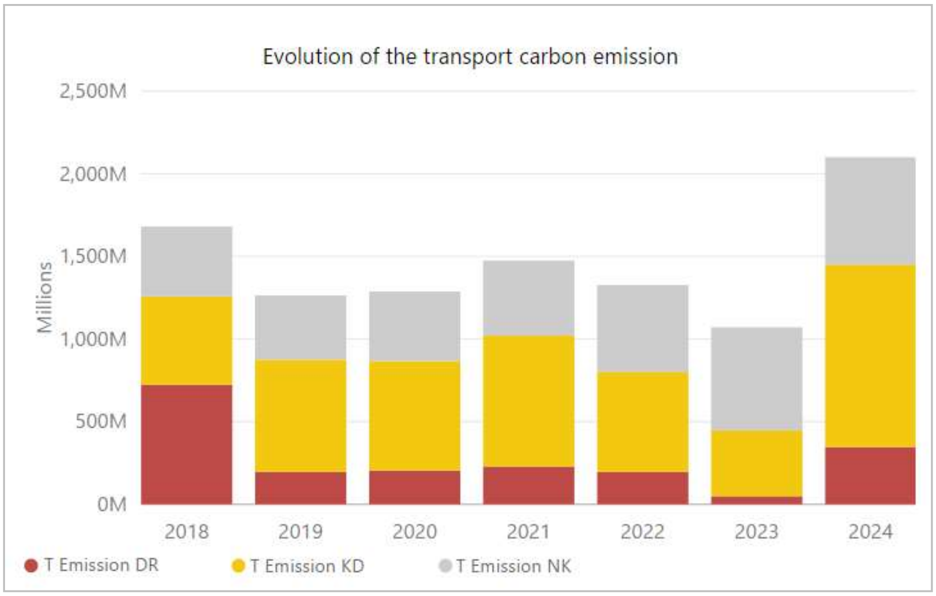


Figure 9-13 Evolution of the transport carbon emission.
Source: Own preparation

The plan for secondary transport is to use road transport, using alternative fuels such as dual vehicle (Compressed Natural Gas (CNG) and Diesel) and CNG. Figure 9-14 shows 2022 implementing both dual and CNG and 2023 using 100% CNG. The solution of the model proposes the use of alternative fuels in 2022 and 2023 because in 2024 the model selects manufacturing alternatives to be implemented. Nevertheless, if the company makes good long-term agreements with local companies, the recommendation would be to keep these initiatives as long as possible.

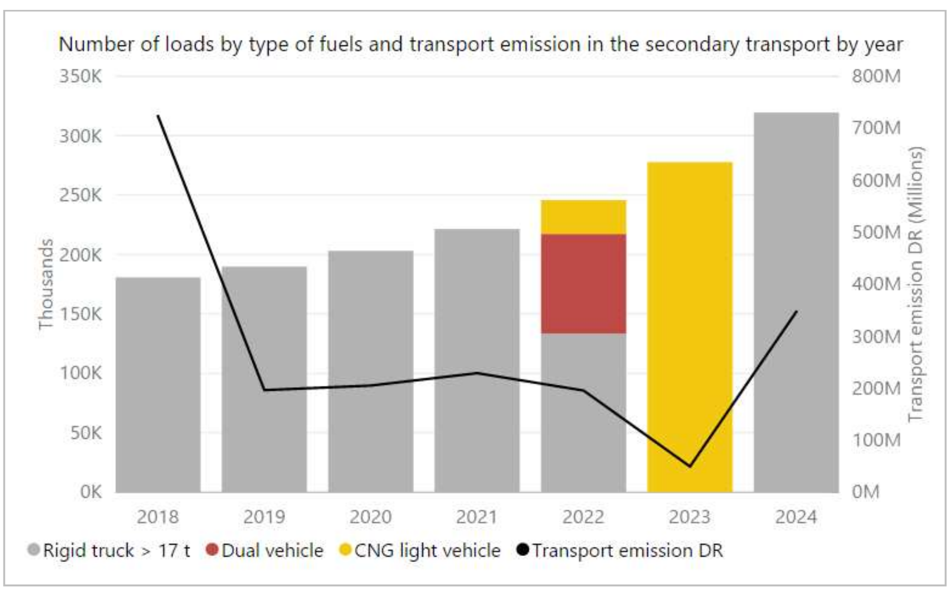


Figure 9-14 Number of loads by type of fuels and transport emission in the secondary transport.
Source: Own preparation

Regarding the primary transport, the company starts to use water-road transport in 2019 as a part of the movements from Germany. Then in 2020 the solution of the model is to use intermodal rail -road transport for the lines between the U.S. factory and warehouses. The effect of those decisions is shown in Figure 9-15.

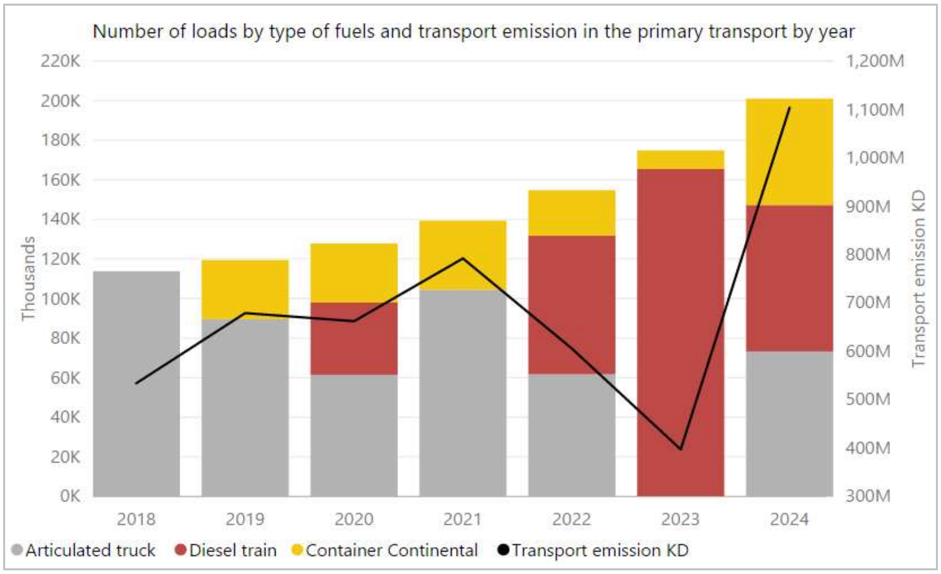


Figure 9-15 Number of loads by type of fuels and transport emission in the primary transport.
Source: Own preparation

9.4.3 A SENSITIVITY ANALYSIS OF THE CARBON FOOTPRINT SCOPE

Depending on the scope used and what the company wants to do with the results, the strategy may come up with different answers. If only the transportation level is considered, distance will be the most relevant parameter. However, if the manufacturing emissions are included, the emphasis may be different. If the carbon emission from suppliers is taken into account, this can cause even further changes.

Once the carbon emission forecast has been made, it is possible to look at all the elements of the supply chain; understand the agreements with all the facilities, the movements, port operations and international shipments. In this section a sensitivity analysis was carried out, based on the 2020 carbon forecast of this case study. Four options are illustrated: 1) the extended scope; 2) the product ownership perspective; 3) GHG scope 1 & 2 and 4) conservative regulatory.

9.4.3.1 OPTION 1: THE EXTENDED SCOPE

The particularity of this first scope is that the emissions from suppliers, as well as the associated transportation, are included. Therefore, this scope includes the carbon emissions of: Distribution Centersand transportation from Distribution Center to Retailer; factories and transportation from Factory to Distribution Center; suppliers and transportation from Supplier to Factory. Normally, the corporate offices should also be included, but the analysis proposed here only takes into account those facilities which are part of the supply network.

This scope is useful in creating a holistic strategy, where decisions related to suppliers are included. The total emission estimated under this scope is 4.5 Million of CO_2e, with most coming from the U.S. factory (21%) and Suppliers (35%); see Table 9-4. The model explained above includes this extended scope.

Table 9-4 Carbon emission split under the extended scope.
Source: Own preparation

Extended	CO2 Emission 2020 [tonne]	Percentage
DC California	7,550	0.2%
DC Georgia	100,587	2%
DC Texas	42,862	1%
Transport DC - Retailer	205,240	5%
US Factory	920,653	21%
German Factory	528,320	12%
Transport Factory - DC	662,185	15%
Supplier China	401,651	9%
Supplier Turkey	417,268	9%
Supplier Ukraine	759,486	17%
Transport Supplier - Factory	419,437	9%
Total	**4,465,238**	**100%**

9.4.3.2 Option 2: The product ownership perspective

The scope of the product ownership perspective includes the total carbon emission, but it does not consider either the emission from suppliers or the transportation from suppliers to factories. Also, in this case a major part of the carbon emission is generated in the factories in the U.S. (37%) and Germany (21%), see Table 9-5.

Table 9-5 Carbon emission split under the product ownership perspective. Initial.
Source: Own preparation

Product ownership perspective	CO2 Emission 2020 [tonne]	Percentage
DC California	7,550	0.3%
DC Georgia	100,587	4%
DC Texas	42,862	2%
Transport DC - Retailer	205,240	8%
US Factory	920,653	37%
German Factory	528,320	21%
Transport Factory - DC	662,185	27%
Total	**2,467,397**	**100%**

9.4.3.3 OPTION 3: GHG SCOPE 1 & SCOPE 2

The GHG Scope 1 and 2 mean that only the company's own carbon emission is taken into account. This is the case of transportation; if it is excluded as a part of the 3PL agreement it is somebody else's. In terms of the factory, the GHG protocol specifies that if the factory is of joint ownership, only the company-owned share of emissions will be considered. Table 9-6 shows how the new split would be; the total is 1.3 million of CO_2 emission, 35% less than the option 1.

Table 9-6 Carbon emission split under GHG Scope 1 & Scope 2.
Source: Own preparation

GHG Scope 1 & Scope 2	**CO2 Emission 2020 [tonne]**	**Percentage**
DC California	7,550	0.6%
DC Georgia	100,587	8%
DC Texas	42,862	3%
US Factory	920,653	69%
German Factory (50%)	264,160	20%
Total	**1,335,811**	**100%**

9.4.3.4 OPTION 4: CONSERVATIVE/REGULATORY

The final option is the conservative and regulatory one; in this case only the three warehouses and the U.S. factory are included. This represents only the United States emission, which could be regulated in California. In this case 1.1 million tonnes of carbon emissions would be considered; see Table 9-7.

Table 9-7 Carbon emission split under Conservative/regulatory.
Source: Own preparation

Conservative/Regulatory	**CO2 Emission 2020 [tonne]**	**Percentage**
DC California	7,550	1%
DC Georgia	100,587	9%
DC Texas	42,862	4%
US Factory	920,653	86%
Total	**1,071,651**	**100%**

The above tables show the four options that a company can use to report its carbon emission, considering the initial supply network that the solution of the model proposes. However, if the new scope is the "product ownership perspective", then constraints related to suppliers need to be eliminated in the mathematical model. Consequently, the model gives a new solution where the alternative of commissioning a new factory in Germany is no longer proposed. The carbon emission with the new supply chain configuration changes from 2.46 Million of CO_2e (see Option 2) to 2.28 Million of CO_2e (-8%), see Table 9-8.

Table 9-8 Carbon emission split under the product ownership perspective. Second proposal.
Source: Own preparation

Product ownership perspective	CO2 Emission 2020 [tonne]	Percentage
DC California	29,997	1.3%
DC Georgia	146,337	6.4%
DC Texas	137,641	6.0%
Transport DC - Retailer	205,240	9.0%
US Factory	1,448,973	63.5%
Transport Factory - DC	313,974	13.8%
Total	**2,282,162**	**100%**

9.4.4 IMPLEMENTATION AND TRACKING

The carbon reduction methodology is aligned with the companies' point of view, the corporate carbon strategy and strategic financial planning are in progress. The ongoing work is demonstrating the viability of the methodology.

Recommendations for the implementation and tracking:

- In order to have a successful carbon emission it is always important to be clear about how to communicate those results.
- In the scope definition, there are other dimensions, such as packaging, which could also have an impact; in this case study the packaging was maintained under the same technology.
- Customers' emissions are another key parameter that could be included in the scope. The distance travelled to collect the products, the recycle options employed and the waste treatment in the landfill for these materials are also important factors in the carbon footprint.
- In the case of joint venture facilities, it is essential to be careful with the carbon emission allocation.

9.5 CONCLUSIONS

- The case study explained in this chapter is a very common picture, where a company has to decide what scope fits better into its carbon strategy. The scope used can change the structure of the mathematical model and, consequently, the outcome of the strategy.
- For creating a carbon emission strategy, it is essential to establish clear goals, understand why the company needs to do so and the methodologies available to do it. This includes determining the scope and understanding the depth, breadth, and precision.
- In this case study, the objective of maximizing the Net Profit (NP) is achieved, whilst the Kg CO_2 per Kg sold is reduced by 33%. To achieve these results the solution of the model is to open two Distribution Centers, one in Georgia and another one in Texas, and open a new factory based in Germany.

- The base of the carbon reduction plan is the implementation of Coal-fuelled CHP for the U.S. factory and the use of green energy in the German factory. In addition to that, the use of CNG and intermodal road – rail is proposed in the secondary transport.

CHAPTER 10

Conclusions and future research

10.1 CONCLUSIONS

In response to the need in the industry, this thesis has introduced a Carbon Reduction Methodology and a mathematical model for designing a supply chain where the net profit is maximized and proposes a set of initiatives for achieving carbon emission targets .

The research of this thesis started with the review of the current literature in this field. GHG Protocol, Guide to PAS 2050, ISO 14064 were some of the standards and normatives reviewed. Additionally, 128 journal articles were reviewed, which were classified according to the carbon emission reduction approach in the supply chain. Although in recent years the number of contributions in this field has increased, there is still a lack of formalized procedures and tools for helping decision makers to develop a Corporate Carbon Strategy with specific plans for achieving targets.

The proposed methodology consists of 4 stages and the development of each has constituted a specific objective of the thesis. The methodology is part of the strategic planning and is aligned with the financial planning of the company.

The first step of the methodology starts with the proposal of a guideline for Corporate Carbon Strategy. This guideline shows, step by step, how to create a carbon strategy from the beginning. Moreover, it includes a complete list of the potential alternatives for carbon reduction in the whole supply network. In the second step, the Corporate Carbon Strategy is evaluated from a financial point of view and is integrated into the strategic finance planning.

In step three of the methodology, a Mixed-Integer Linear Program (MILP) is proposed to obtain a plan for the redesign of the Supply Chain so that: 1) the carbon reduction targets are achieved; 2) the strategic financial plan is taken into account; 3) all the realistic possibilities for redesigning the Supply Chain are contemplated (opening or closing facilities, modifying transport modes, modifying the type of energy used in different facilities, changing suppliers, etc.) and 4) achieve a solution that, taking into account the decisions made in previous stages, determines the actions to be carried out to optimize the economic results of the company.

The horizon plan of the strategy is defined as a part of the Corporate Carbon Strategy and is included as a time variable in the MILP. For every year of the horizon plan there is a carbon emission target, measured in terms of “Kg CO2e/Kg sold”. Besides, there is a constraint which ensures that the yearly target is reached. The strategy for reaching each target is based on the selection of a set of carbon reduction alternatives.

The Carbon Reduction Methodology offers the possibility of exploiting the model according to different views of the organization; it includes the possibility of changing the objective function and / or including new constraints if needed. The flexibility of the model was proved in the first study case, where some constraints were added to adapt the needs of the company to the model.

The carbon reduction methodology, as well as the MILP model, was tested using three case studies. The first is a case based on a company in Brazil which wants to re-design its network due to tax benefits. The solution of the model proposes a new network configuration, where three warehouses were closed and one factory is opened; the result was an increase of 53% in the net profit whilst the carbon efficiency improved by 23%. The Brazilian case study helps to demonstrate the importance of including local agreements, such as tax benefits, in the supply network design. It is useful for improving competitiveness and avoiding the risk of missing out on potential savings.

The second case study illustrates the case of a company with a customer demand based in Spain, which has problems with its product cost. The network is re-designed, changing the factory location from Italy to Poland and closing one warehouse in Vigo (Spain). Because of the changes the net profit after taxes is increased by 74% in the first year. Nevertheless, to compensate for the increase in the carbon emission, due to the increase in the kilometers travelled in the primary transport, the solution of the model proposes a set of initiatives for reducing the carbon impact by 30% until 2023. The case study is also useful to exemplify the fact that water and rail transport is not always the greener solution, but other parameters such as distance or loadfill could be more determinant for carbon reduction.

Finally, the third case used a United States company to show the effect of the scope definition in the carbon strategy. In this case study the net profit increased 86%, whilst the Kg CO_2 per Kg sold is reduced by 33%. To achieve these results the solution of the model is to open two warehouses and also a new factory in Germany. This last decision impacts significantly on the carbon reduction plan, because the type of energy used in Germany is the most environmentally friendly. This case study was also useful in illustrating the effects of the scope and how it may have a significant impact on the carbon reduction strategy.

This thesis has addressed the problem of designing (or redesigning) a Supply Chain as a way to reduce the carbon emission, in an economically viable and, as far as possible, optimal manner. The thesis has been in response to a topic of growing interest for companies, society and governments. The proposed methodology responds to all of these questions by designing a complete and formalized methodology, which also includes a mathematical model to determine the best decisions to be made. The complete proposal was designed and developed in order to facilitate its implementation in the business world.

10.2 Future research

As the literature review shows, the work considering carbon emission reductions in supply chain planning is still scarce, especially regarding the focus on waste management and its link with the CO_2e emissions. Therefore, many possible future research directions can be defined in this area.

In the manufacturing process the following points can be considered as a future line of research:

- Include the carbon emissions related to the waste generated in the process.
- The repacking points could be added to the supply network in case the company subcontracts the packing process.

Many topics in logistics can be considered as another attractive future research direction, the following are some examples :

- Since the loadfill is a key factor in the carbon emission coming from transportation, the possibility of including crossdocking points in the supply chain can reduce the total carbon emission in the network.
- The management of the trucks' return journey can be added to evaluate the impact of reverse logistics in transportation.
- The impact of speed on the carbon emissions related to transportation can also be considered.

The impact of the carbon emissions coming from the final customers as a part of the product's use is not addressed in this thesis, thus the following points can be considered for future research:

- The carbon emissions which are produced by the final customer, as a part of the use of the products.
- Reverse logistics, including packaging recovery, customer returns as well as the managing of obsolete products are not part of the model.

Regarding the methodology, the following points can be considered as future research:

- The mathematical model could include the possibility of fixing some alternatives in the timeline, for instance the use of electric vehicles or the use of intermodal road – rail which may be available for a region in the next few years, but not immediately.
- The methodology could be extended to incorporate other aspects related to sustainability, such as social impact; for instance, if a factory is closed in one place and another commissioned elsewhere, then some jobs will be destroyed in one area and created in another. These aspects

could be taken into account to increase the scope of the sustainability topics in the methodology.

- Some aspects regarding uncertainty and risk can be added.

Publications

The list of publications is listed in this section:

1. Pinto, C., Lusa A. and Coves A.M. (2018). "A proposal for a Carbon reduction strategy ", *Journal of Industrial Engineering and Management*, OmniaScience. Vol 11(3), p445-465. https://doi.org/10.3926/jiem.2518.
2. Pinto, C., Coves A.M. (2014). "The reduction of CO2 emission into the supply network design: A review of current trends in mathematical models", in J. C. Prado-Prado and J. García-Arca (eds.), *Annals of Industrial Engineering 2012* (DOI: 10.1007/978-1-4471-5349-8_16), Springer-Verlag London 2014. (Chapter 16, p131-138).

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Abbreviations

CCS	Corporate Carbon Strategy
CDM	Clean development mechanism
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
COGS	Cost Of Goods Sold
CSR	Corporate Social Responsibility
DEFRA	Department for Environment, Food and Rural Affairs
DR	Distribution Center D – Retailer R
EPC	Energy Performance Certificates
EU ETS	European Union Emission Trading Scheme
GHG	Greenhouse Gas
GP	Goal Programming
GP	Gross Profit
GSN	Green Supply Network
GSNM	Green Supply Network Management
G-VRP	Green Vehicle Routing Problem
GVS	Gross Sales Volume
HGV	Heavy Goods Vehicle
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
JI	Joint implementation
KD	Factory K – Distribution Center D
KPI	Key Performance Indicator
LCA	Life-cycle assessment
LEDs	Light Emitting Diodes
MINLP	Mixed-Integer Nonlinear Program
MOP	Multi-objective programming
NGCC	Natural Gas Combined Cycle
NK	Supplier N – Factory K
NP	Net Profit
NTM	Network and Transport & Environment
NZ ETS	New Zealand Emissions Trading Scheme
PAS 2050	Publicly Available Specification 2050
PC	Pulverized Coal
PNM	Planning and Networking Modelling

PRP	Pollution-Routing Problem
PV	Photovoltaics
SACH	Solar Absorption Cooling and Heating
SCM	Supply Chain Management
SEM	Supply Economic Model
SN	Supply Network
SNM	Supply Network Management
SSN	Sustainable Supply Network
VRP	Vehicle Routing Problem

Glossary of terms

Anaerobic digestion

A process whereby bacteria break down organic material in the absence of oxygen to generate a methane-rich biogas.

Base year

A historic year against which a company's emissions are tracked over time.

Biomass boiler

A boiler that burns fuels such as wood chips, straw and agricultural residues.

Boundaries

GHG accounting and reporting boundaries have some dimensions, i.e. organizational, operational, geographic, business unit, and target boundaries. The inventory boundary regulates which emissions are accounted and reported by the company.

Carbon efficiency

The measure that indicates the total amount of CO_2e to move one Kg of freight.

Carbon footprint

The level of greenhouse gas emissions produced by a product, activity, entity or process of a company

CHP engine

Type of CHP engine, spark ignition or compression ignition internal combustion engine fueled by gas or oil.

Combined heat and power (CHP)

Synchronized generation of electricity and production of heat using a source of mechanical and thermal energy.

Consolidation centers

Regional small-scale stocking points used by some companies, most of them retailers, to consolidate loads from large numbers of smaller suppliers.

CO_2 equivalent (CO_2-e)

The agreed unit of measurement to indicate the global warming potential (GWP) of each of the six greenhouse gases, expressed in terms of the GWP of one unit of carbon dioxide.

Direct GHG emissions

Emissions from sources that are owned or controlled by the reporting company.

Double counting

Two or more reporting companies take ownership of the same emissions or reductions. It should normally be avoided.

Energy consumption

Amount of energy consumed in a process or system, or by an organization or society.

Emission factor

Amount of greenhouse gases emitted, expressed as carbon dioxide equivalent and relative to a unit of activity, i.e. kg CO2e per km.

Feasibility study

A study undertaken to determine the technical, economic and environmental viability of a project.

Gas turbine

A type of Combined heat and power, with an operating principle like a jet engine, fueled by natural gas.

GHG program

A generic term used to refer to any voluntary or mandatory international, national, sub-national, government or non-governmental authority that registers, certifies, or regulates GHG emissions or removals outside the company. For example, CDM, EU ETS, CCX, and CCAR.

Indirect GHG emissions

Emissions that are a consequence of the operations of the reporting company, but occur at sources owned or controlled by another company.

Intergovernmental Panel on Climate Change (IPCC)

Intergovernmental Panel on International body of climate change scientists. The role of the IPCC is to assess the scientific, Climate Change technical and socio-economic information relevant to the understanding of the risk of human-induced climate change.

Kyoto Protocol

A protocol to the United Nations Framework Convention on Climate Change (UNFCCC). Kyoto Protocol aims to meet reduction targets of GHG emissions.

Life cycle

Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to end of life, inclusive of any recycling or recovery activity.

Life cycle assessment (LCA)

Compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle.

Payback period

The length of time taken to recover the cost of an investment through the returns attributable to it.

Product category

Group of products that can fulfil equivalent functions.

Raw material

Primary or secondary material used to produce a product.

Renewable energy

Energy that happens naturally and repeatedly in the environment.

Renewable energy purchased

Amount of purchased energy consumed by a company from renewable sources during the reporting period.

Reporting

Presenting data to internal management and external users such as regulators, shareholders, the general public or specific stakeholder groups.

System boundary

Set of criteria specifying which unit processes are part of a product system (life cycle).

Waste

Materials, co-products, products or emissions which the holder discards or intends, or is required to, discard.

White brands

It is a white label product manufactured by a company and sold by other companies using other brand names.

Terms were mainly based on GHG protocol (WBCSD/WRI, 2004), Guide to PAS 2050 (BSI Guide, 2008) and Carbon Trust (Carbon Trust, 2012)

Appendix Section

Appendix A: Global Warming Potential Values

The following table includes the 100-year time horizon global warming potentials (GWP) relative to CO2. Source: GHG Protocol (WBCSD/WRI, 2004).

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second Assessment Report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	21	25	28
Nitrous oxide	N_2O	310	298	265
Substances controlled by the Montreal Protocol				
CFC-11	CCl_3F	3,800	4,750	4,660
CFC-12	CCl_2F_2	8,100	10,900	10,200
CFC-13	$CClF_3$		14,400	13,900
CFC-113	CCl_2FCClF_2	4,800	6,130	5,820
CFC-114	$CClF_2CClF_2$		10,000	8,590
CFC-115	$CClF_2CF_3$		7,370	7,670
Halon-1301	$CBrF_3$	5,400	7,140	6,290
Halon-1211	$CBrClF_2$		1,890	1,750
Halon-2402	$CBrF_2CBrF_2$		1,640	1,470
Carbon tetrachloride	CCl_4	1,400	1,400	1,730
Methyl bromide	CH_3Br		5	2
Methyl chloroform	CH_3CCl_3	100	146	160

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second assessment report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
HCFC-21	$CHCl_2F$			148
HCFC-22	$CHClF_2$	1,500	1,810	1,760
HCFC-123	$CHCl_2CF_3$	90	77	79
HCFC-124	$CHClFCF_3$	470	609	527
HCFC-141b	CH_3CCl_2F	600	725	782
HCFC-142b	CH_3CClF_2	1,800	2,310	1,980
HCFC-225ca	$CHCl_2CF_2CF_3$		122	127
HCFC-225cb	$CHClFCF_2CClF_2$		595	525
Hydrofluorocarbons (HFCs)				
HFC-23	CHF_3	11,700	14,800	12,400
HFC-32	CH_2F_2	650	675	677
HFC-41	CH_3F_2	150		116
HFC-125	CHF_2CF_3	2,800	3,500	3,170
HFC-134	CHF_2CHF_2	1000		1,120
HFC-134a	CH_2FCF_3	1,300	1,430	1,300
HFC-143	CH_2FCHF_2	300		328
HFC-143a	CH_3CF_3	3,800	4,470	4,800
HFC-152	CH_2FCH_2F			16
HFC-152a	CH_3CHF_2	140	124	138
HFC-161	CH_3CH_2F			4
HFC-227ea	CF_3CHFCF_3	2,900	3,220	3,350
HFC-236cb	$CH_2FCF_2CF_3$			1,210
HFC-236ea	CHF_2CHFCF_3			1,330
HFC-236fa	$CF_3CH_2CF_3$	6,300	9,810	8,060
HFC-245ca	$CH_2FCF_2CHF_2$	560		716
HFC-245fa	CHF2CH2CF3		1,030	858
HFC-365mfc	CH3CF2CH2CF3		794	804
HFC-43-10mee	CF3CHFCHFCF2CF3	1,300	1,640	1,650

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second assessment report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Perfluorinated compounds				
Sulfur hexafluoride	SF_6	23,900	22,800	23,500
Nitrogen trifluoride	NF_3		17,200	16,100
PFC-14	CF_4	6,500	7,390	6,630
PFC-116	C_2F_6	9,200	12,200	11,100
PFC-218	C_3F_8	7,000	8,830	8,900
PFC-318	c-C_4F_8	8,700	10,300	9,540
PFC-31-10	C_4F_{10}	7,000	8,860	9,200
PFC-41-12	C_5F_{12}	7,500	9,160	8,550
PFC-51-14	C_6F_{14}	7,400	9,300	7,910
PCF-91-18	$C_{10}F_{18}$		>7,500	7,190
Trifluoromethyl sulfur pentafluoride	SF_5CF_3		17,700	17,400
Perfluorocyclopropane	c-C_3F_6			9,200
Fluorinated ethers				
HFE-125	CHF_2OCF_3		14,900	12,400
HFE-134	CHF_2OCHF_2		6,320	5,560
HFE-143a	CH_3OCF_3		756	523
HCFE-235da2	$CHF_2OCHClCF_3$		350	491
HFE-245cb2	$CH_3OCF_2CF_3$		708	654
HFE-245fa2	$CHF_2OCH_2CF_3$		659	812
HFE-347mcc3	CH3OCF2CF2CF3		575	530
HFE-347pcf2	CHF2CF2OCH2CF3		580	889
HFE-356pcc3	CH3OCF2CF2CHF2		110	413
HFE-449sl (HFE-7100)	C4F9OCH3		297	421
HFE-569sf2 (HFE-7200)	C4F9OC2H5		59	57
HFE-43-10pccc124 (H-Galden 1040x)	$CHF_2OCF_2OC_2F_4OCHF_2$		1,870	2,820
HFE-236ca12 (HG-10)	CHF2OCF2OCHF2		2,800	5,350

Appendix B: Transportation assumptions

1. Road transport assumptions

According to the emission factors explained by the Network and Transport & Environment (NTM) (Özsalih, 2008), the assumptions for the road transport are:

a) the truck for long distance is an articulated trailer (> 33 t, 22 tons of real capacity) and trucks for medium to short distance are rigid truck (> 3,5 – 7,5t, 5 tons of real capacity), rigid truck (> 7,5 – 17t, 7 tons of real capacity) and rigid truck (>17t, 17 tons of real capacity);
b) the condition of the transportation is ambient temperature;
c) speed, road and driver characteristics are not taken into account.

2. Rail transport assumptions

One of the most influential parameters in rail emissions is the type of traction; for instance, in Central and Western Europe they rely on electricity but in Spain most trains have diesel traction. Therefore, the assumptions for rail transport are:

a) consider an emission factor for rail transport as an average between diesel and electricity traction (if needed);
b) the emission factor assuming a hilly topography as average for the European case;
c) the condition of the transportation is ambient temperature;
d) consider only the load fill rate of the transport unit, not the total transport units in the rail transport;
e) the model does not distinguish between different driving behaviours.

3. Water transport assumptions

Generally, emission factors in water transport depend on the type of ship; for this type of transport mode the assumptions for water transport are:

a) the type of ship should be reviewed, including the type of fuel used.

b) consider only the load fill rate of the transport unit, not the total transport units in the water transport.
c) do not consider the impact of speed or the ship's load factor.

Appendix C: Warehousing design lights initiatives

A. Light sources

Light sources, also called lamps, rather than light bulbs, can be created in three different ways: incandescent, fluorescent or LEDs. Each type of lamps has different characteristics, which are associated with efficiency, lifetime and colour rendering ability; their utilization depends on where and when they should be used.

In incandescent or tungsten lamps the light is created through a wire that glows white hot, although many incandescent lamps are considered inefficient and are being phased out of the market; there are some incandescent lamps which add halogen within the glass surrounding the tungsten element, to be more efficient.

Discharge lighting is another type of lamp, where the light generation occurs within a gas filled envelope. These lamps are characterized by their need to "warm up" to reach full brightness and also because they cannot be turned back on immediately, which impacts on the controllability of the process. Anyhow, they are currently the most commercial lighting and exist in different formats: fluorescent, low pressure sodium, high pressure sodium, high pressure mercury, metal halide or ceramic metal halide.

Light Emitting Diodes (LEDs) are within the solid-state lighting category; they are very small point sources that can appear to be very bright. The LEDs technology has been developed rapidly during recent decades, making their use in commercial lighting viable. LEDs lamps have a very long life, therefore maintenance costs are cut significantly.

Table C-1 explains the main characteristics of the three types of lamps explained above. Compared with incandescent and fluorescents, LED lamps are the most efficient technology in terms of energy and carbon reduction. Nevertheless, some LED bulbs require special fittings; consequently, if a change of fittings is needed it could impact on the cost-benefit ratio.

Modern fluorescent lamps require less energy and seem to be a good alternative to the incandescent lamps. Additionally, they have longer lamp life resulting in fewer maintenance costs and they are safer for glass breakages, which is important for food storage areas.

Table C-1 Type of lamps.
Source: https://electricalnotes.wordpress.com/2011/03/20/hid-lamps/

Energy Efficiency & Energy Costs	 Incandescent Light Bulbs	 Compact Fluorescents	 Light Emitting Diodes (LEDs)
Life Span (average)	1200 hours	10000 hours	50000 hours
Watts of elecricity used (equivalent to 60 watt bulb)	60 watts	14 watts	10 watts
Cost per bulb	$1.25	$4	$36
KWh of electricity used over 50,000 hours	3000	700	500
Cost of electricity (@ 0.10per KWh)	$300	$70	$50
Bulbs needed for 50k hours of use	42	5	1
Equivalent 50k hours bulb expense	$52	$20	$35
Total cost for 50k hours	$352.50	$90.00	$86.00
Carbon Dioxide Emissions (30 bulbs per year)	2041 Kg/year	476 Kg/year	204 Kg/year
Turns on instantly	Yes	No - take time to warm up	Yes
Durability	Not Very Durable - glass or filament can break easily	Not Very Durable - glass can break easily	Very Durable - LEDs can handle jarring and bumping

Although the artificial light technology is improving with time, the easiest way to reduce carbon emission is reducing the total number of lamps used in some specific areas. Some solutions are related with the natural light utilization in the warehouse design or the reflectors replacement by modern reflectors with a mirror effect. Another good alternative for reducing the number of artificial lamps is the daylight harvesting system.

B. Lighting controls

Even when the lamps selected are the most efficient, if they do not work with the correct lighting controls, they could waste energy. Automatic lighting controls are a good way to manage energy in the warehouse, because they regulate the right place, time and light level required at every moment. This kind of device can react to movement, time clock or light.

There are three types of motion sensors, passive infra-red, ultrasonic detection or microwave detection, and they can be used in presence or absence detection mode. Time clock sensors are a very good system in the cases of predicted occupancy areas (loading bays, lavatories) and can be used to change the overall operating mode. Light sensors are used to observe the external natural lighting and calibrate the indoor lighting, or as ceiling mounted light sensors to integrate the artificial and natural lighting.

Based on industry research studies evaluating various control strategies, Table C-2 shows the best estimates of average savings, which may present energy savings by typical application.

Table C-2 LBNL best estimates of average lighting energy savings for various control strategies based on a review of 240 energy savings estimates published in 88 papers and case studies.
Source: Lawrence Berkeley National Laboratory, 2011.

Strategy	**Definition**	**Examples**	**Average energy Savings**
Occupancy	Lighting status changes automatically based on presence of people	Occupancy sensors, timeclocks, energy management system	24%
Personal Tuning	Occupant control of light levels	Dimmers, wireless switches, workstation-specific control, present scene control	31%
Daylight Harvesting	Lighting status changes automatically based on daylight levels	Photo-sensors	28%
Institutional Tuning	Light levels tuned to space needs by application, ballast tuning (reduction of ballast factor), task tuning, lumen maintenance, group controls	Dimmable ballasts, and dimmers and switches used to control group lighting	36%
Multiple Strategies	Any combination of the above		38%

C. Maximize usage of daylight

Using natural light is an optimal way to reduce energy, although this alternative is more effective if it is part of the warehouse design; otherwise, as a part of warehouse upgrades, it could not justify the investments in retrofitting old roof structures.

If this alternative is used in countries with a warmer climate and especially hot summers, it is important to use light but keep heat outside. Some measures, such as usage of shed roofs with the correct orientation or the use of specifically foiled windows can be good solution to this problem.

Furthermore, solar tubes, made up of domes, offer an innovative solution to increase daylight utilization. In this technology, a dome is usually placed outside the building to capture as much daylight as possible, in this way it is able to transport sunlight into the building, harvesting in areas where conventional windows cannot be used.

Figure C – 1 Example of the Solatube system.
Source: Solatube (Solatube, 2017)

Solar Tube technology was developed by SOLATUBE®, there is another solution offered by companies such as Ciralight. Its construction is very similar to solar tube, but it includes an automatic solar tracking system, with mirrors installed inside the dome, to maximize solar light harvesting; see Figure C-1.

Table C-3 shows a cost analysis of a warehouse located in Europe, performed under both technologies with 20 000 m2. The light requirement was assumed to be 150 Lux.

Table C-3 Daily energy systems comparison
Source: (Ciralight, 2017)

Technology	Solatube	Smart Skylights
Type of system	Solatube 330DS	SUNTRACKER type 2 (120 x 120) unit (including: polycarbonate dome, frame, pyramidal diffuser, mirror, GPS controller, curb, light well)
Number of points	300	218
Cost by system (including full installation)	600	1500
Investment [€]	180000	327000
Saving per year [€]	23000	35000
Return of investment	7	10

Appendix D: Case study I data and results

Table D- 1 Demand by region. Case I

	2017	2018	2019	2020	2021	2022	2023
Sao Paulo	100,800	105,840	113,249	123,441	137,020	154,832	178,057
Minas Gerais	100,800	105,840	113,249	123,441	137,020	154,832	178,057
Rio de Janeiro	50,400	52,920	56,624	61,721	68,510	77,416	89,029
Bahia	50,400	52,920	56,624	61,721	68,510	77,416	89,029
Rio Grande do Sul	50,400	52,920	56,624	61,721	68,510	77,416	89,029
Parana	50,400	52,920	56,624	61,721	68,510	77,416	89,029
Pernambuco	100,800	105,840	113,249	123,441	137,020	154,832	178,057
Total	**504,000**	**529,200**	**566,244**	**617,206**	**685,099**	**774,161**	**890,286**

Table D- 2 Operating cost. Case I

	Warehousing	Manufacturing
Operating cost	0.79	1.44

Table D- 3 Emission factor warehousing and manufacturing. Case I

	Level 1	Level 2	Level 3	Level 4
Emission Warehousing	0.79	0.55	0.39	0.27
Emission Manufacturing	1.60	1.44	1.30	

Table D-4 Factor emission and capacity. Case I

Secondary transport	Emission factor	Capacity
Rigid truck 17 t	*0.59*	*15*
Dual vehicle	*0.42*	*15*
Ethanol vehicle	*0.24*	*15*

Primary transport	Emission factor	Capacity
Articulated truck	1.10	*22*
Diesel Train	0.73	*22*
Inland-Upstream	0.50	*22*

Raw Material transport	Emission factor	Capacity
Articulated truck	1.10	*22*
Diesel Train	0.73	*22*
Inland-Upstream	0.50	*22*

Table D- 5 Distance DR. Case I

Distance_DR [Km]	*W_SP*	*W_MG*	*W_BA*	*W_RS*	*W_PE*
Sao Paulo	100	300	1800	1100	2436
Minas Gerais	233	100	952	1182	2385
Rio de Janeiro	1800	1200	1554	1567	2051
Bahia	1100	1300	100	2821	868
Rio Grande do Sul	2776	2043	1165	4019	648
Parana	2783	1300	868	3525	2594
Pernambuco	3895	1300	1149	3854	100

Table D- 6 Distance KD. Case I

Distance_KD [Km]	*Sao Paulo*					*Pernambuco*					*Minas*				
	W_SP	*W_MG*	*W_BA*	*W_RS*	*W_PE*	*W_SP*	*W_MG*	*W_BA*	*W_RS*	*W_PE*	*W_SP*	*W_MG*	*W_BA*	*W_RS*	*W_PE*
Road	150	931	1633	681	1740	1740	1050	595	2490	150	931	150	945	3474	1337
Train	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Water	M	M	1755	807	2430	2430	2897	976	2637	200	M	200	2222	1574	3197

Table D- 7 Distance NK. Case I

	Sao Paulo			*Pernambuco*			*Minas*		
Distance_NK [Km]	*Brazil*	*Germany*	*China*	*Brazil*	*Germany*	*China*	*Brazil*	*Italy*	*China*
Road	2130	M	M	3019	M	M	495	M	M
Train	2330	M	M	3219	M	M	695	M	M
Water	2530	9953	20564	3419	8253	18458	895	10996	21059

Table D- 9 ICMS rate base by state Table. Source: www.portaltributario.com.br

	DESTINO																										
ORIGEM	AC	AL	AM	AP	BA	CE	DF	ES	GO	MA	MT	MS	MG	PA	PB	PR	PE	PI	RN	RS	RJ	RO	RR	SC	SP	SE	TO
AC		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
AL	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
AM	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
AP	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
BA	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
CE	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
DF	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
ES	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
GO	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
MA	12	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
MT	12	12	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
MS	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
MG	7	7	7	7	7	7	7	7	7	7	7	7		7	7	12	7	7	7	12	12	7	7	12	12	7	7
PA	12	12	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12	12
PB	12	12	12	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12	12	12
PR	7	7	7	7	7	7	7	7	7	7	7	7	12	7	7		7	7	7	12	12	7	7	12	12	7	7
PE	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12	12
PI	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12	12
RN	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12	12	12	12	12
RS	7	7	7	7	7	7	7	7	7	7	7	7	12	7	7	12	7	7	7		12	7	7	12	12	7	7
RJ	7	7	7	7	7	7	7	7	7	7	7	7	12	7	7	12	7	7	7	12		7	7	12	12	7	7
RO	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12	12
RR	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12
SC	7	7	7	7	7	7	7	7	7	7	7	7	12	7	7	12	7	7	7	12	12	7	7		12	7	7
SP	7	7	7	7	7	7	7	7	7	7	7	7	12	7	7	12	7	7	7	12	12	7	7	12		7	7
SE	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		12
TO	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	

Table D - 10 Results. Case I

Year	2017	2018	2019	2020	2021	2022	2023
Product quantity [Tonne]	**504,000**	**529,200**	**566,244**	**617,206**	**685,099**	**774,161**	**890,286**
Gross profit [M€]	6,779	7,117	7,616	8,301	9,214	10,412	11,974
Tax [M€]	1,574	1,425	1,528	1,666	1,861	2,088	2,403
NP after taxes [M€]	1,912	2,383	2,616	2,851	3,160	3,561	4,090
Operating W cost [M€]	398	418	447	488	541	612	703
Operating F cost [M€]	726	762	815	889	987	1,124	1,318
Transport cost [M€]	312	119	127	142	160	206	202
Carbon credits [M€]	0	0	0	0	0	0	0
Raw Material cost [M€]	505	531	568	619	679	761	893
Total Cost [M€]	**1,941**	**1,829**	**1,957**	**2,137**	**2,367**	**2,702**	**3,116**
Emission Warehousing [tonne CO2e]	252,000	264,600	283,122	308,603	342,549	387,081	445,143
Emission Factory [tonne CO2e]	806,400	846,720	905,990	987,530	1,096,158	1,167,368	1,139,566
Emission Transport [tonne CO2e]	492,709	310,957	275,137	239,012	226,612	287,312	381,671
Emission DR [tonne CO2e]	218,726	197,458	170,210	124,642	94,510	112,232	216,698
Emission KD [tonne CO2e]	103,578	24,821	11,774	12,833	14,245	16,097	18,511
Emission NK [tonne CO2e]	170,406	88,678	93,153	101,537	117,857	158,984	146,462
Emission Raw Material [tonne CO2e]	354,011	371,711	397,731	433,527	454,349	481,607	625,338
Total emission [tonne CO2e]	1,905,120	1,793,988	1,861,980	1,968,672	2,119,669	2,323,369	2,591,718
Kilometers travelled [KKm]	**815,482**	**487,568**	**495,624**	**540,230**	**587,584**	**742,675**	**779,252**
km travelled DR [KKm]	369,557	333,622	343,288	374,184	396,502	470,850	539,740
km travelled KD [KKm]	105,827	22,582	16,108	17,558	19,489	22,023	25,326
km travelled NK [KKm]	340,098	131,365	136,228	148,488	171,592	249,802	214,186
Loads	**436,403**	**475,787**	**455,398**	**496,384**	**550,987**	**622,615**	**716,007**
Loads DR	210,283	220,797	236,253	257,516	285,842	323,002	371,452
Loads KD	126,647	150,543	107,388	117,053	129,928	146,819	168,842
Loads NK	99,473	104,447	111,758	121,816	135,216	152,794	175,713
Target Carbon Efficiency	3.8	3.4	3.3	3.2	3.1	3.0	2.9
Kg CO2e per Kg sold	3.8	3.4	3.3	3.2	3.1	3.0	2.9
Percentage reduction		-10%	-3%	-3%	-3%	-3%	-3%
Kg CO2e in manufacturing / Kg sold	1.60	1.60	1.60	1.60	1.60	1.51	1.28
Kg CO2e in WHS / Kg sold	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Kg CO2e RM / Kg sold	0.70	0.70	0.70	0.70	0.66	0.62	0.70
Kg CO2e Transport / Kg sold	0.98	0.59	0.49	0.39	0.33	0.37	0.43
Kg CO2e / km travelled	**0.60**	**0.64**	**0.56**	**0.44**	**0.39**	**0.39**	**0.49**
Kg CO2e / km travelled DR	0.59	0.59	0.50	0.33	0.24	0.24	0.40
Kg CO2e / km travelled KD	0.98	1.10	0.73	0.73	0.73	0.73	0.73
Kg CO2e / km travelled NK	0.50	0.68	0.68	0.68	0.69	0.64	0.68
km travelled / Kg sold	**1.62**	**0.921**	**0.875**	**0.875**	**0.858**	**0.959**	**0.875**
kg.CO2 in transport / tonne.km	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.000**	**0.001**
Kg CO2e transport / load	1.13	0.65	0.60	0.48	0.41	0.46	0.53

Appendix E: Case study II data and results

Table E-1 Demand. Case II

	2017	2018	2019	2020	2021	2022	2023
Madrid	96,515	101,726	109,055	118,866	132,066	150,539	173,963
Pais Vasco	71,938	76,098	81,998	89,359	98,759	112,391	128,715
Navarra	50,400	52,920	56,624	61,721	68,510	77,416	89,029
Barcelona	33,600	35,280	37,750	41,147	45,673	51,611	59,352
Aragon	33,600	35,280	37,750	41,147	45,673	51,611	59,352
La Rioja	26,880	28,224	30,200	32,918	36,539	41,289	47,482
Castilla y Leon	23,067	23,272	24,120	26,314	29,513	31,251	35,630
Total	**336,000**	**352,800**	**377,496**	**411,471**	**456,732**	**516,108**	**593,524**

Table E-2 Operating cost. Case II

	Warehousing	Manufacturing
Operating cost	0.99	1.84

Table E-3 Emission factor warehousing and manufacturing. Case II

	Level 1	Level 2	Level 3	Level 4
Emission Warehousing	0.89	0.62	0.44	0.31
Emission Manufacturing	2.10	1.89	1.70	

Table E-4 Factor emission and Capacity. Case II

Secondary transport	Emission factor	Capacity
Rigid truck 17 t	*0.95*	*15*
Dual vehicle	*0.76*	*15*
CNG light vehicle	*0.67*	*15*

Primary transport	Emission factor	Capacity
Articulated truck	1.01	*22*
Diesel Train	0.50	*22*
Inland-Upstream	0.79	*22*

Raw Material transport	Emission factor	Capacity
Articulated truck	1.05	*25*
Diesel Train	0.56	*25*
Inland-Upstream	0.39	*25*

Table E-5 Distance DR. Case II

Distance_DR [Km]	*Segovia*	*Montornes*	*Vigo*
Madrid	185	725	702
Pais Vasco	427	687	780
Navarra	450	575	860
Barcelona	763	123	1253
Aragon	458	417	960
La Rioja	368	604	795
Sevilla	603	1018	727

Table E-6 Distance KD. Case II

Distance_KD [Km]	*Portugal*			*Italy*			*Poland*		
	Segovia	*Montornes*	*Vigo*	*Segovia*	*Montornes*	*Vigo*	*Segovia*	*Montornes*	*Vigo*
Road	738	1351	562	2060	1420	2622	2565	2006	3122
Train	927	1302	M	2208	1485	2770	3009	M	3568
Water	1388	1752	549	2142	1288	3145	2206	1588	3208

Table E-7 Distance NK. Case I

Distance_NK [Km]	*Portugal*			*Italy*			*Poland*		
	Brazil	*Turkey*	*Ukraine*	*Brazil*	*Russia*	*Ukraine*	*Brazil*	*Russia*	*Ukraine*
Road	M	4089	5197	M	1749	1995	M	1033	984
Train	M	M	M	M	M	M	M	M	M
Water	10211	3912	17615	10404	8173	M	13804	M	M

Table E-8 Results. Case II

Year	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Product quantity [Tonne]	**336,000**	**352,800**	**377,496**	**411,471**	**456,732**	**516,108**	**593,524**
Gross profit [M€]	3,175	3,334	3,567	3,888	4,316	4,877	5,608
Tax [M€]	286	300	321	350	388	439	505
NP after taxes [M€]	356	621	792	856	938	989	987
Operating W cost [M€]	299	314	336	366	423	563	780
Operating F cost [M€]	786	437	479	535	594	671	772
Transport cost [M€]	506	560	592	645	723	809	955
Carbon credits [M€]	57	57	57	57	61	65	71
Raw Material cost [M€]	857	900	963	1,050	1,166	1,317	1,515
Total Cost [M€]	**2,506**	**2,269**	**2,427**	**2,653**	**2,966**	**3,424**	**4,092**
Emission Warehousing [tonne CO2e]	268,800	282,240	301,997	329,177	326,368	202,314	128,603
Emission Factory [tonne CO2e]	705,600	740,880	634,193	518,453	575,483	650,296	747,840
Emission Transport [tonne CO2e]	459,564	383,758	425,779	464,100	501,643	582,120	637,536
Emission DR [tonne CO2e]	67,608	55,416	74,453	81,154	76,430	101,792	79,710
Emission KD [tonne CO2e]	181,409	143,755	153,818	167,661	186,248	210,297	247,291
Emission NK [tonne CO2e]	210,547	184,587	197,508	215,284	238,965	270,031	310,536
Emission Raw Material [tonne CO2e]	474,516	498,242	533,119	581,099	645,020	728,873	838,204
Total emission [tonne CO2e]	1,908,480	1,905,120	1,895,088	1,892,829	2,048,515	2,163,603	2,352,183
Kilometers travelled [KKm]	**592,191**	**629,323**	**673,376**	**733,979**	**814,763**	**920,630**	**1,060,581**
km travelled DR [KKm]	70,975	73,048	78,161	85,195	94,475	106,860	119,541
km travelled KD [KKm]	188,722	196,174	209,906	228,798	254,103	286,981	335,233
km travelled NK [KKm]	332,495	360,102	385,309	419,986	466,185	526,789	605,807
Loads	**351,774**	**369,362**	**395,218**	**430,787**	**478,174**	**540,337**	**621,387**
Loads DR	163,553	171,731	183,752	200,290	222,322	251,224	288,907
Loads KD	103,548	108,726	116,337	126,807	140,756	159,054	182,912
Loads NK	84,672	88,906	95,129	103,691	115,097	130,059	149,568
Target Carbon Efficiency	5.7	5.4	5.1	4.8	4.5	4.2	4.0
Kg CO2e per Kg sold	5.7	5.4	5.0	4.6	4.5	4.2	4.0
Percentage reduction		-5%	-7%	-8%	-2%	-7%	-5%
Kg CO2e in manufacturing / Kg sold	2.10	2.10	1.68	1.26	1.26	1.26	1.26
Kg CO2e in WHS / Kg sold	0.80	0.80	0.80	0.80	0.71	0.39	0.22
Kg CO2e RM / Kg sold	1.41	1.41	1.41	1.41	1.41	1.41	1.41
Kg CO2e Transport / Kg sold	1.37	1.09	1.13	1.13	1.10	1.13	1.07
Kg CO2e / km travelled	**0.78**	**0.61**	**0.63**	**0.63**	**0.62**	**0.63**	**0.60**
Kg CO2e / km travelled DR	0.95	0.76	0.95	0.95	0.81	0.95	0.67
Kg CO2e / km travelled KD	0.96	0.73	0.73	0.73	0.73	0.73	0.74
Kg CO2e / km travelled NK	0.63	0.51	0.51	0.51	0.51	0.51	0.51
km travelled / Kg sold	**1.76**	**1.784**	**1.784**	**1.784**	**1.784**	**1.784**	**1.787**
kg.CO2 in transport / tonne.km	**0.002**	**0.002**	**0.002**	**0.002**	**0.001**	**0.001**	**0.001**
Kg CO2e transport / load	1.31	1.04	1.08	1.08	1.05	1.08	1.03

Appendix F: Case study III data and results

Table F- 1 Company's demand per region in Tonnes. Case III

	2018	2019	2020	2021	2022	2023	2024
Texas	120,000	126,000	134,820	146,954	163,119	184,324	211,973
Virginia	88,000	92,400	98,868	107,766	119,620	135,171	155,447
Florida	60,000	63,000	67,410	73,477	81,559	92,162	105,986
Colorado	40,000	42,000	44,940	48,985	54,373	61,441	70,658
New York	40,000	42,000	44,940	48,985	54,373	61,441	70,658
Illinois	32,000	33,600	35,952	39,188	43,498	49,153	56,526
California	20,000	21,000	22,470	24,492	27,186	30,721	35,329
Total	**400,000**	**420,000**	**449,400**	**489,846**	**543,729**	**614,414**	**706,576**

Table F- 2 Operating cost in warehousing and manufacturing in €/tonne. Case III

	Warehousing	Manufacturing
Operating cost	1.19	2.9

Table F- 3 Emission factor warehousing and manufacturing [Kg CO2/tonne]. Case III

	Level 1	Level 2	Level 3	Level 4
Emission Warehousing	0.34	0.24	0.16	0.12
Emission Manufacturing	3.50	3.15	2.84	

Table F- 4 Factor emission [Kg CO2/Km] and Capacity of the truck or container [tonne]. Case III

Secondary transport	Emission factor	Capacity
Articulated truck	*1.21*	*22*
Dual vehicle	*0.72*	*22*
CNG light vehicle	*0.24*	*22*

Primary transport	Emission factor	Capacity
Articulated truck	1.21	*22*
Diesel Train	0.69	*22*
Inland-Upstream	1.82	*22*

Raw Material transport	Emission factor	Capacity
Articulated truck	1.27	*25*
Diesel Train	0.79	*25*
Inland-Upstream	0.39	*25*

Table F- 5 Distance from the Distribution Center to the Customer [Km]. Case III

Distance_DR Km	*W_Georgia*	*W_California*	*W_Texas*
Texas	1856	2261	200
Virginia	822	4263	2258
Florida	588	4341	2191
Colorado	2611	1798	1247
New York	1488	4699	2839
Illinois	1356	3351	1600
California	3946	200	2261

Table F- 6 Distance from the Factory to the Distribution Center [Km]. Case III

	Michigan			*Tokyo*			*Dortmund*		
Distancia_KD en Km	*Georgia*	*California*	*Texas*	*Georgia*	*California*	*Texas*	*Georgia*	*California*	*Texas*
Road	1715	3867	2218	M	M	M	M	M	M
Train	1915	4367	2718	M	M	M	M	M	M
Water	M	M	M	12765	9374	10953	8175	15240	16879

Table F- 7 Distance from the Supplier to the Factory [Km]. Case III

	Michigan			*Tokyo*			*Dortmund*		
Distancia_NK en Km	*China*	*Turkey*	*Ukraine*	*China*	*Turkey*	*Ukraine*	*China*	*Turkey*	*Ukraine*
Road	M	M	M	M	M	M	M	2496	1803
Train	M	M	M	M	M	M	M	M	M
Water	20920	10565	7727	2276	13221	14907	13804	M	M

Table F- 8 Results of the optimization model. Case III

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Product quantity [Tonne]	**400,000**	**420,000**	**449,400**	**489,846**	**543,729**	**614,414**	**706,576**
Gross profit [M€]	7,560	7,938	8,493	9,258	10,276	11,612	13,353
Tax [M€]	680	714	764	833	925	1,045	1,202
NP after taxes [M€]	3,685	3,866	4,438	4,833	5,359	6,013	6,847
Operating W cost [M€]	476	500	535	583	647	731	841
Operating F cost [M€]	1,160	1,144	1,229	1,344	1,521	1,760	2,084
Transport cost [M€]	471	277	293	323	344	399	476
Carbon credits [M€]	50	46	48	49	52	55	59
Raw Material cost [M€]	1,021	1,072	1,147	1,250	1,388	1,568	1,803
Total Cost [M€]	**3,178**	**3,038**	**3,252**	**3,549**	**3,952**	**4,513**	**5,263**
Emission Warehousing [tonne CO2e]	134,400	141,120	150,998	164,588	182,693	206,443	237,410
Emission Factory [tonne CO2e]	1,400,000	1,346,691	1,448,973	1,153,575	1,354,668	1,635,049	662,380
Emission Transport [tonne CO2e]	1,680,167	1,264,095	1,286,862	1,474,314	1,326,569	1,071,095	2,099,817
Emission DR [tonne CO2e]	723,448	196,441	205,240	229,109	195,712	49,622	347,357
Emission KD [tonne CO2e]	533,984	679,012	662,185	791,932	605,798	397,345	1,103,211
Emission NK [tonne CO2e]	422,736	388,642	419,437	453,273	525,059	624,129	649,249
Emission Raw Material [tonne CO2e]	1,404,900	1,475,145	1,578,405	1,720,462	1,909,712	2,157,975	2,481,671
Total emission [tonne CO2e]	4,619,467	4,227,051	4,465,238	4,512,939	4,773,642	5,070,562	5,481,278
Kilometers travelled [KKm]	**2,096,836**	**1,432,205**	**1,532,034**	**1,670,381**	**1,859,551**	**2,182,845**	**2,411,290**
km travelled DR [KKm]	577,668	156,857	163,883	182,942	197,966	208,180	277,362
km travelled KD [KKm]	440,024	434,402	449,351	506,643	456,921	450,407	743,374
km travelled NK [KKm]	1,079,144	840,947	918,800	980,796	1,204,663	1,524,258	1,390,554
Loads	**386,988**	**406,338**	**434,781**	**473,912**	**526,042**	**594,427**	**683,591**
Loads DR	180,799	189,839	203,127	221,409	245,764	277,713	319,370
Loads KD	113,789	119,479	127,842	139,348	154,677	174,785	201,002
Loads NK	92,400	97,020	103,811	113,154	125,601	141,930	163,219
Target Carbon Efficiency	12.0	11.0	9.9	9.3	8.8	8.3	7.8
Kg CO2e per Kg sold	11.5	10.1	9.9	9.2	8.8	8.3	7.8
Percentage reduction		-13%	-1%	-7%	-5%	-6%	-6%
Kg CO2e in manufacturing / Kg sold	3.50	3.21	3.22	2.35	2.49	2.66	0.94
Kg CO2e in WHS / Kg sold	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Kg CO2e RM / Kg sold	3.51	3.51	3.51	3.51	3.51	3.51	3.51
Kg CO2e Transport / Kg sold	4.20	3.01	2.86	3.01	2.44	1.74	2.97
Kg CO2e / km travelled	**0.80**	**0.88**	**0.84**	**0.88**	**0.71**	**0.49**	**0.87**
Kg CO2e / km travelled DR	1.25	1.25	1.25	1.25	0.99	0.24	1.25
Kg CO2e / km travelled KD	1.21	1.56	1.47	1.56	1.33	0.88	1.48
Kg CO2e / km travelled NK	0.39	0.46	0.46	0.46	0.44	0.41	0.47
km travelled / Kg sold	**5.24**	**3.410**	**3.409**	**3.410**	**3.420**	**3.553**	**3.413**
kg.CO2 in transport / tonne.km	**0.002**	**0.002**	**0.002**	**0.002**	**0.001**	**0.001**	**0.001**
Kg CO2e transport / load	4.34	3.11	2.96	3.11	2.52	1.80	3.07