Eindhoven University of Technology

MASTER

Carbon regulated supply chains
calculating and reducing carbon dioxide emissions for an eye health company

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Carbon Regulated Supply Chains:
Calculating and reducing carbon dioxide emissions for an eye health company

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Abstract
This report describes the development of a method to calculate carbon dioxide emissions resulting from air, rail, road and sea transport. Based on the method a tool in Microsoft Access is built and with this tool the carbon dioxide emissions resulting from the transport of lenses of Bausch & Lomb are calculated. Based on these results the expected costs are calculated for four different scenarios, all based on different possible governmental regulations. The method and the calculations give insights in the importance of the different factors. Also different possibilities to reduce the carbon dioxide emissions are described and applied to Bausch & Lomb.
Acknowledgements

This report is the result of the final project of my master. The past five months I have been working fulltime on this project, partly at Bausch & Lomb and partly at Eindhoven University of Technology. I really enjoyed working on it and I learned a lot from it. But besides me, also others contributed to this project and in this section I would like to thank them.

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Not only the people directly involved in this project supported me. I would really like to thank my parents and my sisters: thanks for always being there for me and listening to my (never ending) stories. Also my friends were a great support and a good source for all sorts of information (as always). Here I want to mention my mother and Eelke separately: thanks to both of you for giving me feedback on my thesis. And I would really like to thank you, Tim, for your never ending support and the good insights you gave me.

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Inge van den Akker
Amersfoort, July 2009
Management Summary

The past few years people are paying attention to global warming more and more. Also companies have to start paying attention to the amount of carbon dioxide they emit. This is mainly due to the following three factors:

- **Governments** are actively trying to reduce emissions and one way of doing this is by regulating the amount of carbon dioxide companies are allowed to emit.
- **Consumers** are becoming sensitive for products that are better for the environment.
- **Civil society organizations** are putting pressure on companies to emit less.

This means that companies have to assess and reduce the amount of carbon dioxide they emit. There are several methods for assessment available, but it is not clear which one is best to use in case the emissions resulting from the transport of one company are to be assessed (first research question).

Methods for carbon dioxide emissions calculations

Five different methods (Artemis, EcoTransIT, GHG Protocol, NTM and STREAM) are compared and table 1 gives an overview of their characteristics. It is important that the chosen method has a good balance between a level of detail that is high enough for the calculations to be accurate and that not too much input data is needed for the calculations. Furthermore, the scope of the method has to be at least on Europe. This, together with the fact that the NTM method provides default factors that can be used in case not enough accurate information is available, makes the NTM method the best suiting method for this project.

<table>
<thead>
<tr>
<th>Method</th>
<th>Background</th>
<th>Scope</th>
<th>Level of Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artemis</td>
<td>Well defined</td>
<td>Europe</td>
<td>Very high</td>
</tr>
<tr>
<td>EcoTransIT</td>
<td>Well defined</td>
<td>Europe (excluding some countries)</td>
<td>Medium</td>
</tr>
<tr>
<td>GHG Protocol</td>
<td>Well defined</td>
<td>World, focus on US</td>
<td>Low</td>
</tr>
<tr>
<td>NTM</td>
<td>Well defined</td>
<td>Europe</td>
<td>High</td>
</tr>
<tr>
<td>STREAM</td>
<td>Well defined</td>
<td>The Netherlands</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 1: overview characteristics methodologies

Based on the NTM method a calculation method and a tool in Microsoft Access are developed. This method takes into account some extra factors than the NTM method (like cleaning and heating and cooling). Besides adding some factors, also some of the default factors have been adapted based on company data. The calculations are done as follows: first the emission for one means of transport (for example a truck) is calculated and then these emissions are allocated to the cargo of interest.

Calculate the carbon dioxide emissions for Bausch & Lomb

This project is done at the European Logistics Centre of Bausch & Lomb, an eye health company. The scope of this project is as follows:

*This project focuses on the carbon dioxide emissions in the transport process of lenses from the European Logistics Centre to the customers in the Europe by all carriers.*

Data is gathered about this transport process and based on this data the emissions are calculated. Bausch & Lomb has outsourced all of its transport to different carriers. Most of the line haul transport is done by road and air and the transport of the lenses to the customers in the countries is always done by road. In total the carbon dioxide emissions are 313 tonnes per year. Figure i below shows the total emissions per country per year.
Other main insights resulting from the calculations are:

- **About one third of the total emissions** are caused by the transport to **Spain**. This can be explained by the fact that this line haul transport is done by air transport, which generally results in higher emissions than the other transport modes. Furthermore, the average weight sent daily is quite high and the distance is large.

- Germany, France, Great-Britain, Portugal and Greece all have **high emissions** as well. This can be explained by either high average weights sent each day and/or the use of air transport.

- The countries Belgium, the Netherlands, Luxembourg, Poland and the Czech Republic all have **low emissions**. This can be explained by either low volumes sent each day and/or short distances for the line haul.

- **Air transport** results in more than 60 percent of the total emissions, transport by van in more than 20 percent and transport by larger trucks in more than 10 percent. Transport using the other transport modes all results in very low emissions, because of the fact that the other transport modes are not used a lot.

**Costs of the emissions**

At this moment carbon dioxide emissions resulting from transport are not regulated yet. However, in the (near) future they will be. It is not clear yet what governmental regulations will be implemented and what the costs for emitting one tonne of carbon dioxide will be. Therefore for different scenarios the costs for Bausch & Lomb are calculated the main conclusion that can be drawn from the costs in the different scenarios is that the carbon dioxide costs will increase the transport costs with a relatively small percentage, which is expected to be around 2 percent and maximally 4.2 percent. Furthermore, for Bausch & Lomb only the costs for emissions resulting from air and road transport are significant; the costs for emissions resulting from rail and water transport are so small that they do not really influence the transport costs (mainly due to the fact that these transport modes are barely used).
Reduce carbon dioxide emissions
The second objective of this research was to make an overview of the different possibilities to reduce the carbon dioxide emissions during transport and to compare these possibilities based on their effectiveness and efficiency. The following possibilities are discussed in this research:

Increase the load factors: increasing the load factor of a truck from 50 to 90 percent reduces the carbon dioxide emission with one third. This is a good option when the load factors are low.

Empty returns: the emissions resulting from empty returns are only taken into account when the return is empty on request of the company. Even though the emissions resulting from the empty return trips are not allocated to Bausch & Lomb, there are still possibilities here for Bausch & Lomb. Currently trucks transport lenses to logistics service providers in Great-Britain and return empty and at the same time lenses are transported from the factories to the European Logistics Centre. Combining these shipments can result in a carbon dioxide reduction of about 60 percent.

Use different transport modes: changing to different transport modes can reduce the carbon dioxide emissions up to 90 percent. However, also the costs and time should be taken into account in this possibility; generally changing to a transport mode that emits less carbon dioxide also means longer lead time and this is not possible in all situations. Furthermore, the costs for using different transport modes can differ as well and should therefore also be taken into account when considering changing to another transport mode. Bausch & Lomb can reduce about 30 percent of the emissions with this option.

Inventory: by placing (more) inventory closer to the customer, it is possible to consolidate more orders and/or to use slower means of transport without changing the lead time to the customers. This can reduce the emissions with a percentage up to 90 percent. For Bausch & Lomb the option of opening a distribution centre (DC) in Spain is analysed and it turned out that the emissions indeed are lower in the situation with a DC: about 83 tonnes of carbon dioxide can be saved per year. Also the total costs are lower in the situation with a DC. However, because this is only calculated for one situation, the results can not be generalized and more research should be done about this option.

Carbon offsetting: this possibility does not reduce a company’s carbon dioxide emissions, but it compensates them. This possibility has two main disadvantages. The first one is that it is a costly option and the second one is that it is not known whether carbon offsetting will be included in the governmental regulations. On the other hand, the main advantage is that emissions can be compensated in large amounts and without having to change any transport processes.
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1 Introduction & Background

In the past years, people became more and more aware of the global warming effects and of the depletion of the natural sources of the earth due to human activities. All over the world and especially in Europe, for consumers, politicians and companies global warming is a hot issue. Every day you can find one or more articles about global warming or carbon dioxide emissions in almost every newspaper.

Also academic literature discusses the concepts of global warming and carbon dioxide emissions. However, not all scientists agree on whether the rise of the temperature of the earth’s surface air and water is mainly caused by human influence or caused by other natural influences. But the following consensus does hold among scientists: “Though the forecasts of future CO2-emissions from fossil energy use as well as the magnitude of their influence on global warming are much disputed, the impact of CO2-emissions on global warming itself is widely admitted” (Kessel 2000, Nordell 2003).

Governments from all over the world are actively trying to reduce the carbon dioxide emissions of their countries. A very important international initiative so far is the Kyoto Protocol, which was initially adopted by many countries in 1997. The objective of this protocol is “to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (European Union 2006). It is expected that this protocol will be renewed by the end of 2009 at the United Nations Framework Convention on Climate Change in Copenhagen, Denmark.

The protocol, among other factors, commits governments to actively reduce the carbon dioxide emissions of their countries. They do this in many ways; for example, many governments are changing the sources of electricity from coal plants to wind turbines or solar power. Another way governments are trying to reduce the carbon dioxide emissions of their countries is by limiting companies in the amount of carbon dioxide they are allowed to produce. At this moment there is a carbon emission trading rights system for a few industries, but not for all industries yet. However, it is very likely that carbon dioxide emissions resulting from transport are going to be regulated in the near future as well.

If governments are going to limit the amount of carbon dioxide companies are allowed to emit, companies will have to start assessing and even reducing their carbon dioxide emissions. However, governmental regulations are not the only reason for companies to start paying attention to their carbon dioxide emissions. Consumers are also becoming more aware of global warming and this causes them to become more sensitive for green products; products that have the characteristic that they are better for the environment. Together with the governmental regulations, this will drive companies to assess and reduce their carbon dioxide emissions.

1.1 CRSC Project

Even though global warming and carbon dioxide emissions are a very hot topic at this moment, there has not been done much academic research about carbon dioxide emissions during transport and about how new regulations could influence the supply chains of companies. Because of this lack of academic research and because of their expertise on the subject of supply chains, the European Supply Chain Forum (eSCF) decided to start up the Carbon Regulated Supply Chains project (CRSC project) at the end of the year 2007.
In the first phase of the project, from the end of 2007 till about the beginning of 2009, literature research is done and the objectives of the project are formulated, as follows:

- To understand the impact of the various regulation alternatives on the design and operation of supply chains;
- To assist decision makers in industry by preparing strategies for coping with the upcoming regulations;
- To impact policy makers and the public opinion on the effectiveness and problems of new regulations.

The second phase of the project started at the beginning of 2009 with four simultaneous master thesis projects at four different companies. These companies are all members of the eSCF and they are Bausch & Lomb, Cargill, Dow Chemical and Unilever.

For the second phase of the project the focus is on the transport of products in the supply chain of companies. It is chosen to focus on the transport process and to leave the production process out of scope because of the following:

- The transport processes of different companies can be easily compared because transport processes usually are quite similar. This makes it possible to draw general conclusions about carbon dioxide emissions resulting from transport.
- Production processes differ from each other and it is very hard to compare production processes and to draw general conclusions about the carbon dioxide emissions during the production.

This report describes the project conducted at Bausch & Lomb, an eye health company. Based on the four master thesis projects also a general report is written (CRSC Report, 2009). The description of the different (upcoming) governmental regulations in section 1.2 is taken from this general report, together with section 3.2 about the NTM method and the description of the scenarios in section 5.4. In the future more master thesis projects will be conducted and more research will be done at Eindhoven University of Technology in order to be able to achieve the objectives of the CRSC project.

1.2 The problem

Companies have to start paying attention to the amount of carbon dioxide they emit, but in general they do not know how much they emit and what the possibilities are for reducing the amount of carbon dioxide produced. There are three main drivers why companies are more interested in the amount of carbon dioxide they emit, the first are the (local, national and international) governments, the second are the consumers and the third are civil society organizations. All of these drivers are described in this section.

Governments are thinking of many different ways to make their countries cleaner and different ways of how to reduce the carbon dioxide emissions in their countries. In 2005 the European Union (EU) started the Emission Trading Scheme (ETS). This system limits companies in the amount of carbon dioxide they are allowed to emit with emission rights. If they emit more than they are allowed to, they have to buy more emission rights and if they emit less than they are allowed to, they can sell emission rights. The amount of emission rights decreases over the years and this way the EU wants to reduce the total amount of carbon dioxide emissions. At this moment the following major industries are included in the ETS: power, chemical, steel, paper and pulp, aluminium and cement. The EU is working on plans to include more industries in the near future. At this moment the only transport included in the ETS is electrical rail transport (because of the inclusion of the power section). However, the EU is planning to regulate the emissions resulting from aviation and sea navigation (both short sea and deep sea) in the near future as well. At this moment there are no concrete plans to include emissions from road and
diesel rail transport in the ETS. However, the EU does have other, further developed, plans for road and diesel rail transport: diesel tax and the Euro-vignette.

The diesel tax is a way of increasing the price of diesel and with that reducing the amount of diesel consumed. There are two ways to implement this: with a new carbon tax or by increasing the current national excises. By implementing the diesel tax the EU hopes to reduce the amount of diesel consumed.

Another possible future carbon dioxide regulation is the Euro-Vignette. The goal of this directive is to apply the “polluter pays” principle, where “the variation of the tolls will take into account the environmental burden of the vehicle” (EU 2006). The Euro-Vignette has already been implemented, but not yet for carbon dioxide emissions (EU 2006). However, the European Parliament already discussed including carbon dioxide emissions in the Vignette. The member states are free to set the cost for the environmental burden within the boundaries as stated by the EU directive.

Because of these different existing and upcoming governmental regulations, companies have to become more aware of the amount of carbon dioxide they emit and they might have to reduce it.

Also consumers become more aware of the consequences of carbon dioxide emissions and they start to pay attention to a product’s carbon footprint; the carbon footprint indicates the amount of carbon dioxide that is emitted during the production, packing, transport, etcetera of the product. It happens more and more that customers prefer a more expensive, but more environment-friendly product over a cheaper, but less environment-friendly product. This can be a threat or an opportunity for companies. If companies do not pay attention to carbon dioxide emissions (and other green factors) they run the risk that their competitors do and that customers are switching to the more environment-friendly competitor. This also means that, if a company is paying attention to carbon dioxide emissions (and other green factors), they can use this in their marketing and branding; it is a way to distinguish themselves from their competitors.

There are many civil society organizations focusing at a greener world, because they also see global warming effects. These organizations put pressure on governments and companies to reduce the carbon dioxide emissions and this pressure forces companies to pay attention to it.

Altogether it is important for companies to assess their carbon dioxide emissions. However, there is one problem:

1. **It is not clear which method to use for assessing carbon dioxide emissions during transport.**

There are different methods for assessing the carbon dioxide emissions of a company, but it is not clear which method is best. There is barely any scientific research on this subject and therefore it is important to do research on this. Furthermore, if a company has insights in its carbon dioxide emissions, it is attractive for the company to reduce it. The second problem arises here:

2. **There is no scientific research about how to reduce the carbon dioxide emissions during transport.**

Therefore also on this subject scientific research should be done.
1.3 Structure of the report

The next chapter describes the research design: it gives the problems and sub problems that are researched in this project and it describes how this is researched. Furthermore it gives some background information about Bausch & Lomb and it describes the scope of this research and why this scope is chosen. Then in chapter 3 a comparison is made between different available methodologies and the best suiting method, NTM, is chosen and based on this method the calculation method that is used in this project is described. Chapter 3 ends with a short description of the C CO$_2$ tool that is used to do the calculations. Chapter 4 explains what data is used in this project and how it is gathered.

Based on the data (as described in chapter 4) and the method (as described in chapter 3) the calculations are done and the results of the calculations are given in chapter 5. This chapter starts with giving the results (in different ways), then gives insights in the effects of the use of assumptions in the calculations, compares the emissions resulting from the transport of Bausch & Lomb’s lenses with other emissions and ends with the costs of the carbon dioxide emissions in different scenarios. Chapter 6 describes different ways for reducing carbon dioxide emissions and evaluates whether these different ways are useful for Bausch & Lomb. And in the final chapter, chapter 7, the conclusions and recommendations of this project are described.
2 Research Design

In the previous chapter the problems that should be researched in this project are given and in this chapter it is described how these problems are researched. First the problem is worked out into more detail and sub problems are formulated. Then it is discussed how the research is designed, what method is used, in what kind of environment the research is done and which data is needed. After that the research environment is described in more detail.

2.1 Problems & Sub Problems

The first problem, as formulated in the previous chapter, is as follows:

1  It is not clear which method to use for assessing carbon dioxide emissions during transport.

This does not mean that there are no methods for assessing carbon dioxide emissions available, but it does mean that there is no national or European standard for it. At the moment there are different methods available that can be used for calculating or estimating carbon dioxide emissions. However, for many of these methods it is unclear what theory lies behind the calculations, what the scope of the method exactly is, and what the assumptions made are. These methods can not be used in this research, because it is very important to know the underlying calculations and assumptions. Therefore the first sub problem is as follows:

1a An overview of methods for assessing carbon dioxide emission is needed, together with the underlying theories and assumptions.

If there is an overview of methods with the underlying theories and assumptions, it is possible to compare these methods with each other and to find the method that fits this research best. Therefore the second sub problem is as follows:

1b The different methods should be compared and the best (suiting) method should be applied.

The second problem as formulated in the previous chapter is as follows:

2. There is little scientific research about how to reduce the carbon dioxide emissions during transport.

Companies have a certain amount of carbon dioxide that they emit and it is likely that either now or in the near future they want to reduce this amount. However, in academic literature there is only little written about ways to reduce the carbon dioxide emissions and what is written is mostly about the use of alternative fuels. Of course the use of alternative fuels is a nice possibility for reducing carbon dioxide emissions, but it is only one of the many possibilities. Therefore it is important to make an overview of what possibilities there are and how efficient and effective they are. This results in the following two sub problems:

2a There is no overview of the different possibilities to reduce carbon dioxide emissions during transport.

2b The different possibilities should be compared based on their effectiveness and efficiency.
2.2 Research Approach

In the previous section the (sub) problems are described and in this section the approach that is used to solve the problems is described.

To be able to solve the first problem first a literature review is done to get an overview of which methods currently are available. After that the underlying theories and assumptions of all of these different methods are analysed and an overview of the advantages and disadvantages of the methods is made. Based on this overview the methods are compared to each other and a choice is made which method suits the CRSC project most. The chosen method should at least have the following characteristics:

- The underlying theories and data are well described;
- The scope is at least on Europe but preferably on the whole world;
- The level of detail is high.

A high level is important, because the lower the level of detail is, the less accurate the results are. However, even though an extremely high level of detail results in very accurate results, it also has one major disadvantage: a large amount of data is needed to calculate the emissions and gathering the data will take a lot of time and effort. Therefore it is important to find a method that has a high level of detail but for which the data gathering won’t take too much time.

After one method is chosen, a tool is developed based on this method, which makes it possible for companies to easily use the method. To develop the tool, company input is used to make sure the tool has the functionalities companies expect from it. After the development, the tool is checked and this is again done with the use of company data. Data is gathered from Bausch & Lomb and the carbon dioxide emissions during transport are calculated.

To be able to solve the second problem, first an overview is made of the possibilities there are, both in literature and in the field. After this, for all of the possibilities more background information is sought and the possibilities are described in more detail. Then, the efficiency and effectiveness of the different possibilities is compared and it is researched which possibility suits what kind of situations best.

Part of this research is done at Bausch & Lomb. Because the CRSC project is supported by the European Supply Chain Forum (eSCF), companies from the eSCF were asked whether they were interested in cooperating in this research and Bausch & Lomb responded in a positive way. In the next section more information about Bausch & Lomb is given and in chapter 4 the gathered data is described.

2.3 Bausch & Lomb

It is very important and interesting to do parts of the research in a company because a company can provide data, but also insights in how companies in the field think about this subject. Furthermore, for companies it is very interesting to gain insights in their carbon dioxide emissions and in ways they can reduce the emissions. Therefore, Bausch & Lomb, an eye health company was also interested. The project could be done at their European Logistics Centre. The European Logistics Centre is responsible for the distribution of products in the area of Europe, the Middle-East and Africa, which means that to and from this location always much transport is done. Furthermore, they were willing to share information. These two factors make Bausch & Lomb an appropriate company for the research. In this section more information about Bausch & Lomb is given.
Bausch & Lomb is an eye-health company that produces four different types of products (in appendix 1 examples of these products can be found):

- **Lenses**: contact lenses;
- **Lens care products**: products for maintaining lenses, for example cleaning fluids;
- **Pharmaceuticals**: products that treat eye problems like eye allergies, dry eyes and retinal diseases;
- **Surgery products**: surgical instruments and equipment, but also products like intraocular lenses.

The company is founded in the year 1853 in Rochester, New York by John Jacob Bausch and his friend, Henry Lomb. It started as a small optical goods shop and in the early years, Bausch & Lomb manufactured revolutionary rubber eyeglass frames and other optical products that required a high degree of manufacturing precision. In the 20th century Bausch & Lomb was still a very innovative company and it grew a lot. At this moment it has 13,000 employees worldwide and the products are sold in more than 100 countries.

This research is done at the European Logistics Centre of Bausch & Lomb at Schiphol-Rijk. No production takes place at the European Logistics Centre; it is purely a distribution centre. In appendix 2 a graphical overview of the supply chain for lenses can be found. The supply chains for the other product types have a comparable structure.

### 2.4 Scope

The scope of this project is as follows:

*This project focuses on the carbon dioxide emissions in the transport process of lenses from the European Logistics Centre to the customers in the Europe by all carriers.*

This section explains why this scope is chosen and figure 1 shows a graphical overview of the supply chain structure for lens products with the scope.
Why from the ELC to the customers? The transport process from the ELC to the customers is called the outbound process of Bausch & Lomb and is responsible for about 84% of the transport costs, while the inbound process, the transport process from the factories to the ELC, is only responsible for 16% of the transport costs. This can be explained as follows: for the inbound process the products have to be transported from only a few factories to the ELC, while for the outbound process, the products have to be transported from the ELC to thousands of customers all over Europe. This means that the outbound transport network is finer meshed. Furthermore, in the inbound process the products can be transported as bulk products (using full truck loads for example), while for the outbound process the products are transported in smaller quantities. Because of this not only the costs, but also the carbon dioxide emissions are larger for the outbound process than for the inbound process and therefore the focus of this project is on the outbound process.
Why lenses? Bausch & Lomb has about 14,000 orders every day, of which about 12,000 orders are for lenses, so the numbers of orders for lenses is far more than for the other product groups. Furthermore, the orders for surgical products and pharmaceuticals quite often are urgent orders and for those orders speed is all that counts (and costs and carbon dioxide emissions are of less importance). If we compare lenses and lens care, it can be concluded that the transport costs for lens care are less than the transport costs for lenses. This might seem a little bit strange, because the average weight for lens care is more than the average weight for lenses, but this can be explained by the fact that orders for lens care can be consolidated and that the orders for lens care have less time pressure. Assuming a positive relation between costs and carbon dioxide emissions, it can also be concluded that the carbon dioxide emissions for lenses are larger than for lens care and that it is more interesting to focus on lenses.

Why Europe? The core market of the European Logistics Centre of Bausch & Lomb is the EMEA area, which is Europe, the Middle-East and Africa; about 85% of the lenses they distribute are distributed in this market. The focus within EMEA is on Europe because of the following reasons. Bausch & Lomb has service contracts with their customers (deliver within 24, 48 or 72 hours) and if Bausch & Lomb would like to change the transport mode from flying to shipping for the Middle-East and Africa regions, this would change the lead time from a maximum of 3 to a minimum of 21 days. Bausch & Lomb already indicated that they are not going to change this. Furthermore, it is harder to gather data about the transport to countries outside of Europe than to countries within Europe. The transport of lenses to Turkey is also out of scope because no information is available about this.

Why all carriers? To get the best calculation of carbon dioxide emissions during transport it is important to have as much detailed information as possible. For example information about transport modes and routes is needed. Therefore the details from all carriers should be collected and all carriers should be included in the research.

Why carbon dioxide emissions? There are several greenhouse gases that are bad for the environment and causing, among other, global warming. This research focuses on carbon dioxide emissions because carbon dioxide is the greenhouse gas that will be regulated by governments. Furthermore, a reduction of carbon dioxide generally also leads to a reduction in other greenhouse gases in case of supply chain redesign.

In some cases the customer is responsible for the transport. In these cases the customer picks up the parcels at Bausch & Lomb and the customer is responsible for the costs. Therefore these customers are not in scope of this research. If Bausch & Lomb is not responsible for the transport, they are not responsible for the emissions during this transport either.
3 Research Method

There are different research methodologies and tools available that are designed to determine carbon dioxide emissions. However, all of these methodologies and tools have different scopes, different backgrounds and they seem to give different emission results. Therefore it is very important to compare these methodologies with each other and to check their backgrounds. This is done in the first section of this chapter and after the comparison the choice to use the NTM method is explained. The NTM method is described in more detail in the next section and after that it is described how the method is used in the development of a tool to be able to calculate the emissions.

3.1 Overview of the available methodologies

In this section first the following methodologies that can be used for the calculation of carbon dioxide emissions are discussed:

- ARTEMIS;
- EcoTransIT;
- GHG Protocol;
- NTM;
- Stream.

After the discussion they are compared and one method that suits this project best is chosen.

3.1.1 Artemis

Artemis means Assessment and Reliability of Transport Emission Modeling and Inventory Systems and is a project initiated by the European Commission in the year 2000 (Artemis, 2007). The reason for the start-up of the Artemis project is quite similar to one of the start-up reasons of this project: there are different emission calculation models available, but they all yield different results and have different backgrounds. For the European Commission it is very important to have one good calculation method in order to be able to compare the emissions of the different countries to each other. Therefore the Artemis project was started up.

The Artemis model is based on European data and has a great level of detail. The following factors are a few factors that are taken into account in the calculation of the emissions for road transport and they show this great level of detail:

- Number of kilometres;
- Fleet structure;
- Type of fuel;
- Exhaust technology (direct injection, catalyst, etcetera);
- Vehicle Age;
- Traffic Situations,
3.1.2 EcoTransIT

EcoTransIT stands for Ecological Transport Information Tool and is developed by the Institut für Energie- und Umweltforschung Heidelberg GmbH and it is initiated and supported by several rail companies from Europe (EcoTransIT 2008). The tool has been developed to be able to compare the emissions and energy consumption of different transport modes and focuses on cargo transport and not on passenger transport. EcoTransIT includes more greenhouse gases in the analyses than the other methodologies.

For the calculation of the emissions the following factors are taken into account:

- Origin and destination (the tool calculates the number of kilometres per country);
- Load factor;
- Type of cargo (bulk, average or volume goods);
- Empty trips;
- Vehicle size.

Figure 2 shows which countries are included in the EcoTransIT tool.

![Figure 2: Map of Europe indicating which countries are included in the emission calculation](image-url)
3.1.3 **The GHG Protocol**
The Greenhouse Gas Protocol (GHG Protocol) has been launched in 1998 at the initiative of businesses, non-governmental organizations, governments and other institutes (GHG Protocol, 2005). The scope of the GHG Protocol is the world with a focus on the United States of America. The Protocol distinguishes between three scopes in order to improve transparency:

- **Scope 1:** direct GHG emissions: includes emissions from sources that are owned or controlled by the company.
- **Scope 2:** electricity indirect GHG emissions: includes emissions from the generation of purchased electricity consumed by the company.
- **Scope 3:** other indirect GHG emissions: includes all other emissions that are a consequence of the activities of the company. Examples of scope 3 emissions are extraction and production of purchased materials and transport of purchased fuels.

The GHG Protocol offers two methodologies to calculate the emissions during transport: a fuel-based and a distance-based method. In the fuel-based approach the emissions are calculated by multiplying the CO$_2$ emission with a factor for the fuel type. In the distance-based method, emissions can be calculated by multiplying the distance with a distance based emission factor.

3.1.4 **NTM**
NTM means the Network for Transport and Environment and it is a non profit organization. It started up in 1993 and the aim is to establish a “common base of values on how to calculate the environmental performance for various modes of transport” (NTM Air, 2008; NTM Rail, 2008; NTM Road 2008; NTM Sea 2008). The NTM working group does not collect data itself, but uses other data sources (like EcoTransIT) to base the NTM method on.

The scope of the NTM method is Europe and at this moment the NTM working group is also trying to gather data about the rest of the world. Furthermore, NTM takes into account the following factors in the calculation of the emissions for road transport:

- Number of kilometres;
- Load Factors;
- Weight of the shipment;
- Type of transport mode (NTM defines different types for which values are given);
- Positioning;
- Empty return trips;
- Topography;
- Type of road (urban, rural or motorway).

3.1.5 **STREAM**
STREAM means “Studie naar Transport Emissies van Alle Modaliteiten”, which means study of the transport emissions of all modalities (Boer et al. 2008). The aim of this study is to give an overview of the emissions of the different modes of transport for both cargo and passenger transport and it is done on a request of the Dutch ministries of Transport and Environment.

The STREAM report is based on field data and it is possible to calculate emissions for specific situations. All data used are data from the Netherlands and calculating emissions with this method is quite accurate for the Netherlands, but not for other countries. STREAM is based on a well-to-wheel approach which means that both the emissions from the transport mode itself and the emissions from the winning and refining process of the oil or electricity are taken into account. So the calculations show all
emissions associated with the use of the transport mode. STREAM gives a 7-step approach to calculate emissions and the most important factors that they take into account in the calculations for cargo are:

- Transport mode;
- Capacity;
- Load Factor;
- Number of kilometres;
- Positioning;
- Empty Returns;
- Product Type (bulk or non-bulk).

3.1.6 Comparison of the methodologies
In the previous sections different carbon dioxide emission calculation methodologies have been shortly introduced. It is clear that the methodologies all have different backgrounds, apply to different areas and at different levels. As was described in the previous chapter, the method at least has to comply with the following characteristics:

- The underlying theories and data should be well described (background);
- The scope should be at least on Europe but preferably on the whole world;
- The level of detail should be high.

Table 1 summarizes the characteristics of the different methodologies. In appendix 3 an overview is given of the factors that are taken into account in the different methodologies, to show the difference between the levels of detail.

<table>
<thead>
<tr>
<th>Method</th>
<th>Background</th>
<th>Scope</th>
<th>Level of Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artemis</td>
<td>Well defined</td>
<td>Europe</td>
<td>Very high</td>
</tr>
<tr>
<td>EcoTransIT</td>
<td>Well defined</td>
<td>Europe (excluding some countries)</td>
<td>Medium</td>
</tr>
<tr>
<td>GHG Protocol</td>
<td>Well defined</td>
<td>World, focus on US</td>
<td>Low</td>
</tr>
<tr>
<td>NTM</td>
<td>Well defined</td>
<td>Europe</td>
<td>High</td>
</tr>
<tr>
<td>STREAM</td>
<td>Well defined</td>
<td>The Netherlands</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 1: overview characteristics methodologies

The different methodologies have advantages and disadvantages and based on this the method that suits this research best is chosen. Artemis has a very high level of detail; however, gathering all the data needed to do the calculations is very hard and can be time consuming. Furthermore, Artemis’ focus is on calculating the emissions for a country and not for a company specific and this makes Artemis not suitable for this project. The GHG Protocol has a low level of detail, which is not enough for this project. Both EcoTransIT and STREAM have a medium level of detail, which is a disadvantage, because makes the calculations aggregate. Furthermore, the focus of the STREAM method is only on the Netherlands, while the focus of this project is on Europe. The focus of EcoTransIT does also not exactly match this project’s focus. NTM has a high level of detail and the method makes it possible to calculate the emissions per lane and also per company, the focus is on Europe and the background is well defined. Furthermore, NTM provides default factors that can be used in case not enough accurate information is available and NTM is working on making its method a standard in Europe. This makes that NTM suits this research best. In the next section the NTM method is described in more detail.
3.2 The calculation method

This chapter describes the method that is used to calculate the carbon dioxide emissions resulting from transport. First, general parameters are discussed and then the methodologies to calculate the emissions for the four different transport modes are given. The calculation method is mainly based on the NTM methodologies (NTM Air 2008; NTM Rail 2008; NTM Road 2008; NTM Sea 2008). The Network for Transport and Environment (NTM) is a non profit organization initiated in 1993 with the following objective:

“In order to promote and develop the environmental work in the transport sector, NTM acts for a common and accepted method for calculation of emissions, use of natural resources and other external effects from goods and passenger transport. The method is primarily developed for buyers and sellers of transport services, hence enabling evaluation of the environmental impact from their own transports.” (NTM Road 2008)

The NTM method provides the possibility to calculate the emissions for the following greenhouse gases:

- Carbon monoxide – CO;
- Carbon dioxide – CO$_2$;
- Hydrocarbon – HC;
- Methane – CH$_4$;
- Nitrous Oxide – N$_2$O;
- Non methane hydro carbons – NHMC;
- Nitrogen Oxide – NO$_x$;
- Sulphur dioxide – SO$_2$.

The focus of this project is on carbon dioxide (CO$_2$) emissions and therefore in this report only information related to carbon dioxide emission calculations is given and information about other greenhouse gases is left out.

All calculations are done as follows: first the total emissions of a means of transport are calculated and then these emissions are allocated to the different shipments on it. Before the different modes of transport are described, a general description of the different factors that are relevant for all modes of transport is given.

In the method several average values are given and assumptions are made. It is very important to keep in mind that these values and assumptions are only used if no actual data is available. The use of actual data will always lead to equally reliable and mostly even more reliable and accurate results.

3.2.1 Transport parameters

Transport parameters that are used in the calculations of the emissions for more than one transport mode are described in this section. Specific issues about these parameters or parameters that are unique to one transport mode are described later on in this chapter.

3.2.1.1 Load factors

For road, water and air transport load factor is defined as the percentage of the capacity of the vehicle used, where capacity is expressed in weight, lane metres or twenty-foot equivalent units. The exact factor used will be explained in the different transport types below. Because of practical reasons (modularity), load factor is defined differently for rail transport. Here, load factor is defined as the ratio of the net-weight of the cargo to the gross weight of the train.
In the methodologies of road and air transport the value of the load factor is used both in calculating the carbon dioxide emissions and in allocating the emissions to the cargo. In the rail and water transport methodologies the load factor is only used in allocating the overall carbon dioxide emissions to the company cargo.

In the following sections the average load factor values that are used in case no actual data is available are described for each mode of transport.

**Road transport**
NTM distinguishes between frequent and single shipments and suggests the following load factors for road transport:

- *Frequent shipments*: the transport is carried out repeatedly by a vehicle travelling back and forth between a shipper and a consignee. The load factor is 75 percent.
- *Single shipments*: the transport is carried out once by a vehicle travelling directly from the shipper to the consignee. The load factor is 50 percent.

Note that if the total weight of the shipment is known this value will be used instead of the assumed load factor.

**Rail transport**
Assumptions for the load factors of trains are based on the data from EcoTransIT (Knörr and Reuter, 2005, which is also used by NTM) and summarised in table 2. The assumptions are based on a study conducted by the IFEU.

<table>
<thead>
<tr>
<th>Type of cargo</th>
<th>Load factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk cargo</td>
<td>0.72</td>
</tr>
<tr>
<td>Average cargo</td>
<td>0.58</td>
</tr>
<tr>
<td>Volume cargo</td>
<td>0.44</td>
</tr>
</tbody>
</table>

*Table 2: Load factors for rail transport*

**Water transport**
The load factor of a vessel is calculated according to the unit that is used for expressing the capacity. For tankers and bulk carriers the unit is tonnes, for container vessels it is twenty-foot equivalent units and for Ro-Ro cargo vessels and ferries it is lane meters.

Apart from the different vessel types, vessel transport is subdivided into two categories: water direct and water shuttle. Based on NTM, load factors have been set for each category. The load factors are shown in table 3.

<table>
<thead>
<tr>
<th>Type of transport</th>
<th>Load factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water direct</td>
<td>0.80</td>
</tr>
<tr>
<td>Water shuttle</td>
<td>0.50</td>
</tr>
</tbody>
</table>

*Table 3: Load factors for water transport*

**Air transport**
Two types of aircrafts are used for cargo transport: cargo aircrafts and combined passenger and cargo aircrafts. For cargo aircrafts a single load factor indicating the capacity utilisation is necessary. In combined passenger & cargo aircrafts both a load factor for the passenger part of the aircraft and a load factor for the cargo part of the aircraft are needed.
NTM Air (2008) does not give average load factor values. Therefore, field data has been gathered and based on that an assumption about the average load factor values for air transport was made. A case study resulted on the assumption of load factors of 80 percent for cargo capacity and 85 percent for passenger capacity. The case study included an airline company and a logistics service provider.

3.2.1.2 Terrain factor
Transport in mountainous areas has higher fuel consumption than transport in flat countries. Therefore, a terrain factor is used in the calculations of the carbon dioxide emissions. This terrain factor only holds for rail and road transport, because water and air do not have to cope with height differences in the terrain. NTM defines three categories: flat countries (Denmark, Sweden and The Netherlands), mountainous countries (Austria and Switzerland) and hilly or average countries (all other countries in Europe). NTM proposes different terrain factors for rail and road transport.

The calculation for rail transport as described in section 3.2.3 is the emission calculation for hilly countries, no terrain factor is included. Emissions increase with 20 percent for mountainous and decrease with 20 percent for flat countries (NTM Rail, 2008).

The calculation for road transport as described in section 3.2.4 is the emission calculation for flat countries, no terrain factor is included. Emissions increase with 5 percent for hilly countries and increase with 10 percent for mountainous countries (NTM Road, 2008).

3.2.1.3 Positioning
In many cases, the means of transport is not at the same location as the cargo. As a result, the means of transport has to be transported to the cargo location. The distance travelled by the means of transport, in order to reach the cargo location, is called positioning distance. In case of rail, water and air transport, the positioning distance is often zero, because the cargo is transported to the location of the means of transport (terminal or (air) port). However, this does not mean that positioning never takes place in rail, water and air transport, but that positioning is more common in road transport.

The NTM method describes positioning for air, road and water transport: “NTM suggests that the emissions related to the positioning trip before the transport are calculated and added to the emissions from the vehicle during the actual transport” (NTM Air 2008; NTM Road 2008; NTM Sea 2008). In the next section, the way positioning is included in the emission calculations for the different transport modes in this project, is described.

Air transport
NTM assumes that air transport is always operated using scheduled flights, which means that there are no positioning distances. Company data of the companies included in the case study also showed that all cargo is flown on scheduled flights. Therefore, this assumption is made in this project as well.

Rail transport
The NTM method does not give any information about including emissions from positioning in rail transport. In academic literature no information about this subject can be found either. Two international rail cargo companies were asked whether they could give any information about this subject. The rail companies indicated that it was hard to give a reasonable figure for this, but they indicated that in most cases the positioning distance is negligible in comparison to the total distance (because much rail transport is operated on schedule on a fixed route). Therefore it is assumed that there is no positioning in rail transport.
Road transport
For road transport, NTM gives different values for average positioning distances for frequent and single road transport. Transport data of three companies, with each at least 100 lanes (both frequent and direct transport), showed average positioning distances of 25, 24 and 16 percent. This is in line with the NTM assumption of 20 percent positioning distance for frequent road transport.

For single road transport, NTM does not provide a reliable assumption. Based on the company data, without distinction between different transport modes, the assumption of 20 percent is used in this case as well.

Water transport
Water transport is often operated on regular routes, where there is no need for positioning. However, in some cases there is positioning in case of tramp traffic (transport on non-regular routes). However, tramp traffic does not occur very often and company data, from the case study, does not show any example for tramp traffic. Therefore it is assumed that there is no positioning for water transport.

Allocation
Who should take responsibility for the emissions from positioning can be debated. Some argue that the logistics service providers are responsible for the emissions, using the following reasoning:

- Logistics service providers can combine different shipments, so theoretically they can take a shipment on the route to pick up another shipment. If the logistics service provider does not do this, it is its own responsibility and therefore the logistics service provider is responsible for the emissions resulting from positioning.
- The customer requests a shipment from a certain origin to a destination. Whatever happens before or after the transport is the responsibility of the logistics service provider and the customer cannot influence it.

Others argue that the customers are responsible for the emissions resulting from positioning because:

- The customer chooses the logistics service provider and in this choice the customer can take into account the distance between (the nearest hub of) the logistics service provider and the location where the cargo has to be picked up. This means that the customer can influence the emissions from positioning and is therefore (partially) responsible for the emissions.
- The logistics service provider is not able to find a shipment on the route to pick up the customer’s shipment in most cases, due to the relatively small positioning distance.

In this study, carbon dioxide emissions resulting from positioning are included in the total emission calculation. Based on discussions with stakeholders it can be concluded that the latter arguments outweigh the former arguments.

3.2.1.4 Empty return trips
After transporting a shipment from the origin to the destination, usually the equipment has to return to the origin where the shipment was picked up or to the logistics service provider. Sometimes another shipment is taken on the way back and sometimes the means of transport is returning empty: the latter is called an empty return trip. During an empty return, no cargo is transported, so the emissions need to be allocated in a different way.

However, as discussed in the chapter on the emissions resulting from positioning, there are different opinions about whether the emissions from empty return trips are the responsibility of the customer or the responsibility of the logistics service provider. In this project it is assumed that when the transport is
dedicated to the customer on request of the customer, the emissions from empty return trips are allocated to the customer. However, if the logistics service provider has the possibility to take another shipment on the return trip, the emissions are allocated to the logistics service provider, no matter whether the logistics service provider takes another shipment or not.

**Trade imbalances**

In case of container transport sometimes containers have to be transported empty because of trade-imbalances. For example, in general there is more cargo transport from Asia to Europe than from Europe to Asia, which means that there is a surplus of containers in Europe and a shortage in Asia and that containers have to be transported empty from Europe to Asia. As described in the previous section, empty returns are only taken into account if equipment is dedicated on customer’s request. This also holds for the transport of empty containers: only if they are transported empty on the request of the customer the emissions are allocated to the customer.

3.2.1.5 Cleaning

In several industries the equipment has to be cleaned after usage to prevent contamination of the next load. This is the case in most of the bulk food industries where food resources are transported, for example sugar, cacao and so on. The transport of other products, like plastics and medical equipment requires cleaning after transport as well. Based on a case study involving four members of the European Federation of Tank Cleaning Organisations (the Belgian, Dutch, Italian and Swedish agencies) the conclusion can be drawn that cleaning is in most cases performed using steam. The steam is always generated by burning fossil fuels. Based on the case study it is assumed that an average of 680 Mega Joules of steam (equivalent to 2 cubic metres at 90 degrees Celsius) is needed for cleaning one unit (i.e. container). The process of burning natural gas to get this amount of energy (for cleaning one unit) leads to an emission of 38 kilograms of carbon dioxide. In the calculation of the emissions, this value is used for steam cleaning.

3.2.1.6 Heating

There are several products that need temperature control during or after the transport of the product. The methodologies to determine the extra emissions resulting from temperature control during and after transport are different and therefore they will be discussed separately below.

**During transport**

Certain products need to be delivered at a specified temperature because otherwise they can deteriorate or their physical properties can change. There are three methods of temperature control during transport, this can be heating, cooling or freezing. These three categories are discussed separately below.

- **Heating**: products usually are heated to prevent them from becoming solid (this occurs if the temperature falls below a certain temperature). Heating is not used very often and no relevant information is found, so therefore no average value is given.

- **Cooling**: with cooling is meant the temperature control to keep the product within a specific temperature range above zero degrees Celsius. This is often necessary in food, beverage and medical industries where products often deteriorate at higher temperatures. Field values show an average increase in fuel consumption of 25 percent in case of cooled transport and this value is also used in the calculations. The calculations take into account that the temperature control is using the truck engine, in reality other methods are available (i.e. auxiliary power unit) but these are not considered in this study.

- **Freezing**: with freezing is meant the temperature control to keep products within a specific temperature range below zero degrees Celsius. This is necessary for all frozen products, like ice-cream. Two average values for the increase in fuel consumption due to freezing during
transport were obtained: McKinnon and Campbell (1998) give a value of 26 percent and a logistics service provider gives a value of 20 percent. Therefore an average value of 23 percent is used in the calculations. The value for freezing is smaller than the value for cooling due to colder loading and better isolation.

**After transport**

Temperature control after transport means that the product is cooled or heated after it has been transported. In practice it hardly occurs that a product is cooled after transport and therefore this is not taken into account in this study. Heating after transport on the other hand is used in several cases in practice. For example, several liquids do not change permanently by the reduced temperature but are hard to extract from the transport equipment at lower temperature due to increased viscosity.

Based on a case study among five service providers it is concluded that the main method of increasing the temperature after transport is steam heating and that a small percentage of containers is heated electrically. The steam is generated by using fossil fuels (i.e. natural gas). Based on the case study an average value of 22 kilograms of carbon dioxide per container is determined and this value is used in the calculations. In practice this value is subject to several parameters, such as the weight of the product and the temperature increase. However, because no data is available for these different factors, an average value is used.

**3.2.1.7 Vertical handling**

Intermodal transport is the transport of cargo using multiple modes of transport without any handling of the product itself (like sorting and repacking) when changing modes. In most cases the cargo is packed in containers or on pallets and the containers or pallets are handled. This handling takes place at a terminal and is called vertical handling.

**Containers**

Normally, vertical handling of containers is operated in one out of the following two ways: by a crane or by a reach stacker. A crane can be powered using electrical energy or using a diesel engine. In most cases reach stackers are powered by a diesel engine.

Vertical handling itself consumes energy and thus leads to extra carbon dioxide emissions. To assess the importance of taking vertical handling into account, the emissions need to be quantified. Two transport terminals have been contacted to find an average carbon dioxide emission of a reach stacker and this value can be found in the table below. For the emissions of a crane, the average value of a report by IFEU is used (Knörr and Reuter, 2005) and also this value can be found in table 4.

<table>
<thead>
<tr>
<th>Handling equipment</th>
<th>Average CO$_2$ emission (tonne/handling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crane</td>
<td>0.002</td>
</tr>
<tr>
<td>Reach stacker</td>
<td>0.007</td>
</tr>
</tbody>
</table>

*Table 4: Carbon dioxide emissions for handling*

To come up with final values that can be used in the calculation, another assumption has been made: moving a container from water transport to road, rail or water transport and vice versa is performed with a crane. All other types of vertical handling are assumed to make use of a reach stacker.

**Pallets**

In case pallets are used, forklifts and pallet jacks are used for handling. For forklifts and pallet jacks, no reliable data could be obtained. It is assumed that this type of vertical handling emits the same amount
of carbon dioxide as a reach stacker. The emission per handling (per pallet) is lower, but more handlings are needed to empty or load one truck.

3.2.1.8 Volumetric weight
The emissions resulting from the transport of a shipment are determined by the weight of the shipment, independent of the volume of the shipment. However, the allocation of the emissions can both be done based on actual weight and on volumetric weight. In case there are volumetric products (like for example lenses) on a means of transport (for example a truck) and the truck is full, the allocation should be done based on volumetric weight; in this case the emissions per kilogram of freight on the truck are higher because of the fact that there are volumetric products in there that are taking up much space. However, if the truck is not full, the allocation should be done based on weight, because it is the weight of the shipments that determines the emissions and in this case there is another factor responsible for the fact that the truck is not full (for example that there are no more shipments). For Bausch & Lomb it is assumed that the allocation is always done based on weight, because in most cases the means of transport are not full.

3.2.2 Air transport method
In this section the method that is used for calculating the carbon dioxide emissions from air transport is described. In this section a general description of air transport is given, followed by air transport specific parameters that are used in the calculation. Next, the calculation formula is given and finally the assumptions that are used are described and discussed. This structure is also used in the descriptions of the methodologies for the other transport modes.

Air transport is defined as all cargo that is transported by an aircraft through the air. Air transport has the advantage that it is very fast and therefore has a low delivery time for transport over large distances. However, one of the disadvantages is that it has higher fuel consumption and, with that, more carbon dioxide emissions per tonne kilometre compared to the other transport modes.

Cargo that is transported via air can be transported in two ways:

- In a dedicated cargo aircraft;
- In the cargo hold of a passenger aircraft (this is called belly cargo).

The calculation of the carbon dioxide emissions from air transport is, if not stated differently, based on the NTM air method (NTM Air, 2008). For the calculation the following parameters are necessary:

- Type of aircraft;
- Load factor;
- Weight of the shipment;
- Distance.

The parameters specific to air transport that need additional explanation are described in the next section.

3.2.2.1 Mode specific parameters
If no distance is given but the origin and destination are known, for air transport the distance can easily be calculated using the great circle distance. The formula for this is:

\[ D = \cos(lat_1) \cdot \cos(lat_2) + \cos(lat_2) \cdot \cos(lon_1 - lon_2) \]

where:

- \( D \) Transport distance in kilometres
is split up into two parts: the constant emission part (which corresponds with the emissions during takeoff and landing) and the variable emission part (which corresponds with the constant emissions per kilometre during cruising). Therefore, the calculation of the total emission of an aircraft can be calculated using the following formula (NTM Air, 2008):

$$TE = CEF + VEF \cdot D$$

Where:
- **TE**: Total Emissions in kilograms
- **CEF**: Constant Emission Factor in kilograms
- **VEF**: Variable Emission Factor in kilograms per kilometre
- **D**: Transport distance in kilometres

The NTM method gives different values for the constant and variable emission factors for several aircrafts and for different load factors. In case of dedicated cargo aircrafts the values are given for load factors of 50, 75 and 100 percent.

In order to be able to use load factors that are different than the three given above, NTM provides interpolation formulas. Below the interpolation formula for calculating the constant emission factors (NTM Air, 2008). Interpolation for the variable emission factor is done in the same way.

$$CEF_{x\%} = \frac{CEF_{x_2} + (CEF_{x_2} - CEF_{x_1})}{(y\% - y\%) \cdot (x\% - y\%)}$$

In the formula **x** is the load factor for which the constant emission factor needs to be calculated, **y** is the load factor smaller than **x** for which the constant emission factor is known and **z** is the load factor larger than **x** for which the constant emission factor is known.

The total emission calculated above needs to be allocated to the cargo that is transported. In air transport allocation is based on weight, because weight is the main factor determining the amount of carbon dioxide emissions.

The allocation can be done based on physical weight or on volumetric weight. In the air industry the generally used conversion factor for volumetric weight is 167 kilograms per cubic meter (kg/m³). In the cases where the volumetric weight is larger than the physical weight, the volumetric weight is used for the allocation (NTM Air, 2008).

### 3.2.2.3 Assumptions

The following assumptions are specific for air transport:

- **Linearity between emissions for different load factors:**
  As was described in the calculation paragraph above, using the interpolation formula assumes linearity between emissions for different load factors. NTM indicated that this actually is not the case. However, because linearity between smaller intervals is used (between 0 and 50%,
between 50 and 75% and between 75 and 100%), the effect of this assumption is smaller than assuming linearity between 0% and 100%.

- **Type of fuel:**
  It is assumed that all aircrafts use JetA-1 fuel. JetA-1 fuel is the most commonly used fuel in air transport, in the calculations the assumption is made that all aircrafts use this type of fuel.

### 3.2.3 Rail transport method

Rail transport is defined as cargo transport over land using railroad tracks. There are two types of trains that can be used, either diesel or electricity powered locomotives. At the European continent rail transport is most often carried out by national railway operators active within national borders. In some cases, this means that the train has to stop at the border to switch locomotives (NTM Rail, 2008). Furthermore, not all countries use the same track width and this means that the carts should be changed at the border (this is seen as vertical handling). There are several parameters that influence the emissions during rail transport and these will be discussed below.

#### 3.2.3.1 Mode specific parameters

General transport parameters were discussed in the beginning of this chapter. Rail transport has several specific transport parameters, which are discussed in this section.

- **Traction type:**
  The engine type of the locomotive is one of the most influential parameters for the carbon dioxide emissions. Usually it is not known which part of the route is carried out by a diesel locomotive and which part by an electric locomotive. In the assumptions below it is stated how the method deals with this lack of information.

- **Size of the train:**
  The size of the train is defined as the gross weight of the total train. This is the weight of the train and all cargo on it. In the calculations the specific gross weight of the train is used. If this is not available the user will have to specify one of the train sizes as specified in NTM; short (500 tonnes), average (1000 tonnes) and long (1500 tonnes). (NTM Rail, 2008).

- **Type of cargo:**
  Another factor that should be taken into account is the type of cargo that is transported. For products with a low density, the capacity is limited by volume while the capacity limitation for high density products is weight.

- **Electricity generation:**
  In case an electric locomotive is used, the emissions during transport depend on the way the electricity is generated. The method of electricity generation varies per country and can lead to significant differences in emissions. In Europe the carbon dioxide emission factors for electricity generation vary between 0.00 kg/kWh (Norway, hydropower) and 0.94 kg/kWh (Poland, coal) (Knörr and Reuter, 2005).

### 3.2.3.2 Calculation

This section gives the formulas for the emission calculation for both diesel and electrical trains. First the formulas for both calculations are given, followed by the explanation of the symbols used.

The formula used for diesel transport:

\[
TE = W_d \cdot D \cdot \frac{EF_{CO_2}}{1 \cdot 10^8} \cdot \frac{153.07 \cdot c_2 \cdot W_{CE}^{0.8}}{LF}
\]

For electrical trains, the formula is given by:
The total emission for diesel trains is based on the weight of the company cargo multiplied with the distance travelled. This is multiplied with the emission factor for diesel. The last part of the formula is the calculation of the energy usage per tonne cargo. This is based on the load factor of the train and the total weight of the train.

For the electric rail emissions the formula is more or less the same, the only difference is that the formula is summed over all the countries. This is done because the emission factor is based on the method for electricity generation in each country.

**Eurotunnel train**

A special type of train is the Eurotunnel train between Calais (France) and Dover (Great-Britain) since the total emissions are more or less the same on each trip, slightly varying with the load of the train. The Eurotunnel has a length of 50.5 kilometres. There are two types of trains in the Eurotunnel: passenger trains and cargo trains. Both are electrical trains. Since the beginning of 2008 all electricity is fed from the French electric sub-station.

A cargo train in the Eurotunnel has an average length of 720 meters and weighs maximally 4000 tonnes when loaded. All of the cargo is loaded onto the train in trucks; the cargo is never unloaded from the trucks. The trucks can maximally be 18.75 meters long (with a maximum height of 4.2 meters and a maximum width of 2.6 meters) and the weight of the truck can maximally be 44 tonnes. Using the Eurotunnel will lead to a fixed emission for that part. The emissions will be allocated based on the cargo weight and capacity utilisation of the truck.

### 3.2.3.3 Assumptions

Most assumptions in the rail transport calculation have been made in the transport parameters section. An assumption specific for rail transport is the amount of electric trains and diesel trains used.

**Diesel-electrical split:**

In most countries in the European Union, electrical locomotives are used. However, some parts of the railway system do not have overhead lines. On these parts, or on entire transport routes containing such parts, diesel locomotives are used. For companies it is often hard to obtain data on the diesel-electrical split of rail transport. Therefore an assumption is made. Based on data on European rail transport data of the year 2005 (Eurostat website, 2009), it is assumed that 75 percent of rail transport is electrical. This means that if no data is available for the percentage of electrical emissions the emissions will be
calculated based on the diesel emission formula multiplied by 0.25 and adding the emissions calculated based on the electrical emission formula multiplied by 0.75.

### 3.2.4 Road transport method
Road transport is defined as transport over road. Road transport services are carried out around the world with vehicles ranging from small distribution vans to long road trains. Road transport has the advantage that it is very flexible and has the ability to reach remote locations. On the other hand, the loading capacity is limited by regulations and there might be increasing congestion problems for some regions.

#### 3.2.4.1 Mode specific parameters
In addition to the general transport parameters described in the beginning of this chapter, this section describes parameters specific to road transport.

- **Vehicle type:**
  Road transport can be operated using different vehicle types. Ten different vehicles are identified, from a small pick-up to a large sixty tonnes truck-trailer combination. An overview of the different vehicle types can be found in appendix 4.

- **Road type:**
  Road transport can be operated on different road types. Based on the NTM method (NTM Road, 2008), three road types are used: motorways, urban roads and rural roads.

#### 3.2.4.2 Calculation
For each vehicle type on each road type, fuel consumption values for empty and fully loaded vehicles are given. To calculate the fuel consumption of the specific vehicle and load factor, the following formula is used:

\[
FC_{LF} = FC_{empty} + (FC_{full} - FC_{empty}) \cdot LF
\]

Where:

- \( FC_{LF} \): Fuel consumption at the specified load factor (litres per kilometre)
- \( FC_{empty} \): Fuel consumption of the empty vehicle (litres per kilometre)
- \( FC_{full} \): Fuel consumption of the fully loaded vehicle (litres per kilometre)
- \( LF \): Specified load factor
- \( TE \): Total carbon dioxide emission
- \( D \): Distance (kilometres)
- \( EF_{CO2} \): Emission factor for fuel (kilogram carbon dioxide per litre fuel)

In case of heating, cooling or freezing during transport, the fuel consumption increases. The values have been described before.

In case the company cargo is only part of the cargo transported using the vehicle, the emissions should be allocated to the cargo.Allocation is either based on weight or on volume (volumetric weight); therefore two steps can be used:

**Step 1:** Compare the physical weight of the cargo to the volumetric weight (volume multiplied with 250 kilograms per cubic metre).

**Step 2:** Allocate based on the highest value.
3.2.4.3 Assumptions

The assumptions specific to road transport are described in this section. The assumptions described in the transport parameters section are also valid for road transport.

- **Load factor linearity:**
  A truck that transports a heavier load has higher fuel consumption due to increased rolling resistance and dynamic weight. In this method, the increase in fuel consumption is approximated by a linear function.

- **Traffic situations:**
  The fuel consumption values for different road types is extracted from ARTEMIS (Artemis 2007) and based on multiple roads within each road type. The fuel consumption values are averages for Europe and do not take into account differences between countries or specific traffic conditions.

- **Idling of the truck:**
  The fuel consumption resulting from idling of the truck is not taken into account in the carbon dioxide emissions calculation from road transport.

- **Speed and driver behaviour:**
  Speed and driver behaviour influence the fuel consumption. These factors are not considered in this method. The reason not to consider this part is because it varies per driver and per route and so on. The values used in the calculations lead to an average emissions under average driving behaviour. If one wants the exact emissions based on the driver behaviour one can use the real values as well.

3.2.5 Water transport method

Water transport is defined as transport over sea or inland waterways with diesel oil-powered vessels. To calculate the carbon dioxide emissions from water cargo transport, several parameters are taken into account. These parameters are described in the next section.

The type of vessel has a large impact on the carbon dioxide emission. Each vessel is unique in its fuel consumption, but since vessel information is often hard to obtain, several general vessel types have been used. These vessel types were taken from the NTM method (NTM Sea, 2008). Most vessels have a main engine that produces the power to move the vessel and one or more auxiliary engines that are used for electricity generation that is used by the crew and passengers.

3.2.5.1 Mode specific parameters

Real values for load factor and average cruise speed are hard to obtain. Furthermore, the impact of a change in these parameters on the fuel consumption is hard to predict, because this differs for each individual vessel. NTM has chosen to use default values for load factor and speed and to give a vessel’s fuel consumption per kilometre based on these default values.

For vessels used in inland waterways, three fuel consumption values are given; upstream transport, downstream transport and an average value.

3.2.5.2 Calculation

Based on the vessel type, the fuel consumption value is given. This fuel consumption value is multiplied by the distance and the carbon content of the fuel and this results in the carbon dioxide emissions for the vessel.

\[ TE = FC \cdot D \cdot EF_{CO_2} \]

Where:

- \( TE \) Total carbon dioxide emission
The total emission needs to be allocated to the cargo of different companies that is transported by the vessel. Allocation is done in different ways for different vessel categories:

- Bulk vessels: vessels used to transport bulk cargo in tanks or holds. The allocation is based on weight.
- Container vessels: vessels used to transport containers. The allocation is based on the number of twenty-foot equivalent units (TEU), which are containers with a length of twenty feet.
- Roll-on/Roll-off vessels (RoRo): vessels used to transport trucks or train carts which can drive on and off the vessel. The allocation is based on lane metres (lanem), so the length of all lanes on the vessel.

With the basis for allocation known, the allocation is done by dividing the capacity used for the company cargo by the total used capacity (one of the three capacity types as described above) and multiplying this value with the total emission of the vessel calculated in the previous step.

A problem with this way of allocating emissions to cargo occurs if a vessel transports multiple kinds of cargo and/or passengers. In this case, the total emission is divided between the number of decks and for each deck, the allocation is done using the method described above.

### 3.2.5.3 Assumptions

In the above description of calculating carbon dioxide emissions from water transport, four assumptions are used. This section discusses these assumptions.

- **Load factor and speed are fixed:**  
  For each vessel type, the fuel consumption is given for a fixed load factor and a fixed average speed. In reality, an increase in load factor or speed will result in an increase in the fuel consumption.

- **Only main engine taken into account:**  
  The main engine is the engine that generates power to move the vessel. This engine consumes most of the fuel. The fuel consumed by the auxiliary engines depends on the vessel size and type. A passenger ferry that offers entertainment to its passengers will consume a lot more energy than a bulk vessel with only a small crew. Taking the auxiliary engines into account will increase the carbon dioxide emission of the vessel.

- **Allocating mixed-cargo vessels based on number of decks:**  
  Allocating carbon dioxide emissions evenly over multiple decks assumes that the impact on fuel consumption of all decks is equal. It seems obvious that this is not true in most cases, since most of the time a specific deck will have a larger impact. However, specific information on the impact on fuel consumption is missing, and therefore the effect of this assumption cannot be estimated.

- **Inland waterways use average flow conditions:**  
  Water transport via inland waterways depends on more parameters than used in the calculation. Besides load factor, speed, and auxiliary engines, the flow of the inland waterway also influences the fuel consumption. The flow of an inland waterway depends on the season, the depth of the inland waterway, the location in the inland waterway (more upstream, the current will be stronger), the direction of travel (upstream or downstream) and the waterway itself. Only the direction of travel is taken into account in the value for the fuel consumption. The
values for upstream and downstream fuel consumption are averages of different waterways and different locations on the waterway.

### 3.3 The development of the C CO₂ tool

To be able to determine the carbon dioxide emissions in a convenient and quick way, a tool is developed: the calculate carbon dioxide (C CO₂) tool. First it had to be decided in which software program the tool should be developed. The software program had to comply with the following demands:

- Easy to use;
- Can store and process large amounts of data;
- Possibility to do calculations;
- Accessible for many users.

It is chosen to develop this tool in Microsoft Access, because of the following reasons:

- Microsoft Access is a Microsoft Office program; most people are familiar with Microsoft Office programs which makes the program easier to use.
- Microsoft Access is a database program and is especially designed to store and process large amounts of data.
- It is possible to do (easy) calculations in Microsoft Access.
- Because Microsoft Access is a Microsoft Office program many companies have a license for it or can easily get a license for it, which makes the program more accessible.

The method that is described in section 3.2 is used as a basis for the C CO₂ tool. The data as provided in the method is inserted in different tables and a Visual Basic Code is written to link these tables with each other and to do the right calculations. Also, the tool is designed in such a way that it is possible to enter data in a very easy way and to do the calculations for this data. And to make it easier for everyone to use the tool, a user interface is designed so that someone who does not have any knowledge of Access and Microsoft Visual Basic can also use the tool. When using the tool, one thing that is important to know is the difference between lanes, phases and shipments. This difference is explained in appendix 5.

In figure 3 a screenshot of the main screen of the user interface is given and this picture also shows the main functionalities of the tool:

- Calculate emissions: the emissions can be calculated for data that is imported into the tool from other data sources or data that is manually inserted into the tool. Furthermore, the emissions can be calculated per lane or per shipment.
- View or export reports: it is possible to make reports of the calculations that are done and to save these reports in Microsoft Excel (which is more commonly used in companies for data analysis).
- Company data: it is possible to import company input data for the calculations from for example Microsoft Excel.
- Method data: it is possible that new data is gathered about the method or better assumptions are made; in case this happens it is possible to update the method data with which the calculations are made without having to leave the user interface.
- Manual calculation: it is possible to manually add information and compare the emissions for two different shipments (for example two different modes).
This is a short overview of what is all possible with the tool; an extensive user guide is written in which a more elaborate description of the tool and the design of the tool is given (CRSC Project, 2009).

Figure 3: Screen shot of the Main screen in the Calculate CO₂ tool
4 Data
This chapter is about the data that is needed for the research. Most data is gathered at Bausch & Lomb and is used to determine Bausch & Lomb’s carbon dioxide emissions and to check the assumptions made in the method part. In the first section the type of data that is needed is described, then the process of data gathering is described and the chapter ends with a section about the actual available data.

4.1 Data needed
The data needed for the project is used for the following purposes:

- To determine the carbon dioxide emissions during Bausch & Lomb’s transport; in order to determine the emissions as accurately as possible, data is needed. If there is less company data, the calculations have to be done with more assumptions, which makes the calculations less accurate.
- To check the assumptions that are made in the method; in the method many assumptions are made, for example about positioning distances and empty return trips. These assumptions are used in the calculations if no actual data is given. For example, if for a certain lane no data about the positioning distance is given, the average positioning distance (percentage) as is given in the method is used. With the actual data, some of the assumptions made are checked.

To be able to do this, the following data is gathered:

- Demand data: this is information about the orders placed by the customers and about the customers. It is assumed that all orders placed are also delivered, because Bausch & Lomb does not refuse orders. The following information about the orders and customers is interesting:
  - Date of the order;
  - Number of ordered lenses;
  - Weight of the ordered lenses;
  - Location of the customer.

- Transport data: this is information about how the lenses are transported to the customers. For all combinations of origin and destination, the following information about the transport is of interest for this project:
  - Number of kilometres;
  - Type of transport (air, rail, road or water);
  - Type of transport mode (for example, for road: type of truck);
  - Weight of the lenses of Bausch & Lomb;
  - Weight of the total cargo in the vehicle;
  - Load Factor;
  - Positioning distance (in kilometres or percentages);
  - Empty return;
  - Cleaning (whether cleaning is necessary or not and if so, what type of cleaning);
  - Refrigerating or heating (whether it is necessary to cool or heat the products during or after transport).

If any of these terms are unclear, in chapter 3.2 they are explained in more detail.
4.2 Data gathering
It is important for the project to gather as much data as possible. Therefore the method used for data gathering is very important. The data gathering is done in two phases:

In the first phase the available data in the company was gathered. This was partly done by talking to different people in the company to get an idea about the supply chain structure and how products are distributed to the customers. Several interviews were held with the distribution manager, the general supply chain manager and the supply chain planner for lenses. These interviews were open interviews, which meant that general information about the supply chain structure, the transport process and other relevant issues was asked. The result was a better overview of the supply chain, of how the lenses are distributed to the customers and which data sources there are available at Bausch & Lomb to gather more data. Bausch & Lomb uses different systems to save company data and one that was very useful for this project was the Global Shipping Application. In this application information about the different shipments to the customers is saved, including information about the location of the customers, dates of the shipments, weight of the shipments, carrier used, etcetera.

Because Bausch & Lomb does not do the transport itself, but has outsourced it to different carriers, Bausch & Lomb does not have any information about the transport process. Therefore, in the second phase of the data gathering process, the carriers were contacted. From the carriers mainly transport data was needed. All carriers were sent an email with an explanation of the project, an explanation of the needed data and a Microsoft Excel sheet where the data could be filled out.

In some cases data provided by the carriers (external data) did not match data provided by Bausch & Lomb (internal data). In these cases the following was done:

- In case the difference was very large, both data sources were checked again and the reason(s) of the large difference was analysed. One of the main reasons for a difference in for example the weight of the shipment was that the carriers gave the weight of the shipment of all product types instead of only for lenses or that the carriers gave data per week or per year instead of per day. After analysis, all of the large differences could be explained.
- In case there was a small difference in data (which was usually also still the case after a large difference was solved), the data from the Global Shipping Application was used. This choice was made because the carriers usually give rough estimates and the data from the Global Shipping Application is more accurate and reliable.

The next section describes all relevant data that was gathered.

4.3 Available Data
In the data gathering phase, information is collected. In this section a summary of all the data is given and in appendix 6 a more elaborated overview of the data per country is given.

The European Logistics Centre of Bausch & Lomb is responsible for the transport of lenses in the area of Europe, the Middle-East, Asia and a few more countries. However, the scope of this project is on Europe, so only the transport to customers and distribution centres in Europe is taken into account. Figure 4 shows a map of Europe with all countries that are included in the calculations.
All transport is outsourced to different carriers, which means that Bausch & Lomb does not do any transport itself. The transport to the customers in the European countries usually consists of a combination of a line haul carrier and a local carrier or it consists of one carrier that is responsible for both the line haul and the transport in the country. The line haul usually is done with road transport (type 8 truck) or a combination of road and air transport (for Andorra, Spain, Portugal, Greece and Turkey). The line haul to the United Kingdom is a combination of road and rail transport (through the Channel Tunnel). Furthermore, the delivery to the customers in the countries usually has the following structure: there is one main hub, from where the lenses are transported to smaller hubs/delivery depots. From the main hub and from these delivery depots the customers are served.

In the next section an overview of the gathered data is given for one country, Spain. This overview consists of a text about the transport structure and a graphical overview. Similar overviews for the other countries can be found in appendix 6. Spain is shown here because the line haul to Spain is a road and air combination, which is more complicated than a road line haul. Furthermore, the transport structure in Spain is a perfect example of what the structures generally look like with one main hub and several smaller hubs.

4.3.1 Example Spain
The shipment of lenses from the European Logistics Centre in Schiphol to Spain is done by Kuehne + Nagel and by ASM. Kuehne + Nagel is responsible for the line haul from the European Logistics Centre in the Netherlands to the airport in Spain and ASM is a local carrier in Spain that is responsible for the transport of the lenses in Spain and Andorra. In the rest of this chapter, Andorra is considered to be part of Spain and not mentioned separately.

Kuehne + Nagel picks up one shipment each (working) day at the European Logistics Centre with a medium truck (Road, type 4) and transports it to Schiphol Airport. From there they transport it to the
airport in Madrid with a Boeing 737 (Air, type 10). Kuehne + Nagel indicated that the load factor of this flight is always almost 100%.

ASM picks up the shipment at the airport in Madrid and transports it to the main hub in Madrid. Next to its main hub, ASM uses six hubs. It should be noted that all of these hubs are transition hubs and that no (Bausch & Lomb) products are stored there. All transport by ASM is done by vans (Road, type 2). From the main hub about one third of all customers of Bausch & Lomb in Spain is served directly. The remaining two thirds of customers is served from the other hubs. Figure 5 shows a graphical overview of the distribution of lenses to customers in Spain.

Figure 5: overview of the transport network to Spain

This information is information about the transport network in general and not about the transport per lane. However, for the calculations it is better to have the data per lane because it is more precise data. This data is also gathered (as far as possible) and for Spain it is shown and explained in appendix 7. This shows only a few lanes for Spain, but of course there are more lanes for Spain and of course also for other countries. This data is not included in this report, but can be found in the Microsoft Access Tool.
4.3.2 Missing data and assumptions

As can be seen in this example and also in the other examples in appendix 6, most of the information is very rough information and some information is missing. The problem with gathering data for Bausch & Lomb lies in the fact that Bausch & Lomb has thousands of customers in Europe and that the products are relatively small products. This makes the distribution network very fine-meshed and forces carriers to combine Bausch & Lomb’s cargo with other cargo. This means that in some cases one Bausch & Lomb parcel is transported in a truck together with many different other parcels and that this truck drives a certain route and delivers to different customers on this route. Furthermore, the carriers responsible for the transport of the lenses sometimes have hundreds or even thousands of vans for the final delivery to the customers. This makes it almost impossible for the carriers to give information about load factors, positioning distance, empty returns, etcetera.

The missing data problem was solved by making assumptions. All of the assumptions were based on available data for similar types of countries. An example of this is the assumption about the number of and locations of the delivery depots in Norway. These locations are not given by the carrier and it was also not possible to get them in a different way; therefore an assumption had to be made about this. Norway is quite similar to Sweden regarding size and shape of the country and for both countries it holds that most inhabitants (about 95%) live in the southern part of the country. For Sweden the number of and locations of the delivery depots are known and because of the similarity of the countries, it is assumed that the number of delivery depots and the division of their locations in Norway is similar to the ones in Sweden. This is an example of how the assumptions are made and in the appendix about data (appendix 6) all of the other assumptions are described.

Using assumptions instead of actual data in the calculations makes the results less accurate. The effects of the assumptions on the results are shown in section 5.2.
5 Results

This chapter starts with the results from the carbon dioxide emission calculations and in section 5.2, these emissions are benchmarked. After this, it is discussed what the influence of the different factors that are taken into account in the calculations is. The chapter ends with calculations for the costs of the emissions in different scenarios. For all of the figures shown in this chapter, tables with the exact data can be found in appendix 8 and all of the figures are based on calculations made with the method that is described in chapter 3.

5.1 Results of the calculations

The gathered data, completed with assumptions in case of missing data, is entered in the tool and this way the emissions resulting from the transport of lenses is calculated. In total the carbon dioxide emissions are 313 tonnes per year and on average the emissions are 236 grams of carbon dioxide per tonne kilometre. This last number is also called the emission factor; this factor gives an indication about the average carbon dioxide emission for the transport of one tonne of cargo over a distance of one kilometre and makes it easy to compare different ways of transport.

This section gives the results in several different ways: first a benchmark is given for the total emissions, then the emissions per country are given, then the emissions for the different types of transport, for the different transport modes and finally for the different carriers.

5.1.1 Meaning of the emissions

The total emissions resulting from the distribution of lenses from the European Logistics Centre of Bausch & Lomb to the customers in Europe is 313 tonnes per year. Because it is hard to imagine what this means, in this section this value is compared to other emission values.

A British (governmental supported) website (Act on CO2 website, 2009) gives an average carbon dioxide emission per person per year of 4.46 tonnes. A United Nations website (UN Statistics division website, 2009) gives an average emission per person of 11.10 tonnes per year and another website (Safe climate website, 2009) gives an average emission per American of 20 tonnes per year. These values include transport (public transport, driving a car and flying for holidays), housing (heating and lighting) and the use of electrical appliances. Taking the average of these values results in an emission of about 12 tonnes per person per year. This means that the transport of lenses of Bausch & Lomb results in the same amount of emissions as 26 persons per year.

The British government also has defined the social cost of carbon; “the social cost of carbon measures the full global cost today of an incremental unit of carbon emitted now, summing the full global cost of the damage it imposes over the whole of its time in the atmosphere” (Clarkson and Deyes, 2002) and is valued between 35 and 140 pounds, about 41 and 164 euros. This means that the social cost of the carbon emitted by the transport of lenses of Bausch & Lomb is valued between 12,795 and 51,175 euros.

Furthermore, a same amount of carbon dioxide is emitted with an average passenger car when it drives about 1.8 million kilometres (assuming an average fuel consumption of 15 kilometres per litre).
5.1.2 Results per country
Figure 6 shows the total emissions per country per year. As can be seen the emissions are different for all countries. There is one lane that is responsible for a large part of the emissions, for about one third. This is the transport of lenses from the European Logistics Centre of Bausch & Lomb to carrier ASM in Spain (ES). The high emission can be explained by the following reasons:

- The line haul to Spain is done by air transport and in general air transport results in higher emissions per kilogram of cargo than other types of transport;
- The weight of the shipment is 320 kilograms, which is higher than the average weight (158 kilograms);
- The distance is one of the longest distances; it is 1779 kilometres while the average distance is 389 kilometres.

Because the emissions of Spain are very high compared to the emissions of the other countries, it is hard to see the difference between the emissions of the other countries. Therefore figure 6 also shows the emissions per country without Spain (on the right). This figure shows that Germany (DE), France (FR), Great-Britain (GB), Greece (GR) and Portugal (PT) all have emissions of more than 20 tonnes per year. These emissions are higher than the average over all countries (15.7 tonnes per year). This can mainly be explained by the following reasons:

- High volume: relatively high volumes are sent to Germany, France and Great-Britain on average each day: respectively 290, 611 and 438 kilograms, while the average weight that is sent per country per day is 158 kilograms. This is the main reason why the emissions for these countries are higher than average.

- Air transport: the line haul to Greece and Portugal is done with air transport and this mainly explains the high emissions for these countries.

Figure 7 shows a map with the emissions per country. Belgium (BE), Czech Republic (CZ), Luxembourg (LU), Poland (PL) and the Netherlands (NL) have low emissions. This can be explained by the fact that the average weight of the shipments sent to these countries each day is relatively low (63, 9, 15, 1 and 95 kilograms respectively). The weight of the lenses sent to Belgium and the Netherlands is not as low as for the other countries, but the relatively low weight in combination with the short distance explains the low emissions for these countries.
The countries that are coloured light orange or yellow in figure 7 have an average emission (between 2 and 20 tonnes of carbon dioxide). This can be explained by the facts that the average weight of the lenses sent per day is not extremely high or extremely low and that there is no air transport used for the regular line haul transport. It seems as if the main factors determining the emissions are weight of the shipment and whether air transport is used or not. This is worked out in more detail in section 5.2.

5.1.3 Results for the different types of transport

Figure 8 shows how the emissions are divided over three different types of transport: the regular transport of the lenses to the customers in the countries (in countries), the regular line haul transport to the countries (Line haul), and the non-regular transport that is done by DHL. The left figure shows the percentage of the total emissions that results from the different types of transport and the right figure shows the emission factors for the different types of transport. The emission factor is the amount of carbon dioxide that is emitted in grams per kilogram of freight per kilometre it is transported.

About 6.5 percent of the total weight is sent by DHL while 10 percent of the emissions are resulting from transport done by DHL. This can be explained by the high emission factor for DHL transport. DHL is usually used in cases when the lenses have to be delivered within a short time and therefore DHL uses air transport in almost all of the cases. Furthermore, because of the fact that the orders are usually not regular orders, the transport can be less efficient.
As can be seen in the figure, the largest part of the emissions (59 percent) results from the line haul transport. This can mainly be explained by the fact that for the line haul transport the distances are larger and the volumes are always high (for the transport in the countries the shipments are split up into smaller quantities per means of transport). Even though the line haul transport results in the most emissions, it has the lowest emission factor of all types of transport. This is remarkable because air transport is used in the line haul transport and air transport has a high emission factor. However, air transport is only used for a few of the lanes and the emission factors of the other lanes are very low. This can be explained by the fact that this transport is done in larger volumes and with transport modes with larger capacities, which generally results in lower emission factors. Altogether this results in low emission factors for line haul transport and it can be concluded that if less line haul transport is done by air, the average emission factor would even be lower.

5.1.4 Results for the different transport modes

Figure 9 shows the percentages of the total emissions resulting from transport with the different transport modes and the emissions factors for the different transport modes.

It is generally known that air transport has higher emission factors than the other transport modes and this is also confirmed here; the absolute emission of air transport is the largest amount of all transport modes and the emission factor for air transport for Bausch & Lomb is also about three times as high as for the other transport modes. Transport by van (R02) results in the second highest emission; this can partly be explained by the fact that the emission factor for transport by van is higher than for transport by larger trucks, but also by the fact that most of the transport in the countries is done with vans; a large part of the lenses has to be delivered at customers in big cities and it is easier to use small vans in cities than large trucks. Furthermore, the vans are always used in transport in the countries and never for line haul transport. This means that generally the load factors are lower which also results in higher emissions.

The difference in emissions for the other transport modes can be explained as follows:

Light (R03) and medium (R04) trucks: generally in the network of Bausch & Lomb for the line haul transport large trucks are used and for the transport to the customers in the countries vans are used. Light and medium trucks are not used often and therefore the emissions resulting from these trucks are low.

Figure 9: Emissions per transport mode in percentages of the total emissions (left) and emission factors for the different transport modes (right, see appendix 4 for meanings of abbreviations)
Chunnel: only the transport of lenses to Great-Britain is done via the Chunnel. Even though this is a high volume each day, the emissions are low. This can be explained by the fact that the Chunnel has a low emission factor; the Chunnel trains are electrical trains and the electricity comes from France where the carbon dioxide emissions resulting from the generation of electricity are low. Furthermore, the trains have large capacities, which also results in lower emissions and the tunnel is designed in such a way that the trains have very little resistance.

Ferry: ferry transport is only used in the line haul transport of lenses to Scandinavia and in the transport of lenses to some of the islands of Italy. Less than one percent of the total distance is distance travelled by a ferry. This partly explains the low emissions for ferry transport. Furthermore, transport over water has quite low emissions in comparison with road and air transport.

Truck with trailer (R07) and a tractor with semi-trailer (R08): These types of trucks are mostly used for the line haul transports. For the line haul transport the weights are high and the distances long, but the load factors are higher and larger trucks generally result in lower emissions than smaller trucks.

5.1.5 Different carriers
Bausch & Lomb uses different carriers for the transport of lenses and all of these carriers also have different emissions, as is shown in figure 10. The transport done by the carrier Kuehne + Nagel (K+N) results in the highest emissions. This can be explained by the fact that K+N is responsible for all regular line haul transport that is done by air. The second most emitting carrier is DHL and, as is also described in section 5.1.1, this is because DHL is responsible for the non-regular transport that usually has to be done within a short time and that also results in the use of air transport.

Except for Nouwens Transport (Nou) and TransMed (TrM) all of the other carriers are responsible for the delivery of lenses to customers in one or more countries only. For all of these carriers it holds that their emission mainly depends on the number of countries they deliver lenses in, the size of the countries and the average weight of lenses that has to be delivered there daily in combination with other factors like which transport mode is used and what the average load factors are. All of this data can be found in the data appendix, appendix 6.

TransMed is not only responsible for the transport of lenses in the countries (Austria, Germany and Switzerland), but also for the line haul to these countries. Nouwens transport is responsible for the line haul transport to several countries. The fact that Nouwens Transport is only responsible for line haul transport and not for transport in the countries explains the low emission factor. In general line haul transport has lower emission factors than transport in the countries (which is more fine meshed and generally has lower load factors). This is also shown in section 5.1.2.

![Figure 10: emissions per carrier in percentage of total emissions per year (left) and emission factors per carrier (see appendix 9 for the meanings of the abbreviations)](image-url)
5.2 Comparison of data and assumptions

In some cases there is not enough data available and then the calculations are done based on assumptions. It is important to know what the differences are between results of calculations based on actual data and results of calculations based on assumptions when interpreting the results. This section shows these differences and shows what factors are crucial to make a good calculation, what factors are important and what factors are of less importance. All of the comparisons are done based on emission factors, which means that the results of the comparisons are not biased by other factors (like for example weight).

5.2.1 Transport Mode

To be able to show the differences between the emissions resulting from using different transport modes, the emission factors are calculated. Figure 11 shows these emission factors for all different transport modes except for air transport. The emission factors for air transport are shown in a different figure (figure 12) because of two reasons. First of all because this factor is more than ten times as large as the other factors and secondly because the emission factors for air transport vary over different distances and the emission factors for the other transport modes are always the same. All of the calculations are done based on average figures for load factors and there are no positioning and empty returns included. For air transport the calculations are done based on one of the most often used aircraft types, the Boeing 747. For rail transport the emissions are calculated both for a diesel train and an electrical train. The calculations for road transport are based on the assumption that a tractor with a semi-trailer is used and the calculations for water transport are based on the assumption that a general cargo coastal vessel is used.

Figure 11 shows that the difference between emission factors for the different transport modes is large: the emission factor for diesel rail transport is about three times as high as the emission factor for sea transport. And, as was said before, the emission factor for air transport is more than ten times the emission factor for the other transport modes. This means that it is very important to have information about which mode of transport is used when calculating the carbon dioxide emissions. Bausch & Lomb has this information for all of its lanes.

![Figure 11: the emission factors for the different transport modes](image-url)
Figure 12: the emission factors for air transport for different distances

5.2.2 Transport Type

There is also a large difference between the different types of transport within each transport mode. In general it holds that the emissions per shipment decrease if the capacity of the means of transport is larger, so that the emission factor is smaller for transport types that have more capacity. For different types of aircrafts, trains, trucks and vessels the emissions are calculated. In each graph the following holds: the further to the right, the larger the capacities of the transport modes are. Figure 13 shows this for road transport. Similar figures for air, rail and water transport can be found in appendix 10.

Figure 13: emissions factors for different truck types with different capacities

Bausch & Lomb has information about the transport types for all line hauls, but not for all road transport in the countries. This means that the results of the calculations are less accurate than they would be with all information available. The assumptions about the transport types in countries for which the truck types are not known are based on actual data of other countries. For all countries where the transport types are known (more than half of the countries), the transport to the customers is done with vans. Therefore the assumption is made that the transport to the customers in the countries is always done with a van. Because this is the case for all countries where actual data is available, this seems to be a good assumption. However, when other trucks are used, the difference in results is a factor two to four, so it is important to gather information about this.
5.2.3 Distance
For rail, road and water transport the carbon dioxide emission is a linear function of the distance. This means that a mistake of 20 percent in the distance results in a mistake of 20 percent in the calculated emissions. Therefore it is very important to have the correct distances. For air transport the relation is not linear because the emissions are calculated with a constant emissions factor and a variable emissions factor. The variable emission of a flight is linearly related to the distance, but because of the inclusion of the constant emission factor the total emission of a flight is not. This is due to the fact that for an aircraft a relatively large part of the emissions results from the take-off. This means that the emission factor decreases if a longer distance is flown. This is also shown in figure 12 in section 5.3.1.

If for a lane the origin and destination are known, it is possible to calculate the distance. For Bausch & Lomb the distance is known for all line hauls, but for the transport in the countries not all distances and locations (of hubs) are known. Therefore assumptions are made about the distances in the countries. These assumptions are based on the following:

- Interviews with the carriers in the countries; this resulted in, among others, indications about the number of hubs and routes and an idea about the density of customers in certain areas.
- Locations of hubs and customers in similar countries; some countries are quite similar in terms of area, population density, average weight of lenses sent per day. If for one country the locations of the hubs are known (for example Sweden) and for a similar country the locations are not known (for example Norway), the assumptions about the locations of the hubs in Norway can be based on the locations of the hubs in Sweden.

This way the assumptions are made as accurately as possible. However, the use of assumptions is always less reliable than the use of actual data and since the carbon dioxide emissions of road transport are linearly related to the distance, it is very important to gather more data about the distances. All assumptions are described in appendix 6.

5.2.4 Load Factors
Load factors indicate how much of the capacity of a means of transport is used. The more of the capacity is used, the less the emissions per kilogram of cargo are. Figure 14 shows the emissions factors for different load factors (varying from 10 percent to 100 percent) for a tractor with semi-trailer. For lower load factors, a certain difference in the load factors leads to a larger difference in the emission factor.

![Figure 14: Emission factors for different load factors for a tractor with semi-trailer](image)
In case of bulk products, average load factors usually are almost 100 percent. Lenses however, are usually transported in means of transport with lower load factors. In some lanes for Bausch & Lomb the load factors are not known and in these cases the average load factors as can be found in table 5 are used.

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Load factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.8</td>
</tr>
<tr>
<td>Rail</td>
<td>0.58</td>
</tr>
<tr>
<td>Road</td>
<td>0.75</td>
</tr>
<tr>
<td>Water</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*Table 5: load factors for the different transport modes*

To check whether the assumptions made about the load factors are reasonable the following is done: for all lanes that do have information about the load factors, the emissions are calculated twice: once with the actual given load factors and once with the assumptions. The difference in the overall emissions is only 1.5 percent. However, looking at the emissions for specific lanes, the difference can be up to 35 percent. This can be explained by the fact that some actual load factors are lower than the assumed load factors and some are higher. However, overall the assumed load factors seem to be reasonable and this makes load factors a less important factor to gather information about.

5.2.5 Positioning
An average positioning distance of 20 percent of the total distance is assumed for road transport. For the other transport modes it is assumed that there is no positioning.

There is not many information about actual positioning distances at Bausch & Lomb; only for two lanes this information is available and this is shown in table 6. The average positioning distance is 44 percent, which is more than twice as much as the assumed value. However, because this average is only based on two lanes (of which one has a very high percentage and the other one has a very low percentage), it is not possible to draw conclusions from this. However, based on interviews with carriers it can be concluded that an average positioning distance of 20 percent for road transport is a reasonable assumption. Furthermore, another conclusion that can be drawn from these interviews is that the positioning distance for Bausch & Lomb in most of the cases will not exceed 30 percent of the total distance. The difference between the emissions as a result of calculations with a positioning percentage of 0 percent of the total distance and the assumed positioning percentage of 20 percent is about 12 percent. And the difference between emissions as a result of calculations with a positioning percentage of 30 percent and the assumed load factor of 20 percent is about 5 percent. This means that the deviation of the emission as a result of using assumptions for the positioning distance from the actual emission is maximally 12 percent. This means that information about positioning distances should be gathered, but that it is not a crucial factor.

<table>
<thead>
<tr>
<th>Positioning distance (km)</th>
<th>Total distance (km)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>11</td>
<td>82%</td>
</tr>
<tr>
<td>50</td>
<td>780</td>
<td>6%</td>
</tr>
<tr>
<td>Average percentage</td>
<td></td>
<td>44%</td>
</tr>
</tbody>
</table>

*Table 6: positioning distances*

5.2.6 Empty Returns
It is assumed that when the empty return transport is dedicated to the customer on request of the customer, the emissions are allocated to the customer. This means that in general no empty returns are assumed. For Bausch & Lomb none of the transport is dedicated on request of Bausch & Lomb so this means that indeed no empty returns have to be taken into account.
5.2.7 **Weight**
The weight of the shipment is very important in the calculation of the emissions. The relation between emissions and weight of shipment is a linear relation and that it therefore is important to have information about the weights of the shipments. Bausch & Lomb does have the weights of all shipments and these values are always used in the calculations.

5.2.8 **Conclusion about the different factors**
In the previous sections the influence of using assumptions instead of actual data on the results of the calculations is discussed. In this section conclusions are drawn about how the results for Bausch & Lomb can be influenced because of missing data. This is summarized in table 7.

The left column in the table gives the factor of interest and the column “Possible deviation” gives the theoretical possible deviation from the actual results. For example, when using the wrong transport mode in a calculation, the results of the calculation can deviate from the actual results with a factor 3 to 50. The column “Data B&L” indicates how well Bausch & Lomb’s data about this factor is and the column “Worst case scenario B&L” indicates how much the results from the calculations done for Bausch & Lomb potentially deviate from the actual emissions as a result of missing data for this factor.

Bausch & Lomb has very accurate data about the factors “transport mode”, “empty returns” and “weight”. This means that, based on these factors, there is no deviation in the calculation results from the actual results. For the factor “transport type” the potential deviation is 60 percent. For all line hauls (60 percent of total emission) and for more than half of the other transport the transport types are known, this means that for 20 percent of the transport the transport types are not known. This means that for this 20 percent the maximum deviation is a factor 4, which results in a total deviation of 60 percent. For the factor “distance” it is very hard to estimate the maximum deviation because it is not known how much the distance deviates from the actual distance. The deviation in the results is the same as the deviation in the distance, because the emission is a linear function of the distance. A rough estimation is made that the distance maximally deviates from the actual distance with 30 percent.

This summary shows that it especially is important to gather more information about the transport types and distances (and locations of hubs), because these factors can result in the largest deviations in the results of the calculations of the emissions resulting from the transport of Bausch & Lomb’s lenses.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Possible deviation</th>
<th>Data B&amp;L</th>
<th>Worst case scenario B&amp;L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport mode</td>
<td>Factor 3 – 50</td>
<td>Very well</td>
<td>0</td>
</tr>
<tr>
<td>Transport type</td>
<td>Factor 2 – 4</td>
<td>Ok</td>
<td>60 %</td>
</tr>
<tr>
<td>Distance</td>
<td>Linearly related</td>
<td>Ok</td>
<td>30 %</td>
</tr>
<tr>
<td>Load factor</td>
<td>&lt; 1.5 %</td>
<td>Bad</td>
<td>1.5 %</td>
</tr>
<tr>
<td>Positioning</td>
<td>&lt; 12 %</td>
<td>Ok</td>
<td>5 %</td>
</tr>
<tr>
<td>Empty returns</td>
<td>0</td>
<td>Very well</td>
<td>0</td>
</tr>
<tr>
<td>Weight</td>
<td>Linearly related</td>
<td>Very well</td>
<td>0</td>
</tr>
</tbody>
</table>

*Table 7: conclusions about the different factors*
5.3 Costs of the emissions in different scenarios

This section describes different possible scenarios for the future and gives insights in what the consequences of these scenarios are for Bausch & Lomb (in terms of costs). All scenarios are based on the existing and possible upcoming governmental regulations as described in the introductory section 1.2. This means that other factors that can effect carbon dioxide emissions are not taken into account.

An example of such other effect is the oil price; the oil price is expected to rise the coming years and this can have a similar effect as for example a carbon tax, because the fuel price will increase in both cases.

One European Union initiative that is not described yet is the EURO-norm. EURO-norms are regulations with regard to vehicle engines. These norms have been set to reduce the environmental burden of vehicles by setting an upper value to the emissions of a vehicle. The EURO-norms lead to a reduction of the emission of several greenhouse gases, but not of the carbon dioxide emissions. Therefore these regulations are not taken into account in the scenario analyses.

5.3.1 Scenario 1: only current ETS

This scenario represents the current situation with only the current ETS. This means that no carbon dioxide emissions resulting from transport, except for the emissions resulting from electrical transport, are regulated. This seems to be a strange situation, since the use of electrical transport modes is discouraged compared to the other transport modes while electrical transport modes are the ones emitting the least carbon dioxide. However, it is interesting to look at this scenario, because it represents the current situation. For this scenario three different prices to emit one tonne of carbon dioxide are set. The lower bound price is the current ETS price, which is 15 euros (reference). Based on the average of multiple sources (Blom et al. 2008; Grubb 2006) the expected average price is set at 50 euros and the upper bound price is set at 100 euros per tonne of carbon dioxide emitted.

In this scenario only emissions resulting from electrical trains are included. The only time Bausch & Lomb is making use of an electrical train is for the line haul transport to Great-Britain. The emissions resulting from this transport through the Chunnel are 12.2 kilograms per year. This means that the costs per year for Bausch & Lomb are very low as can be seen in table 8.

<table>
<thead>
<tr>
<th>Price per tonne CO₂ (€)</th>
<th>Costs (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0.18</td>
</tr>
<tr>
<td>Expected</td>
<td>0.61</td>
</tr>
<tr>
<td>High</td>
<td>1.22</td>
</tr>
</tbody>
</table>

Table 8: Costs per year in scenario 1

5.3.2 Scenario 2: current ETS including air and sea transport in combination with the Euro vignette and diesel tax

The current ETS does only include emissions from electrical transport, but not from other types of transport. The EU is planning to include emissions from air and sea transport in the current ETS. Other plans of the EU are the implementation of the Euro vignette and the implementation of the carbon tax. This scenario represents the situation where all of these initiatives are implemented in parallel. This means that emissions resulting from electrical transport, air transport and sea transport will be included in the current ETS and that the emissions resulting from diesel road transport and diesel rail transport are covered by the Diesel Tax. The emissions from road transport are also included in the Euro vignette meaning that road transport is charged twice.
The prices for the ETS will increase slightly due to the extra emissions that are added to the market. The lower bound price is the current ETS price, which is 15 euros (ECX). Based on the average of multiple sources (Blom et al. 2008; Grubb 2006) the expected average price is set at 50 euros without aviation and navigation. The price is expected to increase with 10 percent when aviation and navigation are included (reference). This leads to an average value of 55 euro per tonne carbon dioxide. The upper bound price was set at 100 euros per tonne of carbon dioxide emitted (Grubb, 2006). The maximum is the price that is needed for stabilisation of carbon dioxide emissions as expected by the Carbon Trust. This price is expected to increase with 10 percent as well due to the inclusion of aviation and navigation leading to a value of 110 euros per tonne CO₂.

The general idea of the Diesel Tax is that the tax on diesel will have to be at least equal to the tax on petrol. The assumption is made that the diesel tax will be set at the same level as the petrol tax. Based on the current EU-27 taxes and diesel/petrol prices the average increase per litre of diesel is determined. The diesel price would increase with around 30 eurocents per litre in that case. This is equal to a price of 110 euros per tonne carbon dioxide; this is based on an emission of 2.642 kilograms carbon dioxide per litre diesel.

Minimum prices for the Euro vignette are set by the European Union. The price is fixed per country and each country can decide how much they ask (however, in this analysis a European wide value is assumed). Only part of this price can be allocated to carbon dioxide emissions. This means that only the part of the Euro vignette price for carbon dioxide emissions will be used in the scenario. For the Euro vignette the price is derived as the total social costs of carbon dioxide emissions as determined in the IMPACT study (Maybach et. al., 2008). In this study the cost of emitting one tonne of carbon dioxide is based on damage cost resulting from that emission. An estimate of 70 euros is given for emitting one tonne of carbon dioxide in 2006. The assumption is made that the EU will set the cost of the Euro vignette such that the cost will cover all social costs of the emission. This means that the cost of the Euro vignette becomes 70 euros per tonne carbon dioxide.

Summarizing, the prices per tonne of carbon dioxide emitted in this scenario are as follows:

**Carbon price ETS (including air and sea transport)**
- lower bound (current price): 15 euros;
- expected average price: 55 euros;
- upper bound: 110 euros.

**Carbon price diesel tax (road, diesel rail)**
- expected average price: 110 euros.

**Carbon price Euro vignette (road)**
- expected average price: 70 euros.

For Bausch & Lomb the emissions for rail and water transport are very low which also results in low emission costs of less than one percent of Bausch & Lomb’s total carbon dioxide costs. Therefore they are not shown in the figures in this section. This means that most costs result from air and road transport. Figure 15 shows the costs resulting from the emissions. In this scenario the price for road transport is fixed, but the price for air transport is varying. In case the price per tonne carbon dioxide emitted in air transport is low (15 euros), the costs resulting from this only are about 11 percent of Bausch & Lomb’s total carbon dioxide costs. However, in case this price is high (110 euros) the costs
resulting from air transport are almost half of Bausch & Lomb’s total carbon dioxide costs (47 percent). This shows that different prices in the ETS result in different results for Bausch & Lomb.

Comparing Bausch & Lomb’s carbon dioxide costs with its transport costs shows that the carbon dioxide emission costs are only a small percentage of the total costs, as can also be seen in figure 16. In this scenario the transport costs of Bausch & Lomb will increase between 1.9 and 3.2 percent (when the price for air transport is low and high respectively). This means that even though the costs per tonne carbon dioxide resulting from road transport are high (180 euros as a result of both the diesel tax and the Euro vignette), this does not have much influence on the total costs.
5.3.3 Scenario 3: current ETS including all transport modes

In this scenario all modes of transport will be included in the current ETS. At this moment electrical transport is already included in the ETS, because the generation of electricity is already included. This means that the emissions resulting from transport are in the same ETS as the emissions resulting from the production. The prices per tonne of carbon dioxide emitted that are expected if transport is included in the ETS are based on a report of CE Delft (Boer et al. 2008) and set as follows:

- lower bound (current price): 15 euros;
- expected average price: 65 euros;
- upper bound: 130 euros.

This again results in low carbon dioxide costs compared to the total costs. This scenario will lead to a cost increase of 0.3 percent in case the carbon price is low, 1.5 percent in case the carbon price is as expected and 3.0 percent in case the carbon price is high.

5.3.4 Scenario 4: current ETS and separate transport ETS

All modes of transport, except for electrical transport (both electrical trains and electrical cars), will be included in a separate transport ETS. Electrical transport can not be included in the transport ETS because electricity is already included in the current ETS. If electrical transport would be included in both the current ETS and the transport ETS the emissions resulting from the generation of the electricity would be regulated twice. This means that the following transport modes are included in this transport ETS:

- Air Transport
- Diesel Rail Transport
- Diesel Road Transport
- Water Transport

The prices per tonne of carbon dioxide emitted that are expected in the transport ETS are based on a report of CE Delft (Boer et al. 2008) and set as follows:

- lower bound (current price): 30 euros;
- expected average price: 90 euros;
- upper bound: 180 euros.

Electric train transport is not included in the transport ETS, but is included in the already existing ETS and the prices in this ETS are the same as in scenario 1. This means that the carbon dioxide costs resulting from the electric train transport are also the same as the costs in scenario 1, which means that they are negligible. The costs for the carbon dioxide emissions resulting from the other transport types however, are the highest of all scenarios. But comparing these costs to the transport costs again shows that the carbon dioxide emissions do not have a large influence: in case the carbon dioxide price is low, the transport costs will increase with 0.7 percent; in case the price is as expected, the transport costs will increase with 2.1 percent and in case the price is high, the transport costs will increase with 4.2 percent.
5.3.5 Conclusions about the different scenarios

The main conclusion that can be drawn from the costs in the different scenarios is that the carbon dioxide costs will increase the transport costs with a relatively small percentage, maximally with 4.2 percent. Furthermore, for Bausch & Lomb only the costs for emissions resulting from air and road transport are significant; the costs for emissions resulting from rail and water transport are that small that they do not really influence the transport costs. This means that in scenario 1 (the current situation) Bausch & Lomb does not have any extra costs for carbon dioxide emissions. In the other scenarios both air and road transport are regulated and this does lead to extra costs for Bausch & Lomb. However, it depends on the height of the carbon prices how much the extra costs are. The average of the expected prices of carbon from scenario 2, 3 and 4 is about 2 percent. Not having any more information about the likelihood of the different scenarios, this can be seen as the expected carbon dioxide costs (assuming that the amount of emissions remains the same), which is about 25 thousand euros.

The fact that the costs resulting from carbon dioxide emissions during the transport of Bausch & Lomb are not expected to be large compared to the total transport costs, does not mean that it is not important for Bausch & Lomb to reduce their carbon dioxide emissions. Other drivers, like customers’ preferences for green products or internal drivers to become greener, are also important. And because of these other drivers it is important for Bausch & Lomb to consider reducing their carbon dioxide emissions. The next chapter describes several reduction possibilities.
6 Carbon dioxide reduction possibilities

There are several reasons for Bausch & Lomb to reduce its carbon dioxide emissions during transport. The previous chapter showed that governmental regulations are expected to increase the transport costs with 2 percent and maximally with 4.2 percent, but there are also other drivers. For example, Bausch & Lomb has internal drivers to become greener (which is also the reason why they wanted to work on this project) but also some of their customers are becoming sensitive to greener products (which means that reducing the carbon dioxide emissions during transport can give Bausch & Lomb a competitive advantage).

In general there are different ways of reducing carbon dioxide emissions during transport. In this chapter several ways are described and it is analysed whether these ways could be used to reduce the carbon dioxide emissions of Bausch & Lomb. The main challenges for Bausch & Lomb are:

- Costs; Bausch & Lomb wants to keep the costs as low as possible, so reduction possibilities that are very costly will not be used.
- Time: Bausch & Lomb has service contracts with the customers, which means that the lenses always have to be delivered within a certain time.
- Outsourced transport: Bausch & Lomb has outsourced its transport to several carriers, which means that there are some factors that can not be influenced easily.

6.1 Alternative fuels

At this moment most (road) vehicles drive on traditional fuels: diesel or petrol. However, the past years much research has been done on the use of alternative fuels and more and more vehicles that drive on alternative fuels have been developed. The use of alternative fuels has the following main advantages:

- less carbon dioxide is emitted;
- less dependence on natural sources (oil).

At this moment the most popular and furthest developed alternative fuel vehicles are:

- Bio fuel vehicles;
- Hydrogen vehicles;
- Electric vehicles;
- Vehicles on solar power;
- Hybrid vehicles (this actually is not a vehicle using a different fuel type, but a vehicle that is designed with a battery which makes it more efficient).

Alternative fuel vehicles offer great possibilities for companies to reduce their carbon dioxide emissions in the future. However, at this moment, except maybe for the electric vehicles, the vehicles are not developed far enough in order to be used on a large scale. Furthermore, for Bausch & Lomb it is hard to implement the use of alternative fuel vehicles. Bausch & Lomb’s transport is outsourced to several carriers and Bausch & Lomb can not directly influence the type of vehicles that are used for their transport. In the future Bausch & Lomb could take the number of alternative fuel vehicles a logistics service provider is using into account when choosing a new logistics service provider but at this moment there are not many such service providers yet. The difference in emissions between traditional vehicles and alternative fuel vehicles depends on the type of alternative fuel. For electric vehicles the emissions mainly depend on the way the electricity is generated: in some countries there are no emissions resulting from the generation of electricity, which results in no carbon dioxide emissions for electric vehicles. Using bio fuel reduces the emissions with about 75 percent (Green America website, 2009).
It is very hard to predict the effect of the use of some alternative fuel vehicles on a large scale. For example, if bio fuel is going to be used a lot, this can result in more deforestation and this does also have a negative effect on the global warming on the earth (Energy Portal website, 2009). Altogether it can be concluded that more research about the use of alternative vehicles should be done.

6.2 Changing “strategy”
Not only the type of vehicle, but also the way it is used determines the amount of emissions the vehicle produces. As was also said before, it is hard for Bausch & Lomb to influence the way the vehicles are used, but it is not impossible. This chapter describes if and how Bausch & Lomb can reduce its carbon dioxide emissions by changing factors like load factors, empty returns and different transport modes.

6.2.1 Load factors
As was also shown in section 5.2.1, the load factor of a means of transport has a large influence on the emissions of that means of transport, especially when the load factor is low. Except for some line hauls the shipments of Bausch & Lomb are usually combined with shipments of other companies. The logistics service providers usually are doing this because higher load factors lead to lower costs. Because most logistics service providers are already trying to get load factors as high as possible, not a large amount of emissions can be reduced here. The same holds for the line hauls where only Bausch & Lomb products are transported. If the logistics service providers could combine Bausch & Lomb’s cargo with other company’s cargo, they would do it, so apparently (in most cases) this is not possible. The only way Bausch & Lomb could increase the load factors is by consolidating more orders. However, in most cases this is not possible because of the agreed delivery service of 24 hours to the customers. Altogether, it can be concluded that reducing the carbon dioxide emissions by increasing the load factors is not a very effective option for Bausch & Lomb.

6.2.2 Empty returns
Bausch & Lomb does never have empty returns on request and therefore none of the emissions of empty returns are allocated to Bausch & Lomb in this project. However, it is not known how emissions resulting from empty returns will be included in the different governmental regulations and therefore this section describes how empty returns can be reduced at Bausch & Lomb.

The service logistics providers do already have the option to take another load on the way back. For the transport in the countries, they already do combine different shipments and try to avoid empty returns as much as possible. Data from the service logistics providers in the countries shows that in about 90 percent of the cases they have a return load so that there usually are no empty returns. However, for the line hauls, there are many empty returns. It seems that service logistics providers would take a return load if it was possible, because this saves them costs. Therefore it is assumed here that the logistics service provider would like to take cargo on the way back, but that there is no cargo available for this.

However, Bausch & Lomb can also plan to combine shipments from the factories to the European Logistics Centre with line haul transports of lenses. For example, Bausch & Lomb has a factory close to London and products have to be shipped from this factory to the European Logistics Centre. The possibility of combining this shipment with the line haul transport to Great-Britain should be investigated further, but is interesting, since about 3 tonnes carbon dioxide per year can be reduced. On average an empty return trip emits between 60 and 90 percent of a trip with cargo. This means that this percentage can be saved.
6.2.3 Different transport modes

There is a large difference in emissions when using different modes of transport. This section compares the emissions and costs resulting from transport with different modes. This is only done for the line haul transport; the transport in the countries is very fine-meshed and therefore it is (almost) impossible to use other transport modes than road transport. First a comparison is given for the line haul transport to Great-Britain. It is chosen to work out the transport to Great-Britain in more detail, because the sea has other transport modes than road transport. First a comparison is given for the line haul transport to the emissions and costs resulting from transport with different modes. This is only done for the line haul transport to Great-Britain.

6.2.3.1 Transport to Great-Britain

At this moment Bausch & Lomb uses a combination of road transport and the Channel Tunnel train (also called Chunnel train) for the line haul transport of lenses to Great-Britain. There are three other options for transporting lenses to Great-Britain. Figure 17 shows the different transport possibilities to Great-Britain graphically.

![Figure 17: different transport possibilities to Great-Britain](image)

The carbon dioxide emissions for these four different transport possibilities are calculated using the general assumptions made in the method (about load factor, positioning, etcetera) and the results are shown in figure 18. Air transport results in the highest carbon dioxide emissions and transporting the cargo entirely by rail results in the lowest emissions. However, there already are passenger trains going from Amsterdam to London (via Brussels), but no cargo trains. Therefore this option is not possible yet. At this moment Bausch & Lomb is transporting its lenses by a combination of road and the Chunnel and this results in low carbon dioxide emissions, especially compared to air transport. Comparing road & Chunnel with road & ferry does not seem to show a very large difference in emissions. However, for both lanes the main part of the emissions (4.96 kilograms) is emissions resulting from the road transport. Comparing just the Chunnel and a ferry shows a large difference in emissions: 2.7 kilograms for a ferry and 0.15 kilograms for the Chunnel.

Not only the carbon dioxide emissions are important when considering changing to a different mode: also the costs and the time needed for the transport are important. These are shown in table 9. For the costs the costs of the current situation (Road + Chunnel) are set at 100%. These costs do include carbon dioxide costs already, which are calculated based on the expected carbon dioxide price of 90 euros for all transport modes. From the table it can be concluded that rail transport takes about 3 days, which is quite long and which makes rail transport not possible anymore because of the service contracts with the customers.
Figure 18: emissions for different transport options to Great-Britain

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Emission Costs (€)</th>
<th>% of transport costs</th>
<th>Lead time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>9303</td>
<td>373%</td>
<td>½</td>
</tr>
<tr>
<td>Rail</td>
<td>168</td>
<td>148%</td>
<td>3</td>
</tr>
<tr>
<td>Road + Chunnel</td>
<td>529</td>
<td>100%</td>
<td>1</td>
</tr>
<tr>
<td>Road + Ferry</td>
<td>220</td>
<td>100%</td>
<td>1 ½</td>
</tr>
</tbody>
</table>

Table 9: Overview costs and time for different transport modes for the line haul transport to Great-Britain

6.2.3.2 All Line Hauls

It can be concluded that for all line hauls electrical rail transport results in the lowest emissions and that the costs of rail transport generally are quite low as well (an overview can be found in appendix 13). However, rail transport is also the slowest transport mode (in almost all of the cases) and the costs are a very rough estimate so more information about this should be gathered. Furthermore, air transport results in the highest emissions for all of the countries and in most of the cases also in the highest costs. On the other hand, air transport is the fastest transport mode and the more information about the costs should be gathered. This means that per country a trade off should be made between time on the one hand and emissions and costs on the other hand.

6.3 Inventory

As is described in the previous section, there are different possibilities to reduce Bausch & Lomb’s carbon dioxide emissions, for example by changing to different transport modes. However, in general the transport modes that emit less carbon dioxide are slower means of transport and with most of their customers Bausch & Lomb has 24, 48 or 72 hour delivery service agreements. This means that reducing the emissions by changing to slower transport modes is not possible for many countries. To overcome this, Bausch & Lomb can do the following:

- It can change the delivery service agreements with the customers so that the lenses can be delivered in a longer time, for example a week. This makes it possible to use different, slower transport modes. This also gives options for other ways to reduce the emissions, for example by consolidating more orders; if all orders for two days for one country are consolidated and transported at once instead of in two line haul transports, this can reduce the carbon dioxide emissions (because of higher load factors and less empty kilometres). However, changing the delivery service agreements is not very easy: it will take much effort, partly because of the fact that Bausch & Lomb delivers lenses to many different customers and these customers are not the end-users of the lenses. Furthermore, there is the possibility that the customers are not willing to change the delivery time.
Bausch & Lomb can also solve the service delivery problem by moving inventory closer to the customers. This way if a customer places an order, the lenses have to be transported over a shorter distance in the same time period (24, 48 or 72 hours), which means that slower means of transport can be used and/or more orders can be consolidated. Furthermore, the transport from the European Logistics Centre to the place where the lenses are kept on stock, usually a distribution centre, can also be done with slower, more environmental friendly transport modes. At this moment Bausch & Lomb is already keeping lenses on stock in Italy, Greece and Turkey. In the next section the scenario of opening a DC in Spain is discussed. It is chosen to look at the situation in Spain because the line haul transport to Spain is responsible for a large part of the carbon dioxide emissions and because the distance to Spain is large. Changing this line haul from air transport to road transport would reduce Bausch & Lomb’s emissions with about 30 percent, but is only possible when there is more time available for the line haul transport so when opening a DC.

6.3.1 Opening a new DC in Spain

In this section the costs and carbon dioxide emissions for the situation where a distribution centre is opened in Spain are calculated and compared to the costs and carbon dioxide emissions in the current situation where there is no distribution centre.

Bausch & Lomb has about 30,000 stock keeping units for lenses. A stock keeping unit can be defined as “an item of stock that is completely specified as to function, style, size, colour, and, usually, location” (Silver et al. 1998). This definition explains why Bausch & Lomb has this many stock keeping units: there are many different lens types and every lens type that has many different dioptres and all of these products are different stock keeping units. Because of this large amount of stock keeping units Bausch & Lomb does all of its forecasting and planning on product group level. It is chosen to do this analysis on product group level as well. A product group consists of all lenses of one type with different dioptres. Furthermore, in the existing distribution centres Bausch & Lomb is not keeping all product groups on stock, but only the fast movers. Also in this analysis it is chosen to keep only the fast moving products on stock. In order to determine the fast moving products for Spain, an ABC classification is done. This classification showed that 14 percent of the product groups are responsible for 84 percent of the weight that is sent to Spain. The assumption is made that only these product groups are kept on stock in the distribution centre in Spain. Furthermore, it is assumed that the demand is normally distributed and given the fact that these items are all fast-movers this assumption is reasonable.

There are eight different fast moving product groups that would be kept on stock in the DC in Spain. It is assumed that these lenses are transported by road instead of air and that the other slower moving lenses are still transported by air. Because there are eight different product groups that will be kept on stock, it is chosen to use a periodic-review, order-up-to-level strategy (also called R,S strategy). In this strategy every period (R) an amount of products is ordered that is enough to raise the inventory position to a certain level (S). This strategy is chosen because it is a useful strategy when there is resource sharing (Silver et al. 1998). If a continuous-review strategy would be used, for all the different product groups orders would be placed at different times. This would result in less consolidation and with that in more costs and more carbon dioxide emissions. The calculations that are done are explained in appendix 14 and in the rest of this section the results are given.
Figure 19 shows the different costs for the two different situations: the left (light blue) bars show the costs in the situation with a distribution centre in Spain where most of the line haul transport is done with road transport and a small part is done with air transport and the right (dark blue) bars show the costs in the current situation where there is no DC and where all line haul transport is done with air transport. As can be seen in the figure, in the current situation without DC almost 100 percent of the costs are the air transport costs, while in the situation with a DC the total costs consist of road transport, air transport and holding costs. Furthermore, the total costs are higher in the current situation without a DC than in the situation with DC. Also, the carbon dioxide emissions are a lot lower in the situation with a DC: about 83 tonnes per year can be saved.

Based on this one example it is not possible to draw general conclusions about whether moving inventory closer to the customer leads to lower transport costs. However, it is expected that moving inventory closer to the customer leads to lower emissions and that it also leads to lower costs. This should be researched in more detail in further research.

6.4 Carbon offsetting
A company can also offset emissions, instead of reducing its own emissions. Offsetting means investing in projects that reduce carbon dioxide emissions somewhere else. This way a company can compensate its carbon dioxide emissions.

There are several initiatives in the field of carbon offsetting; different organizations are offering carbon offset projects and several standards have been developed that make it possible to compare different carbon offsetting projects. Many of these projects take place in poorer countries where it is possible to reduce carbon dioxide emissions with lower investments. In general there are three different types of projects:

- Renewable energy projects: these are investments in alternative energy generation project like wind-, solar or biomass projects.
- Energy efficiency projects: in these projects existing energy use is reduced, for example by making equipment more efficient.
- Reforestation projects: forests absorb carbon dioxide and these projects build new forests.
Some transport companies already offer the possibility of carbon offsetting. KLM and DHL for example offer the services that you can calculate and offset the emissions resulting from sending a shipment with them.

For Bausch & Lomb carbon offsetting would be a possibility to compensate their carbon dioxide emissions. However, offsetting carbon dioxide emissions costs money and there are other ways of reducing the emissions that are less costly or cost neutral (as is described earlier in this chapter).

6.5 Marketing possibilities
Consumers are paying more and more attention to the environment and are starting to pay attention to the carbon footprint of a product. It is not possible to give a carbon footprint of the lenses of Bausch & Lomb, because only the emissions resulting from transport are calculated and not the emissions resulting from production or other processes. However, it is still possible to use this study in Bausch & Lomb’s marketing.

At this moment most customers are getting their lenses within one or two days. This means that relatively fast means of transport have to be used that are generally emitting more carbon dioxide. There are two ways this study can be used in marketing:

- Bausch & Lomb can mention that it is assessing and reducing its carbon dioxide emissions. If Bausch & Lomb’s competitors are not doing this, it can be a competitive advantage.

- Customers can be offered the possibility to choose between a fast or a slow delivery of their lenses. Then the difference between the two possibilities can be shown in terms of carbon dioxide emissions. For example, customers in Spain can be offered the possibility to choose between a within 48 hours delivery or a within a week delivery. Roughly, in case of the within a week delivery the emissions for the line haul (road transport) are only 25% of the emissions for within 48 hours delivery (air transport).
7 Conclusions and Recommendations

This chapter gives the conclusions that can be drawn from this study. It starts with describing what method is chosen to assess the carbon dioxide emissions and what the results of the calculations of the emissions resulting from Bausch & Lomb’s transport of lenses are. In section 7.2 general possibilities for reducing carbon dioxide emissions are given and in section 7.3 the possibilities for Bausch & Lomb are given in the form of recommendations. And this chapter ends with giving the limitations of this study and recommendations for further research.

7.1 Assessing carbon dioxide emissions

The first objective of this research was to get an overview of methods for assessing carbon dioxide emissions resulting from transport and to compare the different methods and select the best (suiting) one for this project. This study compared five different methods: Artemis, EcoTransIT, the GHG Protocol, NTM and STREAM and concluded that NTM is best to be used in case the carbon dioxide emissions of one company are to be assessed and the scope of the research is Europe. Furthermore, one of the main advantages of the NTM method is that it provides average values that can be used in case no actual data is available, which is very useful in this research. A carbon dioxide calculation method for this project is developed based on the NTM method; a few factors, like heating, cleaning and vertical handling were added to the original NTM method and some default average values were changed based on field data. Also a tool is developed in Microsoft Access to make it easy to calculate the emissions based on company data.

Using this tool, the carbon dioxide emissions are calculated for the transport of lenses of Bausch & Lomb to customers in Europe. The total emission per year is 313 tonnes. Other main insights resulting from the calculations are:

- About one third of the total emissions are caused by the transport to Spain. This can be explained by the fact that this line haul transport is done by air transport, which generally results in higher emissions than the other transport modes. Furthermore, the average weight sent daily is quite high and the distance is large.

- Germany, France, Great-Britain, Portugal and Greece all have high emissions as well. For the first three countries this can be explained by the high volumes that are sent to these countries each day and for the latter two it can be explained by the fact that the line haul transport is done with air transport.

- The countries Belgium, the Netherlands, Luxembourg, Poland and the Czech Republic all have low emissions. For the latter three countries this can be explained by the low volumes that are sent to these countries each day and for the first two countries it can be explained by low volumes sent each day in combination with a short distance for the line haul.

- Most of the emissions result from the line haul transport (compared with the transport of lenses in the countries and the non-regular transport done by DHL). However the emission factors (amount of carbon dioxide emitted per tonne kilometre) are the lowest for the line haul transport. This can be explained by the facts that the distances are large for the line haul transport and that the line haul transport is done in larger volumes and with transport modes with larger capacities.
- **Air transport** results in more than 60 percent of the total emissions, transport by van in more than 20 percent and transport by larger trucks in more than 10 percent. Transport using the other transport modes all results in very low emissions, because of the fact that the other transport modes are not used a lot.

Also an analysis is done about which factors are important for Bausch & Lomb and which are of less importance. To get more accurate emission results it is important that more information is gathered about the transport types that are used and about the exact distances that are driven in the countries. Using incorrect data for these two factors can result in a maximum deviation from the actual emissions of 60 and 30 percent respectively.

At this moment carbon dioxide emissions resulting from transport are not regulated yet. However, in the (near) future they will be. But it is not clear yet what regulations will be implemented and what the costs for emitting one tonne of carbon dioxide will be. Therefore for different scenarios the costs for Bausch & Lomb are calculated and the main conclusion is that the costs of carbon dioxide emissions resulting from the transport of lenses of Bausch & Lomb will maximally be 4.2 percent of the current transport costs. Furthermore, the expected costs are about 2 percent of the current transport costs.

### 7.2 Possibilities for reducing carbon dioxide emissions

The second objective of this research was to make an overview of the different possibilities to reduce the carbon dioxide emissions during transport and to compare these possibilities based on their effectiveness and efficiency. The following possibilities are discussed in this research:

- **Increase the load factors**: increasing the load factor of a truck from 50 to 90 percent reduces the carbon dioxide emission with **one third.** In situations where the average load factors are low, this is a very good option for reduction.

- **Empty returns**: the emissions resulting from empty returns are only taken into account when the return is empty on request of the company. It does not occur very often that a return is empty on request of the company and therefore in most cases the emissions resulting from empty returns are the responsibility of the carrier. This makes reducing carbon dioxide emissions by reducing the number of empty returns a less efficient option. However, it is always good to combine shipments to prevent an empty return, even if it doesn’t reduce the carbon dioxide emissions allocated to one specific company. On average an empty return trip emits an amount of carbon dioxide that is **between 60 and 90 percent** of the outward journey (with cargo). This means that this percentage can be saved.

- **Use different transport modes**: in general air transport has higher emission factors than road transport and road transport again has higher emission factors than electrical train transport. Changing to different transport modes can reduce the carbon dioxide emissions **up to 90 percent.** However, also the costs and time should be taken into account in this possibility; generally changing to a transport mode that emits less carbon dioxide also means longer lead time and this is not possible in all situations. Furthermore, the costs for using different transport modes can differ as well and should therefore also be taken into account when considering changing to another transport mode.

- **Inventory**: by placing (more) inventory closer to the customer, it is possible to consolidate more orders and/or to use slower means of transport without changing the lead time to the customers. This can reduce the emissions with a percentage **up to 90 percent.** Also for this possibility the costs are very important; holding (more) inventory is an extra cost factor that should be taken into account. In this research for one situation the costs and emissions in a situation with a DC are compared to the costs and
emissions in a situation without a DC. Both the costs and the emissions were higher in the last situation. More research should be done about his.

*Carbon offsetting:* this possibility does not reduce a company’s carbon dioxide emissions, but it compensates them. This possibility has two main disadvantages. The first one is that it is a costly option, while the other options can be done without have to invest extra money or even with a cost reduction. The second disadvantage is that it is not known whether carbon offsetting will be included in the governmental regulations. If it is not included, companies can do it, but it will not affect the amount of carbon dioxide they emit and have to pay for.

### 7.3 Recommendations for Bausch & Lomb

First of all, if Bausch & Lomb wants to know the amount of carbon dioxide that is emitted during the transport of lenses more accurately, more data about the transport types that are used (so for road transport for example, what kind of truck) and about the exact distances (for the transport of the lenses in the countries) should be gathered. However, the current calculations already give a good idea about where most carbon dioxide is emitted and where the possibilities for reduction lie. Bausch & Lomb has the following options to reduce its carbon dioxide emissions:

*Avoid empty returns:* even though the emissions resulting from the empty return trips are not allocated to Bausch & Lomb, there are still possibilities here for Bausch & Lomb. Currently trucks transport lenses to logistics service providers in Great-Britain and return empty and at the same time lenses are transported from the factories to the European Logistics Centre. Combining these shipments can result in a carbon dioxide reduction of about 60 percent and should be investigated in more detail.

*Use different transport modes:* by changing to different transport modes in total about 30 percent of the emissions can be reduced. In section 6.2.3.2 an overview is given what the reductions per country are. The possibilities are discussed based on estimated costs. Bausch & Lomb should gather more information about the exact costs and lead times in case they want to change to different transport modes.

*Inventory:* for the line haul transport to Spain it is checked whether keeping inventory in Spain would reduce the emissions. This is the case, but the costs are higher in the situation with inventory than in the situation without inventory. This means that it is not attractive for Bausch & Lomb to do this. However, this does not mean that this option is not possible in other situations.

At this moment Bausch & Lomb does not have concrete internal goals about carbon dioxide emissions. It would be a good idea to set a goal, like for example: “we want to reduce the carbon dioxide emissions resulting from our total transport with 10 percent by 2015 compared to the current situation without increasing the transport costs”. This goal can be split up into several smaller sub goals and this will make reducing the carbon dioxide emissions more tangible and will probably result in more reductions. Furthermore, if Bausch & Lomb wants to reduce its carbon dioxide emissions, they should gather more information about the costs and lead times for the different lanes for different transport modes.
7.4 Limitations and recommendations for further research

This research is one of the first in its kind and more research about carbon dioxide emissions in the supply chain is needed. Most research is needed about the method that is used for the calculations. It would be very good to gather actual emission data (for example based on fuel consumption) and compare the results from the calculations with the actual emission. This way the calculation method can be checked and sensitivity analyses can be done.

Besides checking and improving the calculation method by gathering actual emission data, this can also be done by gathering more company data. Company data can be used to improve the assumptions about the average default values that are made in the method. For example, now an average positioning distance of 20 percent is used for all road transport. However, it is expected that there is a relation between the total distance of a shipment and the positioning distance percentage; if the total distance is large, it is expected that the positioning distance percentage is smaller than when the total distance is small. With the company data in this research it was not possible to find this relation and therefore more research is needed. Also further research should be done about the following factors:

- Load factors
- Terrain factor
- Cleaning
- Heating (and cooling)
- Vertical handling

Furthermore, some factors, like congestion and speed are not included in the calculations. In this research it is chosen to leave them out of scope, because a balance had to be found between calculating the emissions accurately and not having got to gather too much data. However, in the future it should be researched what the influence of leaving out these factors is.

In this research the costs of the carbon dioxide emissions are calculated for different scenarios. It is important to gather more information about the upcoming regulations and the expectations of the carbon costs. This way better predictions can be done about what the effect of the regulations will be on different supply chains.

One of the emission reduction possibilities discussed in this research is opening a DC. In the situation researched here, the line haul transport to Spain, opening a DC is more expensive than the current situation, even if the costs for carbon dioxide are taken into account. However, this is mainly due to the fact that for this line haul the costs of road transport are unexpectedly higher than the costs of air transport. It is expected that in other situations, where the costs of road transport are equal to or smaller than the costs of air transport (which is mostly the case), holding inventory closer to the customer reduces the carbon dioxide emissions and also the total costs. That is why the influence of inventories on the carbon dioxide emissions should be researched further also when rail or water transport is used. Furthermore, all of the other reduction possibilities should be researched in more detail and in different environments in order to be able to draw industry wide conclusions.
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Appendix 1: Bausch & Lomb’s products
This appendix shows examples for Bausch & Lomb’s products.

Figure 20: an example of a soft contact lens

Figure 21: a Lens Care example: multi-purpose solution

Figure 22: an example of a surgical product: Millennium microsurgical system

Figure 23: an example of a pharmaceutical product: Zylet
Appendix 2: Supply chain structure lens products

Figure 24 shows the supply chain structure for all lens products of Bausch & Lomb.

Appendix 3: Comparison of different methodologies

Table 10 gives an overview of the factors that are taken into account in the calculations of the emissions resulting from transport in the different methodologies. Furthermore, the methodologies that take into account more factors (so the ones further to the right) also have more specific data for the factors. For example, STREAM distinguishes 5 different truck types, NTM 10 and Artemis about 30.

<table>
<thead>
<tr>
<th>GHG</th>
<th>EcoTransIT</th>
<th>STREAM</th>
<th>NTM</th>
<th>Artemis</th>
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<td>Terrain factors</td>
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Table 10: Factors included in the different methodologies
### Appendix 4: The different vehicle types for road transport

Figure 25 shows an overview of the different vehicle types for road transport.

<table>
<thead>
<tr>
<th>No</th>
<th>Illustration</th>
<th>Nomenclature</th>
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<th>Vehicle length (approx.)</th>
<th>Cargo capacity (typical values, inner dimensions)</th>
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<td></td>
<td>(no picture)</td>
<td>(LCV) Pick-up</td>
<td>&lt; 2.5</td>
<td>6 0.6 1 1.8 3 - 6</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>(LCV) Van</td>
<td>&lt; 3.5</td>
<td>7 1.5 3 - 6 3 - 4</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>(MDV) Light lorry/truck</td>
<td>3.5–7</td>
<td>8 5 14 4 - 6</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>(MDV) Medium lorry/truck</td>
<td>7-18</td>
<td>12 7 24 7,7</td>
<td>44</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>(MDV) Heavy lorry/truck</td>
<td>18–28</td>
<td>12 15 24 7,7</td>
<td>44</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>(HDV) Tractor + 'city-trailer'</td>
<td>16 - 26</td>
<td>12 - 15 15 - 16,5 20-28</td>
<td>8 - 12 50-84</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>(HDV) Lorry/truck + trailer</td>
<td>≤ 40</td>
<td>18,75 22 38 7,75 + 7,75 104</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>(HDV) Tractor + semi-trailer</td>
<td>≤ 40</td>
<td>16,5 26 33 13,6 92</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>(HDV) Tractor + MEGA-trailer</td>
<td>40 ≤ 50</td>
<td>16,5 33 33 13,6</td>
<td>110</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>(HDV) Lorry/truck + trailer or semi-trailer on dolly</td>
<td>≤ 60</td>
<td>24 - 25,25 40 51 7,7 + 13,5 149</td>
<td>3</td>
</tr>
</tbody>
</table>

*Figure 25: overview of the different vehicle types for road transport (from NTM Road, 2008)*
Appendix 5: an overview of a lane

Figure 26 shows an overview of a lane. A lane is defined as a combination of a certain origin, destination and period. This means that the transport on one lane can be done by different carriers and/or in different ways. A lane does always consist of at least one phase, but can also consist of multiple phases in case of multimodal transport. A shipment on the other hand is one single transport on a lane. So the transport of one parcel from the European Logistics Centre of Bausch & Lomb at Schiphol to a carrier in Spain on the 10\textsuperscript{th} of December 2008 is one shipment and the transport of another parcel from the European Logistics Centre of Bausch & Lomb at Schiphol to a carrier in Spain on the 11\textsuperscript{th} of December 2008 is a different shipment.

Figure 26: Overview of a lane
Appendix 6: Data

Every country has a different structure, which can have a large impact on the carbon dioxide emissions. In this appendix an overview of the data gathered and assumptions made per country is shown. First this is done for the regular line haul carriers, then for the regular transport in the different countries and then for the non-regular transport which is done by DHL. In the description different types of trucks will be mentioned and the characteristics of these trucks can be found in appendix 4.

Line Haul Carriers

In this section the transport done by the line haul carriers is explained. The two line haul carriers are Nouwens Transport and Kuehne + Nagel. Nouwens Transport is responsible for the road line hauls and Kuehne + Nagel is responsible for the line hauls that are a combination of road and air transport.

Nouwens Transport

Nouwens Transport is responsible for the line hauls to different carriers in different countries, namely to:

- GLS in France
- Bartolini in Italy
- TNT Innight in the Netherlands
- Ciblex in Belgium/Luxembourg
- DX Optical in Great-Britain
- GLS in Great-Britain

They have four pick-ups at the European Logistics Centre at Schiphol each day:

15:00 o’clock: one truck (Road, type 8) picks up shipments for carriers in Great-Britain, Belgium, Luxembourg and Italy and transports these shipments to Breda (where they are sorted)
15:00 o’clock: one truck (Road, type 7) picks up shipments for France and transports them directly to Paris, for the customers in France.
18:00 o’clock: one truck (Road, type 7) picks up shipments for the Netherlands and transports them directly to TNT Innight.
18:00 o’clock: one truck (Road, type 8) picks up shipments for customers in Great-Britain, Belgium, Luxembourg and Italy and transports these shipments to Breda (where they are sorted)

Nouwens Transport does usually not combine the Bausch & Lomb cargo with cargo of other companies, only as an exception. They could also not provide any more (average) information about this and that is why it is assumed that the Bausch & Lomb cargo is never combined with other cargo. Also, Nouwens Transport does usually not pick up cargo on the way back. However, it is their own responsibility whether they do this or not and therefore the emissions of the return trip fall under the responsibility of Nouwens Transport and not under the responsibility of Bausch & Lomb and are not taken into account in this analysis.

As can be seen in the transport network in figure 27, two of the daily pick-ups go to Breda where they are sorted. From there the lenses (and also other Bausch & Lomb products) are transported to the different carriers in the different countries. These transport processes are described in more detail in the country specific descriptions in the next sections.
Kuehne + Nagel is responsible for several line hauls to carriers in the countries. For lenses it is responsible for the transport to the following countries:

- Spain & Andorra (in the rest of this chapter, Andorra is considered to be part of Spain, because it is also treated this way by Bausch & Lomb and by the carriers)
- Portugal

The shipments for these three countries are picked up once a day with a type 4 truck and transported to Schiphol Airport. It is not known what the load factor of this truck is and also not whether other cargo is also taken on this truck. It is assumed that only Bausch & Lomb cargo is picked up. The average weight of the lenses that are sent to Spain each day is 320 kilograms and the average weight of the lenses that are sent to Portugal each day is 55 kilograms. From Schiphol Airport the shipment for Spain and Andorra is flown with a Boeing 747 to the airport in Madrid. And the shipment for Portugal is flown with the same type of aircraft to the airport in Lisbon. Because no information is acquired about the load factor of these aircrafts, the average load factor of 90% is used in the calculations. From the airports in Madrid and Lisbon the shipments are picked up by the local carriers (as is described in the sections about Spain & Andorra and Portugal).

Kuehne + Nagel thinks environmental issues are important. It holds ISO 14001 environmental certification for more than 100 of its locations worldwide. The company’s strategy is to use its capacity as efficient as possible and this results in lower carbon dioxide emissions. Furthermore, one of Kuehne + Nagel’s goals is to reduce emissions and to use environment-friendly technologies, such as solar energy and waste disposal, in new logistics centres (http://www.kn-portal.com).
Local Carriers

The transport of the lenses in the countries is done by local carriers. This section describes per country (or per group of countries) how the transport network is set up.

**Austria, Germany and Switzerland**

- Transmed

The transport of lenses to Germany, Austria and Switzerland is done by Transmed. Transmed is responsible for both the line haul to the countries and for the distribution of the lenses to the customers in the countries. At this moment GLS Transport is also responsible for the transport of a small amount of lenses to these three countries (about 8% of the total weight), but Bausch & Lomb is reducing this amount and changing the carrier for this to Transmed. Therefore it is assumed that the regular transport of all lenses to Germany, Austria and Switzerland is done by Transmed.

Transmed combines the line haul to Germany with the line haul to Austria. The line haul for Switzerland is separate. It is assumed that all lenses for Germany and Austria are transported to the main hub of Transmed in Hanau and that from there the lenses for customers in Germany are shipped to the different distribution centres in Germany and that all lenses for Austria are transported to a main hub in Austria, from where they are transported to the distribution centres in Austria. The line haul transport is done with a type 8 truck and the transport from the main hub in Hanau to the distribution centres and from the distribution centres to the customers is done with a type 2 truck. It is assumed that the line haul from the European Logistics Centre in the Netherlands to Switzerland is also done with a type 8 truck and that the setup of the network in Switzerland is similar to that of Germany (main hub with different distribution centres from where the customers are served). It again is assumed that the transport to the distribution centres in Switzerland and the transport from the distribution centres to the customers are done with type 2 trucks.

It is known that there are 18 distribution centres in Germany (including the main hub in Hanau) and that on average in total 360,000 kilometres are driven per night from the distribution centres to the customers and that this is done by 620 vans. This means that each van drives 580 kilometres on average each night. It is known how many vans are driving from each distribution centre and it is assumed that the cargo is equally divided over all vans. The average weight of the lenses that are distributed in Germany each day is 275 kilograms, which means that 275/620 = 0.44 kilograms are distributed per route.

The number of distribution centres in Austria and Switzerland is not known. Austria and Switzerland are both significantly smaller than Germany both in terms of area (respectively 24% and 12% of the area of Germany) as in terms of inhabitants (respectively 10% and 9%) and demand for lenses (respectively 16% and 19%). They also differ from Germany in the topography: Austria and Switzerland are mountainous countries, while Germany is an average country. Taking this into account
the number of distribution centres in Austria is assumed to be equal to 7 and the number of distribution centres in Switzerland is assumed to be equal to 4. Furthermore, it is assumed that the average number of vans/routes per distribution centre is smaller than the average number of vans/routes per distribution centre in Germany and that the average length of the routes is the same in Austria and Switzerland as it is in Germany.

The transport of lenses to Austria is done by Transmed. This is a daily shipment and the weight of the lenses is 43 kilograms on average each day. The average weight of the lenses shipped to Switzerland is 52 kilograms, of lenses shipped to Germany is 275 kilograms per day.

Figure 29: transport network of Austria, Germany and Switzerland
Belgium and Luxembourg

- Nouwens Transport
- Ciblex

The delivery of lenses in Belgium and Luxembourg is done by Nouwens Transport and Ciblex. Nouwens Transport takes care of the line haul to the main hub of Ciblex in Zaventem, Belgium and from there Ciblex distributes the lenses to other hubs and from there to the customers in these three countries. This process is shown in figure 30.

For Belgium and Luxembourg Nouwens and Ciblex are transporting almost all lenses for Bausch & Lomb, except for express shipments that are done by DHL. Ciblex also delivers a small part of the lenses in the Netherlands. The other parts are transported with TNT innight (shipments during the night) and TNT post (shipments during the day). These transport processes are described in the next section “The Netherlands”. The average weight of the lenses distributed to the customers in the Netherlands by Ciblex is 0.1 kilogram per day. This number is so small that this is not taken into account in the calculation of the emissions.

Nouwens picks up the parcels at Bausch & Lomb twice a day, together with parcels for Italy and Great-Britain and transports these to its main hub in Breda, the Netherlands with a type 8 truck (as is also described in the section about Nouwens). There the parcels are sorted and the parcels for Belgium and Luxembourg are transported to the main hub of Ciblex in Zaventem, Belgium with a type 7 truck by Nouwens Transport. From the main hub of Ciblex the parcels are transported to six different hubs with a type 3 truck by Ciblex:

- Veenendaal, the Netherlands
- Pétange, Luxembourg
- Ghent, Belgium
- Liege, Belgium
- Namur/Namen, Belgium
- Charleroi, Belgium.

From these hubs the lenses are transported to the customers. From all of the hubs together there are 60 different routes to the customers and these routes have an average distance of 220 kilometres.

In Belgium and Luxembourg, Ciblex delivers about 5,000 parcels every day of which 600 are Bausch & Lomb’s parcels. The load factor is 95% on average. This is due to the fact that they use different types of trucks if the sizes of the shipments differ. It is assumed that always a type 3 truck is used by Ciblex, because of the following reasons:

- the sizes do not differ much
- Ciblex does not have exact numbers of which trucks are used
- usually the type 3 truck is used

The average weight of all lenses is 63 kilograms per day for Belgium and 15 kilograms per day for Luxembourg. It is assumed that each hub serves a same number of customers.
To the Czech Republic there is one transport each week and the average weight of this transport is 43 kilograms. It is assumed that this transport is done with a type 8 truck and that the truck has an average load factor. The distance from Schiphol to Prague is 890 kilometres. The transport in the Czech Republic does not fall under the responsibility of the ELC of Bausch & Lomb and therefore the emissions are also not calculated here.
Denmark, Norway, Sweden and Finland

- Pan Nordic Logistics

The transport to the northern part of Europe is done by Pan Nordic Logistics. This service provider uses the capacity of trucks that deliver products from Northern Europe in the rest of Europe and otherwise would return empty. This way of working means that there never are empty returns. The structure is as follows (see also the transport structure in figure 31):

The products are picked up at Bausch & Lomb (Schiphol) and from there they are transported to the central hub in Denmark (at the airport of Copenhagen). This is done by either a number 5 truck (in 20% of the cases) or a number 8 truck (in 80% of the cases). From the hub in Copenhagen the products for Denmark are directly distributed to the different delivery depots in Denmark with a number 8 truck. The products for the other countries, Sweden, Norway and Finland, are transported to the national hubs in the countries and from there the products are distributed to the different delivery depots in the countries. The transport to the national hubs is done by a number 10 truck and the transport from the hubs to the delivery depots is always done by a number 8 truck. All of the before mentioned trucks are using Diesel. The transport from the delivery depots to the customers is done by vans and these vans are all hybrid vans (road number 11). The vans do return empty to the delivery depots, so this is the only part of the network where there are empty return trips.

Because Pan Nordic Logistics buys capacity from other companies, they do not have exact data about load factors, type of trucks, weight of other cargo, etc. Furthermore, there only is data about the locations of the delivery depots in Sweden (and not of Norway, Finland and Denmark). However, Sweden, Norway and Finland are quite alike in the type of country and therefore the network of delivery depots is assumed to be the same in Norway and Finland as in Sweden. Denmark is more like the Netherlands than Sweden qua type of country and therefore it is assumed that the network of delivery depots in Denmark is similar to the one in the Netherlands. Pan Nordic Logistics estimates the positioning distance to be equal to 50 kilometres. The distribution of the customers in Sweden, Norway and Finland is very typical, about 95% of the customers are located in the southern part of the countries. For Sweden the locations of the delivery depots are known, but not for the other countries. For the other countries it is assumed that there is only one delivery depot in the northern part of the country and there are 4 delivery depots in the middle part of the country. Each day on average 155 kilograms of lenses is sent to Denmark, 175 kilograms to Sweden, 114 kilograms to Norway and 20 kilograms to Finland.

It is assumed that from every delivery depot 5 routes are driven to deliver the lenses at the customers and that these routes have an average length of 200 kilometres. This is based on the routes from the delivery centres to the customers in the Netherlands. In the Netherlands the routes have an average length of about 140 kilometres, but because of the fact that Sweden is larger and has a lower population density, it seems reasonable to have a larger average length than in the Netherlands. It is assumed that all demand is equally distributed over the different delivery depots.

The number of delivery depots in Denmark is assumed to be equal to 10. This assumption is based on the facts that the number of delivery depots in the Netherlands is equal to 10 and that Denmark and the Netherlands cover about the same area (43,098 squared kilometres and 41,526 squared kilometres respectively, www.wikipedia.org). The size of the population of Denmark (5.5 million) is only about one third of the size of the population of the Netherlands (16.5 million), which means that the population density is lower in Denmark than in the Netherlands. But on the other hand, Denmark consists of different islands and it seems to make sense to have a delivery depot on all of the larger islands and therefore the number of delivery depots is assumed to be equal to 10. The average distance from the main hub in Copenhagen to the delivery depots is assumed to be equal to 95 kilometres (equal
to the average length from the main hub in the Netherlands to all of the depots). Furthermore, for all of these depots it again is assumed that on average five routes are driven to deliver the lenses to the customers and the length of these routes is assumed to be equal to 140 kilometres (equal to the average length of routes in the Netherlands).

Sweden has 25 delivery depots and based on that it is assumed that Norway and Finland each have 20 delivery depots. Sweden, Norway and Finland are about the same in size (449,964; 385,252 and 338,145 squared kilometres respectively). The reason why the number of delivery depots in Norway and Finland is assumed to be lower than in Sweden is that the sizes of the population of Norway and Finland are about half of the size of the Swedish population (4.5 million, 5.5 million and 9 million inhabitants respectively). As was also stated before, it is assumed that most of the delivery depots are located in the southern part of the countries. The distance between the national hubs and the delivery depots in Norway and Sweden is assumed to be equal to the average distance between the Swedish National Hub and the Swedish delivery depots, which is 360 kilometres. Furthermore, the number of routes again is assumed to be equal to five per delivery depot and the length of the routes is assumed to be equal to 200 kilometres (for reasoning, see above).

As was mentioned before, Pan Nordic Logistics can not give exact load factors. However, they have made the following estimations for the load factors and these are also the load factors that are used in the calculation of the emissions:

<table>
<thead>
<tr>
<th>Transport Lane</th>
<th>LF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bausch &amp; Lomb → Copenhagen Hub</td>
<td>90  %</td>
</tr>
<tr>
<td>Copenhagen Hub → National Hubs</td>
<td>90  %</td>
</tr>
<tr>
<td>National Hubs → Delivery Depots</td>
<td>85  %</td>
</tr>
<tr>
<td>Delivery Depots → Customers</td>
<td>45  %</td>
</tr>
</tbody>
</table>

*Table 11: Load factors for the different transports of Pan Nordic*
Figure 31: transport network of Denmark, Sweden, Finland and Norway
France
- Nouwens Transport
- GLS

Nouwens Transport is responsible for the line haul to France. They pick up the cargo once each day and transport it directly to the main hub of GLS in Paris, France with a type 8 truck. There is no information about the network of GLS in France, so the following assumptions are made:

- The network of GLS in France is similar to the network in Spain; besides the main hub there are several hubs from where the customers are served.
- The number of hubs is equal to 20.
- The average distance from the main hub to the hubs is 500 kilometres (the distance to the areas in the south can be 700 to 800 kilometres and the distance to the areas in the northern part of France is around 200 kilometres).
- The transport from the main hub to the hubs is done by type 8 trucks.
- From every hub ten routes are driven to serve the customers and the length of these routes is 250 kilometres on average.
- The transport from the hubs to the customers is done by type 2 trucks.
- The cargo of Bausch & Lomb is combined with other cargo and therefore the load factor can be assumed to be equal to the average load factor.
- GLS combines delivering and picking up cargo and therefore it is assumed that there are no empty returns.

The average weight of all lenses sent to France each day is 595 kilograms.

*Figure 32: transport network for France*
Great-Britain
- Nouwens
- DX Optical
- GLS

Nouwens Transport is responsible for the line haul to Great-Britain. They do this with a truck type 7 or 8 and this is described in the section about Nouwens Transport. Nouwens Transport delivers lenses to two different carriers in Great-Britain, DX Optical and GLS. First they deliver the lenses at the Service Centre of DX Optical and after that they deliver the lenses to the main hub of GLS.

It is known that the network of DX Optical looks as is shown in figure 33. From the Watford Service Centre all products are first transported to the National Hub in Nuneaton where they are sorted. And from the national hub the products are transported to the delivery service centres from where they are delivered at the customers. DX Optical uses 20 delivery service centres with an average of 30 routes each. It is not known what type of trucks DX Optical is using, but it is assumed that on the tracks from the Watford Service Centre to the National hub and from the National Hub to the Delivery Service Centres type 8 trucks are used and that on the routes from the Delivery Service Centres to the customers type 2 trucks are used. It is also assumed that the average distance from the national hub to the delivery service centres is 200 kilometres and that the average distance of the routes from the delivery service centres to the customers is assumed to be equal to 250 kilometres. The distance from the Watford Service Centre to the National Hub in Nuneaton is 45 kilometres. Furthermore, it is assumed that there are no empty returns in the DX Optical network and that the cargo of Bausch & Lomb is combined with other cargo so that the load factors are as average.

There is nothing known about the network of GLS in Great-Britain. It is assumed that the network consists of one main hub and multiple distribution centres from where the customers are served. It is assumed that there are 15 delivery service centres with 20 routes each. The average distance from the main hub to the distribution centres is assumed to be 200 kilometres and the average distance of the routes from the distribution centres to the customers is assumed to be 300 kilometres. It is assumed that the transport from the main hub to the delivery service centres is done with type 8 trucks and that the transport from the delivery service centres is done with type 2 trucks. Furthermore, it is assumed that there are no empty returns in the GLS network and that the cargo of Bausch & Lomb is combined with other cargo so that the load factors are as average.

The average weight of all lenses sent to Great-Britain each day is 418 kilograms. It is assumed that half of this weight is distributed to the customers by DX Optical and that the other half is distributed by GLS. It is assumed that the lenses are equally distributed over all distribution centres, so that all distribution centres of one carrier distribute a same amount of lenses.
Greece

- K + N

Greece has a distribution centre and delivers to the customers in Greece from there. The European Logistics Centre transports consolidated replenishment orders to Greece once a day with Kuehne + Nagel. It is assumed that Kuehne + Nagel picks up the shipments with a type 4 truck, transport them to the airport in Athens with a type 1 aircraft and transports them to the distribution centre of Bausch & Lomb in Athens with a type 4 truck again. When the products arrive at the distribution centre, they are stored and as soon as there is a customer order, they are picked. B&L Greece uses one carrier, Speedex, for the distribution of the lenses in Greece. About 70% of their parcels are delivered in the area of Athens and the other 30% is delivered outside of Athens in other major cities. They get about 130 orders per day for lenses.

From the distribution centre in Greece the lenses are transported to the main distribution centre of Speedex in Athens by a van (road type 2) once a day. For the area of Athens, from the main distribution centre of Speedex they are transported to smaller distribution centres in the area of Athens by a van (once a day). And from there the lenses are transported to the customers by motorcycles. For all other areas, from the main distribution centre of Speedex the lenses are consolidated with other cargo and taken to the distribution centres of Speedex outside of the area of Athens by a larger truck (road type 4). From these distribution centres the lenses are transported to the customers by motorcycle again. It is
assumed that there are 10 smaller distribution centres in the area of Athens and 10 in the area outside of Athens. The average distance to the distribution centres in the area of Athens is assumed to be equal to 100 kilometres and the average distance to the distribution centres outside of the area of Athens is assumed to be equal to 400 kilometres. The routes from the distribution centres to the customers are assumed to be equal to 100 kilometres for all areas.

Usually there are no empty returns. The carrier tries to combine deliveries and pick ups. Of course, this does not always work out perfectly, so in some cases there are empty returns (about 10% of the routes).

Figure 34 shows a graphical overview of the transport network.

![Figure 34: transport network of Greece](image)

**Italy**
- Nouwens
- Bartolini

The line haul to Italy is done by Nouwens Transport. They pick up the parcels at the European Logistics Centre of Bausch & Lomb with a type 8 truck, take it to their hub in Breda, the Netherlands and from there they transport it to Bartolini in Italy. Each day on average there are 225 kilograms of lenses sent to Italy. Part of this is replenishment of the distribution centre and part goes directly to the customers. The transport directly to the customers as well as the transport from the distribution centre to the customers is done by Bartolini. Because it does not matter for Bartolini whether the products go through the distribution centre or not, this is not taken into account in the calculations.

Bartolini does not own its own trucks; they rent truck capacity from other companies. In total they have about 400 line haul trucks that drive for them and 6,500 city drivers. Because they do not own their own trucks, they do not have very detailed information about the different kind of trucks, about type of fuel, fuel consumption and the exact load factors.

The Bausch & Lomb products are delivered at the depot in Milan. From there Bartolini transports them overnight to the first level hubs by type 8 trucks. From the first level hubs the products are transported either directly to the customers or to one of the second level depots, from where they are transported to the customers. For all of the shipments holds that it is not only Bausch & Lomb’s cargo that is being
transported, but also other cargo. This means that the load factors on average is about 60%. It is assumed that the transport to the customers is done with a type two truck (van). Figure 35 shows the transport process graphically.

It is known that there are 33 first level hubs in Italy and it is assumed that each hub has two second level depots on average. Furthermore, it is assumed, that from each combination of a hub and the two depots, there are five routes to the customers each day and that the customers are equally divided over the different routes. Based on a random sample of distances between hubs and depots of ten, the average number of kilometres between a 1st level hub and a 2nd level depot is 95 kilometres on average. The length of the route is assumed to be equal to 100 kilometres based on the length of routes in different other countries.

Figure 35: transport network of Italy

Poland

- General Carrier

To Poland there are two transports each week with an average weight of 3 kilograms for lenses. It is assumed that this transport is done with a type 8 truck and that also other cargo is taken on this transport, which means that the truck has an average load factor. The distance from Schiphol to Warsaw is about 1200 kilometres. The transport of lenses in Poland does not fall under the responsibility of the ELC of Bausch & Lomb and therefore the emissions are also not calculated here.
Portugal
- Kuehne + Nagel
- GLS

The line haul to Portugal falls under the responsibility of Kuehne + Nagel. They pick up the lenses at Bausch & Lomb once a day together with the cargo for Spain and transport it to Schiphol airport with a type 4 truck. It is assumed that this truck is a dedicated Bausch & Lomb truck. From Schiphol Airport the cargo is transported to the international airport in Lisbon, Portugal with a type 10 aircraft. At the airport the cargo is picked up by GLS Portugal. It is not known what type of trucks GLS is using but it is assumed that all of the transport in Portugal is done by type 2 trucks. This is based on the fact that type 2 trucks are used in quite some countries and also in Spain. And because ASM is the Spanish GLS it seems reasonable that the Portuguese GLS is using the same types of transport as the Spanish GLS.

It is assumed that GLS Portugal transports the cargo from the airport to a main hub near the airport where the cargo can be sorted. The distance to the main hub is assumed to be 50 kilometres. From the main hub the cargo is transported to five different hubs from where it is transported to the customers. It is assumed that from each hub (also the main hub) five routes are driven to deliver the lenses to the customers. It is assumed that the average distance to the hubs is 280 kilometres (based on placing 5 hubs from the north to the south on about the same distances from each other). It is assumed that the routes from the hubs to the customers have an average length of 250 kilometres (assuming that the routes have to cover the distances to the eastern and western parts of Portugal).

The average weight of lenses sent to Portugal each day is 55 kilograms.

![Transport Network of Portugal](image)

**Figure 36: transport network of Portugal**

Spain & Andorra:
- Kuehne + Nagel
- ASM

The shipment of lenses from the European Logistics Centre in Schiphol to Spain is done by Kuehne + Nagel and by ASM. Kuehne + Nagel is responsible for the line haul from the European Logistics Centre in the Netherlands to the airport in Spain and ASM is a local carrier in Spain that is responsible for the transport of the lenses in Spain and Andorra. In the rest of this chapter, Andorra is considered to be part of Spain and not mentioned separately.
Kuehne + Nagel picks up one shipment each (working) day at the European Logistics Centre with a medium truck (Road, type 4) and transports it to Schiphol Airport. From there they transport it to the airport in Madrid with a Boeing 737 (Air, type 10). It is known that the load factor of this flight is always almost 100%.

ASM picks up the shipment at the airport in Madrid and transports it to the main hub in Madrid. Besides its main hub, ASM uses six hubs. All transport by ASM is done by vans (Road, type 2). From the main hub about one third of all customers of Bausch & Lomb in Spain is served directly. The other two third of customers is served from the other hubs as can also be seen in figure 37. The customers in Andorra are also served from the hubs in Spain and included in the calculations of Spain.

The average weight of products shipped to Spain is 320 kilograms. Figure 37 shows a graphical overview of the distribution of lenses in Spain.

Figure 37: transport network of Spain
Turkey
Bausch & Lomb has a distribution centre in Turkey. The transport to and in Turkey is not known and therefore the emissions are not calculated for Turkey.

The Netherlands
- Nouwens Transport
- TNT Post
- TNT In-night

In the Netherlands there are two regular ways lenses are delivered to the customers. One way is by using TNT post and the second way is by using TNT In-night service. Nouwens Transport is responsible for the transport of the lenses from the European Logistics Centre of Bausch & Lomb in Schiphol to the central distribution centre of TNT In-night in Nieuwegein. They do this transport with a type 7 truck.

From the central distribution centre of TNT In-night the lenses are distributed to 9 different depots by TNT with a road 3 or road 4 truck type once a day. And from the depots the lenses are distributed to the customers with a road 2 type once a day. In case of the In-night service of TNT the lenses are delivered at the customers at night. Many opticians have special mailboxes where the lenses can be left behind during the night. Also the lenses of competitors of Bausch & Lomb can be delivered in these boxes. It is known that TNT In-night always picks up other shipments on the way back.

The average weight of lenses that are distributed in the Netherlands is 95 kilogram per day. About half of this weight is sent with TNT In-night, about 44 kilograms. The other half (about 51 kilograms) is sent with TNT Post. Nothing is known about the network of TNT Post, but it is assumed that a same kind of network is used as for TNT In-night and the emissions for TNT Post are also calculated in the same way as for TNT In-night.

It is not known which customers are served from which depot and also the average total weight of the shipments of Bausch & Lomb per depot is not known. However, it is known what the weight of the total cargo per depot is. It is assumed that the distribution of customers of Bausch & Lomb (and with that also of the weight of the products of Bausch & Lomb) is similar to the distribution of all of the customers that are served by TNT (and with that the total weight of the products).
Figure 38: transport network of the Netherlands
Non-regular transport: DHL

DHL is responsible for part of the transport of lenses to all of the countries. DHL is used next to the regular transport channels and Bausch & Lomb makes use of them in case it is not possible to deliver the order in time with the use of the regular transport channel. Because of the structure of the network of DHL (they use many locations, trucks and aircrafts) it is possible for DHL to deliver the parcel within a shorter time than the regular carriers. However, because the lenses always have to be delivered within a shorter time, the costs and the emissions for the transport are generally higher than for the regular transport channels. For example, if DHL has to transport a package with lenses to an optician in Great-Britain, they use an aircraft for the line haul to Great-Britain. The regular line haul transport however is done with a truck and the Chunnel (Nouwens Transport), which is cheaper and emits less carbon dioxide.

DHL could not give much specific information about their network structure. It is known that the main hub of DHL for Europe is in Germany (Leipzig). Furthermore, the load factors of their aircrafts are about 90% on average and for their trucks about 85% on average. The positioning distances are 40 kilometres on average. This is quite low compared to the positioning distances of other transport companies. This can be explained by the fact that DHL has many locations in each country and therefore is always quite close to the customer. DHL has the possibility to pick up other cargo on the way back and does always try to do this. So the return trip does not fall under the responsibility of Bausch & Lomb. Furthermore, DHL does always try to combine cargo for different companies; this is how they can achieve an high average load factor of 85% for road transport and how they can be profitable. This means that Bausch & Lomb’s cargo is combined with cargo of other companies, which reduces the emissions for Bausch & Lomb, because only a small part of the emissions of a truck are allocated to Bausch & Lomb.

To calculate the emissions of the transport done by DHL many assumptions have to be made, because it was not possible to get exact data from DHL. Figure 39 shows an overview of the transport process as it is assumed to be. DHL picks up the shipment at the European Logistics Centre (ELC) of Bausch & Lomb (B&L) with a type 2 truck (a van). DHL transports the shipment to the nearest DHL hub, which is located in Hoofddorp, from where it is sorted and transported with a type 8 truck to Schiphol Airport, from where it is flown with a Boeing 757-200SF to Leipzig Airport in Germany. Leipzig Airport is the main hub of DHL in Europe. Figure 40 shows the European Air Network of DHL and this network shows that DHL has flights to many different cities in Europe. It is assumed that all parcels are flown to the destination countries from the airport in Leipzig with a Boeing 757-200SF and that the parcels are transported to hubs in the countries with a type 8 truck and from the hubs to the customers with a type 2 truck (a van). The distances to the airports (in the capitals of the destination countries) are calculated using EcoTransIT (2008). It is assumed that the average distance from the airport to the hub is 100 kilometres and that the route from the hub to the customers is also 100 kilometres.

Figure 39: Transport network of DHL
DHL is very actively trying to reduce their carbon dioxide emissions. On their website they state that they aim to “reduce their carbon footprint for every letter mailed, every container shipped and every square meter of warehouse space used by 30 percent by the year 2020”. They want to do this using a three-pronged strategy of assessing, reducing and offsetting (DHL website 2009):

- **Assessing**: DHL is setting up a Carbon Accounting system which will be able to measure and document the carbon emissions of all the corporate divisions.
- **Reducing**: DHL is optimising the air and ground fleets, developing innovative technologies, involving subcontractors, etc. (see www.dp-dhl-gogreen.com for more information).
- **Offsetting**: DHL has internal and external project to offset the carbon dioxide emissions. Internal projects are purchasing vehicles with alternative propulsion units and the installation of a solar installation at a hub. External projects are the reforestation of illegally exploited rain forests and the support of a hydroelectric power plant in Brazil.
- **Reducing the carbon dioxide emissions is not the only environmental friendly initiative. Another example is e-billing: they are offering this service in order to reduce the amount of paper needed.**
Appendix 7: Data Spain

In appendix 6 the transport networks to customers in different carriers is given. This information is information about the transport network in general and not about the transport per lane. However, for the calculations it is better to have the data per lane. This data is also gathered and for Spain it is shown and explained in this section. For every country similar data is saved in the Access Tool.

<table>
<thead>
<tr>
<th>Lane ID</th>
<th>Period</th>
<th>Route</th>
<th>Phase</th>
<th>Modality</th>
<th>Carrier</th>
<th>Origin phase country</th>
<th>Origin phase description</th>
<th>Destination phase country</th>
<th>Destination phase description</th>
<th>Transport mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>2008</td>
<td>1</td>
<td>2</td>
<td>R02</td>
<td>ASM</td>
<td>ES</td>
<td>Hub Sevilla</td>
<td>ES</td>
<td>Customers Sevilla</td>
<td>R02</td>
</tr>
<tr>
<td>41</td>
<td>2008</td>
<td>1</td>
<td>1</td>
<td>R02</td>
<td>ASM</td>
<td>ES</td>
<td>ES Airpoport</td>
<td>ES</td>
<td>ASM Madrid HQ</td>
<td>R02</td>
</tr>
<tr>
<td>42</td>
<td>2008</td>
<td>1</td>
<td>2</td>
<td>R02</td>
<td>ASM</td>
<td>ES</td>
<td>Hub Barcelona</td>
<td>ES</td>
<td>Customers Barcelona</td>
<td>R02</td>
</tr>
</tbody>
</table>

Table 12: An example of a few lanes with data about the transport in Spain

The different columns can be explained as follows:

- The data in this table is per lane and in the first column the Lane ID is defined.
- In the second column the Period is defined and, as can be seen here, the data is given per year, 2008 in this case.
- Then the Route and Phase are defined.
- The Modality is road type 2, which is a van, for all of these lanes
- The Carrier responsible for these lanes is ASM.
- After the carrier, the Origins and Destinations are described and after that the Transport mode. The difference between modality and transport mode is that the transport mode only indicates the mode of transport for the particular phase, while the modality indicates the mode of transport for the whole lane (so this can also be a combination of an aircraft and a truck).
• The **Quantity** indicates the number of times per year there has been transport on this lane. If there is a transport once every working day, it is assumed that there are 259 transports per year. This is calculated as follows: 2008 had 262 working days of which 2 days were Christmas (24th and 25th of December) and one day was New year's day and on those days there were no shipments. So in total there were 262 – 3 = 259 shipments. For some lanes there are 10 shipments per work day, which means that there are 10 * 259 = 2590 shipments per year.

• The **Weight** indicates the average weight per time there has been a transport (in tonnes). To calculate the weight per time the assumption is made that the weight is equally divided over the different lanes.

• **TEU** stands for Twenty-foot equivalent unit and this is mainly used in case of containers, so is not used in this project.

• In the **Volume** column the average volume of the parcel can be indicated. This can be used to calculate the volumetric weight.

• In the **Allocation** column can be indicated whether the emissions should be allocated based on the weight or not. If it is chosen not to allocate the emissions, the emissions of the entire transport mode (truck, aircraft, train or boat) is added to the total emissions. For Bausch & Lomb the emissions should always be allocated.

• **Load Factor** can be filled out if the load factor is known. If nothing is filled out here, the value as given in the NTM method is used.

• In the **Positioning** column a positioning distance can be given. For all of these lanes the positioning distance is assumed to be equal to zero, because the carrier has many transports between these locations and it is assumed that these locations are ‘base positions’ for the vans.

• Furthermore, it is also assumed that there are no **empty returns**, because the carrier ASM indicated that usually they take other cargo on the way back.

• **Refrigerating/heating** is never needed for lenses and therefore this column is always set as ‘None’.

• And the same holds for **Cleaning**.

• The last column indicates the number of kilometres per lane and per country, in this case **ES** stands for Spain.
Appendix 8: Results carbon dioxide calculations

This appendix gives the results of the calculations, that are also shown in the graphs in section 5.1. First the results per country are given, then per transport mode and finally per carrier.

<table>
<thead>
<tr>
<th>Country (abbreviation)</th>
<th>Country</th>
<th>Emissions (tonne per year)</th>
<th>Weight (kilograms per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AU</td>
<td>Austria</td>
<td>4.07</td>
<td>43</td>
</tr>
<tr>
<td>BE</td>
<td>Belgium</td>
<td>0.40</td>
<td>63</td>
</tr>
<tr>
<td>CH</td>
<td>Switzerland</td>
<td>5.99</td>
<td>52</td>
</tr>
<tr>
<td>CZ</td>
<td>Czech Republic</td>
<td>0.11</td>
<td>8.6</td>
</tr>
<tr>
<td>DE</td>
<td>Germany</td>
<td>21.66</td>
<td>290</td>
</tr>
<tr>
<td>DK</td>
<td>Denmark</td>
<td>8.02</td>
<td>162</td>
</tr>
<tr>
<td>ES</td>
<td>Spain</td>
<td>115.77</td>
<td>320</td>
</tr>
<tr>
<td>FI</td>
<td>Finland</td>
<td>2.98</td>
<td>27</td>
</tr>
<tr>
<td>FR</td>
<td>France</td>
<td>25.55</td>
<td>611</td>
</tr>
<tr>
<td>GB</td>
<td>Great-Britain</td>
<td>22.44</td>
<td>438</td>
</tr>
<tr>
<td>GR</td>
<td>Greece</td>
<td>24.89</td>
<td>89</td>
</tr>
<tr>
<td>IT</td>
<td>Italy</td>
<td>7.51</td>
<td>225</td>
</tr>
<tr>
<td>LU</td>
<td>Luxembourg</td>
<td>0.13</td>
<td>15</td>
</tr>
<tr>
<td>NL</td>
<td>The Netherlands</td>
<td>1.50</td>
<td>110</td>
</tr>
<tr>
<td>NO</td>
<td>Norway</td>
<td>3.91</td>
<td>114</td>
</tr>
<tr>
<td>PL</td>
<td>Poland</td>
<td>0.02</td>
<td>1</td>
</tr>
<tr>
<td>PT</td>
<td>Portugal</td>
<td>23.29</td>
<td>55</td>
</tr>
<tr>
<td>SE</td>
<td>Sweden</td>
<td>14.41</td>
<td>218</td>
</tr>
</tbody>
</table>

*Table 13: results of the carbon dioxide calculations per country*

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Emissions (tonne per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Mode</td>
<td>166.6323</td>
</tr>
<tr>
<td>Air</td>
<td>85.28608</td>
</tr>
<tr>
<td>Van</td>
<td>0.612215</td>
</tr>
<tr>
<td>Light Truck</td>
<td>0.054206</td>
</tr>
<tr>
<td>Medium Truck</td>
<td>11.66497</td>
</tr>
<tr>
<td>Truck + trailer</td>
<td>19.39381</td>
</tr>
<tr>
<td>Tractor + semi-trailer</td>
<td>0.012174</td>
</tr>
<tr>
<td>Chunnel</td>
<td>0.047334</td>
</tr>
</tbody>
</table>

*Table 14: results of the carbon dioxide calculations per transport mode*
Table 15: results of the carbon dioxide calculations per carrier

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Emissions (tonne per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASM</td>
<td>11.37</td>
</tr>
<tr>
<td>Bartolini</td>
<td>3.88</td>
</tr>
<tr>
<td>Ciblex</td>
<td>0.45</td>
</tr>
<tr>
<td>DHL</td>
<td>30.29</td>
</tr>
<tr>
<td>DX Optical</td>
<td>7.06</td>
</tr>
<tr>
<td>General Carrier</td>
<td>0.01</td>
</tr>
<tr>
<td>GLS FR</td>
<td>19.93</td>
</tr>
<tr>
<td>GLS GB</td>
<td>7.17</td>
</tr>
<tr>
<td>GLS PT</td>
<td>3.08</td>
</tr>
<tr>
<td>K+N</td>
<td>137.76</td>
</tr>
<tr>
<td>Nouwens</td>
<td>12.82</td>
</tr>
<tr>
<td>Pan Nordic</td>
<td>17.24</td>
</tr>
<tr>
<td>Speedex</td>
<td>0.96</td>
</tr>
<tr>
<td>TNT In-Night</td>
<td>0.60</td>
</tr>
<tr>
<td>Transmed</td>
<td>29.66</td>
</tr>
</tbody>
</table>

Appendix 9: Abbreviations for carriers

Table 16 gives an overview of the carriers Bausch & Lomb is using for the transport of lenses with abbreviations that are used in figures.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Carrier Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASM</td>
<td>= ASM</td>
</tr>
<tr>
<td>Bart</td>
<td>= Bartolini</td>
</tr>
<tr>
<td>Ciblex</td>
<td>= Ciblex</td>
</tr>
<tr>
<td>DHL</td>
<td>= DHL</td>
</tr>
<tr>
<td>DX</td>
<td>= DX Optical</td>
</tr>
<tr>
<td>GLS</td>
<td>= GLS</td>
</tr>
<tr>
<td>K+N</td>
<td>= Kuehne + nagel</td>
</tr>
<tr>
<td>Nouwens</td>
<td>= Nouwens Transport</td>
</tr>
<tr>
<td>PanN</td>
<td>= Pan Nordic</td>
</tr>
<tr>
<td>Sp</td>
<td>= Speedex</td>
</tr>
<tr>
<td>TNT</td>
<td>= TNT</td>
</tr>
<tr>
<td>TrM</td>
<td>= Transmed</td>
</tr>
</tbody>
</table>

Table 16: abbreviations used for carrier names
Appendix 10: Emission factors for different transport modes

In this appendix the emission factors for different transport modes are given. First for air transport, then rail, road and water transport.

Figure 43: emission factors for different aircraft types

Figure 44: emission factors for trains with different capacities
Figure 45: Emission factors for different truck types
(the meaning of the abbreviations can be found in appendix 4)

Figure 46: Emission factors for different types of vessels
Appendix 11: Transport Costs
Appendix 12: costs in the different scenarios
Appendix 13: reduction of emissions by changing to different transport modes
Appendix 14: Inventory calculation

This appendix describes the inventory calculation of the distribution centre in Spain. As is also described in section 6.3 a periodic-review, order-up-to-level control system (R,S) is used. It is set that twice every week a replenishment order is placed. The formulas are all taken from Silver et al. (1998).

The following notation is used:

- \( R \) = specified review interval, expressed in years
- \( L \) = replenishment lead time, expressed in years
- \( S \) = order-up-to-level, in units
- \( x_{R+L} \) = expected demand over a review interval plus a replenishment lead time, in units
- \( \sigma_{R+L} \) = standard deviation of errors of forecasts over a review interval plus a replenishment lead time, in units
- \( SS \) = safety stock

Then the formulas are:

- \( SS = S - x_{R+L} \)
- \( SS = k \sigma_{R+L} \)
- \( \text{Prob}\{\text{Stockout in a replenishment cycle}\} = p_{\text{vec}}(k) \)
- \( \text{Expected shortage per replenishment cycle} = \text{ESPRC} = \sigma_{R+L} G_k(k) \)
- \( \text{E (OH)} = \text{expected on hand level} = \frac{Q}{2} + k \sigma_{R+L} \)

Based on these formulas, for the different product groups the average inventories are calculated with the following values:

- \( r \) = inventory carrying charge = 0.25 (€ per € per year)
- \( v \) = unit variable cost = varying per product group (€ per unit)