INTERNATIONAL HELLENIC UNIVERSITY

Supply Chains' Sustainability: Product Carbon Footprint

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SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

OCTOBER 2012

THESSALONIKI – GREECE

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Abstract

This dissertation was written as a part of the MSc in Energy Systems at the International Hellenic University. Here goes a summary of the dissertation. The focus of this research is in the area of climate change and in particular of the Greenhouse Gases (GHG) emissions generated throughout the supply chain of a product. Such a study is important in order to identify which anthropogenic activities generate mostly GHG emissions, which actions can be undertaken so as to mitigate the problem, and the impact of them in the market. The research approach adopted in this dissertation includes an extended review of the literature, regarding the definition of Carbon Footprint (CF), how it can be calculated, in what way enterprises can avail from it, and how it influences the purchases. The findings from this research provide evidence that there is still much work to be done on measuring CF, since yet there aren't common guidelines and standards used in global scale. The main conclusions drawn from this study are that the effective utilization of CF can offer great financial benefits to the companies, while at the same time it can play a significant role in the fight against climate change and in the protection of the environment. This thesis recommends that empirical studies need to be made in order to inquire into the cost-benefit analysis of implementing a CF calculation.

Keywords: *product carbon footprint, sustainable supply chain, life cycle analysis, green supply chain management, green product price*

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1 Introduction

This section includes a clear and brief definition of the subject. Arguments about why it is important and needs to be studied are presented, and the contribution of this dissertation to this subject is described. For the main body of this Thesis an extensive review of the existing literature was conducted using the online search machine *Google Scholar,* which provides the ability to come across all the relevant books, papers, articles, etc published all over the world by redirecting to scientific databases such as the *Science Direct, Springer, Wiley*, etc. The main key words used were "*carbon footprint*", "*carbon footprinting*", "*life cycle analysis*", "*input-output analysis in supply chain*", "*carbon footprint in supply chain*", "*product carbon footprint*", "*sustainable supply chain*", "*carbon price distortions*".

It has been proved and it is already widely known that, due to the global climate change the need for sustainable operations is great and rapidly increasing. *Sustainability* means that the current resources used for the various processes at the moment are not depleting, but are also enough to cover future needs. As a result the term *sustainable development* was introduced, referring to all those activities implemented towards environmental protection and optimization of operations. The establishment of Kyoto Protocol was the sparking for all the environmentally friendly oriented activities from the nations, the organizations, the companies, and the individuals. Specific targets to be reached in certain time were set for all the nations, as well as guidelines and standards for the measuring and the reporting of the greenhouse gases (GHG) emissions. But all this would be pointless without the existence of specific indicators used to measure that development. The first one used was the Ecological Footprint, which evaluates the size of the biotical area needed to cover the needs of a specified population. Apart from the benefits that the ecological footprint offers, it is characterized by some constraints – such as it lacks of dynamic nature, requires recalculation since it only states the current situation, and doesn't propose any measure to be taken – that make it not suitable to be applied in many cases. At that point the *carbon footprint* indicator was introduced.

In simple words, carbon footprint is the total amount of GHG emissions, normalized in *mass units of CO_2 emissions*, generated by all the activities taking place from a start- to an end-point. In the case of a product, it includes the $CO_{2\text{-eq}}$ emissions generated by all the processes taking place along the supply chain of that product, from its production to its consumption. The greenhouse gases that are included in such a study were decided by the Greenhouse Gas Protocol to be the following: Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF_6). Apart from this, there is another categorization of the emissions taken under consideration, namely the direct and those from the energy consumption, and the indirect. It is important to specify that before each study, otherwise implications occur and the complexity of the calculations rises. In addition to this, the *boundaries of the system* need to be clearly defined, i.e. which one will be the first process and which the last one, as well as which of the intermediate process will be included to the study. Then, for each of these processes data need to be gathered and the method used - already measured data or onsite measurements – and the selected/available source or measuring conditions are particularly important, since they have an instant impact on the *quality and reliability of the data* and consequently of the results. For the data processing the preferable method used *Life Cycle Analysis* and more specifically the *Input-Output Analysis*, based on which many models have and are still being developed in order to cover all the different requirements, as each study has its own special characteristics. Other models such as the *"Supply chain Operations Reference (SCOR)"* are used for the calculation of carbon footprint which is actually an aggregation of the measurements from each sub- and basic-process.

As mentioned above, in the case of products, carbon footprint refers to its whole life cycle, including gathering of raw materials, production, warehousing, distribution and consumption. Consequently it affects every stage of it. Each one of these stages consists of other sub-stages, which are also in most cases very important in calculating carbon footprint. Performing such a study on a company – where there are interactions between its departments (e.g. accounting with manufacturing department), as well as with other participants to a product's supply chain such as the suppliers – can be very complex, but also can provide information about the efficiency, the cost and the environmental impact of the company's functional operations, which can prove to be very valuable for reducing the expenditures, become more environmentally friendly and increasing profits. Up until now, it isn't obligatory for all the companies to measure their and their products' carbon footprint. However it is not only the legal framework putting pressure on that direction, but also the consumers' demands for more ecological goods and at the same time in the lowest possible price. This automatically leads to competition between the companies in the same sector, impelling them to follow, even if it was only a market trend. The way that an entity is using carbon footprint for its own benefit, aiming at the same time at the determined targets, is called *Green Supply Chain Management*. Though, apart from the goals, green supply chain management has to deal with other issues too, such as the shareholders' interests and the generated costs implications affecting as a result the product's final price, and even further, the customer's consuming decision. A good and careful design of a GSCM, directed by a formerly implemented carbon footprint study, is necessary in order to meet the various targets.

It is generally accepted that carbon footprinting can rebound to a more efficient operation of a supply chain, characterized by less energy consumption, less wastes and lower production and distribution costs. Carbon footprint can prove to be very powerful for a company's economical development and at the same time contribute highly in environmental protection locally and globally. Furthermore, it can contribute in increasing the company's market share, since the provided information – using carbon labels – distinguishes the product from its similar and by this way influence the purchases. Where this Thesis adds value to this subject is that it provides a comprehensive study defining Carbon Footprint, its pros and cons, specifying where and how it can be applied, which benefits it can offer to the company, the society and the natural environment. Actually, it is a work that up to my knowledge, *no* other similar has yet been published in Greece.

The dissertation is structured as follows: The *first chapter* is the introduction to the subject, presenting briefly its main points. The *second chapter* is a review of the already existing literature concerning the carbon footprint of a product's supply chain, including its definition and putting forward the various arguments regarding the methodologies used, the constraints and the benefits. The *third chapter* presents in detail all the steps that need to be followed before making such a study, accompanied with their advantages, limitations and disadvantages. The *fourth chapter* includes the issues that the decision makers should take under consideration before designing and applying the green supply chain management and the activities that a company should undertake in order to achieve a more efficient and more environmentally-friendly performance. In the *fifth chapter* is discussed in what extent the carbon footprinting and all the processes that it includes affects the company's expenditures and the impact on the final price of the product. And finally, the *sixth chapter* sums up everything discussed previously and presents the conclusions that came up.

2 Review of the Literature

In this section it is presented what has already been published concerning Sustainability, Supply Chains, Carbon Footprint, and how are those combined in order to improve the performance of the supply chain through implementing Green Supply Chain Management.

Sustainability

Sustainability stands for *the use of natural resources in the present to meet the demand without jeopardizing the capability of future generations to meet their own demands* (WCED, 1987). It is the ability to keep living on the long term under the same comfort conditions and with the same development rate. From its definition, sustainability poses some issues, such as the type of resources that will be needed in the future, which is the current limit of each polluting factor so as not to affect the future generations, which policies will result in sustainable solutions, what contribution can market forces make, etc. the introduction of sustainability generated new motives for the companies, and for the consumers too, enhanced by the congruent framework that has been established. It can be approached from various aspects since the many different issues it deals with have to do with both the environment and the human population. All these are combined with the implementation of appropriate policies, taking into account all the relevant constraints (Linton, et al., 2007). In order sustainable development to be achieved, there must be found a combination where the technical, economic, social and environmental constraints are in equilibrium. As a result, the need for evaluating sustainable development (SD) occurred, using specific indicators that have been developed the last decades, which are called *footprints*. A footprint indicates how humans utilize the natural resources and what impact their activities have to the environment. They are distinguished into four categories:

i. Environmental, e.g. Carbon footprint, Water Footprint, Energy footprint, etc,

ii. Social, e.g. Social footprint, human rights footprint, etc,

iii. Economic, e.g. Financial footprint, Economic footprint, and

iv. Combination of the previous, e.g. Exergy footprint, Chemical Footprint. (Cucek, et al., 2012)

Carbon Footprint

It is widely known that the climate changes and this is due to the various anthropogenic activities. This change causes many different problems, such as the temperature rise, melting ice and rise of the sea level, loss of the biodiversity, etc. A human impact with great share to the climate change is the greenhouse effect. Solar radiation passes through the earth's surface and is mostly absorbed by it. The infrared radiation is emitted back by the earth and part of it is absorbed by gases in the atmosphere. Those gases are called greenhouse gases (GHG) and they emit back to the earth the absorbed radiation within the thermal infrared range. The higher their concentration the higher the trapped radiation, leading to global warming, ozone depletion, acid rain, etc. and affecting human health. Those gases are the following: Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF_6). As a result, over the last years the concerns about climate change keep increasing, gaining more and more importance (Prof.Dr. Blecker et al, 2010).

A variety and abundance of appropriate policies is needed to mitigate the problem. One of the first attempts was the Kyoto Protocol, which aimed to the reduction of the aggregation of $CO_{2\text{-}eq}$ anthropogenic emissions of each country, and at the same time not to exceed their assigned amounts in relation to each one's emissions' limit and reduction commitments. Here we have to specify that mostly carbon dioxide is taken under consideration as it is found in greater quantities, and the quantities of the rest gases are converted to CO_2-equivalents. What this agreement provided was the implementation of specific policies and measures in order to strengthen the energy efficiency, to promote the use of renewable energy sources by developing advanced, innovating, sustainable and environmentally friendly technologies, to reduce progressively the market imperfections and the subsidies and to reduce the GHG emissions from every sector. It was also stated that the participating countries should cooperate and exchange information and experience and take care of the effects on climate change, the international trade and the social, economic and environmental impacts to occur. The methodologies used to estimate the emissions must be approved by the Intergovernmental Panel on Climate Change (IPCC). The participating countries are obliged to meet the commitments and in the case of failure each one is responsible for the level of its emissions. Additionally, in March 2007 the European Union Member States came to an arrangement known as the "20-20-20" targets with the objective to act against the climate change and at the same time make EU energy independent and competitive. Those targets provide to have been achieved by the year 2020 a reduction of at least 20% below the levels in 1990 in the GHG emissions, 20% of the EU energy consumption to be covered by energy from renewable energy sources, and such improvement of the energy efficiency that will result in 20% reduction of the primary energy use in comparison with the projected levels. In June 2009 the legal framework was enacted and is binding for all the EU Member States (European Comission, 2010, Kyoto Protocol, 1998).

Ecological footprint (EF) was the first indicator used to estimate the impact of the human activities and the rate of natural resources depletion in a fixed area with respect to the capability to provide them, assuming that there is the possibility to keep abreast of that rate and that this specific area can cover the human needs and absorb the generated wastes. Actually it evaluates the size of the biotical area needed to cover the needs of a specified population. It was introduced in order to be used as an indicator for policy making towards sustainability. The usefulness of EF is that it depicts the effects of the anthropogenic activities in a more distinct way, and if the existing natural resources can support them, i.e. if this way of living is sustainable. It is characterized by some advantages and some restrictions. The most important of the benefits is that it provides a clear and easily understandable result. In addition to this, it is easy to access the necessary data and run the calculation method. It hasn't geographical limitation and can be applied everywhere and it has a standard measurement unit, the hectare, which facilitates comparisons. Another edge is the fact that trade is included in the calculations and also the result is expressed in units of land in relation to the population under study. In contrary to this, there are concerns about the suitability of the used unit. Moreover, from its nature it isn't dynamic and requires recalculation, as any technological improvements aren't included, as well as the underground natural sources and the material flows. What is more, even if the distribution was lessened and sustainability was accomplished, the moral problem of a fair distribution should be under examination. And finally, it only states the current situation and doesn't propose any measure to be taken. It is noteworthy that EF is a factor of anthropogenic pressure on the environment, but it doesn't indicate the real impact of it (Wackernagel & Yount, 1998, Moffatt, 2000, York, et al., 2003). For these reasons and for others that are discussed later on, carbon footprint was introduced.

Definition of Carbon Footprint

In the recent years the term *Carbon Footprint* (CF) is widespread and used by the scientific world, the states and the companies as a means to measure the total GHG emissions of a state, occurring from the domestic anthropogenic activities, or of a company's service or product during its life cycle. Up until now there isn't a unique and standard definition of CF and also it isn't certain which measurement units to be used. Instead, various organizations have provided plenty interpretations describing it. The differences among the existing definitions lye on which gases are taken under consideration, in which units the results are expressed, which processes of the life cycle are taken into account, etc. The reason for this is that the main objective of the studies so far was the development of methodologies to measure and to reduce the emissions, rather than set a certain definition, and as a result each one proposed a definition. CF refers to the total greenhouse gas (GHG) emissions that are related to human activities. In general, it is still controversial whether all different types of gases should be counted or just the carbon dioxide (CO_2) and also if only the direct emissions will be measured or the total amount generated from the life cycle of a product. Furthermore, it constitutes a difficult procedure to measure in practice the CF due to the complexity of the calculations, which must be characterized by completeness and comprehensiveness. There are several parameters adding value to this difficulty such as the used technology and energy sources, the type of the raw materials, the type of the life cycle, and the transportation and distribution system. Moreover the system boundaries must be clearly defined, i.e. the start and the end point of the supply chain of the product under consideration and which of its processes are to be included. The selection of the measurement units (i.e. mass units or area units) is also important as it is necessary to be standard; otherwise any comparisons won't be attainable (Wiedmann & Minx, 2008, East, 2008).

Wiedmann & Minx (2008) proposed the following definition: *"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product"*. According to this, we refer to services or products by individuals, companies, populations, etc counting down both direct and indirect emissions, and the preferable measurement unit is mass unit, because in the case of converting into area units many assumptions need to be made. As far as it concerns the system's boundaries, they point out that the analysis must include all the processes, i.e. raw materials, production, transportation, distribution and utilization, and that attention must be paid to avoid double- or undercounting of emissions (Wiedmann & Minx, 2008). A.J. East (2008) gave another definition of CF: *"A direct measure of greenhouse gas emissions (expressed in tones of carbon dioxide [CO_2] equivalents) caused by a defined activity. At a minimum this measurement includes emissions resulting from activities within the control or ownership of the emitter and indirect emissions resulting from the use of purchased electricity"*. He also names the term carbon footprint as a "buzz word" because it became very popular and very quickly, despite the lack of a fixed definition (East, 2008). According to Dr.Quack, et al. (2010), carbon footprint "*describes the sum of greenhouse gas emissions accumulated during the full life cycle of a product (good or service) in a specified application*".

There are two basic types of carbon footprint. The first one refers to a person or a group of persons. CF can be calculated for the all the range of activities including transportation, habits, the consumed energy for each activity, etc, of an individual (Personal CF) or of the citizens of a city or a state in total (City/State CF). The second refers to a company, regarding the total operation or part of it. A certain company can have its own CF occurring directly or indirectly from the operations in total, including the building facilities, the work of the employees, the consumed energy, the produced goods or services, etc (Organizational CF), or can measure the CF across the supply chain of one of its products (Product CF) (Carbon Trust, 2010). In this Thesis we will mainly focus on the Product Carbon Footprint (PCF).

System Boundaries

It is essential that specific and clear rules are determined on the boundaries of the system at the beginning of a study. By the term boundaries we refer to depth of detail in the calculations and the processes, gases and type of emissions included. The emissions are distinguished in three categories in order to avoid double-counting, and are called Scope One, Scope Two and Scope Three emissions. Scope one refers to the direct emissions that are generated from actions performed by the company exclusively. Scope two stands for those emissions due to the consumed electricity for those actions. And Scope three includes the occurring emissions from products or services produced by others but utilized by the company (East, 2008). The table that follows (Table 1) presents those three main types of emissions.

Scope 1: Direct Emissions	***Scope 2: Consumed Energy***	***Scope 3: Indirect Emissions***
Consumption of Fuels	Electricity	Waste Disposal
Transportation	Heat	Use of Goods/Services produced by others
Emissions from the Production Processes	Steam	Assets Leasehold
	Cooling	Business-travels
		Transportation of Raw Materials to the company
		Production of Raw Materials

Table 1: Categorization of Emissions

It is questionable if it is adequate to measure only Scope one and two emissions so as the results to be realistic and to provide the needed information for the company to make the appropriate changes (Matthews, et al., 2008). Huang et al (2009), in their study for the emissions categorization based on criteria such as the industry and the sector characterization. Due to the lack of specified methodology and norms, they focused on upstream GHG emissions, taking also under consideration those occurring from the employees' business travels (Huang, et al., 2009). Although Scope three emissions cover on average more than 75% of the CF of an industry, it is at its choice if they will be included in its CF or not. The most common is to be disregarded due to the difficulty in finding the necessary data and the complexity of the calculations. Besides, there aren't certain guidelines from the existing protocols but are still in the phase of research and development of the appropriate techniques. It is though very important for the companies to understand that Scope three emissions can largely contribute to establishing more effective policies, in collaboration with the other participants in a supply chain. For example, in the case of companies in the production sector, it has been found that most of their emissions through the supply chain of a product count for Scope three. What was found out as a great opportunity was that if a company is aware of which supplier contributes to higher emissions, it could then more easily make improvements and achieve higher reductions in its supply chains (Huang, et al., 2009). In contrary to this, Matthews et al. (2008) after implementing an input-output life cycle analysis found that whether it is accepted or not to rely on the Scope one and two emissions or not depends on the nature of the company, namely if it basically provides a service – in this case most of the emissions belong to the third category – or if it comes from production sector, so most of the emissions count for the first two categories. They also concluded that there could be another group of emissions, including those related to the delivery, use and disposal of the product. But those can only be measured in average, since yet there isn't detailed data, until many companies start reporting their emissions and in this way a database be created (Matthews, et al., 2008). Another aspect that should be considered is the market research the consumers make before the purchase of a product, as to this could be attributed an appreciable share of the emissions (Dr.Quack, et al., 2010).

Calculation Method

On the way to the establishment of a certain procedure for carbon footprint measurement there are some matters to deal with. Standardization is the key in the whole concept of CF, providing the advantage of making comparisons, and also, you cannot make effective improvements and manage efficiently your CF unless first you have quantified it properly. Firstly, it should be clarified if all GHG are to be measured or only those settled by the Kyoto Protocol. Then the system boundaries should be defined, i.e. which of the life cycle analysis processes will be under investigation, and also how the emissions will be allocated, when for example two or more products share the same warehouse and moreover where the investigation ends should be specified. Furthermore the data sources must be selected either they will be associated to technical operations or to the financial data. A challenge would be for the companies to create a database which would be informed systematically in order to be always up-to-date and at the same time to overcome the difficulties to appear. It is recommended when it comes to products from the same category, not to make a new study for each one, but to elaborate a study and meditate the alternatives, otherwise it would be pointless. Other methods that should be considered are the method of carbon storage, the raw materials and the used energy mix (Dr.Quack, et al., 2010, Hanifan & Hoyle, 2010, Finkbeiner, 2009). It is considered as a basic principle that the measuring method is adjusted to the nature of the product under consideration and the special characteristics of its supply chain, deals with the direct emissions of its life cycle stages, and takes into account the emissions from all GHGs. Granted that, it indicates relevant developments. Hence companies shouldn't stick to a widely used method but instead be eligible and act based on their needs (East, 2008, Grenon, et al., 2007). The following table (Table 2) illustrates which basic steps should be followed - from cradle-to-grave - for the calculation of the carbon footprint.

Organizing the Measuring Methodology		
1st Step	Selection of the Method that will be used:	The method that will be chosen must be in accordance with the existing standards, in order to allow comparisons and ensure accuracy.
2nd Step	Definition of the system's Boundaries	It must be specified which of the company operations or which processes of the supply chain will be takes under consideration.
3rd Step	Gathering of the Data	Attention must be paid in this step, as the quality of the available data determines the accuracy of the result.
4th Step	Calculation of the CF	Due to their complexity, calculations need to be done carefully. Any assumptions made must be reported and explained.
5th Step	Certification of the Output	What would add value to the output is its certification by an authorized organization.

Table 2: Organizing the Measuring Methodology (Carbon Trust, 2010)

As far as it concerns the measurement units, CO_2 emissions are measured in mass units (kg). Any conversion to area units is pointless, since it would require many assumptions to be made, which would have impact on the accuracy of the result. All the GHG emissions are deduced to units of CO_2-equivalents. A CO_2-equivalent is a measurement unit which offers the ability to use and compare all the different GHG emissions on a CO_2 base. For the conversion, the emissions of each gas are multiplied by the corresponding 100-year global warming potential (GWP) (Wiedmann & Minx, 2008, Carbon Trust, 2010).

Where LCA aims is to designate the environmental impacts of a life cycle based on databases and study the improvements that can be done. The three basic steps of LCA are (i) the definition of scope and goal, (ii) the inventory analysis, and (iii) the impact assessment. After each one the results are being evaluated, allowing changes to be made to any of the other steps. The most difficult part in an LCA is to determine the boundaries of the system under investigation, i.e. the included processes, the used energy mix, the materials and how much detailed the analysis will be. Inventory analysis is considered to be the most developed stage of LCA, since it is based on a well-informed database. The impact assessment has also its difficulties. It actually chains the results of the inventory analysis with the environmental consequences to occur. The quality of input the data determines the reliability of the outputs, the evaluation and combination of which leads to suggestions for improvements and developments and eventually to policy making for more efficient operations (Graedel & Allenby, 2009). The methodology of LCA has some uncertainties, which are separated into parameters, model and scenario uncertainty. The first one has to do with the input parameters and the measurement errors that they include, the second with the used model itself and the third one with the tested scenarios for the improvements and changes to be applied. It isn't though standard which one of the three has the largest share, as this depends on the selected LCA model (De Koning, et al., 2010). There are two types of Life Cycle Analysis (LCA), (i) the process-based which is more accurate but requires plenty of time because of the difficulty in gathering the essential data, and (ii) the input-output which includes deviation in the results due to errors and assumptions, but provides efficiency and reduced truncation errors. We should bear in mind though that an input-output life cycle analysis is done for one specific supply chain and for a certain period of time. For another supply chain or another period it must be recalculated. It may also be characterized by deviations due to differences in prices and variations in other parameters, but regardless that it offers significant first indications towards decision-making and eventually CF reduction since it detects all the emissions related to the operation of the company. But for this to be succeeded the protocol organizations need to institute specific framework and directives (Matthews, et al., 2008, Huang, et al., 2009).

Constraints

What is positive about the CF as an indicator is that it is already widely known and comprehensible. It is also in accordance with the new legal frameworks and in comparison to other indicators CF can introduce the impact on the environment more effectively. But there are some drawbacks, such as the fact that the CF databases need to be continuously updated and that it cannot express the efficiency directly like an energy indicator can. The indicators for energy exist and are in use for a much longer time, with the necessary data available and up-to-date. Considering that no one can replace the other, what can only be done is to combine the two types of indicators, in order for the results not to be misleading (Dr.Quack, et al., 2010). Moreover, of significant importance is the fact that the companies generally seek for simpler methodologies, that also require already available data and they base on their results to make decisions and develop policies, because those indications they receive aren't fully trustworthy. This is due to the great correlation of some used factors, such as the ecological footprint and the respective energy needed with other factors like the raw materials or the transportation type. Though, A. Laurent et al. (2012) claim that the use of GHG emissions measurement is adequate, since those gases are involved in each stage of a supply chain, and additionally they are the subject of study of the Intergovernmental Panel on Climate Change (IPCC) and the Kyoto Protocol, and thus, consist the carbon footprint (Laurent, et al., 2012). It is very important however that each approach isn't centered on only one parameter but comprehensive information is gathered, otherwise the results will be misleading. For the same reason all the life cycle processes need to be examined analytically (Schmidt, 2009).

Also noteworthy is the accuracy accompanying the result. This accuracy is estimated based on different scenarios concerning the stages of the supply chain. But the parameters affecting each scenario vary, so actually they cannot be compared and cannot be reliable. At the same time, inasmuch there aren’t detailed databases yet, mean values are largely used until the time that there will be specific and up-to-date data (Schmidt, 2009). A.C. McKinnon (2010) states that the complexity in calculations and the different conditions are significant factors and affect the accuracy of the indicator. Defining the boundaries is a major limitation, vacillating between the direct and indirect emissions through a life cycle. The preferable as mentioned, is to include also the indirect emissions, even if it is difficult to gather the needed data. When it comes to a company, one must be careful with the allocation of the emissions in order to avoid double-counting in the case for example that different products share the same warehouse. It is noteworthy that if a supply chain or a stage of it changes, then changes also the CF and needs to be recalculated, but often companies use an average. Additionally, another major constraint is the cost of implementing a CF measurement. It can be reduced though by simplifying the LCA through focusing on the main processes; using the Life Cycle Analysis databases and software which can carry out complex calculations and save time (McKinnon, 2010).

After the elaboration of a research on whether the CF is an approved indicator or not, using impact assessment methods, A. Laurent et al. (2012) came to the conclusion that CF measurement might give almost the same values for products that belong in a certain category but at the same time they can vary a lot depending on the specific characteristics of each one’s. Provided this, CF cannot be the driving indicator for policy making, without taking under consideration its interactions with other parameters. Despite its great importance and contribution to public information and market activation towards the protection of the environment, arises the need for further research (Laurent, et al., 2012). And as M. Finkbeiner (2009) said, “carbon footprint is too bad to love it, but too good to leave it” meaning that there are many gaps and many constraints to be overcome, but on the other hand it is right now the best weapon we have in order to cope with the threat of the climate change, so the remaining option is to change it and improve it (Finkbeiner, 2009). Equally important is the fact that by focusing on the impacts of the CO_2 and the other GHG emissions, there is risk of ignoring other factors affecting the climate change which will consequently cause or reinforce other problems.

What is suggested is to include also other analyses for the efficiency and sustainability within a CF study (Dr.Quack, et al., 2010).

Carbon Labeling

The aim in carbon labeling of the products is to make the consumers choose a product because it has a lower carbon footprint in comparison to another of the same category. It offers them the ability to make comparisons and select accordingly. In order to be meaningful, carbon labeling has to comprise all the stages the product passes through and by this way give the customer the ability to evaluate and then make or improve the purchasing choices. In other words, it has to provide complete information (Hanifan & Hoyle, 2010, De Koning, et al., 2010, Schmidt, 2009). In reality, this cannot be easily achieved since there isn't a specified measurement methodology and it isn't yet applied to a broad variety of goods. Therefore the information provided to the consumers doesn't have the desirable impact on the consuming behavior and indirectly on the increase of the company's profits (De Koning, et al., 2010).

A label must be clear and intelligible. But even though, if CF is expressed as just a number, it has no meaning for the consumer. There needs to be defined a scale which will characterize the product, based on its CF, and this scale to be shown together with the number of CF, just like for example the Energy Performance Certificate (EPC) of Buildings. Moreover, this result should be certified by an authorized organization, appropriate to do so, so as the label to be trustworthy. What would add value would be the publication each CF study, so that everyone will be able to study it, find the assumptions made, and evaluate its quality. It is preferable for the consumers, that a carbon label is simple and easy to read. It must be well organized and present all the necessary information in a smart way, as long as standardization has been established and the measuring methodology and format of the label is common (Dr.Quack, et al., 2010).

According to A. C. McKinnon (2010) this is one way for the enterprises to play a significant role in the trend for carbon footprint. Thereby the consumers will be guided implicitly to choose those products with lower CO_2 emissions; having at the same time informed them about the environmental benefits. Likewise it leads to economical benefits for the company, improvements in its supply chains and further developments for reducing the CF. On the basis of the consumers, their response cannot be predicted. Nevertheless this isn't the main target of the carbon footprinting to influence their consuming behavior, but the respond to the climate change (McKinnon, 2010). On the contrary, there is the belief that carbon labeling is a different matter than carbon footprinting and that it is needless for the consumers, as it doesn't provide any meaningful information and the argument for this is that CF helps the companies improve their operations and not the consumers to make their behavior more environmentally friendly. Mr. Messem from Carbon Trust (2012) supports and promotes also the carbon labeling and the reason is that they believe that this is the easiest and fastest way to contrive a reduction in CO_2 emissions and eventually come closer to fulfilling the goal for the reduction of global emissions, achieving at the same time efficiency and financial gains. As shown in one of their researches, already a great share of the consumers would prefer a labeled product. Besides, as he mentions, the Department for Environment, Food and Rural Affairs (DEFRA) of the United Kingdom has announced that from April 2013 it will be compulsory for every company listed on the London Stock Exchange to report their GHG emissions, and probably the other governments will follow this too (Messem, 2012). Within the boundaries of the European Union, is already being used the *EU Ecolabel*, which is a tool to evaluate products, regarding carbon footprint, based on the LCA methodology, following standardized guidelines (GHG Protocol[1], PAS2050[2]) (Baldo, et al., 2009).

Supply Chain

Supply chain (SC) has been defined in various ways up until now. What prevails is that it refers to different companies which are connected to each other through the exchange of materials, information and financial transactions. In particular, it is a network of companies which are cooperating in several stages, such as the flow and storage of the raw materials, the production process, and the distribution of the product to the market. Some though argue that the use of the product from the customers and its recycling

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[1] GHG Protocol is a tool for calculating the emissions of every greenhouse gas, used widely from organizations. http://www.ghgprotocol.org/

[2] PAS 2050 (Publicly Available Specification) is a free software developed by the British Standards Institute providing a standardized methodology for measuring the CF based on Life Cycle Analysis. http://www.bsigroup.com

should also be included. The starting point of a SC is the point-of-origin of the product and the ending point is the point-of-consumption, i.e. starts from the gathering of raw materials and ends to its consumption. Before analyzing the SC, it is of significant importance to describe it in a simple way, accurately and to be integrated in a wider strategic plan (Stadtler & Kilger 2008, Mentzer, et al. 2001, Davis 1993). A SC is distinguished in three categories based on its complexity. The first one is the direct supply chain, which is the simplest of the three. It includes only one company, one supplier, and a customer. The second one is the extended supply chain. This one goes deeper into detail as it involves also the suppliers of the supplier and the customers of the customer. And the third one is the ultimate supply chain, which goes even further, including all the direct and indirect suppliers and all the participating organizations and individuals up to the final consumer (Mentzer, et al., 2001).

For evaluating regarding efficiency and implementing improvements, the SC needs to be analyzed, i.e. each step needs to be clearly defined, as well as all the interactions taking place. The structure of each supply chain depends on the policy of each company (Stadtler & Kilger, 2008). In order to assess the performance of a SC certain indicators are used, which are categorized into (i) strategic, (ii) tactical, and (iii) operational. An example of a strategic indicator is the total time needed for a SC to make a circle, or the rate of return on the investment. Tactical indicators are considered among others, the delivery reliability and the effectiveness of distribution planning schedule. An operational indicator is the cost to the company per operation hour, or the frequency of delivery, etc. It should be mentioned here that there isn't an indicator with the capability to be applied in all the processes viewed as if they were a single one, but they need to be appraised by an indicator separately (Gunasekaran, et al., 2001).

Many different definitions have also been published for the term Supply Chain Management (SCM). According to Stadtler & Kilger (2008), SCM is "*the task of integrating organizational units along a supply chain and coordinating material, information and financial flows in order to fulfill (ultimate) customer demands with the aim of improving the competitiveness of a supply chain as a whole*". As it derives from this definition, it is composed of the scope of the management's mentality, the target group, the targets and the numerous ways to accomplish these goals. The purpose of SCM is to increase the effectiveness of the supply chain by making improvements, concerning all the processes taking place along the SC, with the ultimate objective to reduce costs and at the same time satisfy the customers. It is actually the incorporation of the company's policy into the supply chain. SCM is divided into three phases. Firstly, the current situation is being defined. Secondly, the processes where there is room for improvements are being spotted, using the appropriate indicators. And thirdly, the improvements to be made are determined and implemented and the result is being evaluated (Stadtler & Kilger, 2008).

Green Supply Chain Management

Just like the carbon footprint term, various definitions were used until the consolidation of the term *Green Supply Chain Management (GSCM)*, which included mostly the words *sustainable* and *environmental*. It is delineated by some drivers, which include complexity, ecological modernization, information, institutions, resource dependence, social network, stakeholders' benefits and transaction costs. Complexity occurs from the existence of many different factors and the involvement of many parties, like the suppliers, the producers, the stakeholders, etc and it has direct impact on the implementation of strategies. Ecological modernization deals with the environmentally oriented technological improvements and how these are directed by the legislation. The policies adopted by the governments and the consuming behavior of the citizens are very important factors for the GSCM. Information plays a key role, since it matters particularly from where and how the needed data is gathered and how and from whom then is being certified. As far as it concerns the resources, a different mix may prove to be more efficient and more cost-effective. Social network stands for the social relationships between the involved parties, and the commitments and limitations that derive from them. Another factor that generates limitations in policy and decision making is the vested interests of the stakeholders. Finally, transaction costs include all those extra costs that are indirectly associated with the supply chain and that are being invested for the achievement of the best possible dealing between the companies and the consumers (Sarkis, et al., 2011). It has been realized that greater benefits are gained if the focal point is the supply chain instead of the whole company, which means higher efficiency of the operations and processes and reduced costs. But for sustainability to be achieved in a supply chain, attention must also be paid apart from its basic stages to some others that some-times may get neglected. Those are the design of the product, where the depletion of the resources and the effects on the environment should be taken under consideration, the manufacturing of by-products, the produced by-products during use, the extension of the product's life, its end of life, and the recovery processes. But these aspects raise a lot the already existing complexity in calculations, which could lead to increased costs (Linton, et al., 2007).

So far what was attractive for the consumers in a product had to do with the cost, the benefits provided, etc. but recently, in parallel to the agreements of Kyoto Protocol, the "20-20-20" targets of EU, etc, other requirements came to the forefront, like the green supply chains and the scale of interest of the consumers for more eco-friendly products has risen. As B. Sundarakami et al. (2010) state *"green supply chain management can be defined as the integration of environmental thinking into supply chain management, including product design, supplier selection and material sourcing, manufacturing processes, product packaging, delivery of the product to the consumers and end-of-life management of the product after its use"*. With this in mind, high level and detailed planning of complete supply chain on an end-to-end basis is required (Sundarakani, et al., 2010). According to M. A. Starr (2009) the ethical consumption is influenced by several factors, such as education, income, gender, religion, political views and social norms. Education contributes to awareness about the social and environmental impacts of one's decision to consume a specific product and so does also a higher income which sets more flexible economic boundaries. In the case of a more religious target group, it is observed that it is less likely to consume ethically, in contrary to those dealing with the politics indicating influence from social norms. Similarly it is more possible for women to make more ethical selections. The ethical behavior of the consumers could be enhanced via informing the public and promoting environmentally friendly actions, like recycling, energy conservation and use of public transportation. The effectiveness of it depends on the social benefits to be gained and the extra costs to occur (Starr, 2009). On the other hand the stockholders and the equity holders of the companies face the dilemma, whether the activities concerning the climate change are a risk or an opportunity. Their judgment to turn green or not is driven by the pressure for reduction of their GHG emissions applied by the government and international organizations and the possible profits or losses that might occur. What they should have in mind, is that by running on a sustainable way and greening their supply chains, the companies improve their reputation and enhance their brand name, passing the message that they fulfill their commitments to become environmentally responsible (Cunningham, 2008).

There are four factors delimiting the attempt for a more energy-efficient supply chain:

i. The continuous effort to reduce the cost of the energy used,
ii. The legislation forcing the enterprises to get permits for their emissions and/or pay penalties,
iii. The rivalry with the other enterprises for a greater share in the market, and
iv. The wish to make environmentally oriented improvements in the enterprise's productivity, since this leads also to saving money.

Many companies have already realized that the reduction of the carbon emissions via examining each process of the supply chain and making improvements in cooperation with the other collaborators outside the company implies opportunities for cost reduction and more efficient operation of the procedures. For the decision making for carbon reduction there is a driving working procedure that can always be applied. At first, the special characteristics of the supply chain must be investigated paying particular attention on the type and the quantity of energy used in each one stage. Secondly, it should be analyzed from where the majority of the emissions occur and evaluate the margins for improvements. And finally, the best combination of measures should be achieved, regarding the emissions' reduction, the influence upon the company's finances and the convenience in implementing them. Under those circumstances opportunities and solutions can appear, simple and even costless – as long as the analysis is extensive (Grenon, et al., 2007). By making the operations more efficient, energy conservation can be achieved, the services to the customers become more efficient and money is saved. In combination with other improvements, for example in the structure and operation of the building facilities, more savings can be achieved, as well as reduction of the CO_2 emissions. Besides customers are keener on those companies providing green products and that is a path that companies could also follow and seek for green suppliers and in this way make their supply chains green more easily (Cunningham, 2008).

3 Measuring the Carbon Footprint of a Supply Chain

In order to measure and calculate the Carbon Footprint (CF) of a product, first we have to define clearly what CF is. As it was discussed analytically above, CF stands for the sum of the GHG emissions in CO_2-equivalents occurring from all the activities taking place during the life cycle of a product. What also need to be defined are the boundaries of the life cycle, i.e. the supply chain of the product. Namely, it is particularly important to specify the system of our study, which is presented in the first section of this chapter. The second section describes the methodology and the existing models for measuring the GHG emissions and calculating the CF of a product.

3.1 System Specification

This section defines clearly the start and the end point of a supply chain which is under investigation for measuring its carbon footprint. The specific processes of the supply chain for which the measurements will be implemented will also be determined. The supply chain that will be set and used as a driver for the calculations in general, should be characterized by accuracy, consistency and provide the ability for comparisons. This has become mandatory from the already existing legal framework. A fundamental criterion is that the plan of a supply chain for the purpose of carbon footprinting should cover the whole life cycle of the product, from the supplier of raw materials to the ultimate consumer.

Primarily the processes of the supply chain are distinguished generally in production, storage and distribution and each one of them can be studied in more detail concerning the consumed energy and GHG emissions. It is of significant importance to clarify the point where the supply chain of a certain product (good or service) starts. Taking under consideration the Life Cycle Analysis Process – which is described in detail later in that chapter – the SC begins at the point where the necessary raw materials have been produced and lay in each supplier's inventory. In the case that the raw materials come from recycling, then the start point is when the recycling process has been completed and the materials are ready to be delivered (McKinnon, 2010). *Therefore, the first stage of the supply chain taken under consideration for the purposes of measuring carbon footprint is the transfer of the raw materials from each supplier to the company*.

As far as it concerns the end point, things are more complicated. There are several different opinions about where the SC should stop. Generally, it is thought as the most proper choice the point where the product has been purchased by the final consumer, in order for the measurement to be comprehensive. There are arguments claiming that should also be included the emissions from the life stages of the product after the purchase, for example the use of the product, disposal, or recycling. But in that case, it is really difficult to gather the required data, which makes the implementation of CF measurement almost impossible for these stages. Additionally, the fact that nowadays many purchases are made through the internet, accompanied by delivery to the consumer's place, calls for attention since it must be decided to whom are those emissions attributed (McKinnon, 2010). But those are particular cases. In the frame of general reference, *the last stage of the supply chain is the distribution of the final product to the retailers*. The start- and the end-point have common characteristics, since both of them deal with transport. The amount of emissions as well as of the consumed energy depends on the type of transportation, the type of fuel used, and the distance covered. And those stand for the emissions from non-stationary sources (i.e. trucks and other vehicles used).

The intermediate stages include the *production process* and the *warehousing*. During production occurs the greatest proportion of emissions and the largest share of energy is consumed. At this stage, the emissions depend on the type of machinery used and the intensity of production rate. It includes any required processing of the raw materials, and their blending for the production of the product. There are numerous different products and as a result countless production methods depending on the product's nature. At the stage of storage, the emissions depend on the type of packaging, the vehicles or used machinery, the trade policy and the density of all these activities.

All those mentioned above are mostly general guidelines. Each one of these stages mentioned above is connected to other substages and then each one of them to others and if we choose to study them all in detail the boundaries become enlarged. This results to increased complexity of the calculations and increased difficulty in fulfilling the assessment. Although interactions between the company and other companies aren't fully reflected, some specific – but wide – standards are set concerning the limits and the structure of a supply chain when preparing to measure the carbon footprint. But before the implementation on a certain product, those guidelines should be adjusted to the special characteristics of the product and its supply chain and the data availability. For this reason further detailed investigation is needed, to identify the exact routes that the product follows, to detect the hotspots regarding the emissions, and determine the assumptions that need to be made in order to overcome difficulties and obstacles, and avoid complexity in the calculations.

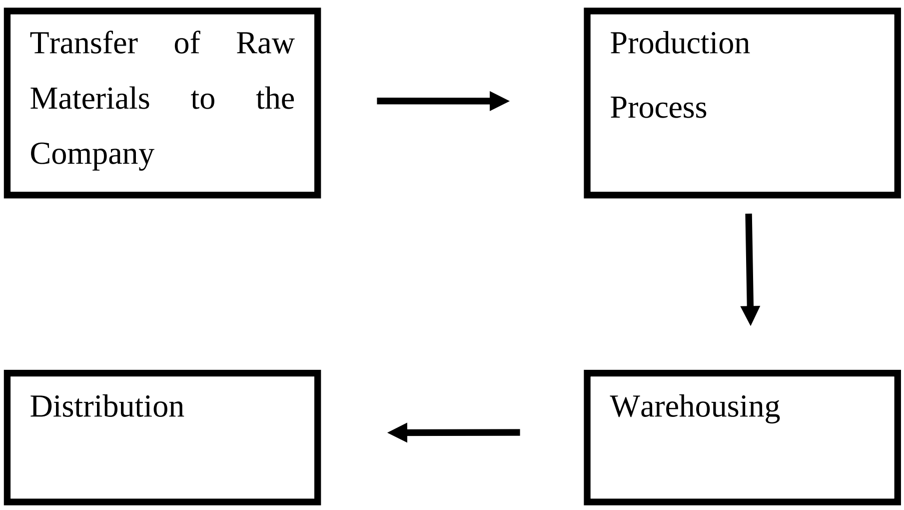

Diagram 1: Supply Chain Plan for Carbon Footprinting

Since the system boundaries have been specified, the first step before applying a CF measuring methodology has been completed. It is of great importance, because it forms the basis for the implementation of the next steps, which are discussed below.

3.2 Measuring Carbon Footprint

In general, the procedure followed with aim to calculate the CF of a product's supply chain consists of five basic steps, among which there is great interdependence. But firstly, the boundaries of the system have to be clearly defined, regarding the included processes (as discussed extensively in the previous section), the types of emissions included, etc. And secondly, the units that will be used must be also specified in order to facilitate the calculations and for the result to be comparable to the results from other studies. As it has already been justified above, the emissions should be measured in mass units (kg) and the result, the CF, should be expressed into CO_2-eq per kg of product. The first step to be accomplished is to analyze the parts of the product in detail into its raw materials, co- and by-products, various transportations and warehousing, in order to understand which the required data to be gathered is. It is often that there isn't available data for the raw materials, or it is limited, since they are actually products, each one with its own CF that usually hasn't been calculated yet. The second step includes the design of an analytical map representing all the processes under consideration taking place throughout the supply chain – based on the already defined system boundaries. The third step is the adjustment of the system as it has been planned to the special characteristics of the product under examination. Here is the point where all the necessary assumptions are made in order to overcome the arising difficulties. The next step is the collection of the primary and secondary data. And the next and last step is the CF calculation (Murray, et al., 15/03/2007).

The various methodologies for calculating the CF of an entity were developed during the recent years in a very fast pace. In order to achieve their establishment it was mandatory to follow certain specifications that meet the governments' policies, as well as fit to companies' strategic management. In contrast to that, the development of the scientific knowledge hasn't followed that rapidly. Combining this with the fact that the supply chains nowadays are particularly complex and a great share of them are expanded internationally, it is obvious that a very clear framework needs to be defined which will help to deal with the upcoming barriers. This framework is already provided by the Life Cycle Analysis, although it doesn't cover fully the requirements of product carbon footprinting. The basic concept for measuring the PCF is that the overall amounts of GHG emissions associated with each one stage of the product's life cycle must be calculated and aggregated in order to give as an output a single number. Since the life cycle (and therefore the supply chain) is being examined from the start- to the end-point, it is also called “cradle-to-grave analysis”. To begin with, we should explain what Life Cycle Analysis (LCA – also called Life Cycle Assessment or Environmental LCA) is. It is a methodology which examines in detail the environmental impacts of each process taking place in order to produce a product, with respect to several parameters such as the GHG emissions, the consumed water and energy and the wastes, and is adjusted each time to the nature of the product. In the case of carbon footprinting the focus is on the GHG emissions. After the establishment of carbon trading systems, such as the European Trading Scheme (ETS), the establishment of standards became mandatory. Those standards can be found in the following resources:

- GHG Protocol of the World Resource Institute/World Business Council on Sustainable Development (WRI/WBCSD): there are the “Product Life Cycle Accounting and Reporting Standard” and the “Corporate Accounting and Reporting Standard: Guidelines for Value Chain (Scope III) Accounting and Reporting”, which include guidelines for the GHG emissions in each sector and in general, and for the evaluation of the reductions after the implementation of relevant actions,
- ISO 14064 (Parts 1 &2): determines the appropriate framework for the boundaries definition, GHG emissions measurement and provides guidelines for the GHG emissions reduction,
- Publicly Available Specification – 2050 (PAS – 2050) of British Standard Institution (BSI): sets the framework (determination of system boundaries, quality of data, measurement units, etc.) for estimating the GHG emissions of a product’s life cycle, based on ISO 14040/44 standards for LCA,
- IPCC Guidelines for National GHG Inventories (2006): they are guidelines concerning the reporting of the GHG emissions (categorized into energy, agriculture, waste, forestry and other land use, and industrial process and product use) from each participating country in a comparable way,
- ISO 14025: provides a standard regarding LCA, and
- ISO 14067: includes a standard for PCF.

Apart from those there are also other guidelines that have been enacted, from several organizations such as the Department of Food and Rural Affair (DEFRA) and Carbon

Trust in United Kingdom, the Environmental Protection Agency (EPA) in USA. Organizations like World Wildlife Fund Climate Servers, California Climate Registry and The Climate Registry (in USA) have based on them and developed their own methodologies (Pandey, et al., 2011, Plassmann, et al., 2010).

3.2.1 Selection of Emissions

The system boundaries don't only refer to which supply chain processes are to be included, but also which types of gases will be taken under consideration. It is controversial which GHG emissions to include when measuring CF. In some cases all the six gases indicated by the Kyoto Protocol are being measured and in other cases some of them are selected or even only the CO_2 emissions. In general until now which gases were to be chosen, depended on the type of the product, on which guideline was being followed, and on the required accuracy. Though, the existing standards suggest that all the six Kyoto gases should be taken under consideration (Pandey, et al., 2011).

Apart from this it needs to be clarified whether only the direct or also the indirect emissions are to be attributed to the company or not. In order to deal more easily with the emissions they are distinguished into Scope I, Scope II and Scope III. As discussed before, Scope I stands for all the direct emissions occurring onsite from operations that the company owns or controls, Scope II for the indirect emissions, produced from the consumed energy (electricity, heat, steam, etc.), and Scope III includes all the indirect emissions from products or services produced by others but utilized by the company. Indirect emissions are included in both Scope II and III categories, but those in the second category occur from the production or consumption or transmission, etc of energy by the company under examination and not by other parties. Those are covered by the third category, provided that they are within the specified boundaries. But still the Scope III emissions haven't been clearly defined and there is uncertainty the emissions from which activities exactly are included. That is the main reason why most of the studies that have already been conducted haven't included them, since they increase the complexity of the calculations and the inserted uncertainty and this fact justifies why in most of the standards it is optional if those emissions are to be included or not. Nevertheless it needs to be specified to what extend a specific company is responsible for the produced emissions, namely to specify the limits of Scope III. It becomes even more difficult when including embodied emissions due to international trade, because many assumptions need to be made and it is even harder to set a boundary. On the contrary to this, the expected improvements to the supply chain management and the tracking of the emissions will enhance the accounting of those emissions. When taken under consideration only the first two categories of emissions (Scope II & II) the CF is called *Basic* or *Primary Carbon Footprint*, and if the Scope III emissions are also included then it is called *Full Carbon Footprint*. According to Pandey, et al., (2011) 72% worldwide of the companies do not include the indirect emissions, although in most of the cases those constitute the greater share of the emissions. For example, in companies from the production and construction sector the majority of emissions account for Scope I and II whereas this is reversed for companies that offer services. It has also been under discussion is the introduction of another category, named Scope IV, which will empody those emissions linked exclusively to the life of the product after its distribution to the retailers, including its delivery, use, and disposal. Considering that more and more companies report their emissions, a database could be created (Pandey, et al., 2011). This would facilitate the calculation of Scope III and IV emissions. But then again it at the discretion of each company whether it will take the responsibility for those emissions or not.

Apart from that categorization of the emissions and the selection of which are to be included in the study, they also must be allocated, so that it will be clarified which mounts are attributed to which product when for example two or more products share the same warehouse, transportation vehicle, or handling equipment. Also allocation of emissions is required for those products or for those processes that take place at the same time regarding the energy consumption. This part of the study mandates great attention, since the complexity rises with the raise of disaggregation. Some criteria that could be useful in determining who emits and how much are the weight and size of each product, potential special characteristics, the process time, etc. But a standard set of criteria cannot be set, hence in most cases it is a matter of the practitioner's personal judgement. However there are some issues that could provide some guidance. Firstly, when it comes to deciding between two products, the determination must be done at a point of the load free from the constraints of mass or volume which hinder the comparisons. Secondly, since the products also have different height, it needs to be specified if the allocation will be done in two-dimensions or three-dimensions basis. Thirdly, it should also be considered the density of the load of two different products varies (e.g. due to different production time, or different number of orders), resulting in high- and low-density loads. The former is characterized by a higher energy consumption – therefore more emissios – and the latter requires more space. And finally, it should be examined during transportation, whether in a coplete round the emissions will be distributed on average to all the carried products or it will be based on the actual distance needed for each product (McKinnon, 2010).

3.2.2 Data Collection

What adds great value to the quality of the results and the study in general, is the quality and the type of the emissions data used. Consequently, after deciding the boundaries of the system concerning the processes and the types of gases, the next important thing is to gather the appropriate data. There are two ways of gathering the needed data for estimating CF; either by measuring onsite in real time, or by using appropriate models and emission factors. The decision is based on several criteria, such as the objective of the study, the required reliability, the attainability, as well as the cost of the method. Up until now the second one, i.e. appropriate models and emission factors, has been mostly used. The input data originates from the fuel and energy consumption and other similar parameters, providing the amounts of generated emissions (mainly CO_2). The existing protocols as well as various state institutions provide a wide range of emission factors, which though require to be verified, as they differ from one geographical region or operational sector to another. However there are types of emissions' sources for which it is preferable, or more appropriate, to implement direct measurements. Examples are the use of special tools such as sensors for chemical, biological, optical or photo acoustic infrared measurements, and measuring gases in combination with a chromatograph for analyzing the GHGs. At the same time relevant databases are being developed worldwide concerning CO_2 emissions or GHG in general, as well as inventories about energy and fuels consumption. Regardless that direct measurements are definitely more precise and acknowledged globally, their cost might be discouraging in cases. As a result, low cost methods are being developed to confront such obstacles. In like manner, there cases where indirect calculations could provide equally qualitative outputs, if adjusted to the nature of the product under study. In addition to this, the GHG protocol provides already customized tools for every sector which are globally accepted. Moreover, there have already been created monitoring systems for GHG counting which record continuously and are being further developed. And in order to increase and improve their depth of detail and comprehensiveness, they are complemented with private inventories. The utilization of satellites adds also value to the quality of these databases by monitoring GHG emissions (e.g. the Japanese "greenhouse gas observing satellite", "Vulcan Project" of NASA & US Department of Energy). All these recordings have to be in relation to a specified base. This can be a certain year or an annual average of a certain period to compare to. The base that will be chosen is of significant importance, as every comparison to it actually indicates the changes and improvements that need to be made in the technology used and/or the supply chain management. What is suggested from the GHG protocol is that as base year, should be chosen the one that is earlier, given that it provides reliable data, depending always on the objective. At the present time, the year 1990 has been determined as base year in most databases, due to the commitment to reduce CO_2-eq emissions to the levels of 1990 (UNFCC) (Pandey, et al., 2011).

At this point, all the needed steps before applying the measuring methodology – which as discussed above is the Life Cycle Analysis – on the product under investigation have been completed. All the required inputs have been gathered, providing the ability for the practitioner to implement carbon footprinting, but LCA has its own requirements and limitations, which are being discussed below.

3.2.3 Life Cycle Analysis

There is an extensive literature on LCA and how it works and in this Thesis we will not expand very deeply on how it works. LCA consists of the following phases: the set of the goal, the Life Cycle Inventory Analysis (LCI), the Life Cycle Impact assessment (LCIA), and the Life Cycle Interpretation. At the first phase, it is important to define the scope and the limits of the system. The reason for this is to avoid any omissions and to adjust the method to a specific product. LCI examines which are the inputs to the system, from mass to energy, and the outputs which are the environmental impacts. The included processes are the gathering and validation of the data, the allocation and the calculations. LCIA includes the classification of the outputs, their characterization, and finally normalization and weighting. During characterization the contribution of each input is examined. Normalization converts the outputs in order to make them comparable, but for this to be succeeded weighting is required, which provides the possibility to rank them based on their importance. Interpretation is implemented for the results' evaluation and to make conclusions (Benedetto & Klemes, 2009).

Though, LCA methodology is accompanied by some constraints, which are actually sources of uncertainties. Some of them are frequent to other similar methods too. In the first place it has to be mentioned that it isn't a standardized method, which means that it isn't always the same calculation model used. Similarly not all the studies examine the same emissions categories (Scope I, II, III) or the same GHGs, and as a result comparisons aren't always applicable. A great barrier to the results' quality and reliability is the data quality and availability, as any contained error or obscurity is transferred to the output. The intermittent data determine the assumptions that will be made. What is preferable, is the inputs to correspond to as longer period of time as possible. A significant limitation of the method itself is the absence of site-specific data, meaning that already from the beginning of a study using LCA certain assumptions are essential. Equally important is the definition of the system boundaries since the wider they are, the more complex are the calculations, in which contributes also the selected process model. In order to overcome these difficulties appropriate assumptions are made to simplify the system, but it needs to be done very carefully to avoid oversimplification. All these assumptions made in order to facilitate the calculations procedure and/or cover the lack of data have a direct impact on the accuracy of the result. As another limitation which could act as disincentive, is the high cost of implementing a full LCA due to extensive data collection and processing. The use of hybrid methods that overcome many of these difficulties isn't though widespread yet (Benedetto & Klemes, 2009, Ross, et al., 2002, Bolwig & Gibbon, 2009). Coupled with the above mentioned is the fact that in each study arise some problems for which there is no guideline from the existing protocols and the practitioner has to decide on himself what to do, and this hinders the comparability of the used model. However this requires special attention, as results might come up that the practitioner will not be able to justify. And that is why the available protocols need to be further developed (Plassmann, et al., 2010).

There are two basic types of LCA of measuring the GHG emissions for the purpose of calculating the CF. The first one is called “Bottom-up” or “Process Analysis (PA)” and the second “top-down” or “Input-Output Analysis (IO)”. In the PA – which has been designed from the beginning for detecting the environmental impacts arising from products – the emissions are categorized based on their source, which makes it easier to handle the calculations. The model is based principally on the processing of micro-economical data of primary and secondary operations, resulting in output of high accuracy. Firstly, all the processes taking place are being identified. Then, the arising emissions are being measured and finally aggregated. Although in both cases the extend of the error margin cannot be clear, it is more appropriate to be used in small companies in order not to underestimate the CF instead of large companies where emissions of some activities might be overlaid and as a result obtain a greater error. Additionally this type of analysis enables the identification of the areas in which improvements can or should be made, but it is a costly method and requires intensive labour (Pandey, et al., 2011, Wiedmann, 2009).

The IO is based on an economic input-output model which is modified to include also environmental parameters (EIO), based on linear algebra. It was firstly introduced in 1936 by Leontief, but wasn’t widespread until recently due to lack of data. It links the environmental data from each sector to their financial transactions throughout the supply chain. The data used is macro-economical. Considering y as the output – which is the product – vector (list) and x as the input – which is the raw materials – vector, the inputs-outputs matrix is represented algebraically with the equation (1):

$$x = (I + A + A*A + A*A*A + ...)* y \qquad \textit{Equation (1)}$$

$$x = (I – A)^{-1} * y ,$$

where I is called “identity matrix” and the A, $A*A$, $A*A*A$, ... stand for the existing supply chains for producing the under study product. This equation provides the ability to expand the boundaries if desired and also protects from double-counting. In practice, the output of each process is multiplied with its environmental impact per currency unit (e.g. euro, dollar). Small amounts of emissions can also be included, as well as intersectoral transactions, although because of this at the same time uncertainties are inserted. Thanks to its nature, all the parameters can be included without demanding assumptions. The EIO has been proved to be efficient when implemented for large companies or product-groups (or countries), estimating the whole upstream or downstream emissions. Though it takes for granted homogeneity of the data and thus it isn't suitable to be applied to a single product (Pandey, et al., 2011, Wiedmann, 2009, Huang, et al., 2009). In order to avoid the introduction of an extra error, arising from the assumption that import and domestic production are identical (i.e. same environmental intensities and SCs structure) considering it as taking place in a single region, there has been developed another type of IO called "Multi-Regional Input-Output Analysis (MRIO)". This model can overcome that problem by procuring the necessary data from international databases and can be adjusted to the nature of the study as well. MRIO gives an analytical and comprehensive depiction of all the direct and indirect emissions related to every performed process providing the ability for detecting the emissions hotspots. Since the emissions of the entire supply chain are included, the accuracy of the result is enhanced. Also comparisons to other models can be generally easily made. The differences in results – for a specific product – that might be observed are mainly due to the following reason. The stages of the supply chain that are included in each study have to be the same, as well as the assumptions made, otherwise different emissions will be measured and as a result a different CF will ensue. Another constraint is the fact that often the different nations have set different sector-specific variables, making it necessary to make more assumptions (Minx, et al., 2009, Huang, et al., 2009). In addition to this, there is another approach used called "Structural Path Analysis (SPA)", which is also based on input-output approach. A single supply chain is considered as a path. By using SPA the path is broken down into the constituent parts in detail. The basic concept is the same with the other IO models. It is often used to evaluate a set of supply chains (e.g. the supply chains of a company/sector etc) by ranking them from the highest to the lowest CF. Namely it facilitates comparisons and indicates where improvements should be made (Huang, et al., 2009).

Both methods, PA and EIO, have already been applied many times for estimating the CF. Though, since they both have their strengths and weaknesses, it was deem as necessary to overcome the difficulties. It has been found that the best solution for this was to integrate the PA and EIO analysis into a third type called "IO-LCA Hybrid", modified each time so as to be adjusted as well as possible to the entity under study. In this type, the PA covers the small amounts of emissions and the IO the rest of them. By this way the advantages of each model are preserved, like the comprehensiveness, the accuracy and the flexibility in the calculations. Given that, this Hybrid LCA approach is considered as the most appropriate to be applied for carbon footprinting, even though still isn't widely used (Pandey, et al., 2011, Wiedmann, 2009). Despite this, there are some barriers inhibiting this method from becoming widespread. The most obvious one is the complexity that characterizes the calculations. In order to be dealt with, it is necessary for the practitioner to have advanced knowledge in the environmental science and the economic theory, as well as in IO analysis. There are though tools that have been developed recently, which facilitate the implementation of this hybrid method but yet haven't been adequately promoted and established for use. Equally important is the fact that there are arguments concerning the extent of the uncertainty in the output, when comparing the Hybrid IO-LCA to the PA. There are claims that due to the aggregation of uncertainties, IO eventually offers less precise output than PA. Although this may be true, it cannot be accepted utterly, since the final accuracy in practice depends on several factors, such as the special characteristics of the product under examination, the quality and data availability, and the model's modification (Wiedmann, 2009).

All the available measuring models are characterized by advantages and disadvantages, which offer the ability to the practitioner to select the most appropriate for each study. At the beginning of a study there are some questions to be answered in order to choose the right model. One of the determining factors is the time horizon. For example, in studies that the available economic and environmental data refer to a certain year only, the models based on input-output analysis aren't suitable, unless additional data is used. On the other hand, this problem can be dealt if the specified time horizon is viewed from another aspect, e.g. if this one year is analyzed into days, or months. Another factor is the type of the available data. How recent the obtained data is, its quality and homogeneity affect significantly the model. Also, in some cases it might be adequate to use averages but in others detailed data is required, for which IO models aren't appropriate. Moreover, the cost of applying the model and the intensity of labour that requires indicate also which one should be used. IO models are cost-efficient and easy to handle as soon as they have been modified to the special requirements of the study and are ready for use. And finally, very important is the comprehensiveness that characterizes each model and its depth of detail. The level of detail though is dependent on the scope of the study and the existing data. In reality those two can exist at the expense of each other, since their combination leads to increased complexity, as well as to a raise of the costs and workload. In the case that a greater level of detail is desired, then the most appropriate model would be the IO-LCA Hybrid. On the contrary, if comprehensiveness is more preferable, then the IO models are more suitable (Minx, et al., 2009).

After dealing with and having clarified all these matters regarding the measuring methodology, what follows is the methodology of calculating the final output of the study, namely the CF. This, is generally considered to be less complex. The next section discusses how CF is being calculated, the existing limitations, and which issues require attention.

3.2.4 Carbon Footprint Calculation

In practice, the procedure followed to calculate the CF of a supply chain consists of six steps (Table 3). At first, the basic processes are being identified. What is important to be done next is to detect the sub-processes taking place from which also occur significant amounts of GHG emissions. At this stage, some processes are selected to be included in the calculations and some others not by making necessary assumptions. Those decisions have to be made deliberately. A model that is being used for that reason is the "Supply chain Operations Reference (SCOR)", developed by the US Supply Chain Council. It consists of four hierarchical levels of processes. Level 1 – called "Top Level" – includes typically the basic types of processes, called "Plan", "Source", "Make", "Deliver" and "Return". In each study are included those that are within the determined system boundaries. Level 2 – called "Configuration Level" – includes all the sub-processes which consist the basic ones (up to 30 per each). Level 3 – called "Process Element Level" – specifies for each secondary process its components, performance and practices. And Level 4 – called "Implementation Level" – includes strategies to be applied to each one of these components. Not all the levels are always included in a study, as this often raises a lot the complexity. One or more of them are excluded, depending on the scope of the study. Afterwards, the emissions of each sub-process are being measured onsite – or calculated with the emission factors – and aggregated. And finally the emissions of each core process are being summed up (Wick, et al., 2010). Up to the present, all the emissions have been measured and divided into categories. The next step is to convert them into CO_2-equivalents (CO_2-eq) using the appropriate emission factors which are given from the IPCC. Some entities have calculated their CF in Carbon-equivalent (C-eq) but its expression in CO_2-eq is much more widespread (McKinnon, 2010).

1st	**2nd**
Identification of basic processes.	Detection of sub-processes.
3rd	**4th**
Sub-processes' emissions measurement/calculation.	Aggregation of sub-processes' emissions.
5th	**6th**
Final aggregation.	Conversion into CO_2-eq.

Table 3: Carbon Footprint Calculation Procedure

In order for the CF to provide comprehensive information, except for the error margin, it has to be accompanied by the time in which it refers to, i.e. in which the emissions have been measured. Namely it has to be mentioned if it is calculated either once only, or annually, or periodically. In the case of "one-time emission" the CF is calculated only once. Examples of such cases are events that happen only once and do not last, e.g. a world conference. By the same token an infrastructure project has only one CF, calculated once, as far as it concerns its construction. But regarding its operation, the CF is being calculated periodically or annually. The most common is annually. Another case is when we study a service, where the CF is calculated for example per travel, or per product, per project, etc (Pandey, et al., 2011). In the case of the supply chain of a certain product, the CF is calculated once per supply chain. In practice, it is common in companies that often at least one part of a specific supply chain changes, for example one supplier, or the distribution system and this leads to a different CF. In like manner, some products may share some similar processes, generating similar amounts of emissions. In such cases, CF must be recalculated since it is a different supply chain. But this is doubtful to be done, and the most likely is that companies will recur to averages (McKinnon, 2010).

4 Green Supply Chain Management

It has already been presented in the previous chapter what carbon footprint is, which are the steps followed before applying a measuring methodology, which one is the most appropriate, which limitations exist and how these can be overcome, and finally how the CF of the supply chain of a certain product is being calculated. But all this would be meaningless, unless CF is being used as a guide for improving the effectiveness and the efficiency in operations. Now, in this chapter is being discussed how can be achieved the appropriate strategies and policy making for a more efficient operation of the supply chain of a product, increase of cost and energy savings and at the same time reducing the carbon footprint. At first it is presented what supply chain management in general is, and afterwards the integration to it of environmental considerations, i.e. green supply chain management is being studied.

4.1 Supply Chain Management

Supply chain management (SCM) includes all the required activities to produce a product (good or service) attuned in such a manner, so as to achieve specific goals and meet the various obligations. The Global Supply Chain Forum has defined SCM as "*the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders*" (Croxton, et al., 2001). It is a process used to detect how and where in the supply chain money can be saved, and at the same time discloses the opportunities for higher profits. It is very important for every entity, concerning all the stages from gathering the raw materials to product distribution to the retailers and/or the ultimate customers, including also all the collaborations with third parties. The more the collaborators are, the more complicated gets the management, especially if the transactions are international. Another hurdle is the consumers' demands and preferences, as well as the society and the competitors (Hervani, et al., 2005). According to Cooper, et al. (1997), “the objective of SCM is to lower the total amount of resources required to provide the necessary level of customer service to a specific segment”, together with other activities implemented (described below) in order to increase the value of the supply chain, and eventually of the company. Essential prerequisites for an effective SCM are that it must be generally accepted from the decision-makers and the stakeholders that improvements are needed, which improvements they have to commit to implement and cooperate for that goal, as well as a commonly agreed target which one they will support (Croxton, et al., 2001).

There are eight processes of SCM, defined by the Global Supply Chain Forum, that are particulary important and interact with each other. The first is the “*Customer Relationship Management*” process which includes the guidelines for constructing and preserving the relationship with the potential customers, selecting the appropriate target groups and categorize them, with the aim to minimize the demand-variations and the redudant activities that do not actually produce profits. The second is the “*Customer Service Management*” process which is responsible for the contact with the customers, regarding for example the availability of the products, the status of their orders, the shipping dates, etc – and that flow of information is in real-time – as well as for the monitoring and reporting of their performance. The third process is the “*Demand Management*” whose object is actually to balance out the demand with the supply capability. For this to be achieved, forecasting of the demand is required – based on e.g. historical data, sales predictions, promotion activities, market researches, etc taking also under consideration possible interruptions in supply or sudden great variations in demand – and at the same time increase the flexibility in opeerations, reduce the inherent uncertainties, and finally achieve synchronization with the operations that follow, like manufacturing. “*Order Fulfillment*” is the fourth process, which has as objective the incorporation of the production, marketing, and the distribution in order to satisfy the customers’ requirements, while reducing the total cost of the end-product. Its basic operation is the planning of the distribution network, which affects directly the cost and the overall performance. In this process it is also determined how the orders will be organized and scheduled from the point that they are generated to the point that the product is ready to be delivered by the customer, which consequently means that it includes funtions of the other management processes. The fifth process is the

“Manufacturing Flow Management” aims at succeeding an adequate level of flexibility in the stage of production, such that will allow an effective operation. Here the capacity is joint with the demand, in order to make a plan of the manufacturing process, estimate the time required for a unit to be produced – which has a direct impact on the production capacity – and determine the necessary infrastructure and equipment. The sixth one is the “*Procurement*”, or as it has been renamed the “*Supplier Relationship Management*”, studying the collaborations with the suppliers, which can affect greatly the performance of the manufacturing and the entire supply chain. The cooperations are being evaluated using appropriate critiria – such as their technological capabilities and the reliability – so that it will be determined which of them will be interrupted and which maintained. “*Product Development and Commercialization*” is the seventh of the management processes, with the scope to introduce new products to the market and ensure a rapid penetration. The time needed for a new product to get established to the market is very important, since it determines the success of this new investment. The sources for such a new investment and the incentives for it are being examined as well as the expected reaction of the customers. And finally, the eighth one is the “Returns Management” which deals with the everyday product-returns, including all the activities taking place – such as inspection, return of parts to suppliers, remanufacturing, reselling, etc. The procedure followed must be as short as possible otherwise it has negative impact on the already decreased value of the product. Also, the reasons of each return are being examined – so that improvements are applied where is needed – and credit is provided to the unsatisfied customer (Croxton, et al., 2001).

The performance of a supply chain is evaluated by several appopriate measures which calculate its efficiency, and their output is also used for directing the planning of SCM. Those performance measures are distinguished into qualitative, quantitative – further separated into cost- and customer-responsiveness-based – and those used in designing a supply chain. Qualitative are called those that cannot be quantified and are expressed in other ways. They study the consumer satisfaction before, during and after the purchase, the flexibility of the supply chain to adapt to random variations in demand, the appraisal of the communication (regarding information and materials flow) of the various processes throughout the supply chain and of the inherent risk of every activity, and the performance of raw materials’ supply. As quantitative are characterized the measures which are used for estimations regarding the minimization of cost, inventory investment, product delivery lateness, and manufacturing time, and the maximization of rate of orders, sales, profits, and return on investment. Some of those measures are also used in the decision-making before planning a supply chain, like the cost minimization, profit mazimization, available system capacity maximization, stockout probabiblity minimization, and others (Beamon, 1998).

In order to improve the performance of a supply chain various policies are being implemented in the context of SCM, like reverse logistics, closed-loop supply chains, triple bottom line, etc. Reverse logistics are activities taking place throughout the supply chain, but with an opposite direction, i.e. from the end- to the start-point, such as recycling. A closed-loop supply chain – as well as the extended producer responsibility – is a strategy which also refers to reversed to the supply chain activities, including all of them linked to every process of the supply chain, together with those by third parties. The triple bottom line is coordinated by the aspect of profits, the environment aspect and the social aspect – by which the whole supply chain is actually oriented – having as objective to achieve a sustainable supply chain via making improvements after measurements and reports of their results. Research and Development contributes to the upgrade of the supply chain's performance too, through exploiting the scientific knowledge in combination with existing and new technologies (Wick, et al., 2010).

4.2 Green Supply Chain Management

In general when the word *green* is used to characterize a product, a process, etc, it brings in mind that it is environmentally-friendly. Nevertheless in practice it has been used in those cases that the company is complied with the relevant regulations or follows the market trends. Similarly, up until recently, the decision-makers didn't use to take under consideration also the green dimension when designing a SCM, since it wasn't viewed as something adding value to the company and thus making it more competitive. After the enforcement of the CO_2 emissions permits, and considering that they will not be affordable in the future (for both producers and consumers), the various entities could only act in such a way, that their emissions would be reduced via more efficient supply chains and at the same time save money. For the time being it seems as an option, but in the near future it will become mandatory. And as a matter of fact, studies already conducted have proven that being green affects positively the performance of a supply chain, not to mention that the environmental activities implemented by a company cannot on their own cause a negative impact on its performance (e.g. reduce the return on investment) (Kim & Min, 2011).

Green supply chain management (GSCM) is an advanced SCM, enriched with environmental considerations, improving the performance of the supply chain and making it sustainable, dealing with the efficient operation of the various processes – such as the product design, the process design, the purchasing and their combination – as well as their management. It is driven by the interactions between the natural environment and the supply chain, but above all, by the objectives of the manager. It has been defined as "*integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life*" (Srivastava, 2007). During the last decade various characterizations have been used, such as "environmental purchasing", "sustainable supply network management", "supply and demand sustainability in corporate social responsibility networks", green purchasing and procurement", "green logistics", "environmental logistics", "supply chain environmental management", and "sustainable supply chains". According to Hervani, et al. (2005), it is the output of the aggregation of green purchasing, green materials management, green marketing, and reverse logistics. It is important that before each strategic decision, everything concerning the supply chain has been examined in detail and with accuracy. The decision makers also need to realize that in the case that another method was used to calculate CF of the same product, even the slightest differences have impact on the results, and they need to know the extent of the impacts too before taking new decisions. By the same token they need to know the uncertainties accompanying the used method and the calculated CF, in order to be able to evaluate the situation correctly and design a successful SCM (Srivastava, 2007, Hervani, et al., 2005, Sarkis, et al., 2011).

Incentives for a company to apply GSCM are the existing legal framework, the consumers' preferences, and the company's policy. It is essential to know what caused the need for measuring the CF of a specific product. In contrary to those incentives, constraints may appear, like the inserted cost or the poor cooperation with the others participating in the supply chain. What needs to be clarified is that it doesn't have to do only with the development of environmentally-friendly processes which just generate extra costs; it is actually a framework though which the supply chain complies with the relative regulations and the market trends and consequently adds value to the company. Green investments can contribute to energy and resources conservation, emissions and wastes reduction and increased efficiency. GSCM can be approached from three different perspectives, which prove its ability to provide the advantage to the supply chain to become competitive. In the first one, the *Reactive approach*, the environmental part of the management plays the most important role, aiming to the reduction of the environmental impact. The objective of the second approach, named *Proactive approach*, is the recycling and the production of green products. And the third one, the *Value-Seeking approach*, concerns the company's strategy, oriented to green activities. If all these processes are designed analytically, a web of organizational relationships (including customers, companies, and other organizations) will come up, with the inter-organizational to have the greatest share (Srivastava, 2007, Hervani, et al., 2005). According to Sarkis, et al. (2011), there are nine organizational theories that are applied to GSCM, presented briefly in the following table (Table 4). It is also generally accepted that it would be pointless to develop a GSCM, unless its performance was being measured somehow, so as to make evaluations and identify where further improvements need to be done. In the following section is being presented how this can be achieved, which constraints exist, and which tools are being used.

4.3 Green Supply Chain Management Performance Measurement

This unit presents the tools and the framework in which a GSCM performance measurement is being developed, referring to the boundaries of the system and the exercised pressures to it. A GSCM is implemented for several reasons, such as compliance with the regulations via specific verifications, improvements and developments within the company for more environmentally-friendly, efficient and cost-saving operations, and to respond to the pressures forced by organizations like the Non-Governmental Organizations and prove a green operation (Hervani, et al., 2005).

Organizational Theories of GSCM

Complexity Theory	Includes all the barriers that increase the complexity of GSCM and how it can be confronted.
Ecological Modernization	Examines the technological developments that can be implemented towards environmental protection.
Information Theory	Suggests that there must be a flow of information regarding environmental performance between the producers and the customers as they face it from different aspects.
Institutional Theory	Studies the extent of impact that the external pressures have on the company's organizational activities.
Resource based View	Supports the belief that competitiveness can be enhanced by preferring resources that aren't conventional and cannot be easily substituted.
Resource Dependence Theory	Emphasizes on achieving collaborations that are performing effectively in the longtime.
Social Network Theory	Refers to the interplays among the participating entities, focusing on their density and centralization.
Stakeholder Theory	Discusses the pressures forced by the stakeholders for increase of earnings because of the impact of the generated externalities on them.
Transaction Cost Economics	Its main object is the required activities and expenditures for achieving cooperation between the producer and the customer.

Table 4: Organizational Theories of GSCM (Sarkis, et al., 2011)

Pressures on GSCM Performance Measurement

The pressures on the GSCM performance measurement are divided into internal and external. The category of internal pressures includes the constraints that appear due to the cost of implementing such a performance measurement and the policy of each company concerning the desirable profits, other management and performance systems and their quality, and the company's specific standards. Of significant importance are the resources that a company exploits for the manufacturing of a product, as well as for its own operation. Additionally, the innovativeness (concerning environment) that characterizes a company and especially the monitoring of the performance of the processes taking place can have a great impact on the environmental considerations when making management/policy decisions. Of course, for all these to lead to achieving goals it is prerequisite that there is the relevant specific knowledge (e.g. for the technology upgrade, the implementation of specific measurements, the financial decisions, etc), not to mention that all the changes and improvements made have to get integrated into the company's operation hereinafter (Hervani, et al., 2005). The pressures that are being exercised by external factors refer to the competitors, the existing and the new regulations, the community, the demands of the market, the collaborators, etc. The importance of each one of these factors varies in each case, depending on the nature and the special characteristics of the company under study. It has been observed that the most important ones are the regulations, the consumers' behavior and the actions of the competitors, resulting to development of improvements and innovations for better performance. The contribution of collaborators such as the suppliers plays also an important role and cannot be disregarded. Similarly, other factors that set constraints and requirements are the liability and continuity that must characterize the company and the call for benchmarking to several standards such as the international standards (Hervani, et al., 2005).

Performance Indicators

The measurement of the GSCM performance is based on the use of a variety of specific indicators (described analytically in ISO 14031 and 14001 standards), and all are equally important. The selection of which indicators will be used depends on the company's strategic plan and the targets to be reached. However it cannot always be easily decided which to use because there are plenty and many are similar to each other. The only thing for sure is that there need to be both financial and environmental. There are also other difficulties regarding their implementation, i.e. which is the appropriate way to measure them or the most suitable time. Those are matters that need to be dealt, although they cannot be approached in an absolute manner since not all the companies have common characteristics, a fact that requires special attention. As far as it concerns the environmental indicators, another aspect is the level of "environmentally-friendly" each company is willing to reach, in association with the relevant regulations. The following table (Table 5) presents a list of those indicators (Hervani, et al., 2005). At this point it needs to be stated that all these indicators, can be used both for evaluating an already existing GSCM – and as a result for redesigning it – and for designing it at the first place. This depends on the required cost and labor, and of course on the goals of the company and the strategy that follows. The next paragraph describes the procedure that is being followed in order to design an effective GSCM.

Table 5: Performance Indicators (Hervani, et al., 2005)		
“fugitive non-point air emissions”	“spill and leak prevention”	“site remediation costs under applicable laws and regulations”
“stack or point air emissions”	“inventory control”	“major awards received”
“discharges to receiving streams and water bodies”	“raw material modification”	“total energy use”
“underground injection on-site”	“process modifications”	“total electricity use”
“releases to land on-site”	“cleaning and decreasing”	“total fuel use”
“discharges to publicly owned treatment works”	“surface preparation and finishing”	“other energy use”
“other off-site transfers”	“product modifications”	“total materials use other than fuel”
“on-site and off-site energy recovery”	“employee and participative management”	“total water use”
“on-site and off-site recycling”	“publicly available missions and values statements”	“habitat improvements and damages due to enterprise operations”
“on-site or off-site treatment”	“management systems pertaining to social & environmental performance”	“quantity of non-product output returned to process or market by recycling or reuse”
“non-production releases”	“magnitude and nature of penalties for non-compliance”	“major environmental, social and economic impacts associated with the life cycle of products and services”
“source reduction activities”	“number, volume, and nature of accidental or non-routine releases to land, air, and water”	“formal, written commitments requiring an evaluation of life cycle impacts”
“pollution prevention opportunity audits”	“costs associated with environmental compliance”	“programs or procedures to prevent or minimize potentially adverse impacts of products and services”
“materials balances audits”	“environmental liabilities under applicable laws and regulations”	“procedures to assist product and service designers to create products or services with reduced adverse life cycle impact”

Designing GSCM Performance Measurement

When designing such a system, first of all some fundamental questions must be answered. One of the most important issues is to define the goals, namely for what reason the performance measurement is being developed and which are the targets to be achieved. Similarly, it has to be adjusted to the special characteristics of the supply chain under examination and correspond to its nature and strategy. Another issue is how it will be developed. The ISO 14032 standard provides the necessary guidelines for designing such a process, which center in on the planning, the implementation, the evaluation and the potential improvements that appear after it, regarding the environmental conditions, the operation and the implemented management. For the evaluation, except for the collection and the analysis of the relevant data, monitoring is essential and all the data need to be associated, which means that it the performance measurement must have a dynamic nature. ISO 14001 is the standard for certifying it. Another key point is to encompass to the measurement the interests and the concerns of the various stakeholders. Furthermore, one of the most compelling issues is which performance indicators will be used for the assessment of such a process, and it can be difficult since there is abundance of them. A performance measurement can be very extensive, fact that makes it labor-intensive and raises the cost. Therefore a cost/benefit analysis is also required. Of course, how extensive the assessment will be depends also on the size and the sector of the company under study (Beamon, 1999).

With all these in mind it is significant also to know, which one is the right professional to choose, who will have the appropriate knowledge for the design and the supervision of the whole process. Finally, in order for the assessment to be comprehensive effective, it should be linked to the other performance measurement systems of the company, and hence their combination to offer a holistic view of the company's operation and performance, in relation to the goals set (Hervani, et al., 2005). The ISO 14000 standard sets the rules that a company has to follow: (i) environmental impact analysis must be assessed repeatedly for the already existing products and operations as well as for the new ones, (ii) the determined strategies aiming to protect the environment should be implemented in every level and improved as much as possible, (iii) all the processes should be monitored continuously and numerical targets should be set, (iv) there must be a back-up plan in case that the company fails to comply with the relevant regulations, and

(v) the collaborators' activities should be reviewed, in order to make certain that they also operate in parallel directions (Beamon, 1999). The following paragraph presents some of the tools that are being used in order to achieve those targets.

Tools of GSCM Performance Measurement

There are already some tools available, others functioning adequately and others being improved, and at the same time more are being developed. Both those that are still under development and those already in practice are distinguished in some standard types such as the "analytical hierarchy process tools", "activity-based costing tools", "design for environmental analysis tools", "balanced scorecard tools", and "life cycle analysis tools". An example of life cycle analysis tool is the "Ecological supply chain analysis", which is based on the great correlation of the LCA and the GSCM, presenting its results in maps and graphs, and also provides the ability for comparisons between products, with weakness in the existence of multiple parties in a supply chain and lack of impartiality in some aspects. The analytical hierarchy process tools associate the environmental impacts with the strategic goals. In fact, there isn't yet a certain tool adequate and suitable for every case and the choice which one or ones will be used depends on the objectives, the special characteristics, the level of difficulty, the data availability, the cost of implementation and the required knowledge. Other problems that the practitioners face are the luck of trust on the objectivity and effectiveness of the various tools, the technology and verification issues, and the requisite responsibility that every party must show (Hervani, et al., 2005). In reality, none of them will have an effective impact on developing the GSCM unless the emissions are being monitored, in order to evaluate the applied changes and developments. The following paragraph discusses about emissions monitoring.

Emissions Monitoring

In the group of the ISO 14040 standards as well as in the PAS 2050 there isn't guidance clearly defined over the monitoring of the emissions, which is useful not only to know the value of CF, but also contributes in the evaluation of the supply chain's performance. All the direct and indirect emissions due to processes under the control of the company under study need to be monitored continuously, in correlation to the GSCM that has been adopted from the company. ISO 14064 provides rules for that, but in general until now haven’t been developed tools to assess the monitoring at product level, although there is great interest around it. Scipioni, et al. (2012) held a confirmative purposed research with the aim to figure out if the integration of the ISO 14040 and 14064 standards for the monitoring, the management and the reporting of the GHG emissions at product level is attainable and that it can provide reliable and realistic output. They based their model on the ISO 14064 and enhanced it with the ISO 14040 standard, namely, they coordinated the emissions’ monitoring and management (the former) with the life cycle approach (the latter). They separeted their work in five stages for better analysis of the model, taking as a reference in each one the requirements of both standards. At first, the scope of the research is being defined. Then, the boundaries of every level the research are being determined, regarding the finantial and operational dimension, and follows the determination of the functional boundaries, concerning the processes of the supply chain and the types of emissions (Scope I, II, III) to be included. The next stage is the most labor-intensive as it includes the data collection, quantification of the emissions and calculation of the product’s CF. The last stage accounts for the emissions’ monitoring, including review of the boundaries, the selected base-year, the inventory, the methodology used for all the calculations, and of the effectiveness of the implemented management. What they concluded is that this model can be applied to a product successfully, offering to the entity the ability to understand its functions, how and to what extent they affect the environment, what impact all these and the various improvements implemeted have on its finances, and eventually providing the chance to apply an improved management in order to achieve better performance (Scipioni, et al., 2012).

For the purpose of monitoring, it wouldn’t be feasible from time and cost point of view to re-measure and re-calculate several times. Consequently, in order for it to be implemented efficiently and effectively, the process of calculating CF needs to have a dynamic nature. Namely, all the materials included in the processes taking place over the supply chain of a product need to be uniquely identified and linked to the corresponding amounts of emissions. Dada, et al. (2008), presented for that reason the use of the “Electronic Product code (EPC)”. When EPC is being used, every material can be detected, everywhere to the supply chain from the start- to the end-point. The ability to add extra information anytime is also offered. Granted that, CF could be calculated at any time, more easily and less costly. EPC could be applied to the final products too, making it easier to inform the public, acting additionally to carbon labeling (Dada, et al., 2008). Apart from those measures already implemented for the improvement of the supply chain's performance, there are several others within the GSCM that can be put into effect to address a high CF, which are discussed in the next section.

4.4 Mitigation Measures

Some fundamental strategies are the reduction of the resources used, the re-use of materials, and the recycling in every stage. The product could be redesigned and its supply chain re-planned, taking under consideration the emissions hotspots that where found after implementing CF measurement. Additionally, the potential investments in renewable energy should be investigated, and there could be a market research for new suppliers or collaborators in general, having as a criterion for their selection their carbon emissions. Also, the company's policy could be revised in order to be environmentally oriented (e.g. revision of the existing SCM). Another action – which though is in general difficult to be achieved – is to keep through developments the emissions due to the production process within the legal rates, as well as making improvements to the logistics. Moreover, if the storage duration was reduced and the packaging and distribution systems were improved by applying more efficient and green solutions, it could lead to fewer emissions attributed to the supply chain. By the same token, the energy efficiency of the company's premises and vehicles could be improved. If the life of the product after the purchase is also included, then reuse and/or recycling help in reducing the emissions of its life cycle in total. And last but not least, informing the public about the CF of the products (e.g. by carbon labeling) in order to improve their consuming behavior can have substantial results (Sundarakani, et al., 2010). Though, it is of significant importance to realize that when making alternations to a single stage of a supply chain, attention must be paid in order to avoid reverberations to the rest of them. This is called "Domino Effect". For example, if a company chooses another raw material that produces less carbon emissions but its supply requires larger distances to be covered or more frequent, in that case eventually higher amounts of emissions are being generated, and as a result the change that was made to the management actually failed (Barrow, 2011).

5 Impact of Carbon Footprint on Product Price

So far it has been discussed what CF is, which measuring methodologies are the most appropriate and what constraints there are, and how can this affect the policy making of a company and the adopted SCM. Nevertheless it is very important to examine also the generated financial burden due to CF for both the enterprises and the consuming public. In this chapter it is discussed briefly how it occurs, where the consumers base their consuming decisions. The activities of an enterprise for reducing the carbon footprint in a supply chain affect the final cost of the product in a high degree but it varies for different entities and different products. And finally, there is also the issue of who will bear the difference in final price, the producer or the customer.

Costs Generation

Among the other regulations and standards established in the Kyoto Protocol, it was also instituted a cap-and-trade system as a metric that would help to reduce the GHG emissions and maintain them under specific levels. Within this system, it is determined for every entity how much CO_2-eq it is allowed to emit (cap) and is provided with the commensurate free permits. In the case that a company emits less than it is allowed, it can sell the surplus of its permits to other companies, and if it emits more, then it can buy permits from others (trade). The prices set for such exchanges are based on the principle of supply and demand. Over the years those provided free credits will be less, so as to motivate the various entities to make changes and improvements with the goal to become green (Ratnatunga, 2008). In order for the companies to maintain their CO_2 emissions below a certain level, they have to invest on improvements and developments on their equipment and operations, make collaborations with suppliers or in general with entities that also are environmentally friendly oriented, and establish such a GSCM that avoids the sources of high emissions and at the same time support the implementation of activities that generate less emissions. Inevitably extra cost is inserted to the operation of the enterprise for every emitted unit of CO_2, which is passed through to the staff, the shareholders and of course the customers. There are many different options on how to improve the supply chain's performance and reduce the emissions, each one with different cost, having a different impact on the price of the final product and the entity's earnings. This is a great challenge for the decision-makers, bearing in mind the constraints set by the customers – regarding the price coupled with the quality offered – and the demands of the stockholders for higher profits (Grainger & Kolstad, 2010). In addition to this, according to a survey conducted by Bolwig and Gibbon (2009), a typical LCA may cost from €2500 to €6000. Other data of the survey showed that a more advanced LCA may cost from $5000 to $15000, and can even exceed $70000, depending on the size of the company and the size and complexity of the supply chain under study. They also gathered some data about the verification cost, which may range from €1500 to €5000, or according to other data from $100 to $250 for small entities and from $1000 to $5000 for large entities, per product (Bolwig, S. & Gibbon, P., 2009). Apart from all those limitations, the customers' consuming choices also put significant pressures on the decisions of the policy makers regarding the final price, an issue that is being argued below.

Green Purchasing

Some examples of *green purchases* are the consumption of electricity produced from renewable energy sources (e.g. photovoltaics, wind turbines, etc), packages for food or various objects made out of environmentally friendly or recycled materials, organic food, devices that demand less energy consumption for their operation, etc. But for all these to be produced, an extra cost is inserted, which results to a higher final price of the product. In general the consumers are aware of this fact, and those who have already decided to behave green, are going to accept that higher cost. In that case, that environmentally friendly product gets more appealing and competitive to the "conventional" ones. How the consumers determine which product or whether to buy it or not is coordinated by social and personal behavioral characteristics. There is the type of consumers that attach great importance to the ability of the product to maximize its utility. And there are also the consuming preferences of each customer that direct their choices. What is more, it is expected by the society and perhaps also by the close social environment of an individual that each purchase made will be characterized as *green*, namely the consumers are expected to make their selections in a moral way, since environmental awareness is nowadays widespread. And that is a dilemma that the consumers face, of which the companies are aware, and aspire to take advantage of it. Additionally, those consumers that consider important a green purchase, do not have the same incomes and as a result cannot afford the same expenditures or to the same extent, a fact that companies also have to include in their decision making. At this point the managers face the quandary between the cost – which has to be attractive to the consumers and at the same time generate profit to the company – and the product quality offered – which has to meet the consumers' expectations (Conrad, 2005, Ambec & Lanoie, 2008). According to D'Souza, et al. (2006), yet there isn't a study proving a certain connection between the consumers' environmental behavior and their consuming decisions. Instead, it has been found out that they are keen on consuming green products, but without any abatement in quality or price increase. Consequently, of significant importance is the need to pass to the consuming public all the information about the offered benefits, in order to support the arguments about the reasons for which they should purchase the green product. Apart from advertising, this can be achieved effectively via product-labeling. A label, and in our case, a carbon label, basically informs the consumer about the exact environmental impact of each product's life cycle, but also enhances the product's green aspect, promotes the company's reputation of performing sustainably. Besides, the impression that the consumers have regarding the level of the company's environmental performance is substantial. In addition to this, previous purchases of green products can also influence the consuming criteria in either positive or negative way in comparison with the similar. A prior negative impression can act catalytically against a future purchase. A research conducted by D'Souza, et al. (2006), studying various variables such as the type of labels used, the product price, the corporate and product perception, the biodegradability etc, showed that unlike the existing regulation and the corporate and product perception, previous experiences have the greatest impact on purchase decisions (D'Souza, et al., 2006).

Price Implications

As far as it concerns the supply chain of a product, as it has already been mentioned in the previous chapters (*Chapter 3*), the generated emissions of each product's life cycle have to be calculated separately, so as to estimate then its own financial burden too. It is certain that the extra cost is transferred to the ultimate consumer, but what really matters is the extent of the surcharge. However, the price increase has a simultaneous impact on both consumers and producers, since a potential decrease in sales results in decrease of company's earnings, affecting also the company's competitiveness. Consumers demand in general a more environmental performance of the companies, without settling for reduced quality or increased price. It is not easy for them to realize and consider all the constraints and parameters in pricing since they are not involved directly. The environmental accounting offers the ability to the decision-makers to evaluate the existing circumstances and quantify the various constraints aiming at designing a GSCM that will be implemented successfully and result in a price of the final product such that satisfies both consumers' expectations for green products in better quality and lower price, and shareholders' demand for a larger market share, and hence increased of the profits with upward trend. But at the same time it has to justify why someone should prefer his company's product instead of another similar one. The final price has to reflect the benefits arising from the applied GSCM, in order for it to be another initiative for the consumers to prefer this product from another which is not characterized by sustainability. It is a fact that the higher cost of green products is an important barrier in their promotion, despite the continuously growing preference that has been observed for them. Nevertheless, this cannot be used as an alibi by the managers in the case they design and implement a not that successful GSCM. It is difficult for the decision makers to predict how the consumers will react in a certain pricing and even if there were some indications about it, it is even harder to translate it into cash flows. Apart from this, the natural resources are equally available to everyone, so cannot be quantified and measured in monetary terms, but can only be appraised based on what the company on the one hand and the consumers on the other hand consider as more valuable. And that is also where a purchase decision is based (Grainger & Kolstad, 2010, Swarr, 2006).

As stated above, the optimal for an entity is to apply a GSCM through which it will achieve increased revenues and decreased costs. There are many improvements that can be done, but from the company's point of view, above all, it has to remain competitive. And according to Ambec & Lanoie (2008), implementing improvements through applying a GSCM doesn't necessarily means increased costs, since revenues are generated that can offset the occurring expenditures. The cost imposed on the customers could be reduced, if the earnings from the implemented developments were used to cover the cost of measuring and monitoring the CO_2 emissions and of the permits. There have been conducted studies proving that simple mitigation measures (like those discussed in Chapter 4) can save money for the company in amounts adequate to cover the overall cost of carbon footprinting firstly, and flowingly increase those savings in combination with the potential increase in sales (Grainger & Kolstad, 2010). In that hypothetical successfully implemented scenario, the company is now operating green with the obligations to the relevant regulations fulfilled, the operational costs are reduced making savings for the development of the new GSCM and the other necessary expenditures, the product quality is improved, and the consumers' preferences and expectations are satisfied without bearing themselves the occuring financial burden – since it has been absorbed by the company – leading to increased consumption of the product under study, namely conquer a greater share of the market, generating consequenty higher profits.

6 Conclusions

This Thesis has given an account of and the reasons for the importance and the growing use of *Carbon Footprint (CF)* indicator. As stated above, it is a value representing the total amount of GHG emissions in mass units of CO_2, generated during a process by anthropogenic activities. Out study refers to products in general, so in that case it includes all the amounts emitted during the life cycle of a certain product. CF is the development of ecological footprint indicator, used in order to quantify the impact of the human activities and the rate of natural resources depletion in a fixed area and finds its origins in *sustainable development*. Sustainability has highlighted the need for more environmentally friendly operations and resource savings. It has been concluded that this issue can be dealt with appropriate mitigation policies, which will aim at increased efficiency of operations, improved management for resource and energy conservation, and reduced waste. Provided that, specific indicators were developed, such as CF. In order for CF to be easy to use and facilitate is applicability in great scale, there have been developed specific standards and methodologies. Firstly, with the Kyoto Protocol were established the greenhouse gases to be taken under consideration, which are Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF_6). The next step is to define the system boundaries, and the measuring and calculation models used. The purpose of the current study was to try to determine those issues, since they are still questionable in the literature, as well as to answer the questions first of how CF can be better utilized by an enterprise, aiming for more efficient and more environmentally operation, having as ultimate target to increase profits and to comply with the relevant legislation, and second to inquire the impact of CF implementation on the market trends and the final price of the product.

After an extensive literature review, it has been detected that it is essential to specify the start- and the end-point of a study on CF, as well as the included process with accuracy, in order to set a standard worldwide framework and enable comparisons. Due to two main reasons, which are the high level of complexity and the limited data availability, we came up with the conclusion that the area of a CF study regarding the supply chain of a certain product should generally start at the transfer of the raw materials from each supplier to the company and should end at the distribution of the final product to the retailers. The intermediate processes to be included are the production process and the warehousing. Of course, those are the core stages that include many sub-stages, which vary from one product type or sector to another, which cannot all be included due to raised complexity and costs, but in each case the practitioner has to decide which are to be included or excluded and the required assumptions, based on the product's special features and the importance of each process. Furthermore, our research also showed that the most appropriate emissions measuring methodology to be applied – which is already for decades extensively used – is the Life Cycle Analysis (LCA). There have already been developed many models of LCA concerning CF, each one of them having specific advantages and disadvantages. To date, based also on the existing constraints, we deem the Input-Output – LCA Hybrid model as the most suitable model to be used for a CF study, since it combines the strengths of the Environmental Input-Output and the Process Analysis, fact that makes it appropriate for a wider range of applications. That is the core stage of calculating CF, since after having measured all the emissions from all processes, CF is more like a simple aggregation of all of them.

The second major finding of this Thesis was that CF can actually have a great influence on an entity's functions. Since the performance of the adopted supply chain management has been measured – using specific performance indicators – and after having calculated the CF of a certain supply chain, those findings can be utilized by the decision-makers in order to develop a green supply chain management (GSCM), with the goals of more efficient performance, reduced costs, larger market share with growing trend, compliance with the legislation and production of green products. GSCM represents the integration of environmental concerns into the supply chain management, regarding all the activities from the collection of raw materials to the product's distribution. There are many constraints and obstacles that the managers have to overcome – like the inherent risk in decisions, the high costs or the miss-cooperation of the participants – but the derived benefits for the company justify the need for implementing a GSCM. At this point it should be mentioned that apart from the company itself, namely the shareholders, all the participants in a supply chain play an important role in its successful implementation, including the employees, the suppliers, and the other collaborators. Without their cooperation and/or their willingness to follow such a strategy, the desirable results cannot be achieved. Nevertheless, a GSCM cannot be effective without the monitoring of emissions for the evaluation of its performance, in order to apply further improvements if and where needed.

Finally, the conclusions drawn concerning the market and price implications due to CF are that there is indeed a great relevance between them. The costs arising from conducting a CF measurement and implementing improvements and developments can be significant, but there are strong indications that not only they can be covered by the earnings which are expected to be high – but also that the profits can be increased, with upward trend.

The evidence from this Thesis suggests that an environmental strategy leads to an environmental performance of the company, enhancing eventually its competitive advantage and at the same time its economic performance. This is one of the reasons that the need for the consumers to trust the product carbon footprint and the carbon labeling is emerging. The green practices applied in the supply chain should be reflected in every stage of it, otherwise it won't result in the desired outcome. The actual aim that managers should have is to design such a GSCM, which will have the greatest possible influence on public's consuming behavior, towards increased sales, and as a result higher profits. In the long run, it seems that the breadth of CF application will keep growing, mainly reinforced by the established legislation and the market trends, as well as by overcoming all the barriers existing at the moment. And such a progress will also reduce the inserted costs, making carbon footprinting more affordable for both the entities and the consumers. A number of limitations though need to be noted regarding the present study. The conducted literature review showed that there is almost no empirical evidence of how CF is integrated in a SCM and on the actual impact of CF on the company's performance. Additionally, up to my knowledge there aren't empirical studies investigating how the final price of the product is being affected, and consequently the sales, as well as the variation of the company's profits after applying GSCM in association with the generated expenditures and occurring revenues.

The current findings add to a growing body of literature on carbon footprinting, its importance and utilization, in particular to the Greek literature. However, it is recommended that further research be undertaken in the following areas. Predominately, further work has to be done in order to determine an internationally accepted CF standard, with common guidelines, so that there will be no inaccuracy in the methodology used and comparisons will be easily made. In like manner, empirical and practical investigations are needed, which will study the cost-benefit analysis of implementing carbon footprinting, as well as the payback period. Moreover, when measuring CF, more attention needs to be paid in the inventory and the warehousing, inasmuch up until now, the focus is on the transportation and the manufacturing process. Likewise, studies should be conducted concerning the sector of services, since the majority of the existing ones refer to goods.

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Appendix

Calculation Tools for Carbon Footprint

Publicly Available Tools	GHG Protocol BILAN Carbone CONNEKT CO2-meetlat EcoTransIT World SmartWay SmartWay Europe Gronn godstransport/Smartrans/SEMBA
Commercial Tools	CARBON FTA DB Schenker DHL GO GREEN ECO-calculator Kuehne & Nagel (K&N) MARTRANS Metro-Group-Logistics VERSIT+ Tofuture - CSM

Table 6: Calculation Tools for Carbon Footprint (Makela & Auvinen, 23/11/2011)

Standards and Guidelines for Carbon Footprint

IPCC 1996 and 2006 Guidelines	Guidelines set by IPCC regarding national GHG inventories
GHG Protocol	Includes guidelines and tools for GHG accounting, for different sectors.
PAS 2050 and 2060	Guidelines and methodology for measuring and reporting CF.
ISO 1400 series	Group of ISO standards concerning climate change, LCA, environmental management and labeling.
ISO 14067	Standard about Product CF.

Table 7: Standards and Guidelines for Carbon Footprint

GHG Emissions Databases

UK Department for Environment, Food and Rural Affairs	Intergovernmental Panel on Climate Change Guidelines for national GHG Inventories	Versit+ (Traffic emissions)
EX-TREMIS (EU energy Consumption Emissions)	EMEP/EEA (Air Pollutant emission inventory)	LIPASTO (Calculation system for Traffic Exhaust emissions and Energy Consumption in Finland)
HBEFA (Handbook Emission Factors for Road Transport)	TREMOD (Calculation software for energy consumption emissions in association with HBEFA)	NTM (Database and environmental performance Calculator by the Network for Transport and Environment)
JRC Well-to-wheels (WTW) analyses (Database for automotive fuels & powertrains)	COPERT (Software tool for air pollutant & road transport GHG emissions calculation)	European Life Cycle Database

Table 8: GHG Emissions Databases (Makela & Auvinen, 23/11/2011)