Determining system boundaries for carbon footprint analyses of greenhouse horticultural products in the Netherlands

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Determining system boundaries for Carbon Footprint analyses of greenhouse horticultural products in the Netherlands

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Abstract (Press release)

Research at TU/e has succeeded in making a cradle-to-gate Carbon Footprint analysis of the greenhouse horticultural products belonging to the groups vegetables, fruit and cut flowers, produced in the Netherlands, more accurate. A Carbon Footprint measures the contribution of a product or process to climate change by mapping emitted greenhouse gases. A group consists of processes and/or inputs used to produce or facilitate the production of greenhouse horticultural products which can (potentially) contribute to a Carbon Footprint. These groups could emit greenhouse gases during raw material acquisition, production and the waste management phase with regard to the group. While it was formerly thought that the greenhouse itself could be excluded from the system boundaries, this research shows that this group (greenhouse and all equipment inside and attached to the greenhouse) always significantly contributes to a Carbon Footprint and should therefore always be included. Furthermore the thesis created the potential to perform Carbon Footprint analysis more efficient in future by validating and implementing a suggested model. It has been concluded that seeds, pesticides and other pest management always provide an insignificant contribution to the Carbon Footprint. This knowledge contributes to understanding the impacts of horticultural products and is of great importance to be able to determine possibilities to lower the Carbon Footprint of these products.

The result is stated in the master thesis by Carlijn Aalbers, supervised by Ir. A.F. Kirkels and Dr.ir. G.P.J. Verbong from the faculty Industrial Engineering and Innovation Sciences and Ir. J. Scholten from the company Blonk Milieu Advies.

A Carbon Footprint analysis measures the contribution of a product or process to climate change by mapping emitted greenhouse gases. System boundaries define which processes are included in the Carbon Footprint analysis and which are not. Nowadays many parts within the technical system are excluded due to a lack of data and too little awareness of their contribution to the Carbon Footprint. By determining rules of thumb for system boundaries for different contexts, more insight can be gained in the covered (considered to be (in)significant) and/or unknown areas. Consequently, insights from researching system boundaries could result in more precise or more efficient Carbon Footprint studies in the future.

In this research, the method of modeling has been used. A Carbon Footprint Analysis is required to use the standard which states that at least 95% of the anticipated life cycle greenhouse gas emissions and removals associated with the object of research shall be included in the assessment. Therefore, first an approximately 100% Carbon Footprint is determined in order to provide a streamlined method to calculate 95% of the Carbon Footprint. Thereafter the model is developed by quantitative research. A trial test of the model was intended. Unfortunately the accuracy of the model could not be validated due to a lack of data.

Up to now it was assumed that the groups seeds, pesticides, substrate, energy, young plant material, fertilizer, external CO₂ fertilizer and packaging add up to 95% of the Carbon Footprint. This now appears to be incorrect: in fact the determined 100% Carbon Footprint nowadays is incomplete. The groups capital goods, materials for soil covering, consumables and other pest management (e.g. nets, fences etc. and biological control such as plants and insects) need to be added, while seeds and pesticides are excluded to give a more complete view of the 100% Carbon Footprint. The results reveal that energy and the greenhouse should always be included in the system boundaries in order to determine 95% of the total Carbon Footprint. Other pest management can always be excluded from the system boundaries while inclusion of the other groups in the system boundaries is context specific.
Aalbers has been carrying out her research at the company Blonk Milieu Advies. Blonk Milieu Advies is a company that specializes in (applying) Carbon Footprint methodology in the field of food and agriculture. They try to perform Carbon Footprints in the most accurate way given individual situations and requirements.
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<td>Blonk Milieu Advies</td>
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<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>CF</td>
<td>Carbon Footprint</td>
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<tr>
<td>CML</td>
<td>Institute of Environmental Sciences</td>
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<tr>
<td>CO$_2$-eq</td>
<td>Carbon dioxide equivalent</td>
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<tr>
<td>Eq</td>
<td>Equivalent</td>
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<tr>
<td>EZ</td>
<td>Ministry of Economic affairs</td>
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<tr>
<td>EL&amp;I</td>
<td>Ministry of Economic affairs, Agriculture and Innovation</td>
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<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>LCA</td>
<td>Life Cycle Assessment</td>
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<td>LCI</td>
<td>Life Cycle Inventory</td>
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<td>LNV</td>
<td>Ministry of Agriculture, Nature and Food quality</td>
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<td>LUC</td>
<td>Land use change</td>
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<td>VROM</td>
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Summary

Life Cycle Analysis (LCA) has become a popular method to study the sustainability of a variety of products and processes. Carbon Footprinting (CF) is one of the analyses within an LCA. CF is able to measure one of the environmental impacts, namely the contribution of the product or process to climate change. This is done by mapping emitted greenhouse gases (GHG).

The horticulture sector and the Dutch government have signed the covenant Clean and Economical Agro sectors where among other things agreements have been made about the reduction of greenhouse gases (GHGs). Moreover, a significant CO₂ reduction is still possible. These two facts make CF a very interesting analysis for the horticultural sector.

The system boundaries define which processes are included in the CF analysis and which are not. The determination of system boundaries applied on the CF of greenhouse horticultural products will be researched. In this thesis the greenhouse horticultural products fruit, vegetables and cut flowers, produced in the Netherlands will be researched till the product leaves the production site. Nowadays many groups within the technical system are excluded due to a lack of data and too little awareness of their contribution to the CF. By determining rules of thumb for system boundaries for different contexts, more insight can be gained in the covered (considered to be insignificant) and/or unknown areas.

The research question of this study is whether a model can be developed which defines appropriate system boundaries in a CF analysis for greenhouse horticultural products, cultivated in the Netherlands. The produced model could reveal more about which parts are important in the life cycles of greenhouse horticultural products and which part is that small (<5% of the total CF) that it could be estimated in future LCAs. Consequently, these insights could result in more precise or more efficient CF studies in the future.

The theory of CF is based on science of climate change. Climate change is the impact of human emissions on radiative forcing of the atmosphere. The higher the radiative forcing of a particular GHG, the more it will contribute to climate change.

The research methodology used is modeling. The procedure can be divided in three main phases: demarcation, development of the model and the last phase: testing the model and giving conclusions and recommendations. Some phases include research steps that are part of more than one phase.

Phase 1: Demarcation is needed as an inevitable preparation for the rest of the research. Besides the demarcation of the subject of the thesis, the demarcation of research consists of the scope of an approximately 100% CF. A Carbon Footprint Analysis is required to use the standard which states that at least 95% of the anticipated life cycle greenhouse gas emissions and removals associated with the object of research shall be included in the assessment. Therefore, first an approximately 100% Carbon Footprint is determined in order to provide a streamlined method to calculate 95% of the Carbon Footprint (BSI, 2011). A draft of the approximately 100% CF system boundaries is made on the basis of a flowchart and literature study. The draft is revised by conducting expert interviews. Those will provide insight in categorization of groups and the feasibility of data collection for each specific group. Groups consist of processes and/or inputs used to produce or facilitate the production of greenhouse horticultural products which can (potentially) contribute to a CF. In addition experience of BMA and the pilot project will indicate the group’s feasibility of data collection. A Carbon Footprint Analysis is required to use the standard which states that all sources of emissions and
processes for removal anticipated to make a material contribution to the life cycle greenhouse gas emissions on the functional unit shall be included in the assessment (BSI, 2011). Therefore, groups which contribute less than 0.5% to the whole CF per ha will be excluded on the basis of a quantitative research. For this quantitative analysis, literature, a pilot study and communication with resource producers or sellers will form a quantitative dataset.

Phase 2: Development of the model starts with determining the functionalities of the model. Hereafter relations will be qualitatively explored by using literature research and the other means discussed in phase 1. The data provides insights in where significant carbon emission is present in the chain. Furthermore insignificant data will be graded, whenever needed, by taking into account time, effort and money needed to collect these data obtained from the interviews, pilot and literature research. From the revealed patterns hypothesis are derived. Thereafter more advanced and quantitative tests will be conducted, with help of the quantitative dataset, in order to develop a quantitative model. Conditions can be set derived from the analysis and varied accurately in this phase.

Phase 3: In this phase the model is tested on real cases selected by criterion sampling. It can be analysed whether the outcome of the model indeed represent 95% of the approximately total CF for real cases, by determining both the 95% CF by the model and the 100% CF based on extensive research, given by the system boundaries of the model, per case. Instead of conducting the research cycle again to improve the model, recommendations about conducting this cycle again will be discussed. This discussion focuses on the basis of the model, the test results and practical experience.

The LCA used, is the accounting type of LCA, since it is used for this thesis to be able to compare different product lifecycles. Furthermore the scope of the LCA is based on popular and specific regulations, unless deviating from the rules can result in a more complete and detailed analysis.

The conclusion is that it is possible to develop a model which defines appropriate system boundaries in a CF analysis for the greenhouse horticultural products cut flowers, fruit and vegetables, cultivated in the Netherlands. However, at this moment this model cannot be validated. It is only possible to validate this model if growers are interested and permit themselves to do a CF or if subsidies make it profitable to implement the research. It will cost a lot of money and time to implement the model, which presumably will not counterbalance the benefits.

Nevertheless, the insights gained on the basis of the model, have succeeded in making a cradle-to-gate Carbon Footprint (CF) analysis of the horticultural products belonging to vegetables, fruit and cut flowers, produced in the Netherlands, more accurate. While it was formerly thought that the greenhouse itself could be excluded from the system boundaries, this research shows this group always significantly contributes to a CF and should therefore always be included in the CF analysis. In addition it has been concluded that seeds, pesticides and other pest management always provide an insignificant contribution to the CF. This knowledge contributes to understanding the impacts of horticultural products and is of great importance to be able to determine possibilities to lower the CF of these products. These insights can result in more precise or more efficient CF studies in the future.

Up to now it was assumed that the groups seeds, pesticides, substrate, energy, young plant material, fertilizer and external CO₂ fertilizer and packaging will add up to 95% of the CF. This now appears to be incorrect: in fact the determined 100% CF nowadays is incomplete. Addition of the groups capital goods, materials for soil covering, consumables and other pest management is required to give a more complete view of the 100% CF, while the groups seeds and pesticides can be excluded. From the results it becomes clear that energy and the greenhouse should always be included in the system.
boundaries in order to determine 95% of the total CF. Other pest management can always be excluded from the system boundaries while inclusion of the other groups in the system boundaries is context specific.

The uncertainty in extreme cases of the contribution of the greenhouse is still quite large, because it is only been tested on several cases, but it is for now the best available indicator. In addition the indicator which estimates the CF of the greenhouse faces only little sensitivity. A disadvantage is that the indicator for the CF of the greenhouse implies that when using less glass, your CF will get lower, however this could have effects on the magnitude of the CF of other groups. Therefore, premature decisions should not be made on the basis of the CF value of the group capital goods 1 alone.
1. Introduction

1.1 Introduction into Life Cycle Analysis and Carbon Footprint

Life Cycle Analysis (LCA) has become a popular method to study the sustainability of a variety of products and processes. However, the methodology of LCA is relatively young. The study for Coca-Cola from 1969-1970 is generally considered to be the first LCA study (Guinée, 1995; Heiskanen, 2000; Weidema, 1997). Furthermore, many methods used in LCA are controversial in certain areas of interest. For example, carbon sequestration by crops in the case of food products. LCA methodology is still in development. Different standardization protocols are in circulation (BSI, 2008; ISO, 2006, 2011; PCR, 2010; J. PCR, 2010). This is the reason why there are a lot of scientific papers written about system boundaries (Löfgren, Tillman, & Rinde, 2011; Weidema, 1997). The system boundaries define which processes are included in the analysis and which are not. In addition, papers have also been written on other aspects of LCA such as weighting methods (Ahlroth, Nilsson, Finnveden, Hjelm, & Hochschorner, 2011; Goran Finnveden et al., 2009; Soares, Toffoletto, & Deschenes, 2006) and allocation (Cherubini, Strømmana, & Ulgiati, 2011; Marvuglia, Cellura, & Heijungs, 2010; Sayagha, Venturaa, Hoanga, Franc, & Jullien, 2010). The most widely applied LCA focus on impacts on the environment. Social and social-economical LCA are scarcely out of the egg.

Amongst LCAs there are different impacts on the environment. Carbon Footprinting is one of the analyses within an LCA which is able to measure one of the environmental impacts, namely climate change. A carbon footprint analysis is used to measure the contribution of climate change by emitted greenhouse gases (GHG). The matching indicator used to measure climate change is radiative forcing (i.e. heat radiation absorption) (Guinée, 2002). Table 1 by Broekema and Scholten gives an overview of the midpoint and end point impact categories (Broekema & Scholten, 2012, p. 8). Within the first step of LCA the researcher can select the relevant categories for their goal of the study. The indicator climate change is presented bold, to state the selection of the LCA in this research. From now on this demarcation in LCA will be referred as the Carbon Footprint (CF) analysis. To summarize: a CF describes climate change, expressed in the total amount of radiative forcing per unit product. In the next paragraph the choice for this CF demarcation will be exemplified.
1.2 Significance of CF for the greenhouse horticultural sector

Society wants to reduce CO₂ emission in order to reduce climate change. Therefore retailers require a lower carbon footprint (CF) of products. Due to this societal pressure, the sector horticulture and the Dutch government in the form of the former ministries LNV, VROM, EZ (now merged to EL&I) and others, have signed the covenant Clean and Economical Agro sectors ("Energie. Productschap Tuinbouw," 2011). Within this covenant, among other things, agreements have been made about the reduction of greenhouse gasses (GHGs) and energy reduction. Horticulture is innovatively trying to reduce CO₂. CF analysis can provide insights in the emissions and identify possibilities to lower these emissions ("CO2 Emissietool en protocol," 2010).

Since 5 to 10 years, LCAs are applied in the agricultural sector. Nowadays the focus within LCA is on CF, because this is a very important topic from a market perspective. LCA is a powerful tool to understand impacts of production. One of the main applications of an LCA is to determine possibilities to improve products (Baumann & Tillman, 2004, p.40). The willingness of horticulture to reduce CO₂-emmissions (Joustra et al., 2011), combined with the fact that a significant CO₂ reduction is still possible (Daniëls et al., 2006; de Rooij, 2008), makes CF a very interesting analysis for the horticultural sector.
1.3 Goal of the thesis

In most current LCAs on greenhouse horticulture, capital goods are excluded from system boundaries (Blonk, 2011; R. Frischknecht, H.-J. Althaus, C. Bauer, G. Doka, T. Heck, N. Junghbluth, D. Kellenberger, et al., 2007). However, research reveals that they can have a significant contribution in a CF of greenhouse horticultural products. Sometimes the inclusion of capital goods even represents a share of 30-40% of total carbon emissions in greenhouse horticulture (Blonk, 2011). Several studies assess the question if capital goods should be included in other fields and for diverse impact categories (Baumann & Tillman, 2004; Blengini & Busto, 2009; Erzinger, Dux, Zimmermann, & Badertscher Fawaz, 2003; R. Frischknecht, H.-J. Althaus, C. Bauer, G. Doka, T. Heck, N. Junghbluth, D. Kellenberger, et al., 2007; Møller, 2010). Besides this example of capital goods, new rules of thumb for system boundaries might be applicable for other parts of a CF as well. Heijungs et al. state it is difficult to determine system boundaries in different contexts, and that research is needed to demonstrate if rules of thumb can be given (Heijungs et al., 1992). This determination of system boundaries is exactly what will be researched in this thesis, applied on greenhouse horticulture.

System boundaries are the boundaries of the researched product. This can relate to natural systems, geography, time and technical systems. The definition of system boundaries in an LCA, depends on individual situations (resources available) and requirements (originated from the goal of research) and the consideration whether different processes or activities (assumptions) have a significant effect on the total LCA. Individual situations and requirements could relate for example to a certain time span, the problem definition or the knowledge of the person. If a certain activity is considered to have an insignificant effect, it is left out the system boundaries (Møller, 2010). This implies that certain (parts of) activities can be considered insignificant while they are significant and vice versa. Furthermore it implies that some (parts of) activities are not discussed at all, because people do not know about their existence. In Figure 1 this explanation can be viewed schematically. The bold lines show the system boundaries the way people define them currently. The green boxes represent the ideal system boundaries. In the ideal case, all the red boxes are left out of scope. The orange box needs to be included only if it fits the researchers goal and limitations (such as time). It is therefore case specific if (parts of) the orange box should be included within the system boundaries or not. For example, it could be wise to include (part of) the orange box into system boundaries if good indicators can be found that decrease time needed for data collection.

![Figure 1 Schematic overview of current and ideal system boundaries and parts excluded from the system boundaries](image)

By determining rules of thumb for system boundaries for different contexts, more insight can be gained in the covered (considered to be significant) and/or unknown areas. In the course of time contexts and LCA methodology can change by innovations or new knowledge. Therefore, it is possible that the way activities are currently in- or excluded from the analysis, is not valid anymore. In that case new rules of thumb have to be determined.

The subject has a methodological nature. Insight into LCA methodology will be gained by reflection on the LCA methodology. Experience in the field of LCA reveals that a small percentage of results of an LCA are relatively hard to find, time consuming and costs expensive. The produced model could
reveal more about which parts are important in the life cycles of greenhouse horticultural products and which part is that small (<5% of the total CF) that it could be estimated in future LCAs. Consequently, this could result in more precise or more efficient LCA studies in the future.

1.4 Research questions

The research question of this study is:

“Can a model be developed which defines appropriate system boundaries in a CF analysis for greenhouse horticultural products, cultivated in the Netherlands?”

The main goal of a CF analysis is to require insight into at least 95% of the total CF when system boundaries are determined based on the standards of PAS2050 for a cradle-to-gate scope (BSI, 2008, p. 13). The other 5% of carbon emission may be estimated. It seems like the choice for a specific mix of process systems will have a significant influence on the measured CF of the product and the contribution of capital goods in the CF.

To be able to answer the research question, system boundaries should be determined, in order to determine an approximately, 100% CF of the product. It should also be determined which data will be relevant to include into the model. This means it should be researched whether the system boundaries which match the scope of the study are feasible. In other words, it will be researched which system boundaries are appropriate in order to be able to perform data collection needed to calculate the CF.

1.5 Scope of the thesis

This thesis is limited to CF within the LCA methodology. This study focuses on system boundaries of CFs of the products: cut flowers, fruit and vegetables produced in greenhouses made of glass. Glass is the most applied material as cover for greenhouses in the Netherlands, because of its good light transmittance and strength (glastuinbouw, 2008). The study does not cover pot plants, because of the time span of the study, the literature availability and differences between pot plants and the other mentioned products. The thesis is limited to the Netherlands and the moment the product leaves the producer. These limitations are required to be able to collect enough accurate data. Furthermore the Netherlands is one of the three most important greenhouse horticultural countries within the European Union (de Rooij, 2008, p. 205). Because this study is already demarcated to several dimensions and comparisons need to be made between cases in this thesis, this study focuses on cut-off criteria in the dimension of technical systems. Cut-off criteria are used to make the CF analysis feasible and match the scope of the study.

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1 The new PAS 2050 (2011) demands that all sources are taken into account which contribute more than 1% (BSI, 2011). It is decided to exclude this new rule included in the new PAS, because this PAS was published during research and makes the objective of this study to make research more efficient for growers potentially more difficult to obtain. A comparison with the former situation is hard to make, when other rules apply for the new situation. It would therefore no longer be a fair comparison. For the same reason, the 99% input rule (PCR, 2010, p.11) of the PCR is not adopted.
1.6 Organization of the thesis
Chapter 1 has been briefly discussing the connection between LCA and CF. Subsequently, there is elaborated on the relevance of the thesis. The goal and research question of this thesis are defined. Proceeding from this goal and research question the scope will be defined.

Chapter 2 treats the different methods used in this research. First of all the theory behind CF will be explained briefly. Subsequently the methodology of modeling comes up for discussion. Thereafter the procedure followed during this research is treated. This is an elaboration on the methodology of modeling specified on this analysis. To conclude there will be dealt with the scope of the LCA in the last paragraph, because LCA is the methodology which is used as a means to conduct this research. In this part there will be elaborated on methodological decisions.

Chapter 3 gives an overview of the results of the research. It treats the functionalities of the model. Subsequently the adjustment of groups is considered in order to form a relevant and feasible approximately 100% CF. At least as important is the development of the qualitative and quantitative model which is discussed thereafter. The chapter ends with a sensitivity study on the CF of the group capital goods 1, which mainly consists out of the greenhouse.

Chapter 4 discusses the implications of this study. After this, the conclusions of this study will be treated. The chapter will be closed with the recommendations for the application of the insights gained from this study and suggestions for future research.
2. Methods

This chapter starts with a brief description of the theory behind Carbon Footprinting. Thereafter the method of modeling is treated. Proceeding from this method, the procedure of this research will be discussed. Subsequently the methodology of CF is discussed and there is elaborated on basic methodological decisions. It is decided to discuss the aim and scope of LCA in the methodology section in order to make comparisons with other CF studies easier. By discussing these two different methodologies (modeling and LCA) used in this thesis separately, an attempt is made to create more structure and keep the section on LCA methodology neat. It is now clear that the methodology of modeling is the methodology used to conduct the research, while the methodology of LCA is used as a means needed to execute the study as well as a cause for executing this study. Therefore, knowledge about (the applied) LCA methodology will help to better understand the aim and relevance of this thesis.

2.1 Theory behind carbon footprinting

The theory behind CF is climate change. Climate change is the impact of human emissions on radiative forcing of the atmosphere (Guinée, 2002). A CF describes climate change, expressed in the total amount of radiative forcing (W/m²) per unit product. GHG is naturally present in the atmosphere, but human and production processes can result in additional GHG. GHG absorbs and emits radiation at various wavelengths emitted from clouds, the atmosphere and the surface of the earth. The higher the radiative forcing of the kind of GHG, the more it will contribute to climate change. Most of these emissions enhance radiative forcing and therefore contribute to global warming. This phenomenon is widely known as the ‘greenhouse effect’. The Global Warming Potential (GWP) is an equivalent for the radiative forcing impact of a mass-based unit GHG relative to one unit of carbon dioxide in a given period of time. The GWP, is the characterization factor and is used to calculate the CF of a specific amount of GHG emissions, which are emitted during the life cycle of a product.

The carbon footprint of a product indicates how large the impact of a product is on our environment. Determination of a CF gives insight into the amount of contribution of different parts to the CF and the specific total amount of CF. These results give growers the possibilities to lower their carbon footprint. The CF calculation is based on LCA methodology.

A limitation of this theory is that our environment can get affected by other factors besides GHG emissions. Other categories, besides climate change, which give an indication of how large the impact of a product on our environment is, are for example: acidification, eutrophication, photochemical oxidant formation and abiotic depletion (Baumann & Tillman, 2004). These factors are not taken into account in this thesis. However, it is proven that an LCA can give a totally different conclusion if other impact categories are also taken into account (Montero, Antón, Torrellas, Ruijs, & Vermeulen, 2010), which might affect the improvement on the product. For instance, in the paper of Hellinga and Blonk it is stated that energy, fertilizers and pesticides have the largest environmental impact in greenhouse horticulture (Hellinga & Blonk, 2003), while this thesis explains this is not the case for the CF analyses.
Besides the theory of climate change, other limitations play a role considering the CF methodology itself. Limitations of CF methodology are designing system boundaries, functional unit, selection and availability of appropriate data sources, allocation rules and assumptions considering transport and waste management. Furthermore data can vary in time and can be location specific. Value choices are inevitable before a carbon footprint can be calculated. It is obvious that trade-offs need to be made during this research. The decisions of these trade-offs in combination with the limited time span, which is set for this thesis, will be treated in paragraph 2.3 and paragraph 2.4. All these choices influence the result of the carbon footprint calculation. This implies that the accuracy of a carbon footprint is limited and difficult to determine. Furthermore, comparisons between carbon footprint analyses are only valid when their methodological choices are identical. Paragraph 4.1 elaborates on how this limitation affects the used procedure during this thesis.

In paragraph 1.5 the scope of the thesis subject was explained, which leaves two other scopes unexplained, namely the scope of modeling and the scope of CF. The methodology of modeling will be explained in paragraph 2.2, while an elaboration on the scope of the model is given in paragraph 3.1. In paragraph 2.4 an elaboration on the scope of LCA will be given.

### 2.2 Modeling methodology

The methodology which is used is modeling. In modeling first of all the domain and functionality which the eventual model needs to fulfill will be well-defined. Based on this demarcation, a conceptual model will be developed. The conceptual model defines which data might be used as an input for the quantitative model, because relations between input and output of the model will be revealed during research. This conceptual model will help to find knowledge gaps, because a search is needed for data which can be retrieved for every case and are relevant for the next steps in this study. Development of this model could help to conduct and value CF analyses of greenhouse horticultural products more consciously. It can make people aware of what the value of the CF result does (not) include. In addition, it might lead to future research which can make CF analyses more accurate in future. Furthermore, it can initiate the provision of new solutions to decrease a CF, because so far covered parts could be revealed by the development of the model, which significantly contribute to the CF. Besides these advantages, a conceptual model will give a clear overview about the whole situation in the horticultural sector. This overview will benefit communications between different actors, because it could help to align the concept of system boundaries of CF in the horticultural sector and the discussion around it.
Once the conceptual model is developed, a quantitative model is framed. In this step the model is transformed into a usable, quantitative interpretation, in the form of a flow diagram. In this step usable variables from the conceptual model will become measurable to define relations. The relation between reality, the demarcation of research, conceptual model and the quantitative model is shown in Figure 2. Notice that the model only describes what is now known and relevant for reality and for the specific context. This means that the model will be a simplification of reality. In the section “Recommendations” will be discussed what this context implies for further research.

2.3 Procedure
Now the goal of the research, the research question, the theory and the methodology are discussed, a procedure can be developed to structure the research. This procedure is shown in Figure 3. The procedure can be divided in three main phases: demarcation, development of the model and the last phase: testing the model with accompanied conclusions and recommendations. All steps adding to the completion of a phase are enclosed by a rectangle. Therefore, it is possible that some means of analysis belong to different phases.
2 Methods

Figure 3 Visual overview of the procedure of research
2 Methods

2.3.1 Demarcation
The research needs to be demarcated in order to be able to execute the research in the time span of this thesis. The demarcation of research consist of the demarcation of the subject of the thesis and the scope of the approximately 100% CF. A flowchart will be made to gain insight in the process of producing horticultural products, which is helpful to give an overview of the process. This overview is useful for creating a scope and develop technical system boundaries. System boundaries for an approximately 100% analysis must be determined in order to know what is meant by the whole CF. This makes it possible to test in the third phase if 95% of the whole CF can be determined by making use of the model. After all, the model can only be tested, when rules applying to the test are stated clear in the beginning.

An overview of different groups which can (potentially) contribute to a CF will be given on the basis of the revision of PAS 2011-1 by Blonk (Blonk, 2011). The reason for applying this top down approach is that a clear overview will remain. When a bottom up approach would be used, it is never clear when enough effort and time is put to unravel data of missing parts.

Interviews will reveal if these groups are chosen well, whether groups are missing, which groups should be merged and which groups are likely to contribute most. If data for a group contributes less than 0,5% of the whole CF, the group will be excluded from the 100% analysis after all. To find out whether groups are less than 0,5% minima and maxima data are put in an overview. By maximizing one group in turn, while minimizing the other groups it is revealed which groups always give an insignificant contribution to the CF. The pilot project, communication with producers or sellers relating to different parts of the CF and literature are consulted to determine the minimum and maximum CF per group per one ha. If data are not available, the results from the pilot project will be used. The pilot project and experience of BMA will indicate if it is feasible to collect all data for a group. In paragraph 3.1 there will be elaborated on the magnitude and feasibility of criteria. By this analysis the groups can be adapted.

2.3.2 Development of the model
Secondly the model will be developed. The domain of the model needs to be defined and the functionalities will be determined. This is accomplished by reasoning what the model should be able to do and how this can be implemented. First of all the research element is determined. Hereafter relations will be qualitatively explored by using literature research and the other means discussed in the former paragraph. The data provide insights about where significant carbon emission will be present in the chain. Furthermore insignificant data will be graded by taking into account time, effort and money needed to collect these data, whenever needed. From this literature research and interviews patterns will be revealed. From these patterns hypotheses will be derived. It will be determined what happens if certain inputs or outputs will be varied and, if possible, why this relation can be determined. From those results, a conceptual model will be set-up. Thereafter more advanced and quantitative tests will be executed, with help of the minimum-maximum dataset, in order to develop a quantitative model. Conditions can be set derived from the analysis and varied accurately in this phase.
2.3.3 Tests, recommendations and conclusion

When this quantitative model is developed it will be tested on real-life cases. The CF of the horticultural product with the predetermined system boundaries will be determined; after this the CF with the system boundaries which results from the model will be determined of the same product. Hereafter it can be analysed whether the outcome of the model indeed represent 95% of the approximately total CF for real-life cases. A search has been done for products which are likely to have a high variety in model output. In this way various growers, which are willing to deliver the required data, will be selected by criterion sampling.

Possible deviations between reality and the predictions of the model can be reduced by conducting the research cycle again. In this case, instead of conducting the research cycle again, recommendations about conducting this cycle again will be discussed. This discussion will focus on the basis of the model, the test results and practical experience. From the results conclusions will be drawn.

2.4 Principles and assumptions of the CF analysis

As already mentioned in paragraph 2.2, it is very important that the same methodological choices are made to be able to compare carbon footprints within this study. Therefore, to be able to replicate the experiment and be able to gain a better apprehension of this thesis, the principles and assumptions applied, will be stated in this paragraph. The choices are compared with the standards of the BSI (PAS 2050) and the Swedish PCR (BSI, 2011; PCR, 2010). The Japanese PCR for vegetables is more specific, but it excludes greenhouse products in its scope (J. PCR, 2010, p.1). Therefore the Japanese PCR is not a good standard to compare these methodologies. In case of a conflicting decision or specification of decisions, these choices will be justified. Noteworthy rules will also receive attention. System boundaries for an approximately 100% predictive CF of the product with a cradle-to-gate scope, are determined with the help of the experience from BMA and methodology documents like PAS2050. Only processes on which the grower has direct or indirect influence will be included, unless BMA states differently.

2.4.1 Goal of the CF analysis

The goal of the Carbon Footprint analysis is to find out which activities in the life cycle, on which the grower has an influence, contribute most to climate change associated with greenhouse horticultural products. These activities or groups are called ‘hot-spots’. In this way, improvement possibilities can be found in the life cycles of greenhouse horticultural products. The results will be communicated to and used by growers and their system advisors. Now, the kind of LCA applied is discussed, because it can have consequences for decisions concerning the scope of this CF. This LCA, is the accounting type of LCA, because it is conducted for this thesis in order to be able to compare different product lifecycles. However, for the grower it is a stand-alone LCA, which needs to identify ‘hot-spots’ in the product lifecycle. The kind of LCA differs from what might be expected (a consequential LCA) based on the goal of the CF analysis. This is the case, because the goal of this thesis differs from the goal of the CFs individually.

2.4.2 Scope of the CF analysis

Greenhouse horticultural products from three different categories (fruit, vegetables and cut flowers) will be modeled for the Netherlands. This means that various greenhouse horticultural products will
be analyzed for which sufficient data can be found by growers who are willing to supply their data for this study. Preferably, there will be a large variety in output of the system boundary model between the different case-studies.

### 2.4.3 Carbon Footprint methodology

This subparagraph will give an overview on how a carbon footprint is generally calculated. First of all, some background information is needed about terminology used in CF analysis. The impact category is chosen as climate change conform CML’s guide to the ISO standards (Guinée, 2002). The category indicator is infrared radiative forcing (W/m²). The characterization model is the baseline model of 100 years of the Intergovernmental Panel on Climate Change (IPCC). The characterization factor, GWP, converts LCI data (given in kg of GHGs to the air) to kilograms of CO₂-equivalents per functional unit (ISO, 2006). The unit of indicator result will be kg CO₂-eq.

(A partition of the) CF of a product or process is calculated by multiplication of the carbon dioxide equivalent (CO₂-eq) by the mass (m) of the accompanied GHG (n), which were emitted during the life cycle of the product. Subsequently this summation is divided by the total units of the produced product. The model which defines the GWP of different gases is the characterization model. The model is developed by the IPCC. In formula it will look like this:

\[
CF = \sum_{n=1}^{63} \frac{GWP_n \cdot m_n}{U}
\]

Where:

**CF** = (partition of) CF in kg CO₂-eq/unit

**GWP**ₙ = CO₂-eq of the GHG n, in total there are 63 GWP defined

**m**ₙ = kg GHG n (related to the partition) emitted for one production/process year

**U** = amount of units of the product in one year

### 2.4.4 Functional unit

The functional unit of fruits and vegetables is chosen as one kg product of sufficient quality including packaging material conform PCR (PCR, 2010). The functional unit of cut flowers is chosen as 10 stems of sufficient quality including packaging material ("Draft PAS 2050-1 Assessment of life cycle greenhouse gas emissions - Supplementary requirements for the application of PAS 2050 to horticultural products," 2011, p. 6). If the fruits, vegetables and flowers are sold to the sellers under normal circumstances, the assumption is made that the product is of sufficient quality.

### 2.4.5 Initial flow map

An initial flowchart is made, which applies to fruit, vegetables and cut flower products mentioned in subparagraph 2.4.2. The initial flowchart is developed with the help of the Japanese PCR and Draft PAS 2050-1 ("Draft PAS 2050-1 Assessment of life cycle greenhouse gas emissions - Supplementary
requirements for the application of PAS 2050 to horticultural products,” 2011; J. PCR, 2010). Figure 4 shows the initial flowchart for the carbon footprint of greenhouse horticultural products.

The definition which is used for capital goods in horticulture is the following: “All goods, with a lifespan longer than a year, that have a purpose to create optimal growing conditions. In practice this involves all goods and materials that are part of the housing, equipment, installations, interior and exterior needed for cultivation, including the goods for repair and maintenance.” (Blonk, 2011).

Figure 4 Initial flowchart in aid of the carbon footprint analysis of greenhouse horticultural products
2.4.6 System boundaries and allocation
A classification of system boundaries for an approximately 100% predictive LCA has been made according to Tillman and Baumann. Choices for system boundaries can have a significant effect on the result of an LCA (Göran Finnveden & Ekvall, 1998). The system boundaries are discussed per dimension.

2.4.6.1. Boundaries in relation to natural systems
The life cycles of greenhouse horticultural products are all defined from cradle to gate, in which gate is defined as greenhouse horticultural products ready to leave the production site (BSI, 2011, p.13). In this study a cradle-to-gate scope is chosen, because a grower has no influence on to whom they sell their product and thus on what will happen with it in the use and waste phase. Flowers, fruit and vegetables are substitution goods, by origin homogeneous products which are mainly sold by auction. Therefore the power is mainly at the sellers side instead of the suppliers side, which is the case for heterogeneous and complementary goods. This is the reason why growers hardly have any influence on the means and distances of transportation. It is decided to include young plant material and seeds in the CF. Although growers do not have an influence on the production, it is still recommended to include these groups by the Swedish and Japanese PCR as well as PAS 2050-1 (Blonk, 2011; PCR, 2010; J. PCR, 2010). The cradle-to-gate life cycle of horticultural products includes its production, but not the use and waste treatment phase of the horticultural product. However, the potential impact of delayed emissions occurring in or after the phase of use of the product will be taken into account conform the draft PAS 2050-1 (“Draft PAS 2050-1 Assessment of life cycle greenhouse gas emissions - Supplementary requirements for the application of PAS 2050 to horticultural products,” 2011, p.6). This means the assumption is made that regardless of the use of the product, all GHG emissions absorbed by the plant will be emitted during use or waste disposal of the product. This means, conform PAS 2011, removals of CO₂, arising from absorption of CO₂ for photosynthesis for the plant will be excluded from analysis (BSI, 2011, p.9). Furthermore land use change will be excluded from analysis, not similar to PAS 2011 (BSI, 2011, p.10), because this will always be zero in the case of greenhouse horticulture in the Netherlands according to the land use change expert of BMA (Ponsioen, 2011). Furthermore, land use change (LUC) is all about processes which happened in the past and therefore fits consequential LCA, but not the accounting type of LCA. Therefore, it is not required to include it, even if the number of LUC was higher than zero, because a farmer has no influence on this past in order to reduce the product he or she produces now. However, it will be interesting to calculate land use (apart from the CF) for (consequential) LCAs when a different scope is applied in future studies.

2.4.6.2. Geographical boundaries
The origin of raw materials of capital goods is assumed not to be well defined, and therefore average values will be used. Averages for the Netherlands will be used when electricity is used from the grid. The sensitivity of the environment to different pollutants will be taken into account globally, because the GHG emissions are not restricted to a specific area or country.
2.4.6.3. **Time boundaries**

The LCA is of accounting nature: it asks what the environmental impact is of a produced product. The view is retrospective, because the product itself is not a long-lived product. Furthermore, the life span of capital goods will be estimated. A choice has been made to use the economic life span of capital goods instead of the technical life span, to be sure not to make an underestimation of the footprint. The assessment of GHG emissions will cover the period of one year of the life cycle of the horticultural product. In case of a perennials, representative, average data will be collected. Activities occurring outside this time span will be included, as long as they are involved in the production of the product (ISO, 2011).

2.4.6.4. **Boundaries within the technical systems:**

*Cut-off criteria*

It has been decided to model the system from cradle-to-gate, which means that the distribution, use and waste treatment of the horticultural product are excluded from the analysis. The life cycle of the product stops as soon as the product is wrapped at the grower and ready for transport to a new business. Because an accounting LCA will be executed, the study should be as complete as possible. Capital goods are excluded, unless they make a significant contribution to the CF (BSI, 2011, p.14). According to the Swedish PCR, every good with a life expectancy longer than three years and other capital goods should be excluded (PCR, 2010, p.9). However, there is research which reveals that capital goods are accountable for a significant part of the carbon footprint (Blonk, 2011). Therefore, we will not cut off capital goods from this LCA (Baumann & Tillman, 2004). Personnel related environmental impact is not included in the LCA since this is usually not the case and will make the research impracticable in this short time span (Baumann & Tillman, 2004). Finally, resource related issues (like a lack of time, data or financial sources) will be cut-off from the process. Reliable models or values for data are used when available, in order to collect data which are otherwise hard to obtain. If none of this is possible, data will be estimated or excluded. Primary data will be collected as much as possible.

Emissions from the waste management phase of all used materials during production and raw material acquisition will be included in the analysis. According to the PCR, environmental impacts related to waste deposited in landfills should not be included in the system boundaries, while according to BSI they should be included (BSI, 2011). The PCR is used, because it is more specific, it only takes transport to the landfill into consideration (PCR, 2010, p.9). Conform PAS 2050 recycling of the material or energy generation from waste will not be taken into consideration. However, energy generation from waste will be taken into account in this research, just like recycling in the case of building materials to be more accurate. It will also be taken into account, that not all inputs will be produced from virgin material. Sometimes a part of the virgin material will be substituted by recycled material. In this case the mass percentages of the waste which is recycled will be used, instead of the mass percentages of recycled material used during the production phase. This decision has to do with the feasibility of collecting the required data. It is known that these percentages are dependent on industry, which will provide these data. Often they will try to grade this percentages higher than they actually are. This is due to the fact they need a higher recycling percentage in favor to achieve their requirements concerning agreements and regulations. For instance, the recycling percentage could be increased by not taking into account percentages of waste which are dumped before and during the recycling process. Due to large uncertainties in this area, a sensitivity analysis will be conducted, in which an analysis will be made what will change when 100% recycled or 100% virgin material will be used for the production of input materials for the horticultural process. All the waste for which
GHG will be emitted during the waste management stage which will be used in another process system, like the production of compost from plant waste, will be accounted to this business or their consumer. Therefore zero emissions of these waste management processes are assumed.

In Table 2 all groups are named with a description whenever needed on the basis of literature study. The initial flow map in paragraph 2.4.5 could be seen as a summary of this table.

<table>
<thead>
<tr>
<th>Name group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeds</td>
<td>Glass wool, rock wool, potting soil, coco peat etc.</td>
</tr>
<tr>
<td>Young plants</td>
<td></td>
</tr>
<tr>
<td>Substrate</td>
<td>Synthetic and mineral, such as nitrate, urea or sulphate based, P₂O₅, K₂O or lime</td>
</tr>
<tr>
<td>Organic fertilizer</td>
<td>Such as manure, compost, mulch, co-products from industry</td>
</tr>
<tr>
<td>External CO₂ fertilizer</td>
<td>From fossil origin or biogenic fuels, supplied by a third party</td>
</tr>
<tr>
<td>Pesticides</td>
<td>Herbicides, insecticides, fongicides, biocides</td>
</tr>
<tr>
<td>Other pest management</td>
<td>Nets, fences etc. and biological control such as plants and insects</td>
</tr>
<tr>
<td>Fuels</td>
<td>Gas, diesel, kerosene, propane, fuels from biogenic origin, other</td>
</tr>
<tr>
<td>Imported heat</td>
<td>Heat supply from third parties</td>
</tr>
<tr>
<td>Imported electricity</td>
<td>Used for acquiring geothermal energy, other electricity use such as lighting, pumping etc.</td>
</tr>
<tr>
<td>Packaging materials for raw material input</td>
<td>Foils, containers, pots</td>
</tr>
<tr>
<td>Materials for soil covering</td>
<td>Plastic foil etc.</td>
</tr>
<tr>
<td>Materials to guide growth</td>
<td>Wires (steel, nylon), nails, tape, posts etc.</td>
</tr>
<tr>
<td>Packaging materials for the final product</td>
<td>Labels included</td>
</tr>
<tr>
<td>Consumables for maintenance of capital goods</td>
<td>Non-fuel oil, cleaning products like soil fumigants, cooling agents and urea.</td>
</tr>
<tr>
<td>Capital goods 1</td>
<td>Production of the Greenhouse and all equipment inside and attached to the greenhouse. Greenhouses (incl. foundation, pavement, flooring and piling), cultivation grooves, CO₂ installation, drainpipes, condense pipes, drip pipes, heat transport tubes, roof sprinklers, blinds installation, sprinkle installation (inside) etc.</td>
</tr>
<tr>
<td>Capital goods 2</td>
<td>Production of machines, transport means on the farm and other energy using equipment. Heat pump, pumps, aquifer, CHP, boiler, geothermal installation, aggregate, solar panels and suchlike, silo’s (as heat- or liquid CO₂ storage), flue gas purifier, water basin, sorting installation, packaging line, seal installation, stacking machine, cooling installations, tiny means of transport.</td>
</tr>
<tr>
<td>Capital goods 3</td>
<td>Production of buildings, roads and other pavements and floor covering. This includes for example the boiler house, CHP house, geothermal house, cold store, fertilizer-water mixing room, process accommodation, office, canteen, changing room, loading and unloading space (dock shelter) road to the greenhouse, climate control room, pavements aside the greenhouse and floor covering of the buildings.</td>
</tr>
<tr>
<td>Maintenance of all capital goods</td>
<td>Includes maintenance for all 3 capital goods groups: new parts, third party maintenance, inspections, etc.</td>
</tr>
</tbody>
</table>

Table 2 Division into groups on the basis of the revision of PAS 2011-1 (Blonk, 2011)

**Boundaries in relation to other products’ life cycles.**

Several allocation problems can come across during the analysis of the product. For instance, CHPs can provide a surplus of generated electricity to the grid, while the generated warmth will be used in the greenhouse. Furthermore, capital goods might be recycled or be built out of recycled material (open-loop recycling), additional CO₂ can be supplied by factories for which the CO₂ is a by-product from their production chain (multi-output), different crops can grow in the same greenhouse making use of one total amount of CO₂ (multi-input) and so on. A choice was made for partitioning to deal
with allocation problems in the life cycle, because this is the best way to deal with accounting LCA’s according to Baumann and Tillman (Baumann & Tillman, 2004).

The allocation partitioning factor is different for each allocation problem. In the case of a CHP electricity, heat and CO$_2$ are produced and used for different purposes. The rule about CHPs conform BSI 2008 PAS 2050 will be used where the emissions are allocated to heat and electricity, corresponding to the amount of useful energy, which depends on the specific CHP input (BSI, 2008).

To avoid double counting, CO$_2$ as a by-product of the energy used will not be counted again. However, external CO$_2$ fertilizer, provided by third parties, must get a label of GHG emissions. The allocation of GHGs between co-products will be conducted in proportion to the economic value of the products and the ratio between the products produced, because a physical relationship alone cannot be used for this allocation (ISO, 2006). However, it is possible that some companies are not willing to supply the total outputs of their production process. In the case of a simple process a calculation can be made to determine their total GHG emissions. However, when their produced product is too complex to allocate or when the third party does not want to give numbers, a 0.5 kg CO$_2$-eq/kgCO$_2$ will be used, conform PAS 2050-1. This number is chosen to encourage the companies to provide numbers, because it is a fairly high emission factor.

When different crops share different inputs, the allocation will be based on economic value of the end product. This is because it is impracticable to take mass in consideration since plants may vary a lot in mass during the production process and the percentage of final product of the whole crop can differ considerably.

2.4.7 Data quality requirements
Data quality factors can be grouped in three different categories: relevance, accessibility and reliability. The first five subparagraphs relate to the concept relevance. Reproducibility and consistency relate to accessibility, while precision and consistency relate to reliability.

**Time-related coverage**
The primary data collection period will be the most recent year from which data is available. To let the research be independent of seasonal differences, the average in one year will be used as primary data. However, if the yield of the year highly deviates with respect to other years, due to exceptional external conditions, average data from previous years can be used.

**Geographical coverage**
Site specific data will be used for all the processes in the production stage. If specific data cannot be retrieved for produced heat and electricity, the average mix for the country will be used. Generic data will be used to determine GHG emissions from other parts of the process, like the production of one kg fertilizer. These data will be collected from databases or scientific papers.

**Technology coverage**
The specific type of technology to produce the product will be researched. For example, some growers will cultivate their own young plants, while other growers will buy them from a supplier. Site-specific and marginal data will be collected as much as possible. Suppliers from all capital goods will be consulted if this is possible.
2 Methods

Completeness
As much data as possible will be measured. Secondary data needs to be representative for the product.

Representativeness
Site-specific data will be verified in order to know they are representative. Furthermore, growers will be asked if the values they will supply are representative in a specific time frame. The LCA is more of the accounting type and therefore average data fit very well when secondary data need to be collected. However, as far marginal data can be found they will be used, because some marginal data can really make a difference for the grower, when used instead of average data. When needed input data cannot be found, a pragmatic approach will be applied. When there are suspicious specific average data, a sensitivity study will be conducted on these data.

Reproducibility
Site-specific data obtained from the growers and suppliers will be verified with bookkeeping documents of the growers. References to all sources for obtaining secondary data will be provided.

Consistency
Data will always be first tried to collect site-specific. If this is not possible, an average from a database will be used as long as this database is representative for the specific production process. If there is no database available, values from products in similar scientific studies will be used. If it is impossible, data will be estimated.

Precision
Data with the least variance will be preferred.
3. Results: Development of the model and trial validation

3.1 Functionalities of the model
The domain of the model is already partly demarcated in paragraph 1.5, where the scope of the research has been discussed. However, additional demarcations are needed. This has to do with the functionalities that the model should be able to offer. The goal of development of the model is to gain insight in the relevancy of groups contributing to the CF. The research element is cut-off criteria. Cut-off criteria are used to make the CF analysis feasible and matching the scope of the study. The model determines for all imaginary different contexts which groups are part of the 95% CF and which groups are insignificantly contributing to the CF and therefore not relevant. Therefore the outcome of the model will be groups which are needed for data collection in order to define 95% of the CF, representing the cut-off criteria. Therefore the groups in Table 2 need to be adapted in order to define an approximately 100% CF with groups for which data collection is feasible and simultaneously make a relevant (>0.5%) contribution to the CF in some specific contexts (see Appendix A2). This adapted approximately 100% CF determination together with the scope of the thesis will form the domain of the model.

Next to what the outcome of the model must contain, there will be elaborated on other functionalities of the model in order to set up standard practices to adapt the groups in the next paragraph. For the carbon footprint the usual data collection conditions of Blonk Milieu Advies are applied. This means that data collection should take at most 2 days for the grower. Furthermore it is assumed that a grower does not want to put more money in the research as usual. This means the data collection step will stay his/her responsibility. This requirement is strengthened by the financial difficulties in the horticultural sector at the moment. Furthermore consultants and researchers do not want to put extra time in the CF analysis, which comes down at no more than 5 days of data analysis preparation, analysis and writing including a report (J. Scholten, 2011). The model should have the possibility to be implemented in a self-sustaining way.

The conceptual model will reveal which variables will be relevant for the research. Relations will explain the effect of an independent variable on another independent variable or the dependent variable (the cut-off criteria). The variables and the effect of the relations will be made measurable in the quantitative model. First of all groups which contribute less than 5% will be summed. If they do not add up to more than 5%, the remaining groups will form automatically at least 95% of the CF. However, when this is not the case, the groups which are the most feasible for data collection will get priority in order to reach the 95% CF.

Now the functionalities of the model are discussed, standard practices which are needed to develop the models will be explained. The preliminary defined groups will be adapted first using the interviews. Secondly, groups which effect the data collection for taking over two days will be identified during the pilot project. These groups are excluded from the approximately 100% system boundaries if no good proxy for these groups can be found. The third next step is to derive minimum and maximum CF values per group. Subgroups will be distinguished, whenever there is an indication this will be useful. By constantly deriving unique extreme cases by setting all groups at the minimum and changing separately each group to a maximum, can be found what each group contributes maximally to the total CF in percentage points. This will already give clues which groups could be relevant and which are not. Groups which represent at their max. less than 0.5% of the CF will be
excluded from the approximately 100% system boundaries. This procedure will be repeated till every group contributes 0.5% or more to the approximately 100% CF. When these steps are conducted, the approximately 100% system boundaries are derived. These boundaries are necessary to make validation of the future model possible.

From the revealed patterns during the determination of the 100% CF, hypotheses will be derived. It will be determined what happens if certain inputs or outputs will be varied. If possible it will be derived what influences the variations in inputs of the determined relations. From those results, a conceptual model will be set-up. Thereafter more advanced and quantitative tests will be executed, with help of the minimum-maximum dataset, in order to develop a quantitative model. For development of the quantitative model the variables and scenarios will be researched more deeply and other scenarios can be developed as support. In this way the variables can hopefully be made measurable and the model can become quantitative. The largest insignificant groups (contributing less than 5% to the CF) will be graded by taking into account time, effort and money needed to collect these data, when the significant data do not add up to 95%. From this literature research, the pilot and interviews patterns will be revealed regarding time, effort and money to collect data per group.

Summarized, the model should fulfill the following functionalities. The implemented model should be able to cope with the information that growers and suppliers of process systems have (indirectly) available in a self-sustained way. The CF data collection plus the time to fill in the model cannot take more than two days. The output should consist of groups which form at least 95% of the approximately 100% CF. This outcome will represent the technical system boundaries or cut-off criteria. Next paragraph will mind one’s p’s and q’s regarding the domain.

### 3.2 Detailing the contribution of groups

#### 3.2.1 Energy and fertilizers

Considering the interviews it appears that it is wise to combine fuels and imported heat. In addition imported electricity can be added to this group, because these three groups are all dependent on each other, while it is not clear what the main indicators are which influence the magnitude of these groups. An example is when heat is imported, less fuels will be used, while it is likely that more electricity is used, because chances are lower that a CHP is in operation. The results of magnitude mentioned in the interviews vary a lot, while the interviewees agree broadly speaking on the indicators. The fact that the interviewed experts do not know the magnitude and the exact influence of indicators which can influence the magnitude of imported electricity is an indication that indicators will be impossible to find. Fuels, imported heat and imported electricity influence each other in an unquantifiable manner. Therefore, it will make the rest of the research better feasible if these will be merged to one group. When indicators are unknown, the remaining option to predict the magnitude of this merged group is measuring. In this way, large mistakes in the quantitative model can be avoided. Besides, the interviews reveal that imported electricity is one of the most feasible groups to find. Furthermore it is stated that the groups synthetic and organic fertilizer is better combined as one group, since they are

---

2 It is chosen to set the limit at 0.5%, because the new PAS states that groups contributing 1% or more to the CF need to be included in any case (BSI, 2011). This gives the impression that a limit should be lower than 1% at least. In this way the percentage is relatively not so close to 1% while simultaneously 0.5% states an insignificant contribution of which it is not likely that the sum of groups will become significantly large.

3 The ones constituting the missing percentage points to form 95% of the CF and cost the least time, effort and money will get priority. They are assumed to be the most feasible groups to confirm the functionalities of the model.
substitutes according to Vermeulen. To give an example, if cultivation is biological only organic fertilizer will be used and therefore no synthetic fertilizer is used.

### 3.2.2 Transport
In appendix A8, it can be seen that often the producer and production location of input materials is unknown by the grower. As a consequence transport details cannot be retrieved. In the pilot case these data were estimated by worst case scenario’s. Those distances are estimated, which is justifiable as this transport contributes a negligible amount of total CF according to Vermeulen (see the interview transcript). This statement is confirmed by the results of the min-max analysis in appendix A11. Experts from Blonk Milieu Advies also supports that the CF of transport of input materials is negligible. In addition, these estimations consumed too much time in practice. Therefore transport is excluded from the approximately 100% system boundaries for all groups.

### 3.2.3 Maintenance
An indicator for maintenance seemed like a good idea, because there is no specific CF information on this subject. The following indicator was applied. An assumption was made that the percentage of maintenance costs for capital goods considering the product price of the produced product will be equivalent to the ratio of CF maintenance of the CF of all capital goods. In formula: Maintenance in euro/ revenues of product = CF maintenance\(_{\text{cap2+3}}\) / (CF\(_{\text{Subtotal}}\) + CF maintenance\(_{\text{cap2+3}}\)). This rule is inspired by the article of Frischknecht. In this article it is stated that a high level of maintenance compared to product price will indicate whether capital goods contribute to the CF (R. Frischknecht, H.-J. Althaus, C. Bauer, G. Doka, T. Heck, N. Junghbluth, D. Kellenberger, et al., 2007).

However, during the pilot it turned out that maintenance costs were really high. Especially the maintenance of the CHP was responsible for more than 2/3 of total maintenance. It seemed not realistic that this amount of money is spend on parts, but that most of the maintenance consisted mostly of employment, taxes and profits. By analyzing the report of Nijdam and Wilting it can be noted that the CF per euro for maintenance is mostly much lower than the CF for goods (Nijdam & Wilting, 2003). Furthermore the data about maintenance of CHPs, which can be found in the Ecoinvent database, shows CF values (included transportation) which are really low. For the pilot project the value would be 0.08%\(^4\) regarding to the case using the indicator (Ecoinvent, 2007) in the most optimistic case (assuming linearity and a micro gas turbine). Maintenance seems to include mainly employment when it comes to machinery (Kippersluis). Therefore, the CF of this employment (mainly existing of travelling) can be calculated, which is 35%\(^5\) of the total CF outcome by using the indicator. However we tend to make a large overestimation by assuming all paid euro’s are spend on transportation and schooling when using this as EF (Nijdam & Wilting, 2003, p.73). In practice taxes should be paid, other costs for the company should be covered and profits will be made. So we can conclude from these calculations that the indicator is not a good predictor and the CF is likely to play

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\(^4\) According to Ecoinvent a micro gas turbine of 100kW with 50,000 hours of operation has 192.35 kg CO\(_2\)eq per lifetime. When this number is multiplied by the electric power of the CHP (linearity) and the hours of operation divided by 50,000 hours the outcome is the CF of maintenance according to Ecoinvent. When this number is divided by the number of the outcome of the indicator model of maintenance, it has been calculated this consist of 0.08%. The numbers can only be found in the appendix A11, since it is confidential information.

\(^5\) Per 672 euro’s spend on employment 944 kg CO\(_2\)eq will be emitted. By dividing the amount spend on maintenance by 672 euro and multiply this answer by the 944 kg CO\(_2\)eq and finally divide by the total CF of maintenance calculated by the indicator there is found that this is 35% of the indicator.
a role less than 0.5% in the total CF. Besides, maintenance is already included in agricultural buildings and machinery (Nemecek; & Kagi, 2007, p.54). By excluding the group maintenance, the problem of double counting is simultaneously solved. Furthermore, since maintenance is already included in agricultural buildings and machinery, it supports the view that maintenance per capital good is estimated far higher by the indicator than is actually the case. Data on infrastructure required for maintenance of machinery is not included, because no adequate values are available (Nemecek; & Kagi, 2007, p.60). When values on maintenance in the EcoInvent database are analyzed, it can be noted that maintenance can fluctuate tremendously amongst different capital goods. CF percentage of maintenance fluctuate from 1.3% to 77.1% of the capital good itself. The 1.3% matches the CHP of the example, but the calculation in footnote 4 indicates that the percentage of maintenance of the total CF of the horticultural product is almost 1,000 times smaller than 1.3%. However, the other few examples have nothing to do with capital goods used in greenhouse horticulture. The only conclusion that can be drawn is that there is not much specific information available focused on capital goods in horticulture and the assumption to assume the linear relation in the indicator is not justified.

### 3.2.4 Capital goods 1 and capital goods 2

Capital goods 1 and capital goods 2 are proposed by PAS 2050-1 not to be taken into account yet. In order to determine if it is feasible to take into account the groups capital goods 1 and capital goods 2, data collected by Vermeulen (P. C. M. Vermeulen, 2009) are used for analysis. Vermeulen collected detailed data on all capital goods used in horticulture except for piling, some machines and other buildings than the greenhouse. He did this for various greenhouse horticultural companies. A strawberry, tomato, rose, pot plant on a concrete floor, pot plants at a table, soil cultivation and flowers in a gutter horticultural cultivation of 4 ha are analyzed to get a good comparison.

First of all, the group greenhouse and all equipment inside the greenhouse is considered including irrigation equipment. The second group which is considered is all other equipment outside the greenhouse which are mainly used for energy purposes or use energy themselves. For all groups the CF is calculated per subgroup. After this calculation it will be possible to determine how much data is needed in order to determine this CF. If it costs too much time, money or effort to collect the data or if these data are impossible to find an indicator is searched. When no good indicator can be found the conclusion will be that it is not feasible to calculate a CF of this group. Furthermore, the total CF for the groups capital goods 1 and 2 can be found in Table 3 for the whole mass of capital goods together per group per year. Moreover an indication of the contribution of the different groups to the total CF of the greenhouse horticultural product is given. This data should be interpreted carefully, since the scope of the different data is not always the same as is described in paragraph 1 and it is not known if the data really belongs to the specific product to which it is related. To clarify, the total CF of a strawberry may vary from the total CF for strawberry of which capital goods data are collected. Since, there were no accompanied total CF for these specific farms available, data which is available for the same kind of horticultural products is used to calculate the numbers which represent the contribution of the groups capital goods 1 and 2. If data were available on different products which could relate to the dataset, a maximum and a minimum calculation were conducted on the basis of the values of the CF. These calculations are based on data presented in the report of Peter Vermeulen which gives indicators on horticultural products and the study by Scholten et al. which provides different values for pot plant CFs (Scholten, Kool, & Benninga, 2008; P.C.M. Vermeulen, 2010, pp., p.13).
<table>
<thead>
<tr>
<th>Number of subgroups for which data collection is needed</th>
<th>Feasible?</th>
<th>Total CF group</th>
<th>% total CF</th>
<th>Min % tot. CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strawberry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse</td>
<td>31</td>
<td>No</td>
<td>357·10³</td>
<td>13.5%</td>
</tr>
<tr>
<td>Other equipment</td>
<td>2</td>
<td>Could be</td>
<td>19·10³</td>
<td>0.7%</td>
</tr>
<tr>
<td>Tomato</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse</td>
<td>29</td>
<td>No</td>
<td>312·10³</td>
<td>11.8%</td>
</tr>
<tr>
<td>Other equipment</td>
<td>4</td>
<td>Could be</td>
<td>38·10³</td>
<td>1.4%</td>
</tr>
<tr>
<td>Rose</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse</td>
<td>32</td>
<td>No</td>
<td>410·10³</td>
<td>2.4%</td>
</tr>
<tr>
<td>Other equipment</td>
<td>4</td>
<td>Could be</td>
<td>38·10³</td>
<td>0.2%</td>
</tr>
<tr>
<td>Potplant on table</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse</td>
<td>26</td>
<td>No</td>
<td>470·10³</td>
<td>3.5%</td>
</tr>
<tr>
<td>Other equipment</td>
<td>4</td>
<td>Could be</td>
<td>38·10³</td>
<td>0.3%</td>
</tr>
<tr>
<td>Potplant on concrete soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse</td>
<td>20</td>
<td>No</td>
<td>454·10³</td>
<td>3.4%</td>
</tr>
<tr>
<td>Other equipment</td>
<td>4</td>
<td>Could be</td>
<td>39·10³</td>
<td>0.3%</td>
</tr>
<tr>
<td>Cultivation in soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse</td>
<td>23</td>
<td>No</td>
<td>267·10³</td>
<td>11.8%</td>
</tr>
<tr>
<td>Other equipment</td>
<td>4</td>
<td>Could be</td>
<td>38·10³</td>
<td>1.7%</td>
</tr>
<tr>
<td>Flowers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse</td>
<td>27</td>
<td>No</td>
<td>300·10³</td>
<td>n.i.a.</td>
</tr>
<tr>
<td>Other equipment</td>
<td>4</td>
<td>Could be</td>
<td>38·10³</td>
<td>n.i.a.</td>
</tr>
</tbody>
</table>

Table 3  Feasibility study on the current determination of CF of groups capital goods 1 and capital goods 2

The analysis reveals that a greenhouse with all accompanied materials in or at the greenhouse is a very complex group. This is supported by the interview with Vermeulen, who states it took an enormous amount of time to map and measure all subgroups in order to be able to calculate the CF of the different capital goods inside a greenhouse (Appendix A2). To give an idea how much the largest subgroups contribute to the total CF of the group capital goods 1, the percentages of subgroups which ever exceed 9% will be discussed. Glass in covering contributes 7-12%, “oprolbuis trekdraden” 9-16%, “verwarming pijpen” 7-18%, “plant goten” 7-10%, “buis en tafel steun drager horizonataal” 10% and concrete floor 36% of the total amount of the CF of the group greenhouse. The last three mentioned subgroups are substitutes for one another and can be substituted by soil as well. Only in the case of pot plants on concrete, the largest subgroups contribute more than 50% all together. The rest of the group consists mostly of small subgroups below 3%. The magnitude and variety of these numbers per group shows that it is not feasible to calculate a representative CF on the basis of a realistic amount of data, which needs to be collected with the help of the grower, within this master thesis. However, from Table 3 can also be concluded that the total CF of the group capital goods 1 can make a significant contribution to the total CF of a horticultural product. This feasibility study
implicates that this group can only be taken into account in this thesis if a good indicator can be developed, due to the feasibility of data collection.

It seems not easy to find the right indicator. For instance an estimation on the basis of costs for buying different materials seems not a clever analysis, because prices of building materials fluctuate a lot over time. That is, prices of building materials are highly dependent on energy prices among other things (Bloks, 2011). When a look is taken at other large subgroups, glass in covering seems the most reliable indicator and furthermore it seems feasible to collect data on this subject. A standardized location, is a location converted into a squared 4 ha farm. When the individual non-standardized cases are also taken into account the following results are obtained, shown in Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Strawberry</th>
<th>Tomato</th>
<th>Rose</th>
<th>Soil cultivation</th>
<th>Flowers in gutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>% glass in covering of total capital goods 1 for standardized 4 ha location</td>
<td>9.1%</td>
<td>10.6%</td>
<td>8.0%</td>
<td>12.2%</td>
<td>10.9%</td>
</tr>
<tr>
<td>% glass in covering of total capital goods 1 individual non-standardized location</td>
<td>8.6%</td>
<td>10.7%</td>
<td>7.2%</td>
<td>12.3%</td>
<td>10.5%</td>
</tr>
</tbody>
</table>

Table 4 Contribution of glass in covering to capital goods 1

If it is assumed 10% of capital goods 1 consist out of glass in covering there is a slight uncertainty. The standard division which fluctuates between 2.3% (12.3-10) and 2.8% (10-7.2) can lead to a maximum miscalculation up to about 19.0% in the total CF. However, as this greenhouse group can have a contribution up to 57% of the total CF (Bloks, 2011), an even larger error can exist if a CF of a horticultural product is determined at the moment if no indicator will be used. Furthermore this maximum miscalculation is only evident for extreme cases. Therefore this amount of miscalculation can be accepted.

In the group capital goods 2, data about at most six subgroups should be asked in order to reveal 95% of the total CF. These subgroups are amongst others: boiler, heat buffer, CHP, and water storage silo’s. In this group, the heat buffer is in every case at least 49% of the total CF of this group and makes it by far the largest contributor to this group. A flue gas cleaner probably attributes an insignificant amount to the CF. The low amount of other equipment in the case of strawberry cultivation could rely on the fact that this cultivation is not using a CHP. The pilot project reveals much additional data need to be asked in order to include all other equipment as well and this data is most of the time not easy deliverable. Therefore a choice was made to ask about the same equipment that Vermeulen mapped (P. C. M. Vermeulen, 2009), plus the subgroups fertilizer tanks and tiny means of transport (e.g. harvest wagons), these bring the total to six subgroups. If data are not available, numbers will be estimated by the grower or with the numbers present in the Excel sheet of Vermeulen (P. C. M. Vermeulen, 2009).

It is concluded that it is not feasible to include capital goods 1 at this moment the way it has been done once by Vermeulen, because too many data needs to be asked in order to calculate a accurate CF. Therefore an indicator based on the amount glass in deck has been developed to estimate capital goods 1. Data can be collected for capital goods 2, but limited to the larger subgroups of capital goods in combination with the goods Vermeulen researched in his data file.

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6 Standard deviations are 2.3% and 2.8% and the largest contribution capital goods 1 has in a total CF in literature found is 57% ((Bloks, 2011)) (((0.023*10+1)*57)= 70.11 > (70.11-57)/(70.11+(100-57))=11.6% and (((0.028*10-1)*57))= -41.04 > (-41.04+57)/(41.04+(100-57))= 19.0%).
3.2.5 Capital goods 3
The data collection of this group faces the same problem as capital goods 1. Before the case study was conducted it was already known that it will be unfeasible to ask all data for the CF of the group buildings (Blok, 2011). Therefore an indicator is developed which is based on the study of Blok about the CF of a standard office (Blok, 2010). To make a precise estimation the size of the building in length, width and number of floors of the building are asked. In addition the type of construction, partitioning and the façade system will be asked to calculate the CF of a building. All parts of the building are included except piling (Blok, 2010).

3.2.6 Seeds and Pesticides
When the group seeds or pesticides is maximised, while the other groups are minimized it contributes less than 0.5% to the approximately 100% CF. This means seeds and pesticides are excluded from the scope, because they are always negligible groups.

3.2.7 Packaging materials for input materials
It was not feasible to collect data for packaging material for input materials during the pilot. This was mainly caused due to the fact that packaging materials were already thrown away, packaging materials were not separately measurable from their content and often the kind of material is unknown. Therefore an attempt was made to find an solution on the spot. Data which was available were waste streams. These waste streams were divided into green waste, paper and cardboard waste and remaining waste. There is no overview what these waste streams include exactly. Furthermore, even when an EF would be available, double counting would be possible, since some goods used are consumable items. In addition waste from employees could be included in this waste as well. Therefore, it is known each garbage group includes more than only input materials. This means packaging materials for input materials are excluded, since no good indicator could be found.

3.2.8 Substrate
Packaging materials of substrate were taken formerly separately into account in the group packaging materials for input materials. Substrate including the packaging, is mainly transported back to the supplier or a company which is responsible for recycling the substrate. Since the group packaging material of input materials is removed from the CF, but there are average values for using substrate (including packaging and transportation) available for the Netherlands, packaging materials and transport of substrate will be included into the group substrate. In this way the CF will be more complete.

3.2.9 Conclusion
Transport is excluded from all groups except substrate, due to its insignificant contribution to the total CF and because it is not feasible to collect these data. Maintenance and packaging materials for the inputs are excluded from the scope, because it is presently unfeasible to collect data on this subject. The invented indicators turned out not to be working well. There is not a lot of information on this
subject available in scientific literature at this moment. It might be possible to find a good proxy in future. Seeds and pesticides are excluded from the approximately 100% scope, because they are in every case insignificant groups. Organic and Synthetic fertilizer can be merged to a new group called fertilizer. Fuels, imported heat and imported electricity can be merged to the new group energy. These groups are merged, because the magnitude of the single groups depend on each other.

Although the data collection of several remaining groups takes a lot of effort, it is possible to collect this data in three days. Some data collection is conducted with the help of indicators, other data should be collected by weighing and searching in handbooks and phone calls were needed to collect data. All other data can be easily found or estimated in case it is not available.

### 3.3 Definition approximately 100% CF

The result of the adaptation of the technical system boundaries of the CF defined in groups, defined in the former paragraph, is shown in an overview in Table 5. The groups in this table are included into the approximately 100% CF. Transport is excluded from all groups, except for substrate. Furthermore the group packaging materials for raw material input is no separate group anymore and only taken into account in the group substrate. The groups are reduced from twenty to thirteen groups and represent the cut-off criteria to obtain an approximately 100% CF. The other system boundaries stay unaltered like stated in paragraph 2.4.6.

<table>
<thead>
<tr>
<th>Name group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young plants</td>
<td></td>
</tr>
<tr>
<td>Substrate</td>
<td>Glass wool, rock wool, potting soil, coco peat etc. including transport and packaging.</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Synthetic and mineral fertilizer, such as nitrate, urea or sulphate based, P2O5, K2O or lime. Organic fertilizer. Such as manure, compost, mulch, co-products from industry</td>
</tr>
<tr>
<td>External CO2 fertilizer</td>
<td>From fossil origin or biogenic fuels, supplied by a third party</td>
</tr>
<tr>
<td>Other pest management</td>
<td>Nets, fences etc. and biological control such as plants and insects</td>
</tr>
<tr>
<td>Energy</td>
<td>Gas, diesel, kerosene, propane, fuels from biogenic origin. Heat supply from third parties and imported electricity.</td>
</tr>
<tr>
<td>Materials for soil covering</td>
<td>Plastic foil etc.</td>
</tr>
<tr>
<td>Materials to guide growth</td>
<td>Wires (steel, nylon), nails, tape, posts etc.</td>
</tr>
<tr>
<td>Packaging materials for the final product</td>
<td>Labels included</td>
</tr>
<tr>
<td>Consumables for maintenance of capital goods</td>
<td>Non fuel oil, cleaning products like soil fumigants, cooling agents and urea.</td>
</tr>
<tr>
<td>Capital goods 1</td>
<td>Production of the Greenhouse and all equipment inside and attached to the greenhouse. Greenhouses (incl. foundation, pavement, flooring and piling), cultivation grooves, CO2 installation, drainpipes, condense pipes, drip pipes, heat transport tubes, roof sprinklers, blinds installation, sprinkle installation, roof transport tubes, roof sprinklers, blinds installation, sprinkle installation, roof transport tubes, roof sprinklers.</td>
</tr>
<tr>
<td>Capital goods 2</td>
<td>Production of machines, transport means on the farm and other energy using equipment. Heat pump, pumps, aquifer, CHP, boiler, geothermal installation, aggregate, solar panels and suchlike, silo’s (as heat- or liquid CO2 storage), flue gas purifier, water basin, sorting installation, packaging line, seal installation, stacking machine, cooling installations, tiny means of transport.</td>
</tr>
<tr>
<td>Capital goods 3</td>
<td>Production of buildings, roads and other pavements and floor covering. This includes for example the boiler house, CHP house, geothermal house, cold store, fertilizer-water mixing room, process accommodation, office, canteen, changing room, loading and unloading space (dock shelter) road to the greenhouse, climate control room, pavements aside the greenhouse and floor covering of the buildings.</td>
</tr>
</tbody>
</table>

Table 5 Result of adaptation of groups presented by means of a revised division into groups
3 Results: Development of the model and trial validation

3.4 Conceptual model

Potential relevant groups with a CF ≥ 0.5% are identified by determining their minimum and maximum contribution. In order to develop the conceptual model, these maximum and minimum values are utilized again. Appendix A10 exactly explains how these minima and maxima were determined. The resulting minimum and maximum values are represented in appendix A11. Distinctions are made whenever indicated this might be useful for the conceptual or quantitative model. Therefore eight scenarios were developed. One distinction is made between vegetables/fruits and cut flowers. Another distinction is whether substrate was used or not. The third distinction was whether a CHP was used or not. In total this gives eight cases. All cases were considered to use the minimum of energy CF when a choice had to be made between geothermal heating or other heating. By constantly deriving unique extreme cases by setting all groups at the minimum and changing separately each group to a maximum, the relative maximum extreme values can be found. By analyzing the different extreme scenarios the conceptual model is developed. The identification of important indicators which determine the minimum and maximum values and the effect of groups on one another will be explained in this paragraph.

First of all, in every case energy plays a significant role, ranging from 19% till 96% of the total CF. Furthermore capital goods 1 almost always plays a significant role, except when the CF of energy is extremely high. Packaging materials are almost always significant in the case of vegetables/fruits. Other pest management is never high enough to be able to be part of the 95% CF (see appendix A11). If other groups play a significant role depends on some underlying factors specified in the hypothesis if these factors are known. The dependent and independent variables can be viewed in Figure 5. The relations between those variables are represented as numbers, sometimes with accompanied letters, each relating to the explained relations in the texts below. These relations and their underlying indicators are discussed in the text below. Also an explanation about how the model should be interpreted will be discussed below Figure 5.

![Figure 5 Conceptual model](image)

The various relations are derived from the minimum-maximum cases and their underlying calculations which are given in appendices A10 and A11. The minimum and maximum cases represent the CF in kg CO₂-equivalent per group per ha. In Figure 5, the research element is centered. A relation is indirect when one independent variable (for example the box “External CO₂ fertilizing” in Figure 5) is in between the research element and another variable. While a relation with only one arrow represents a direct effect. An arrow merges with another arrow to show an nuanced view. This
merging arrow shows that the variable from the added box, will influence the magnitude of the direct effect. In fact, the independent variable fossil energy always applies to such a variegated view. The higher the amount of fossil energy, the smaller other groups will be and therefore they have an higher probability of all other groups not to be part of the groups which form 95% of the total CF. However, for the overview, boxes of all groups needed to show this complete view are left out of this figure. The relations stated below discuss and elaborate on the effects stated in the conceptual model.

Relation 1.
The more fossil energy use, the less other groups play a role and the smaller the role per remaining group will be. All groups are affected.

Relation 2.
The kind of crop (including the plantation density) will have influence on the contribution of fertilizer, materials to guide growth, capital goods 2, substrate, young plant material and packaging to the CF (Scholten, 2011) (appendix A11).
- a. Fruit and vegetables generally need more fertilizer and substrate, than flowers
- b. In addition to relation 2a, when polyurethane is used as substrate it is more likely that substrate will be significant.
- c. In addition to relation 2a, when peat is used instead of substrate it is more likely that fertilizer will be significant and substrate becomes insignificant.
- d. Flowers need more young plant material than fruit/vegetables, because those young plants have a generally higher plantation density.
- e. In addition to d, whether young plant material is produced heated or cold will influence if young plant material is significant or not. Whenever heated, the more likely young plant material is expected to be significant.
- f. Tomatoes, generally need the packages with the highest CF per ha.
- g. Tomatoes or vegetables on lines, generally have a higher value for the group materials to guide growth, than flowers.
- h. The kind of capital goods 2 used depends on the needs of the crop. Water consuming crops are for example more likely to have a water silo. Where energy consuming crops are, for example, more likely to need a heat buffer, CHP and flue gas cleaner.
- i. In addition to h, the larger the scale, the less capital goods 2 will play a role, because of scale advantages.

Relation 3.
The larger the farm, the less capital goods 3 are relatively needed due to scale advantages and therefore capital goods will contribute less.

Relation 4.
Whether or not external CO$_2$ fertilizer is applied, will influence if this group will be significant. In addition to this relation, it is generally assumed, the more energy intensive the farm, the more external CO$_2$ fertilizer is used.

Relation 5.
- a. Consumables could play a role when a lot of flue gases need to be cleaned.
- b. However, this effect will be counteracted if the farm uses a lot of fossil fuels. Once more fossil energy is required it is likely relatively less flue gases need to be cleaned, because of the differences in peaks over the year between heat demand and CO$_2$ demand. This has to do
with the fact that external CO₂ is especially needed in summer, because there is more CO₂ available in winter when fossil fuels are used by the grower to heat and lighten the crops. However, during summer CHP and boilers do generate less heat and light, because of higher temperatures and more light during this season. The effect is there is less CO₂ available in summer from the boiler and CHP than needed. Relatively more fossil fuels and external CO₂ fertilizer contributing to the CF compared to consumables are needed. Therefore even when there is a surplus of CO₂ produced in winter by the grower, the increase in a use of fossil fuels results in a lower average contribution of the CF of consumables.

Relation 6.
Other pest management will never play a role, while energy will always be included into the 95% CF.

The analysis for the conceptual model provides the following insights about important variables for the outcome of the model. The first is that the group energy should always be included and the group other pest management never. Secondly, which other groups will be included into the 95% CF is highly dependent on the values of the magnitude of the group energy and capital goods 1. The other variables play a less significant role, but could still be important for differentiating different outcomes of the model. These lessons learned will be taken into account in the quantitative data analysis.

3.5 Quantitative model
In this paragraph the decision model which can be viewed in Figure 6 is developed. This model produces an outcome (SB) of the groups which must be included in the CF analysis in order to obtain at least 95% of the total CF. In other words: the outcome of the model is presented by setting appropriate technical system boundaries (SB) which consist of the groups (see Table 6 for the legend of the numbered groups) which are mentioned in the diamonds. In these diamonds the value of the CF expressed in CO₂-eq/ha of those summed groups is compared to the value in the diamond which has the same unit.

This model is generally developed by analyzing what the contribution of groups is in different contexts. In addition rules regarding a rank of importance is analyzed per context or in general when needed.

The model serves as the basis for an automated data request. This data request will determine, during the process of data collection, which additional data must be filled in and which data are not required. However, in this thesis the trial validation of the model occurs manually. This is the case since, development of this automated data questionnaire is left out of the scope of this research. In addition a 100% CF needs to be determined, so all data need to be asked, in order to validate whether the model really determined at least 95% of the total CF.
3 Results: Development of the model and trial validation

Figure 6 Quantitative model for the benefit of the determination of system boundaries
3.5.1 Arguments for the step-by-step methodology to develop the model

Since the interviewees are to a large extent inconsistent during the interviews and contradict each other at many points, this data is largely unusable for the analysis. However, it gives some guidelines in which direction to look for and it insinuates that it will be a very difficult task to quantify the model in the right way. Furthermore it reveals that it is likely that a lot of information will remain hidden after this research, because even experts do not know the exact mechanisms about how energy influences the CF in detail.

The distribution between individual cases is extraordinary large. Therefore, when measures which are taken to save energy are known, only estimation within a very large margin can be done (Hellinga & Blonk, 2003). This implies it is better to make a model based on numbers from growers than indicators with an input of practical information from the grower alone, when it comes to energy. Besides, energy information is always needed during the data generation process, so determining the CF of energy per ha seems the most efficient option to make a start for modelling the system boundaries.

Besides energy, capital goods 1 always need to be part of the outcome, since these will always be two groups which contribute, as being large groups, to the 95% CF. Often specific quantitative data is not given in literature or confidential, as in case for the EUPHORUS project (see Appendix A2). However, specific quantitative data is required in order to be able to quantitatively predict what will happen to the values per group when data directly from a grower are available. Thus exception of rules due to the specific context and lack of precise context specific data, make the idea to include groups bit by bit seem the best decision for multiple contexts. The grower delivers indirect data in order to determine the CF for groups which are required as an input of the automated model. Thus, it is inevitable that some of the quantitative data used are based on the data from the pilot project, since these data are currently one of the few quantitative data available for some groups.

3.5.2 Development of the model

First of all several important practical distinctions are made in order to develop main contexts. This is done by using knowledge from the former paragraph, personal communication during the pilot, personal communication during the min-max sheet development and several case studies conducted by Blonk Milieu Advies. A division between energy extensive/intensive farms seems logical due to their high differences in energy use and outcome (confidential case studies BMA and personal communication during the pilot). A greenhouse is energy intensive if the gas equivalent is 25 m$^3$/m$^2$ or more ((SMK), 2012). In CFs from literature a distinction can generally be made between intensive...
and extensive energy use. Based on information provided by KWIN and a CF calculation an assumption is made that the intensive energy CF ranges from \(565 \cdot 10^3\) kg CO\(_2\)-eq/ha (=2.260 kg CO\(_2\)-eq/m\(^3\) *25.0 m\(^3\)/m\(^2\) *10,000 m\(^2\)) to the maximum value for the group energy, which is \(3,781 \cdot 10^3\) (=2.467 kg CO\(_2\)-eq/m\(^3\) *101.1 m\(^3\)/m\(^2\) + 0.447 kg CO\(_2\)-eq/kWh *288 kWh) *10,000 m\(^2\) (P.C.M. Vermeulen, 2010). It is assumed that no CHP in combination with electricity supply from the grid is used in this specific case. Instead a boiler with the input natural gas is assumed.

Furthermore a distinction is made between fruit/vegetables and cut flowers, considering the qualitative model. After this, the order of magnitude or the largeness of chances of values per case should be determined. To make the model fit on one page, abbreviations are used in the quantitative model and the accompanying explanation. The abbreviations can be found in Table 6.

<table>
<thead>
<tr>
<th></th>
<th>Abbreviations of groups by means of numeration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young plant material</td>
</tr>
<tr>
<td>2</td>
<td>Substrate</td>
</tr>
<tr>
<td>3</td>
<td>Synthetic fertilizer</td>
</tr>
<tr>
<td>4</td>
<td>External CO(_2) fertilizer</td>
</tr>
<tr>
<td>5</td>
<td>Other pest management</td>
</tr>
<tr>
<td>6</td>
<td>Fuels, imported heat and electricity</td>
</tr>
<tr>
<td>7</td>
<td>Materials for soil covering (plastic foil etc.)</td>
</tr>
<tr>
<td>8</td>
<td>Materials to guide growth</td>
</tr>
<tr>
<td>9</td>
<td>Packaging materials for the final product</td>
</tr>
<tr>
<td>10</td>
<td>Consumables for maintenance of capital goods</td>
</tr>
<tr>
<td>11</td>
<td>Capital goods 1</td>
</tr>
<tr>
<td>12</td>
<td>Capital goods 2</td>
</tr>
<tr>
<td>13</td>
<td>Capital goods 3</td>
</tr>
</tbody>
</table>

Secondly the prioritization of groups per main context is discussed. The order which can be viewed in Figure 6 is followed from left to right: energy intensive + fruit vegetable, energy intensive + cut flowers, energy extensive + fruit vegetable and energy extensive + cut flowers.

When cultivation is energy intensive, it is generally the case that external CO\(_2\) is applied, and therefore it plays a significant role (Smit, 2010, p.13). From other cases it is known that generally fertilizer, packaging materials and young plant material contribute in this order to CFs of vegetables/fruit of intensive cultivation (confidential case studies BMA). However, from the min-max sheet and the pilot case it is known that packaging materials can contribute more to the CF than fertilizer, therefore those two groups are switched. Because it is assumed that capital goods 3 generally are not at their maximum in this case, since it is assumed that growers are generally large scale in the energy intensive category, groups 2, 10 and 13 follow just after capital goods 2 in the case of fruit vegetables. For the group capital goods 2, scale is less important, because more specialized equipment is generally needed at an energy intensive farm. Group 8 is assumed to have a larger chance to be larger than group 7, because group 8 is larger for the most common crops in the Netherlands. Therefore, those groups are switched in the case of cut flowers.

In addition, for energy intensive cultivation in the case of flowers, the CF of young plant material has a high chance of being large, assuming heated production of the young plant material (appendix A11). Fertilizer is generally lower in the case of flowers (Haas, 2012), therefore packaging material is asked
just before fertilizer. In this category groups 2 and 10 are switched in order with respect to the discussed category focussed on fruit/vegetables, because generally less substrate is consumed in the case of flowers.

When cultivation is energy extensive it is generally not the case that external CO₂ is applied and therefore it is likely to play only a large role if applied (Smit, 2010, p.13). From other cases it is known that generally packaging materials and fertilizer contribute in this order to CFs of vegetables/fruit of extensive cultivation (confidential case studies BMA). In this case capital goods 3 is assumed to be larger than in the intensive category, because in this case it is assumed greenhouses are often smaller, as they have less scale profits, due to the fact they usually use less equipment. Therefore capital goods 3 is placed just before young plant material. After that group 12, 2, 10, 7 and 8 follow. While capital goods 2 is expected to be far lower than in the intensive category, this is also the case for soil covering. Since it is assumed that less consumables are used, because the energy extensive category does not always use extra CO₂, this group is placed right after substrate. In this case group 7 comes before 8, because the common grown vegetables are not present in the case of vegetables/fruits combined with extensive cultivation. Those two groups are switched in the case of extensive cut flower production, because materials to guide growth are always used for cultivation of cut flowers. Packaging materials are assumed to generally have a larger contribution than young plant material, because young plants for this category are mainly not that densely cultivated compared to the other category. Fertilizer is generally lower in the case of flowers, therefore capital goods 3 and young plant material is asked just before fertilizer. After that, 12, 10 and 2 are asked. Because substrate is commonly less used in the case of flowers, because it mainly has a larger life span than in the case of vegetables.

The numbers in the model are constituted by the qualitative characteristics, combined with the average of minimum and maximum (subgroup) value if no additional information about the variety in data or how to quantitatively determine probable values is known. An average value is chosen, because it is highly unlikely that all values which are unknown/ not measured will be maximised or minimised. It is the best there is for now. In cases where additional information is known another approach could be applied. For example in the case of soil covering the maximum value will be used, since it is known this is used at high scale in energy intensive vegetable cultivation, so it is quantitatively measurable (Mohammadkhani & Sonneveld, 2004, p.9). In Figure 6 the quantitative model is shown. The system boundaries (SB) exist of the system boundaries named in the last decision box, unless when indicated differently (system boundaries at the bottom of the figure).

3.5.3 Reflection on the model
The model is an interaction between determining the CF of one or more groups and the determination of system boundaries. This means that before implementation of the model is a fact, a more elaborated data file should be used than presently is the case. This results in more precise CFs, but unfeasible practice due to a decrease in efficiency. Another option is to communicate with the grower after each step of data request in order to analyze if more data is needed. It is imaginable that this will result in several cases of more efficient use (the cases when only one or few groups are needed), but it is expected to result in less efficient data collection and data analysis in other cases. Furthermore it is
expected that the model will result in a more precise CF. This means the unimplemented model will provide only a minor advantage.

When the model is implemented it allows the direct determination of the CF. However, before this implementation will be available, a lot of work has to be done in order to obtain the desired efficiency. Research on user-friendliness is needed to obtain a perfectly filled data sheet with appropriate effort. More research on EFs is needed and the model should be precisely programmed in order to guarantee no bugs in the implemented model. Only if these elements are studied well, implementation can become successful.

3.6 Trial validation of the model

Because there is no implemented model it is difficult to find cases with help of criteria sampling. Implementing the model is beyond the scope of this research, while the interaction method will cost too much time. Therefore a choice has been made to sample cases on the characteristics, energy intensiveness and kind of crop. This was expected to result in four cases in total on which a trial validation of the model can be conducted.

During the research process there is strived to fill in the model and collect the data for the approximately 100% CF for validation in not more than 3 days per location. Because of the reward of a provided free CF, it was assumed that these growers can afford to put a little bit more time in the data collection process compared to the two days which were assumed reasonable in a paid 95% CF analysis. This is convenient because it is expected that the small groups take relatively far more time to collect data about, than the groups which are included in the 95% CF.

Despite all efforts to find growers willing to deliver the data for this trial validation, it did not work out. One grower surprisingly filled in the data questionnaire when no results were expected anymore. However the group fertilizers was not filled in precisely enough, while this is the group on which experience reveals that it can be found easily, because it is a legal liability. In addition to this, many other small groups were missing at first. These facts cause uncertainty around the reliability of the data provided. The data cannot be verified as reliable by the completion of this thesis, due to a limitation of time. This makes that an analysis of those data will not contribute to this research. However, the time consumed to collect this data was approximately 5-6 hours according to the grower. This supports the assumption that data collection is well feasible in two or three days.

If the differences between predictions and measured values are small, but systematic, the quantitative value relating to a variable would probably not be well chosen. In this case these parameters should be determined more accurately, with data from other greenhouse horticultural growers. If differences between the measured values and the predictions of the model are large, the correlations between them are usually not well understood. In this case first qualitative relations would need to be explored more, to gain better insight. Thereafter the quantitative relations should be researched again.

Due to missing trial case data, no results of cases are present. Therefore the result of the pilot case is presented here to illustrate the relevance of the model and the results of this pilot are discussed by comparing this outcome with the model and the usual procedure followed by BMA.
3 Results: Development of the model and trial validation

<table>
<thead>
<tr>
<th>Group</th>
<th>% of total CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Young plant material</td>
<td>0.3</td>
</tr>
<tr>
<td>2. Substrate</td>
<td>0.3</td>
</tr>
<tr>
<td>3. Fertilizer</td>
<td>1.5</td>
</tr>
<tr>
<td>4. External CO₂ fertilizer</td>
<td>4.2</td>
</tr>
<tr>
<td>5. Other pest management</td>
<td>0.0</td>
</tr>
<tr>
<td>6. Energy</td>
<td>8.4</td>
</tr>
<tr>
<td>7. Materials for soil covering (plastic foil etc.)</td>
<td>0.4</td>
</tr>
<tr>
<td>8. Materials to guide growth</td>
<td>0.3</td>
</tr>
<tr>
<td>9. Packaging materials for the final product</td>
<td>3.9</td>
</tr>
<tr>
<td>10. Consumables for maintenance of capital goods</td>
<td>0.1</td>
</tr>
<tr>
<td>11. Capital goods 1</td>
<td>3.7</td>
</tr>
<tr>
<td>12. Capital goods 2</td>
<td>0.7</td>
</tr>
<tr>
<td>13. Capital goods 3</td>
<td>0.4</td>
</tr>
<tr>
<td>Total CF</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 7 Relative results of the pilot case

Usually groups 1, 2, 3, 4, 6 and 9 are taken into account. In addition seeds and pesticides are normally included. These groups add up to 94% of the total CF in this pilot. However, in the optimal case groups 4, 6, 9 and 11 are taken into account, which contribute 95% of the total CF. If the model would be used, exactly these groups would have been taken into account. These results partly support the assumption that a CF can be made more precise and efficient, compared to the method which is used by BMA. These results cannot support the assumption completely, because it is partly a matter of circular reasoning. This reasoning manifest itself by the application of several values of the pilot project in order to create the model.

In appendix A9 the results of the pilot can be viewed schematically. It includes results founded on the draft that was used initially, as well as the final determination of the 100% CF. Furthermore the confidential file with absolute numbers can be found here, for people which have permission to view it.

3.7 Sensitivity analysis

A sensitivity analysis is conducted on capital goods 1, because this is the main group for which the underlying calculations are transparent and for which there is reason to think a large deviation could be found. All subgroups for which a specific rate of recycling is stated in Ecoinvent will be included. This means the EFs for aluminum and copper will be calculated again for the case of 100% virgin material and 100% recycled material, while plastics are left out of scope. Researching underlying mechanisms from all imaginable other EFs is beyond the scope of this research. It is assumed all sources which are used to determine the EFs in this research has considered these underlying mechanisms carefully. With those EFs new minimum and maximum values for the group capital goods 1 are calculated on the basis of a new determination of the contribution of glass to be able to change the value of the determined indicator.

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The new EFs for aluminum are 4.75 kg CO₂-eq/kg and 15.7 kg CO₂-eq/kg. The new values for copper are 3.63 kg CO₂-eq/kg and 3.69 kg CO₂-eq/kg. When Table 8 and Table 9 are compared to Table 4 Contribution of glass in covering to capital goods 1, it can be viewed that in case of 100% recycling the group capital goods will increase with 40.8%. In case of 100% virgin material the group capital goods will decrease with 3.0%. This means the group is not that sensitive that it is able to influence the structure of the model. Therefore it can still be concluded capital goods 1 always plays a role in the CF of a horticultural product.

<table>
<thead>
<tr>
<th></th>
<th>Strawberry</th>
<th>Tomato</th>
<th>Rose</th>
<th>Soil cultivation</th>
<th>Flowers in gutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>% glass in covering of total capital goods 1 for standardized 4 ha location</td>
<td>9.3%</td>
<td>10.8%</td>
<td>8.2%</td>
<td>12.5%</td>
<td>11.1%</td>
</tr>
<tr>
<td>% glass in covering of total for capital goods 1 individual non standardized location</td>
<td>8.8%</td>
<td>11.0%</td>
<td>7.4%</td>
<td>12.6%</td>
<td>10.8%</td>
</tr>
</tbody>
</table>

Table 8 Contribution of glass to the CF of capital goods 1 for 100% recycled scenario

<table>
<thead>
<tr>
<th></th>
<th>Strawberry</th>
<th>Tomato</th>
<th>Rose</th>
<th>Soil cultivation</th>
<th>Flowers in gutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>% glass in covering of total capital goods 1 for standardized 4 ha location</td>
<td>6.9%</td>
<td>7.5%</td>
<td>5.6%</td>
<td>8.4%</td>
<td>7.7%</td>
</tr>
<tr>
<td>% glass in covering of total for capital goods 1 individual non standardized location</td>
<td>6.4%</td>
<td>7.6%</td>
<td>5.1%</td>
<td>8.4%</td>
<td>7.5%</td>
</tr>
</tbody>
</table>

Table 9 Contribution of glass to the CF of capital goods 1 for 100% virgin scenario

8 (0.00%*12.376)+(100%*1.3785)+3.369 = 4.75 and (100%*12.376)+(0.00%*1.3785)+3.369 = 15.7 (EAA, 2004; Ecoinvent, 2007, aluminium, primary, at plant +aluminium, secondary, from old scrap, at plant+aluminium product manufacturing, average metal working))

9 1.8352*(1.8545*0.00%)+(1.7939*100%)= 3.63 and 1.8352*(1.8545*100%)+(1.7939*0.00%)= 3.69 (Ecoinvent, 2007)copper product manufacturing, average metal workings+copper, primary, at refinery+copper, secondary, at refinery; Nedcoat, 2011)
4. Discussion, conclusions and recommendations

4.1 Discussion

A general rule of thumb which result from this thesis is that the groups energy and capital goods 1 always contribute to the 95% CF. Compared to usual practice, seeds and pesticides can always be left out of scope since they always contribute less than 0.5% of a CF. Furthermore other pest management will never be part of the 95% CF, because this group is always insignificant. An indication of the contribution of other groups can be made for most common cases. From the experience of BMA and literature, it is known CFs are mainly conducted on energy intensive products. Next to capital goods 1 and energy, external CO₂ fertilizer should always be included. After this, the groups young plant material, fertilizer and packaging material can be included in the system boundaries. Subsequently it is expected that the following order of inclusion will be needed: capital goods 2, consumables for maintenance of capital goods, substrate and capital goods 3 shall be included. Thereafter in the case of vegetables/fruit the group soil covering should be prioritized before materials to guide growth, while in the case of flowers it will be vice versa. However, this estimation is subjective and not well defined, because many horticultural products were never researched before. Nevertheless, these indications can help researchers which need to conduct CFs of horticultural greenhouse products in future. It is best to know many inclusions of groups depend on the fact if it is used or not and therefore it will always be worth to consider the production process of the company at first.

It is not expected that implementation of the model, which is expected to result in more efficiency and more preciseness, will become reality in near future. The reason for this is a lack of interest to invest in implementation of the model, because only few growers can permit themselves a paid CF of their product and because of the current savings of the government on the Commodity board of horticulture it is expected that no subsidies for this research will be found. Growers are facing hard times due to the financial problems in the horticultural sector and many growers are not interested in the CF of their products (see appendix A2). Furthermore, at this moment it seems unfeasible to validate the model, due to a lack of willingness to put in effort, a lack of time or a lack of data from greenhouse horticultural growers. To summarize, it will cost a lot of money and time to implement the model, which presumably will not counterbalance the benefits.

The relatively large difference between Table 3 and the calculated contribution of capital goods in the min-max analysis can be explained by the fact that not every CF has the same scope and that the values of literature research only were included for calculation. This literature research is limited compared to the min-max cases, which enclose more cases than could be found in literature.

The uncertainty in extreme cases of capital goods 1 is still quite large, but for now the best available indicator. Another disadvantage is that the indicator implies that when using less glass, the CF will get lower, however this could have effects on the magnitude of the CF of other groups. Therefore, premature decisions should not be made on the basis of the CF value of the group capital goods 1 alone.

The accuracy of data remains a limitation of this research. Because only average data could be found in literature and the sample size of data collection by personal communication was small, it is very uncertain how accurate the data is used in the min-max cases. Therefore, it can only be estimated at this moment how well the model works and whether all relevant context is really included in the
Discussion, conclusions and recommendations

model. However, this is always a limitation in CFs on horticultural products (experience of BMA). At least some new insight has been gained on the contribution of several groups to the total CF during this research, however it is not (known to be) perfect yet.

4.2 Conclusions

It can be concluded that it is possible to develop a model which defines appropriate system boundaries in a CF analysis for the greenhouse horticultural products cut flowers, fruit and vegetables, cultivated in the Netherlands. However, at this moment this model cannot be validated. It is only possible to validate this model if growers are interested and permit themselves to do a CF or if subsidies make it profitable to implement the research.

The present model will generally only provide a minor advantage. Efficiency is lowered in several cases, only for energy intensive cases a higher efficiency is expected. However, preciseness of the CF is expected to generally increase. On the other hand, the model is not validated and therefore cannot be used in practice. Even a trial validation could not be conducted and therefore it is simply unknown if the model predicts well.

The large disadvantage of the model is, when incorrect data are filled in, the model may fail in some cases. In this case failing means that the model generates incorrect system boundaries which can cause the model to generate too broad or too narrow system boundaries. If this is the case, the data collection process needs to be performed again. In the worst case the grower has filled in a lot of unnecessary data and therefore lost time and effort for which he gets nothing in return. In some of these cases it might turn out that the old way of collecting data is more efficient in the end. When data are filled in incorrectly in the old system, only one group needs to be improved.

The groups included in the 95% CFs were feasible for data collection in the pilot and/or literature cases. However, this does not necessarily mean that data collection of those groups is feasible in all cases. An interactive process needs to be used for the model in order to determine which groups will be part of the system boundaries, because quantitative data are not fully accessible at this moment.

The groups recently included in an approximately 100% CF, differ from the ones which are important. Figure 7 shows the overview of the current (usual) situation, the appropriate exclusion (approximately 100% CF of this research) and the model (95% of the CF). The bold lines include all groups which are usually included in the system boundaries of a CF analysis. The yellow, green and light red boxes form the 100% determined CF in this research. Notice that the dark red box is considered of insignificant value for the 100% CF, although these groups were usually included in common practice. The light red box represents the group which always needs to be excluded from the system boundaries. The model is calculating the system boundaries required to calculate a 95% CF by using the data collection of several groups mentioned in the green and yellow boxes. The green boxes represent the groups which always need to be included in the system boundaries. The yellow boxes represent the groups for which inclusion in the system boundaries is dependent on the specific context.
The largest difference between usual practice and reality is that seeds and pesticides are considered to be significant, but are insignificant in reality. In addition capital goods always have a significant contribution to the CF of horticultural products produced in the Netherlands. Therefore it can be concluded that it would be wise to implement these two rules of thumb in practice, because it is feasible to collect these data and it will result in more efficient and precise CFs. For the yellow groups, more research is needed in order to create a working model, because they are very context specific.

The choice for a specific mix of process systems can indeed have a significant influence on the measured CF of the product and the contribution of capital goods 2 and capital goods 3 in the CF.

Furthermore more insight is gained in the thought of Vermeulen that till now it was not clear how much urea could contributed to the CF. This research shows it is a subgroup which can contribute more than 1% in some cases and might even add up to almost 5.5% of the total CF, which implicates urea is required to include in the majority of the CF analysis according to the new PAS and in some cases also in the current PAS.

It is conspicuous that this research reveals it is feasible to make a fair comparison between two products which have different system boundaries. This is the case because each outcome will differ at most 5.3%. This fact in combination with a potential win in efficiency and accuracy can argue in favor of an adjustment of the current LCA methodology. This adjustment implies to determine system boundaries on the basis of which groups are relevant to include per selected impact category instead of equating the selection of groups for all selected impact categories. Clarity of system boundaries may decline. If this is the case will depend on the application of this new LCA methodology. The large benefit of applying this new LCA methodology with regard to the current LCA methodology, will be an improvement in accuracy and efficiency in LCA research.

### 4.3 Recommendations

As already stated in paragraph 2.1, climate change is only one of the many environmental impacts that a product has. Furthermore, the relevance of different impacts can vary between products. Different impacts can be in conflict when decisions about adjustments of products are made. LCA is used to make an informed decision regarding environmental impacts. Therefore it is useful to perform the same kind of research on the other impact categories that can be part of an LCA. In this way, growers can make a better informed decision about the adjustment of the product. In addition, people can become more aware of the fact that other environmental impacts can have an equally relevant or even larger effect on the environment besides climate change.
As already stated in paragraph 1.3, contexts and LCA methodology can change in the future by innovations or new knowledge. Therefore it is possible that the way activities are currently left in or out scope, will no longer be valid in the future. In that case, new rules of thumb need to be given. Therefore, repeating this research after occurrence of new innovations or environmental changes, and conducting it more extensively, is necessary to remain up-to-date.

One group of factors can play a large role in the CF, while playing a negligible role in another environmental category and vice versa. This study has shown that it is more efficient to set system boundaries considering the characteristics of the product and production decisions or circumstances. Therefore, an LCA could be more efficiently conducted by setting system boundaries per LCA category oriented to the product, instead of setting the same system boundaries for all categories for one product. In this way LCAs could become more precise, less laborious and less time consuming. This will require more research on other categories within the LCA for horticultural products.

Because human mistakes could appear in using the model, it would be wise to research if and how this can be prevented. The system could be researched on how user-friendly the implemented model will be and how it can be improved. For example, many growers stated that a lot of data which is required for the CF analysis was not available. It might be helpful to include clues in the data collection sheets about where to find information on data which is not likely to be easily found. In this way, CF analysis can be made more efficient and data collection can be made easier for the grower.

The model has not provided insight in several underlying mechanisms. For example it is not understood how energy demand and the specific mix of sources which are used by the grower to provide this energy can be estimated accurately in a quantitative manner. It is recommended to explore the mechanisms behind energy and capital goods. In this way more elucidation and more precision in the CF analysis can be obtained in future. This could help the growers and their advisors to take better founded and more effective decisions to lower these ‘hot-spots’.

As discussed, it can be viewed in the EcoInvent database that maintenance can fluctuate tremendously between different capital goods. In general, CF percentages of maintenance fluctuate from 1.3% to 77.1% of the CF of the capital good itself. Because of these large differences and the knowledge gap on the contribution of maintenance to CFs, more research on CFs of maintenance is recommended. Another group that requires more extensive research on its contribution, is packaging material of different input products.

As discussed in paragraph 3.2, the indicator for capital goods 1 can lead to a significant maximum miscalculation in the total CF. There is a need to be conscious of this error for the extreme cases in which this miscalculation might exist. Because it is a rather large uncertainty, more research is recommended to find out how precisely this indicator really estimates and to explore the chances to improve this indicator.

An average value is often chosen for inclusion in the model, because it is highly unlikely that all values which are unknown/not measured will be maximal or minimal. For now, this was the best available option. It is thus recommended to conduct research to collect more data on consumption behaviour on farms to unravel quantitative correlations.

The implications from the model could be used for practice in the following way, until implantation is reality: always include the groups energy and capital goods 1, thereafter groups can be included in the prioritising order as has been stated in the model. Whenever data of a group is not available, the value can be estimated. If this is not possible, the analysis should exclude the group. The analysis should
revise the groups in prioritising order and include each group only if enough resources are available and the requirements of the research fit this approach. However, this should be done with marginal notes and an explication of the known values of the groups which have been excluded from the system boundaries. Therefore it can be concluded that it is not favourable to stick to the new PAS, which prescribes inclusion of all groups which contribute 1% or more to the total, at any cost.
Acknowledgements

During the realization of this thesis I have been accompanied and supported by many people. It is a pleasure to thank those who made this thesis possible.

First I offer my sincerest gratitude to my first supervisor from TU/e, Ir. A.F. Kirkels, who has supported me throughout my thesis with his knowledge, patience and advice whilst providing me some useful insights. I attribute the level of my Master’s degree to his criticism.

I am grateful to Ir. Hans Blonk for giving me the opportunity to conduct this research as an internship at his company Blonk Milieu Advies. I would like to show my gratitude to my supervisor Ir. J. Scholten from the company Blonk Milieu Advies for sharing his knowledge and expertise in the field of CF. I would like to thank him for the advice and insight throughout my work and also for his helpful comments on the first draft of this paper. I would like to thank all colleagues from Blonk Milieu Advies for sharing their expertise, contacts and letting me make use of all knowledge and software available in the company.

I also like to thank my second supervisor from TU/e, Dr.ir. G.P.J. Verbong, for his effort to read and criticize this thesis.

I would like to thank Tom Ouwerling for his effort to help me find growers to conduct the trial validation.

Many thanks also to Bente Aalbers and Joep de Groot for reading my report and giving me valuable criticism.

Special thanks to Peter Vermeulen and Jaap Vreugdenhil, who participated in interviews for this thesis. I am grateful for the literature Peter Vermeulen provided me with and for the effort to read through the transcript of the interview.

I am very grateful for the cooperation, time and interest of all people I met on Hortifair and all personal communication by phone for the min-max datasheet collection.

And finally, thanks to the growers who I will not name, because of confidential reasons. Thank you for executing the pilot project on your company. The value of your contributions to this thesis far exceeds the compensation. In addition, I would like to thank another grower for his effort to provide data for the test case.
References


A1. Interview questions

Inleiding tot het interview

 Dit interview neem ik af voor mijn afstudeerproject aan de TU/e en het bedrijf Blonk Milieu Advies. Het doel van het interview is om informatie te krijgen over welke groepen en contexten belangrijk en onbelangrijk zijn voor het bepalen van een efficiënte Carbon Footprint voor glastuinbouwproducten in Europa, die inzicht zal geven in minstens 95% van een bij benadering totale CF. Om precies te weten waar we over praten, zal ik eerst de scope definitie die ik heb bepaald specificeren, om een bij benadering 100% CF, te berekenen.

Alle producten en processen die zich binnen de systeemgrenzen afspelen worden gepresenteerd in het stroomschema. De volgende scope is bepaald:

De CF van de glastuinbouw producten uit kassen in Europa is gedefinieerd voor groenten en fruit als CO₂-equivalent per kg van het product, inclusief verpakkingsmateriaal en voor snijbloemen als CO₂-equivalent per 10 stelen, verpakkingsmateriaal inbegrepen. De levenscyclus van glastuinbouw producten is gedefinieerd van de wieg tot poort, waar poort wordt gedefinieerd als het moment waarop tuinbouwproducten klaar zijn om het glastuinbouwbedrijf te verlaten. De gebruiksfase en de afvalfase van het tuinbouwproduct worden dus niet meegenomen. Echter, de uitstoot van broeikasgassen die door de plant opgenomen worden, zijn verondersteld te worden uitgestoten tijdens het gebruik of afvalverwerking en leveren dus geen reductie van de CF op.

Primaire data zullen zoveel mogelijk worden verzameld. Gemiddelde emissiefactoren zullen worden gebruikt, indien mogelijk, om de CF van de grondstoffen te bepalen. Als dit niet mogelijk is zal een pragmatische aanpak worden toegepast. Gemiddelden per land zullen worden gebruikt wanneer de elektriciteit wordt gebruikt van het net.

Emissies van de afvalfase van alle gebruikte materialen tijdens de productie en grondstoffen die gebruikt worden zullen worden genomen in de analyse. Massa percentages van het afval dat wordt gerecycled zullen worden gebruikt wanneer naar grondstoffen wordt gekeken, in plaats van de massa percentages van gerecycled materiaal die wordt gebruikt tijdens de productiefase.

Verdeling is gekozen om om te gaan met allocatie problemen. Deze verdeling tussen co-producten zal worden bepaald m.b.v. de verhouding van economische waarde tussen de producten en de verhouding tussen de geproduceerde producten. Wanneer deze gegevens niet kunnen worden verkregen of berekend door gebruik te maken van de fysische kenmerken van een proces, zal er gebruik worden gemaakt van een 0,5 kg CO₂-eq/kgCO₂ conform PAS 2050-1.

Verder heb ik een lijst meegebracht van groepen. Dit is een opsomming van alle groepen en hierna uitgesplitst in alle mogelijke producten op een glastuinbouwbedrijf die deel uit kunnen maken van de bij benadering 100% CF.

Ik geef deze lijst aan u zodra we beginnen met het interview, zodat u het kunt gebruiken als een geheugensteun tijdens het interview. Ik zal u een aantal vragen stellen over de context en de mix van producten en processen voor de glastuinbouw in Europa. Na dit zal ik wat diepere vragen stellen aan de hand van uw antwoorden. Ik zal afsluiten met enkele praktische vragen.

Ik heb gezocht naar mensen met een achtergrond in de carbon footprint en glastuinbouw of carbon footprint-en LCA-methodiek, dus heb ik u geselecteerd voor het interview. Om mijn onderzoek af te ronden in de periode van 5 maanden, heb ik gekozen het interview in deze periode af te nemen, zodat
ik basiskennis heb over de onderwerpen, maar er wel genoeg tijd over is om alle resultaten te analyseren en het tweede deel van de onderzoek uit te voeren. Dit tweede deel zal bestaan uit de ontwikkeling van een model gebaseerd op de interviews en literatuur analyse. Ik test dit model door de bij benadering 100% carbon footprint te bepalen en de carbon footprint na toepassing van het model van het liefst negen verschillende bedrijven en zal deze resultaten interpreteren. De analyse van het interview zal worden opgenomen in het afstudeerverslag dat openbaar is. Alle transcripten van interviews worden opgenomen in de bijlagen van het verslag, die niet openbaar zijn, maar wel zullen worden bekeken door mijn begeleiders. Ik heb een lijst van vragen die ik u zal stellen. U hoeft niet meer te doen dan het geven van een nauwkeurig en volledig antwoord op de vragen. Als u het niet erg vindt, zal ik het interview opnemen om zeker te weten dat er geen verbale bijdrage van het interview verloren zal gaan en om tijd te besparen. Niemand, behalve ik, zal luisteren naar de tape. Ik zal de tape zo snel mogelijk wissen. Als het transcript van het interview klaar is, zal ik het naar u mailen. Als u wilt kunt u hier commentaar op leveren. Wanneer het onderzoek klaar is, verwacht eind februari, zal ik het verslag opstellen. Ik denk dat het interview ongeveer twee uur in beslag zal nemen. Dit is wat ik u wilde vertellen. Is het allemaal duidelijk? Is dit een afspraak?

Hierbij geef ik u de lijst met groepen <geef de lijst met groepen> en we zullen beginnen met de eerste vraag.

### Interview vragen

Het gaat bij de eerste twee vragen om systeemgrenzen die leiden tot ten minste 95% van de bij benadering totale carbon footprint volgens mijn scope van een glastuinbouw product, geproduceerd in Europa.

1. Wij denken zelf dat de factoren systemen, processen, klimaat en mogelijk ook andere factoren van invloed kunnen zijn bij het stellen van passende systeemgrenzen. Welke factoren zijn volgens u belangrijk om passende systeemgrenzen te bepalen?

2. Welke aanzienlijk verschillende scenario's, in relatie tot het bepalen van geschikte systeemgrenzen, kunt u onderscheiden? Het is de bedoeling dat u de scenario's creëert aan de hand van het maken van karakteristieke mixen van de factoren die u belangrijk achten. Een scenario ziet er als volgt uit:

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<tr>
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</tr>
<tr>
<td>0-Z aantal gespecificeerde eigenschappen van factor c</td>
</tr>
<tr>
<td>Etc.</td>
</tr>
</tbody>
</table>

In de volgende vragen zal er dieper worden ingegaan op de geformuleerde scenario's in vraag 2. Elk scenario is een specifieke mix van eigenschappen van de door u geïdentificeerde factoren.

3. Welk percentage van de bij benadering totale CF van een totaal cradle-to-gate CF van het product kan worden toegeschreven aan groep x?

4. A. Zou het antwoord op de eerste vraag variëren wanneer ieder scenario dat is genoemd in vraag 2 apart beschouwen?
   B Zo ja, wat zouden de percentages voor de verschillende gevallen zijn?
   C Zo nee, waarom niet?
Herhaal de vragen 3 en 4 tot alle groepen, niet beantwoord door literatuuronderzoek tot nu toe, zijn behandeld.

Voor alle groepen toegeschreven een percentage van 5% of lager, worden de volgende drie vragen gesteld: <Vraag 5-7 zal herhaald worden per groep, die wordt aangegeven door literatuur of door de geïnterviewde als toekennen van 5% of minder van de totale CF>

5. Hoeveel financiële kosten zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de financiële kosten, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel financiële kosten (VGFC)
   □ Veel financiële kosten (GFC)
   □ Redelijk veel financiële kosten (QFC)
   □ Vergelijkbare financiële kosten (SFC)
   □ Redelijk weinig financiële kosten (RLFC)
   □ Weinig financiële kosten (LFC)
   □ Zeer weinig financiële kosten (VLFC)
   □ Geen antwoord (NA)
   □ Geen mening (NO)

6. Hoeveel tijd zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de tijd, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel tijd (VMT)
   □ Veel tijd (MT)
   □ Redelijke veel tijd (RT)
   □ Vergelijkbare tijd (ST)
   □ Redelijk weinig tijd (RLT)
   □ Weinig tijd (LT)
   □ Zeer weinig tijd (VLT)
   □ Geen antwoord (NA)
   □ Geen mening (NO)

7. Hoeveel moeite (=complexiteit, onzekerheid en frustratie) zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de moeite, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel moeite (VME)
   □ Veel moeite (ME)
   □ Redelijk veel moeite (RME)
   □ Vergelijkbare moeite (SE)
   □ Redelijk weinig moeite (RLE)
   □ Weinig moeite (LE)
   □ Zeer weinig moeite (VLE)
   □ Geen antwoord (NA)
   □ Geen mening (NO)

Kent u iemand anders die ik zeker zou moeten interviewen voor dit onderzoek?
Kent u kapitaalgoederenleveranciers of glastuinbouw bedrijven in Nederland, Spanje of Italië, die groenten, fruit of snijbloemen telen die mogelijk data willen leveren voor het tweede deel van mijn onderzoek in ruil voor een berekening van hun CF? Zo ja, kunt u mij hun contactgegevens geven?

Heeft u literatuur met betrekking tot deze studie, die zou kunnen helpen voor dit onderzoek?
Groups different CO₂-eq contributions

In all groups production, use, disposal and transportation are included according to scope!

1. Seeds
2. Young plants
3. Substrate production and transport (glass wool, rock wool, potting soil, coco, peat etc.)
4. Synthetic fertilizer (synthetic and mineral, such as nitrate, urea or sulphate based, P2O5, K2O or lime)
5. Organic fertilizer (such as manure, compost, mulch, co-products from industry)
6. External CO₂ fertilizer (from fossil origin or biogenic fuels)
7. Pesticides (herbicides, insecticides, fungicides, biocides, soil fumigants)
8. Other pest management (nets, fences etc. and biological control such as plants and insects)
9. Fuels (Gas, diesel, kerosene, propane, fuels from biogenic origin, other)
10. Imported heat
11. Imported electricity (use for acquiring geothermal energy, other electricity use such as lighting, pumping etc.)
12. Packaging materials for raw material input (foils, containers, pots)
13. Materials for soil covering (plastic foil etc.)
14. Materials to guide growth (wires (steel, nylon), nails, tape, posts etc.)
15. Packaging materials for the final product (labels included)
16. Consumables for maintenance of capital goods (non fuel oil, cleaning products, cooling agents, urea)
17. Capital goods 1) Production of the Greenhouse and all equipment inside and attached to the greenhouse (Greenhouses (incl. foundation, pavement, flooring and piling), plastic tunnels, cultivation grooves, CO₂ installation, drainpipes, condense pipes, drip pipes, heat transport tubes, roof sprinklers, sprinkle installation (inside), cover wash installation)
18. Capital goods 2) Production of machines, transport means on the farm and other energy using equipment (heat pump, pumps, aquifer, CHP, boiler, geothermal installation, aggregate, solar panels and suchlike, silo’s (as heat- or liquid CO₂ storage), climate computer, flue gas purifier, drip-unit where water and fertilizer are mixed, gas and electricity pipes, water tanks (including dirty water tank, filter and clean water tank), water basin, lights, blinds installation, cover washing machine, sorting installation, packaging line, seal installation, stacking machine, cooling installations, tiny means of transport)
19. Capital goods 3) Production of buildings, roads and other pavements and floor covering (boiler house, CHP house, geothermal house, cold store, fertilizer-water mixing room, process accommodation, office, canteen, changing room, loading and unloading space (dock shelter) road to the greenhouse, climate control room, pavements aside the greenhouse, floor covering of the buildings).
20. Maintenance of all capital goods (Includes maintenance for all 3 capital goods groups: new parts, third party maintenance, inspections and such like.)
A2. Interview transcripts

Naam van de geïnterviewde: Peter Vermeulen

Datum en tijd: 13 oktober 2011, 9.10-12.10 uur
Plaats: Violierenweg 1, Bleiswijk

Interview vragen

Het gaat bij de eerste twee vragen om systeemgrenzen die leiden tot ten minste 95% van de bij benadering totale carbon footprint volgens mijn scope van een glastuinbouw product, geproduceerd in Europa.

1. Wij denken zelf dat de factoren systemen, processen, klimaat en mogelijk ook andere factoren van invloed kunnen zijn bij het stellen van passende systeemgrenzen. Welke factoren zijn volgens u belangrijk om passende systeemgrenzen te bepalen?

Poeh, van wat we in de glastuinbouw tegenkomen is energie heel belangrijk. Voor de meeste glastuinbouw is dit 50-60% van de CO₂ emissie. Het aankopen van CO₂ en hoe we daarmee omgaan is ook een belangrijk verhaal. Wat daarna komt zijn de meststoffen. Als je naar het systeem in het productiebedrijf kijkt is de aankoop van plantmateriaal belangrijk, die hebben we altijd op 10% gesteld van wat er in de productiefase plaatsvindt. Dat ligt er een beetje aan of je een meerjarig of eenjarig gewas hebt. Een roos heeft bijvoorbeeld 5 jarige teelt, dan is het plantmateriaal anders dan bijvoorbeeld bij een tomaat of komkommer.

Dus een belangrijke factor is met een hoeveeljarig product er wordt gewerkt?

Ja, in de glastuinbouw heb je ruwweg de meerjarige teelten (rozen, gerbera, anjer, Alstroemeria etc.), korte teelten, deze vinden enkele keren per jaar plaats, zoals chrysant, sla, bladgroente, radijs en een jaar rond zoals tomaat.

De tijdsspanne van teelt lijkt me een goed voorbeeld van een antwoord op deze vraag, maar wat ik eigenlijk bedoel met de vraag is of bepaalde factoren van invloed kunnen zijn op wat je mee zal nemen in een CF als systeemgrens. U noemde bijvoorbeeld energie, meststoffen en CO₂. Maar is het dan bijvoorbeeld ook zo in de energie?

In de energie heb je het ingewikkelde verhaal van WKK. Tien jaar geleden stond er een ketel in de kas om warmte en CO₂ te produceren, een dagwarmte buffer werd gebruikt. Sinds begin 2000 kon je stroom gaan verkopen, dus kon er gebruik worden gemaakt van een WKK. Hierdoor kwamen allocatieproblemen aan het licht, doordat er ook elektriciteit werd geproduceerd en aan het net werd terug geleverd.

Maar is het gebruik van een WKK van invloed op wat je meeneemt in de CF, het klinkt meer als een allocatieprobleem?

Nee, je moet in ieder geval de teruglevering van stroom meenemen.

Ja, dat hoort ook in mijn scope. Maar is het enerzijds in de CF betaalbaar en enerzijds een allocatieprobleem?

De productie van energie neem je altijd mee ja, ook al vindt deze buiten het productiebedrijf glastuinbouw plaats.
Maar is het dan alsnog een factor om een passende systeemgrens te bepalen?

Je kan discussiëren of je de WKK als aparte unit ziet die energie aanlevert.

Waarom denkt u dat dit invloed gaat hebben uiteindelijk op wat je wel of niet mee gaat nemen in de CF?

Nee, ik denk dat je de WKK altijd mee moet nemen net zoals in jouw scope, dus dan is de WKK (het hebben ervan of niet) geen factor die van invloed is om te bepalen wat er binnen de 95% zal gaan vallen.

En het aankopen van CO₂ is dat een factor die systeemgrenzen gaat veranderen?

Nee, dit zie ik vergelijkbaar met het aankopen van aardgas. Er worden gewoon producten ingekocht.

En meststoffen?

Nee, dat zijn vergelijkbare dingen. Het wordt alleen wat anders als je een bedrijf hebt wat gaat werken met een biovergister, samen met een veehouder en een akkerbouwer. Dan wordt het een heel complex geheel en weet ik ook niet waar je systeemgrenzen moet gaan leggen.

Maar dat zie ik meer als allocatie. Voor systeemgrenzen kijk ik meer naar welke processen en systemen je meeneemt bij de berekening van je CF. Als een product of proces onderdeel is van twee bedrijven dan zien we dat wel hoe we de broeikasemissies dan weer gaan verdelen over die bedrijven. U zei net al dat met een hoeveel jarig product je te maken hebt van invloed kan zijn, maar ziet u nog andere factoren en denkt u ook dat de systemen waarmee je werkt, de processen en het klimaat van invloed kunnen zijn op het bepalen van systeemgrenzen?

Nee, op de getallen wel, maar de systeemgrenzen niet.

Het gaat er om systeemgrenzen zo te bepalen dat je minimaal 95% van de CF te pakken hebt. Dus je splits 5% of minder af en zou die overige 5% of minder verschillen naarmate je bepaalde factoren in overweging meeneemt?

Ja, ok. In Nederland is energie heel belangrijk, in Spanje is misschien de watergift heel belangrijk, in andere landen zal misschien de bemesting veel belangrijker zijn. Mest op een zandgrond zal anders zijn. De belangrijkste factor in andere Europese landen die verschilt nadrukkelijk van Nederland.

Waar ligt dat aan?

Het klimaat is anders en de bodemvruchtbaarheid als je in de grond teelt.

2. Welke aanzienlijk verschillende scenario’s, in relatie tot het bepalen van geschikte systeemgrenzen, kunt u onderscheiden? Het is de bedoeling dat u de scenario’s creëert aan de hand van het maken van karakteristieke mixen van de factoren die u belangrijk acht.

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<td>Etc.</td>
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</table>
Ik zit bijvoorbeeld te denken aan een roos die in januari geproduceerd is en een andere footprint heeft dan een die geproduceerd is in juni, maar dan kom je aan een toerekeningprobleem. Bij een chrysant is dat anders, die is na 10-14 weken klaar. Bij een roos heb je 5 maanden nodig om deze productief te maken en moet je warm houden in de winter, hoe ga je dat dan toerekenen aan die vijf jaar en dergelijke.

In mijn scope gaan we uit van gemiddelden over een jaar, dus dan is de seizoensfactor uitgesloten. Tenzij je een bepaald product bijvoorbeeld enkel in juni produceert en de rest van het jaar een ander product. Zou dit dan als nog een factor zijn waardoor de percentages die worden toegeschreven aan groepen kunnen verschillen?

Ja, het seizoen is zeker iets wat de systeemgrenzen kan beïnvloeden. Een tomaat in de zomer geproduceerd heeft nog geen derde deel van de energie nodig als een tomaat in januari geproduceerd nodig heeft, zelfs met toerekening wordt dat niet geheel vereffend.

Factor: Seizoenen
Eigenschappen: Winter: Oktober tot maart Zomer: April tot september

Factor: teeltplan
Eigenschappen: Minder dan een jaar De jaar rond teelt Meerjarige teelt

Landenfactoren zijn denk ik wel wezenlijk. Bij mediterrane landen is energie bijna onbelangrijk en dan gaat gewasbestrijding bijvoorbeeld wel meespelen en bijvoorbeeld transport, maar dat neem jij niet mee hè?

Nee, maar wel het transport dat nodig is voor de input van goederen We zijn ons er wel van bewust dat het transport als het product de poort verlaat ook substantieel is, maar die laten we toch buiten beschouwing.

Ok, maar ik denk dat het transport van inputs geen wezenlijke bijdrage levert aan de CF.

Factor: geografie
Eigenschappen: Noord Europa (boven Bretagne) Mediterraan (onder Bretagne)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Eigenschap factor seizoen</th>
<th>Eigenschap factor teeltplan</th>
<th>Eigenschap factor geografie</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Winter</td>
<td>Minder dan een jaar</td>
<td>Mediterraan</td>
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<td>2</td>
<td>Winter</td>
<td>Een jaar rond</td>
<td>Mediterraan</td>
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<tr>
<td>3</td>
<td>Winter</td>
<td>Meerjarig</td>
<td>Mediterraan</td>
</tr>
<tr>
<td>4</td>
<td>Zomer</td>
<td>Minder dan een jaar</td>
<td>Mediterraan</td>
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<td>5</td>
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<td>Een jaar rond</td>
<td>Mediterraan</td>
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<tr>
<td>6</td>
<td>Zomer</td>
<td>Meerjarig</td>
<td>Mediterraan</td>
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<tr>
<td>7</td>
<td>Winter</td>
<td>Minder dan een jaar</td>
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<td>8</td>
<td>Winter</td>
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<tr>
<td>9</td>
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<td>10</td>
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<td>Minder dan een jaar</td>
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<tr>
<td>12</td>
<td>Zomer</td>
<td>Meerjarig</td>
<td>Noord Europa</td>
</tr>
</tbody>
</table>

In de volgende vragen zal er dieper worden ingegaan op de geformuleerde scenario’s in vraag 2: dus elk scenario is een specifieke mix van eigenschappen van de door u geïdentificeerde factoren.

64
3. Welk percentage van de bij benadering totale CF van een totaal cradle-to-gate CF van het product kan worden toegeschreven aan groep x?

4. A. Zou het antwoord op de eerste vraag variëren wanneer ieder scenario dat is genoemd in vraag 2 apart beschouwen?
   B Zo ja, wat zouden de percentages voor de verschillende gevallen zijn?
   C Zo nee, waarom niet?
   <Herhaal de vragen 3 en 4 tot alle groepen, niet beantwoord door literatuuronderzoek tot nu toe, zijn behandeld.

Voor alle groepen toegeschreven een percentage van 5% of lager, worden de volgende drie vragen gesteld: <Vraag 5-7 zal herhaald worden per groep, die wordt aangegeven door literatuur of door de geïnterviewde als toekennen van 5% of minder van de totale CF>

5. Hoeveel financiële kosten zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de financiële kosten, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel financiële kosten (VGFC)
   □ Veel financiële kosten (GFC)
   □ Redelijk veel financiële kosten (QFC)
   □ Vergelijkbare financiële kosten (SFC)
   □ Redelijk weinig financiële kosten (RLFC)
   □ Weinig financiële kosten (LFC)
   □ Zeer weinig financiële kosten (VLFC)
   □ Geen antwoord (NA)
   □ Geen mening (NO)

6. Hoeveel tijd zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de tijd, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel tijd (VMT)
   □ Veel tijd (MT)
   □ Redelijke veel tijd (RT)
   □ Vergelijkbare tijd (ST)
   □ Redelijk weinig tijd (RLT)
   □ Weinig tijd (LT)
   □ Zeer weinig tijd (VLT)
   □ Geen antwoord (NA)
   □ Geen mening (NO)

7. Hoeveel moeite (=complexiteit, onzekerheid en frustratie) zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de moeite, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel moeite (VME)
   □ Veel moeite (ME)
   □ Redelijk veel moeite (RME)
   □ Vergelijkbare moeite (SE)
Antwoorden voor vraag 3-7

* Groep 5 wordt gebruikt bij een biologisch bedrijf, groep 4 wordt gebruikt bij een ander bedrijf. Er is geen mix, dus er is altijd 5% voor groep 4 of 5.

** Groep 9 en 10 vervangen elkaar

Voor alles geldt voor vraag 6 geldt Noord-Europa: kost zeer veel tijd en Zuid-Europa kost zeer veel tijd en is hopeloos. Je moet de goede personen te pakken krijgen en dit gaat weken tijd kosten, vooral de voor de kleine groepen. De ingevulde waarden in NL zijn ook toepasbaar voor alle MPS klanten.

*** Voor Noord-Europa geldt: kost zeer veel tijd en Zuid-Europa kost zeer veel tijd en is hopeloos. De ingevulde waarden in NL zijn ook toepasbaar voor alle MPS klanten van groepen 4, 5, 8, 9 en 10.

Over groep 11: bedrijven die veel belichten maken een deel van hun elektriciteit en de bedrijven die weinig belichten maken meestal alle elektriciteit die zij nodig hebben zelf. Bijna ieder bedrijf heeft een WKK, behalve sla bedrijven en kleine bedrijven van bijvoorbeeld 1 ha, want dat is te duur. Maar bedrijven van boven de 2-3 ha, waar wordt gestookt, zullen bijna altijd een WKK hebben in Nederland. In de rest van Europa niet vaak, omdat dit ligt aan het feit of ze bereik hebben tot aardgas. Als er gebruik wordt gemaakt van andere brandstoffen voor een WKK kan de CO₂ niet goed gedoseerd worden of er moet wel heel veel schoongemaakt worden. De WKK is gekomen om de CO₂ te kunnen gebruiken. In de sierteelt is die al heel vroeg gekomen (jaren 80-90), omdat een WKK goedkoper was dan het leggen van een elektriciteitsleiding naar het bedrijf, terwijl de gasleiding er al was. Toen de wet er kwam dat je elektriciteit aan het net mocht terugleveren omstreeks 2000, zijn er ook WKKs gekomen op bedrijven groter dan 2 ha. 10% van de Nederlandse elektriciteitsproductie komt nu uit de glastuinbouw, dus we zijn elektriciteit producent i.p.v. consument geworden in de loop der jaren. De waarde voor groep 11 hangt af of je met belichte of niet belichte teelt te maken hebt.

Over groep 16: ik weet alleen niet hoeveel ureum mee gaat tellen wat in de rookgasreinigers gebruikt wordt om de NOx weg te vangen. Het chemische proces heb ik even niet helder. Je zou hiervoor naar Codinox (het meest gebruikte product voor de verwijdering van NOx in de glastuinbouw) moeten googelen of het bedrijf Hanwel die dit verkoopt (Edit: op de website van Codinox staat niets over de chemische reactie)

Over groep 17-19 zit ik te twijfelen over de verdeling, maar bij elkaar is dit ongeveer 15-20%.

De CF van water zou ik wel meenemen in het mediterrane klimaat, want het aanleggen van kanalen, het maken van stuwmeren en het pompen is nodig om steden van drinkwater te voorzien in Spanje. Als de glastuinbouw erbij komt, moet dit allemaal vergroot worden en moeten er irrigatiesystemen komen. Het zal niet makkelijk zijn om hier gegevens te krijgen. De meren zullen groter moeten worden naarmate er meer glastuinbouw komt. Maar je zou ook kunnen zeggen dat dit bij de overheid hoort, dus er is een allocatieprobleem aan wie je dit toereken. In de rest van Europa wordt enkel gebruikt gemaakt van regenwater en bassins, dus deze stel ik op 0.
N.a.v. Case 3: dus dat het een meerderjarige plant is wil nog niet zeggen dat het een bloem is die veel belichting nodig heeft?

Nee, ik denk dat er in het mediterrane gebied bijna niet belicht wordt.

Bij scenario’s 4-6 heb je niet veel brandstoffen nodig, omdat het zomer is. Echter, de elektriciteitsvraag blijft ongeveer hetzelfde, want er moet meer gepompt worden, omdat de planten meer water nodig hebben, maar verlichting en machines voor warmteopwekking hebben weer minder elektriciteit nodig.

In Spanje wordt in de zomer haast niet geteeld, want dan is het te warm om te koelen. Soms ligt een deel dus gewoon leeg in de zomer. Zodra de temperaturen boven de 30 graden gaan lopen, dit ligt ook aan de ligging (of de kassen in de bergen liggen).

Is mediterraan dan wel een goede factor?

Ja daar zit ik nu ook aan te denken, je moet altijd naar het teeltplan vragen om te kijken of er koeling nodig is in de zomer. Een betere factor is dan een mediterraan klimaat waar teelten plaatsvinden in de zomer en waar de temperatuur in de zomer boven de 30 graden uit stijgt. Water wordt dan een belangrijke factor met name wanneer je kijkt naar de koeling die nodig is.

Over case 7: Gelijk aan het begin, want het is de korte teelt, die zijn meestal niet zo heel energie rovend.

Over cases 8 en 9: energievraag wordt hoger, want er is een hogere warmtevraag.

Case 10: De energievraag gaat omlaag, want het is zomer. Groep 11 gaat omlaag, omdat er minder belichting nodig is.
<table>
<thead>
<tr>
<th>Groep</th>
<th>General (NL) in %</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3 =gelijk aan case 2</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6 =gelijk aan case 5</th>
<th>Case 7 =gelijk aan general</th>
<th>Case 8</th>
<th>Case 9 =gelijk aan case 8</th>
<th>Case 10</th>
<th>Case 11</th>
<th>Case 12 =gelijk aan case 11</th>
<th>5) Financiële kosten</th>
<th>6) Tijd v. NL***</th>
<th>7) Moeite</th>
</tr>
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<tbody>
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Bij vraag 3-4 geldt dat de rest evenredig omhoog of naar beneden wordt gesteld.

**Vraag 5 over financiële kosten**

Groep 1 weinig financiële kosten, want het valt of staat met de bereidheid om de gegevens vrij te geven, want de gegevens om de CF te berekenen (dezelfde als de glastuinder heeft) zijn er wel. Voor de jonge planten is dat in principe hetzelfde, ze registreren anders. Zaad is wel moeilijker, omdat je het toe moet rekenen aan verschillende soorten zaden en het kan van heel ergens anders op de wereld vandaan komen. Zaad maakt meestal een erg klein deel uit van de CF, behalve bij radijs of sla. Het is vergelijkbaar met een tuinbouwbedrijf, dus ik ga voor vergelijkbare financiële kosten voor groep 2 en voor groep 1 voor veel financiële kosten.

Van groep 4 is de database bekend, dus vergelijkbaar.

Van groep 5 is zeer moeilijk. Dit wordt makkelijker als ze het eenmaal hebben uitgezocht, maar meest veranderd ook constant van samenstelling. In de scope die ik toepas gaan we uit van een pragmatische aanpak en nemen we van organische meststoffen enkel het transport mee, omdat we ervan uitgaan dat tuinders niets hiervoor betalen aan het boerenbedrijf en het dus bij de CF van het boerenbedrijf hoort. Veranderd het antwoord hierdoor?

Ja, dan is het vergelijkbaar. Het is wel erg discutabel om dit op deze manier te doen, hiermee maak je het ene bedrijf gelukkig en het andere ongelukkiger.

Groep 6 is aan de meter bekend hoeveel er gebruikt wordt, dus vergelijkbaar. Groep 7 t/m 11, 13, 15 en 16 zijn ook almaal bekend, dus vergelijkbaar.

Groep 12 is toch meten wat je binnen krijgt. 14 wat meer. 17 t/m 19 zijn denk ik veel, want dat moet wel in kaart gebracht worden. Er is een programma om materiaalgebruik uit te rekenen, CASTA van meneer van t Hart, wel enkel voor de kas zelf. Zelf ben ik een keer bezig geweest om materialen in de kas op te meten en te fotograferen. Voor EUPHORUS heb ik een inventarisatie gemaakt van allerlei onderdelen van de kas.

**Dat is interessant, daar zullen we straks op terug komen.**

Groep 20 is niet makkelijk om te bepalen, je hebt echt registratiesystemen nodig, dit kost veel tijd relatief naar de getallen die je ervoor terugkrijgt. Je moet echt kijken welk stofje wel of niet van invloed is.

Voor alle groepen geldt dat de registratiesystemen op bedrijven in Europa vaak goed zijn, dit is slechter in noordoost Europa, daar is geen echte registratie. Vaak door de cultuur is deze ook in mediterrane landen niet op orde. In Saoedi-Arabië en Hongarije heb ik die ervaring, maar verder heb ik daar geen ervaring mee.

**Vraag 6 overtijd**

Ook hierbij is een splitting van Zuid-Europes en Noord-Europes nodig. Voor Zuid-Europa heb ik de neiging om te zeggen, begin er maar niet aan, dit zal buitengewoon veel tijd kosten om alle informatie voor alle groepen te pakken te krijgen. Je moet bijna naar die mensen toe en met de mensen in de boekhouding gaan kijken als ze die al hebben. Je moet dus gaan leunen tegen een EUPHORUS project, waar dat soort pogingen al gedaan zijn, dan kom je wat dichter bij de gegevens.

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In Nederland, België, Duitsland, Denemarken, Zweden en Noorwegen worden redelijk goed gegevens bijgehouden. Je hebt alleen de juiste contactpersoon nodig, dat is niet echt makkelijk. Zeker voor die kleine getallen wordt dit moeizaam. Dat kost echt veel tijd en dan praat je over heel veel telefoontjes. Dat kost echt weken tijd. Pesticiden gebruik, synthetische meststoffen en brandstofgebruik kun je terughalen door naar MPS te gaan. Dat is een verplichte registratie voor NL, ik weet niet of dat voor heel Europa geldt. MPS heeft ook buitenlandse klanten, ze registreren per bedrijf, maar geven dit niet individueel vrij. Je kan het bedrijf dan zelf naar de MPS registratie vragen.

Vraag 7 over moeite

Voor Noord Europa veel moeite en Zuid Europa zeer veel moeite voor alle kleine groepen. Ik denk dat je bij de tuinders ook veel irritatie gaat krijgen over of dit nou belangrijk is e.d.

Praktische vragen

Wilt u iets toevoegen aan het interview?

Niet zoveel, alleen weet waar je aan begonnen bent. Ik denk ook dat je erop voorbereid moet zijn dat tuinders en producenten er niet op zitten te springen om mee te werken. Er zijn momenteel grote financiële problemen in de glastuinbouw en bedrijven zijn veelal niet geïnteresseerd in een CF, verwacht geen hartelijk ontvangst. Je moet echt krediet op proberen te bouwen. Als je op dit niveau tuinders gaat bevragen zul je het contact zeer snel kwijt zijn.

Kent u iemand anders die ik zeker zou moeten interviewen voor dit onderzoek?

Anne Gaasbeek zou je meer methodische vragen over welke grenzen waarom zijn gekozen kunnen stellen en ze heeft ervaring met glastuinbouwers in Spanje, Zweden en Frankrijk, maar ze zit waarschijnlijk niet in de getallen. Zij zou ook andere adressen aan kunnen leveren.

En buiten Nederland?

Ja er waren Britten die vreemde aannames hebben gedaan bij het maken van CFs voor glastuinbouwproducten en naar aanleiding daarvan is toen de speciale PAS 2050-1 voor tuinbouwproducten ontwikkeld. Wellicht weet Anne nog wie die Britten waren. Uit hun onderzoek kwam dat de CF van Britse glastuinbouwproducten veel beter is dan Nederland en misschien ook nog wel beter dan die van Spanje.

Voor de rest zijn er niet veel mensen bezig met CF. Voor bedrijven die certificering doen voor CF in het algemeen, zou je bij de TUFs (in Duitsland, zoiets als Nederlands meetinstituut in NL) moeten zijn en vorig jaar was er in november een meeting op Schiphol waarbij mensen uit heel Europa overgevlogen zijn die bezig zijn met CO₂ footprint. Maar zij houden er andere allocatiemethoden op na en onderling verschillen ze ook in methoden. Ze zullen geen getallen kunnen produceren, maar ze hebben wel ervaring met hoe je het berekenen van een CF aanpakt.

Je kan aan Anne de lijst van de aanwezigen van de meeting op Schiphol vragen, want deze ging over CF en glastuinbouw. De meeting was georganiseerd door Hans Blonk, PT en BSI om tot een Nederlandse aanvulling op de glastuinbouw van PAS2050 voor glastuinbouw te komen.
Kent u kapitaalgoederenleveranciers of glastuinbouw bedrijven in Nederland, Spanje of Italië, die groenten, fruit of snijbloemen telen die mogelijk data willen leveren voor het tweede deel van mijn onderzoek in ruil voor een berekening van hun CF? Zo ja, kunt u mij hun contactgegevens geven?

Ja, die zal ik je geven.

Heeft u literatuur met betrekking tot deze studie, die zou kunnen helpen voor dit onderzoek?

Ja het Excel bestand waarmee je materiaalgebruik kan berekenen zal ik geven en alle artikelen van mij die niet indirect toegankelijk zijn vanaf de website, waar je naar vroeg, zal ik geven. CASTA is nog specifieker, maar dit Excel bestand heb ik zelf gemaakt, maar communiceer niet over de bedrijven. Een abstract van Vermeulen, P.C.M.; Myrtille, D.G. (2010) A model to calculate the CO₂ footprint of greenhouse crops In: ISHS 28th Int. Horticultural Congress - Science and Horticulture for People - Abstracts Volume II (Symposia). - Lisbon, Portugal : ISHS, ISHS 28th Int. Horticultural Congress - Science and Horticulture for People was een intentie voor een artikel, maar dat is er niet meer van gekomen. Ik zal wel de bijbehorende presentatie of poster erbij zoeken. Het boek van Hans Blonk (Berekening voor agroketens) heb je al gevonden via de website, maar ik zal hem je nog geven met de handleiding, want er zijn drie versies van en de bijlage ontbreekt online, maar de inhoud is ongeveer hetzelfde.


Dit was de laatste vraag. Hartelijk dank voor uw deelname. Als het transcript van het interview af is zal ik het naar u sturen, u kunt hierop commentaar leveren als u wilt. Wanneer het onderzoek klaar is, wat ik eind februari verwacht, zal ik u mijn verslag sturen.
Naam van de geïnterviewde: Jaap Vreugdenhil

Jaap Vreugdenhil is adviseur energie. Het bureau geeft advies over energiezaken, nieuwbouw en techniek, makelaardij en bedrijfskunde in de glastuinbouw. M.b.t. energie richten ze zich op contractbegeleiding bij kwekers. Daarnaast begeleiden ze duurzame projecten o.a. aardwarmteprojecten. Ook hebben ze workshops gegeven aan kwekers over verduurzaming. Binnen dit werkveld is er ook contact met mensen die een CF willen laten uitrekenen, dus dat heeft Jaap laatst gedaan. Tijdens deze opdracht is er contact geweest met Blonk, omdat zij de methodiek PAS 2050-1 hebben ontwikkeld voor de tuinbouw in opdracht van PT. In het verleden hebben andere collega’s van Jaap al vaker een CF berekend.

Datum en tijd: 18 oktober 2011, 10.50-12.20 uur
Plaats: Tiendweg 18, Naaldwijk

Interview vragen

Het gaat bij de eerste twee vragen om systeemgrenzen die leiden tot minstens 95% van de bij benadering totale carbon footprint volgens mijn scope van een glastuinbouw product, geproduceerd in Europa.

1. Wij denken zelf dat de factoren systemen, processen, klimaat en mogelijk ook andere factoren van invloed kunnen zijn bij het stellen van passende systeemgrenzen. Welke factoren zijn volgens u belangrijk om passende systeemgrenzen te bepalen?

Zou je daar een voorbeeld van kunnen geven?

Ja, bijvoorbeeld bij klimaat zou u kunnen denken aan de situatie dat er gebieden zijn waar veel sneeuw valt en gebieden waar geen sneeuw valt. Als de kas veel sneeuw op het dak krijgt, moet de constructie sterk genoeg zijn om het gewicht van de sneeuw te kunnen dragen. In dit geval zou het dus kunnen zijn dat de constructie van deze kas meer materiaal behoeft als in het geval dat de kas in een gebied staat waar het niet sneeuwt. Dit zou dus uiteindelijk invloed kunnen hebben op de CF en misschien wel een invloed waarin in het ene geval de kas buiten de systeemgrenzen zal liggen, omdat deze een niet significant deel van de CF bedraagt.

Ja het is wel een fundamentele kwestie of je kapitaalgoederen wel of niet meeneemt. Je zou eerst goed moeten inventariseren hoeveel je toerekent aan de kas. Maar als je vindt dat je dat moet meenemen, omdat het onderling veel variëteit vertoont en in sommige gevallen significant is, dan vind ik dat je het in alle gevallen mee moet nemen.

Binnen kassen in Nederland zit niet veel verschil. Er zit veel glas op, er zit aluminium en staal in. Nieuwbouwkassen zijn onderling vergelijkbaar wat dat betreft. Maar als je kijkt naar het buitenland, daar heb je veel meer plastic kassen en dan kan ik me voorstellen dat dit natuurlijk wel een verschil maakt.

Op wat voor een manier maakt dat een verschil?

Nou ja, plastic is geen glas. Het is een ander materiaal, er zit minder staal in.

Maar denkt u dan dat het aandeel van de CF voor deze groep daardoor gaat veranderen?

Ik weet natuurlijk niet hoeveel CF je aan plastic en aan glas toeschrijft, maar ik zie wel grote verschillen ertussen waardoor het vanuit dat oogpunt wel tot verschillen kan leiden.
Maar denkt u dat dit van invloed is of een groep wel of niet in de 95% CF wordt meegenomen?

Nee, ik denk het eigenlijk niet, maar ik heb geen goed beeld over hoeveel van de CF er aan een kas wordt toegeschreven.

Dan is dat dus geen factor.

Nee. Je moet natuurlijk weten dat het overgrote deel van de CF in Nederland door energie wordt veroorzaakt. Dit houdt in het verstoken van brandstof en hoe je daar dan verder mee omgaat. Vaak wordt er dan ook nog elektriciteit terug geleverd en de vraag is hoe je daarmee omgaat met je systeemgrenzen. Voor die kassen moet je de emissies eigenlijk weten om dit te kunnen plaatsen. Daarbij moet je weten dat kassen een lange levensduur hebben en je dit dus verdeelt over een x aantal jaren. Dan denk ik dat dit in verhouding tot de CF van energie wel meevalt.

Dus misschien is het wel een factor?

Het zal een grensgeval zijn. Het zal in het geval van een plastic kas zeker anders zijn.

Kunt u nog andere factoren noemen en denkt u ook dat de factor systemen bijvoorbeeld een rol speelt? U noemde bijvoorbeeld al energie. Denkt u dat het aandeel van de CF in bepaalde gevallen onder de 5% komt, als je kijkt naar groepen m.b.t. energie, genoemd op het verstrekte blad met groepen? Of denkt u dat dit altdijd wel 5% of meer is?

Dit hangt ervan af wat voor tuinbouwbedrijf je hebt. Als je belicht en je importeert hiervoor elektriciteit, dan is dit natuurlijk zeker meer dan 5% van je CF. Als je niet belicht en je gebruikt enkel elektriciteit voor je bedrijf, dan kan ik me voorstellen dat dit minder dan 5% is.

Dus belichting is ook een factor?

Ja belichting is gewoon een belangrijke factor, daarnaast heb ik gezien uit de studie die ik heb gedaan, dat de standaardhoeveelheid zonder belichting die je gebruikt ook een belangrijk deel uitmaakt. Standaard is 7 kWh/m² en qua warmte en gas is dat 35 kuub, dus gewone elektriciteit moet je denk ik wel altijd meetellen.

Ok, dus dat is wel substantieel, altijd meer dan 5%? Dus dan is het elektriciteitsverbruik dus eigenlijk geen factor.

Ja, dat klopt.

We hebben nu als factor mogelijk het soort kas. Denkt u dat er nog andere factoren zijn?

Grondbedekking is in de meeste gevallen niet significant, maar er zijn altijd uitzonderingen.

Wat zijn de uitzonderingen?

Bij een teelt die weinig energie verbruikt wordt het aandeel van grondbedekking natuurlijk al snel meer t.o.v. de totale CF. Het is een relatief verhaal, verhoudingen maken uit.

U zegt dus nu dat de grondbedekking in dit geval significant zou kunnen worden, dus is energieverbruik een factor volgens u.

Dit is een belangrijke factor. Naarmate energie belangrijk wordt, spelen andere factoren een kleinere rol. Ik kan me ook voorstellen dat kapitaal goederen gaan meetellen als het energieverbruik laag is.
Appendix 2 Interview transcripts

Maar ik heb zelf niet goed een idee over hoe die verhoudingen liggen, omdat in die eerdere studie die we gedaan hebben, gebaseerd op de richtlijnen van Blonk, die kapitaalgoederen buiten beschouwing zijn gebleven.

_Ik snap dat u niet helemaal precies alles kan weten maar, we proberen gewoon dingen op het spoor te komen d.m.v. dit interview. Het is dus prima als u schattingen maakt, of gewoon uw vermoedens uitspreekt._

Mijn voorkeur zou er uiteindelijk naar uitgaan om kapitaalgoederen helemaal buiten beschouwing te laten. In algemene zin zeg ik zal bodembedekking geen significante rol spelen. Hetzelfde geldt voor materialen om de groei te leiden, want dat zijn maar een paar touwtjes. Verpakkingsmateriaal telt waarschijnlijk dan weer net wel mee en onderhoudsproducten e.d. weer net niet.

_Een bepaalde gevallen dan net wel of ligt dat aan het energiegebruik?_

Ja ook, maar er worden over het algemeen niet veel producten gebruikt heb ik het idee. Vooral water en ontsmettingsmiddelen worden gebruikt. Ik kan me niet voorstellen dat dit een grote emissie veroorzaakt.

_Is dan de factor naarmate onderhoudsproducten veel gebruikt worden, zou je onderhoudsproducten e.d. wel mee moeten nemen?_

Nee, maar ik denk dat het in algemene zin niet veel gebruikt wordt in de tuinbouw.

_Maar ik ben dus op zoek naar de uitzonderingsgevallen. Denkt u dat onderhoudsproducten e.d. ooit boven de 5% zullen uitkomen?_

Ik denk het niet. Nee.

In de intensieve tuinbouw in Nederland denk ik dat kapitaalgoederen vaak minder dan 5% van de totale CF uitmaken, zonder dat ik dat geïnventariseerd heb. Dit komt omdat er veel energie wordt verbruikt en daardoor gaan deze groepen minder meetellen.

_Maar wat zou dan van invloed kunnen zijn waardoor deze groepen wel significant worden?_

Als je minder energie gaat gebruiken of duurzame energie gebruikt. Duurzame energie zou mijn inziens niet moeten meetellen in de CF of enkel deels wat je aan de productie voor die energie toerekent.

_Ja, de emissies die vrijkomen om het mogelijk te maken die energie te kunnen produceren ga ik wel meenemen in het onderzoek. Het aandeel duurzame energie is dus ook een factor volgens u._

De groep gebouwen e.d. (19) is denk ik nooit significant en dan nog blijft de vraag of je dit wel mee zou moeten willen rekenen. Onderhoud is altijd heel weinig, in ieder geval veel minder dan de productie van die goederen.

Ik zal even samenvatten wat we tot nu toe hebben aan factoren. De soort kas, het energiegebruik en het percentage duurzame energie.

Ja ik denk dat de factor energiegebruik erg belangrijk is in de Nederlandse glastuinbouw, waardoor andere groepen van een minder belang zijn.
Kunt u nog andere factoren noemen? U praat nu vooral over Nederland, maar we hebben het over heel Europa.

Nee, het klimaat zit al in het energieverbruik, dus ik denk dat we het zo wel hebben.

2. Welke aanzienlijk verschillende scenario’s, in relatie tot het bepalen van geschikte systeemgrenzen, kunt u onderscheiden? Het is de bedoeling dat u de scenario’s creëert aan de hand van het maken van karakteristieke mixen van de factoren die u belangrijk acht.

Een scenario ziet er als volgt uit:

<table>
<thead>
<tr>
<th>Scenario α:</th>
<th>0-X aantal gespecificeerde eigenschappen van factor a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-Y aantal gespecificeerde eigenschappen van factor b</td>
</tr>
<tr>
<td></td>
<td>0-Z aantal gespecificeerde eigenschappen van factor c</td>
</tr>
</tbody>
</table>
Etc.

De factor soort kas, zou ik onder willen verdelen in verschillende dekmaterialen (platen) en constructiematerialen als volgt.

Factor: Soort dekmateriaal | Eigenschappen | Kunststof | Plastic (o.a. folie) | Glas
Factor: constructiematerialen | Eigenschappen | Onbekend hoe dit in te delen is, maar je zou het kunnen bepalen aan de hand van het massa constructiemateriaal van de kas zelf per vierkante meter per kg product (dit houdt in: staal, aluminium en dekmaterialen zoals bovengenoemd).

Toch denk ik dat de factor constructiematerialen los staat van het soort dekmaterialen. Maar ik weet niet wat veel en weinig is, omdat ik niet weet wat de kas weegt. Ik denk dat je uiteindelijk enkel naar dekmaterialen moet gaan kijken, want ik weet anders niet over welke verhoudingen we praten. Ik wil de factor constructiematerialen niet meenemen in de scenario’s.


Hoe zou u deze eigenschap willen onderverdelen?

Daar is geen onderverdeling van toepassing is, want het is eigenlijk altijd veel in de tuinbouw. Dit is niet goed in te delen, we onderscheiden daarom koude teelt (welke naderhand niet van invloed op de groepen is als we kijken naar plastic of kunststof) en warme teelt (welke altijd van invloed is op de groepen). Onder warme teelt wordt in dit geval verstaan dat de kas een temperatuur van boven de 18 graden Celsius heeft het hele jaar door.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Eigenschap factor dek materiaal</th>
<th>Eigenschap factor energiegebruik</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kunststof of plastic</td>
<td>Koude teelt</td>
</tr>
<tr>
<td>2</td>
<td>Glas</td>
<td>Koude teelt</td>
</tr>
<tr>
<td>3</td>
<td>Kunststof</td>
<td>Warme teelt</td>
</tr>
<tr>
<td>4</td>
<td>Plastic</td>
<td>Warme teelt</td>
</tr>
<tr>
<td>5</td>
<td>Glas</td>
<td>Warme teelt</td>
</tr>
</tbody>
</table>

In de volgende vragen zal er dieper worden ingegaan op de geformuleerde scenario’s in vraag 2. Elk scenario is een specifieke mix van eigenschappen van de door u geïdentificeerde factoren.
3. Welk percentage van de bij benadering totale CF van een totaal cradle-to-gate CF van het product kan worden toegeschreven aan groep x?

4. A. Zou het antwoord op de eerste vraag variëren wanneer ieder scenario dat is genoemd in vraag 2 apart beschouwen?
   B. Zo ja, wat zouden de percentages voor de verschillende gevallen zijn?
   C. Zo nee, waarom niet?
   <Herhaal de vragen 3 en 4 tot alle groepen, niet beantwoord door literatuuronderzoek tot nu toe, zijn behandeld.

Voor alle groepen toegeschreven een percentage van 5% of lager, worden de volgende drie vragen gesteld: <Vraag 5-7 zal herhaald worden per groep, die wordt aangegeven door literatuur of door de geïnterviewde als toekennen van 5% of minder van de totale CF>

5. Hoeveel financiële kosten zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de financiële kosten, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel financiële kosten (VGFC)
   □ Veel financiële kosten (GFC)
   □ Redelijk veel financiële kosten (QFC)
   □ Vergelijkbare financiële kosten (SFC)
   □ Redelijk weinig financiële kosten (RLFC)
   □ Weinig financiële kosten (LFC)
   □ Zeer weinig financiële kosten (VLFC)
   □ Geen antwoord (NA)
   □ Geen mening (NO)

6. Hoeveel tijd zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de tijd, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel tijd (VMT)
   □ Veel tijd (MT)
   □ Redelijke veel tijd (RT)
   □ Vergelijkbare tijd (ST)
   □ Redelijk weinig tijd (RLT)
   □ Weinig tijd (LT)
   □ Zeer weinig tijd (VLT)
   □ Geen antwoord (NA)
   □ Geen mening (NO)

7. Hoeveel moeite (=complexiteit, onzekerheid en frustratie) zou het kosten om CF gegevens voor groep x te verzamelen in vergelijking met de moeite, die het gemiddeld kost om gegevens voor de groepen die verantwoordelijk zijn voor 5% of meer van de totale CF te verzamelen?
   □ Zeer veel moeite (VME)
   □ Veel moeite (ME)
   □ Redelijk veel moeite (RME)
   □ Vergelijkbare moeite (SE)
We zitten nu op ongeveer 124, hoe wilt u dat naar beneden bijstellen?

Naar rato. De overgebleven percentages veranderen mee naar rato t.o.v. de eerste groep, de ingevulde groepen zijn vaste percentages bij scenario’s 2 t/m 5. Kapitaalgoederen wordt eerst bijgesteld a.d.v. eerdere uitspraken, maar later wordt dit toch weer terug omlaag gesteld voor de cases 2 t/m 5, omdat het bij nader inzien toch nooit significant is. Water in mediterrane gebieden zie ik niet als significante bijdrage, maar ik durf er eigenlijk geen uitspraak over te doen.

Vraag 5 over financiële kosten

Data voor plantmateriaal verzamelen kost redelijk veel tijd, omdat het een aparte studie op zich is. Voor synthetische meststoffen wordt veel met normen gewerkt, maar ik weet niet of producenten onderling veel verschillen, maar als je literatuurstudie doet hoeft het niet veel te kosten. Verpakkingsmaterialen voor het product is redelijk weinig, want dit kun je nagaan op de kwekerij hoeveel er gebruikt is. De groep consumptietoekomst is redelijk veel omdat je moet uitzoeken wat er precies is gebruikt en waarvoor het is gebruikt: voor de teelt of kapitaalgoederen. 17,18 en 19 is veel, want je moet alles precies gaan inventariseren.
**Vraag 6 over tijd**

Voor zaden kost dat veel tijd, als je het precies wilt bepalen, maar als je de emissiefactor van een zaad weet, dan ben je er zo uit.

*We zullen daar tijdens de studie pragmatisch mee omgaan en naar waarden in de literatuur in zo'n geval zoeken.*

Ja hetzelfde geldt voor jonge planten als je het echt wilt weten. Voor sustraat en kunstmest zijn sowieso literatuurstudies dus die kosten weinig tijd. Externe CO₂ wordt gewoon gemeten, je moet wel literatuurstudie doen naar de allocatieprocedure. Ander pestmanagement zal heel variabel zijn, omdat dit afhankt van wat iemand doet en hoe diep je erin wilt gaan, dat gaat je gewoon veel tijd kosten. Brandstof kun je eenvoudig inzichtelijk krijgen. Geïmporteerde warmte is ook een kwestie van metingen en literatuurstudie, dus dat hoeft niet veel tijd te kosten. Geïmporteerde elektriciteit is ook een kwestie van literatuurstudie, dus kost ook niet veel tijd. Verpakkingsmaterialen kost wat meer tijd, maar is ook literatuurstudie. Bodembedekking en materialen om groei te sturen kost ook weinig tijd, want het gaat over materialen en emissie factoren, dus dat is gewoon literatuurstudie.

**U denkt dat de telers die informatie hebben?**

Ja, de teler weet precies wat hij gebruikt, maar niet de emissiefactor. Consumabels kost misschien wat meer tijd, omdat dat wat gunstiger ligt, maar toch redelijk weinig tijd. Als je de kapitaalgoederen allemaal wil gaan inventariseren kost dat zeer veel tijd, daar kom je gewoon niet uit.

**Vraag 7 over moeite**

Dit is natuurlijk vergelijkbaar met de vorige vraag, want als iets veel moeite kost dan wekt het gewoon veel frustratie op. Kunstmest wordt verplicht geregistreerd, dus kost weinig moeite. Alles wat je kan inventariseren, wat uit registratie komt, kost weinig moeite. CO₂ wordt gemeten, pesticiden wordt geregistreerd, dat zou je zo moeten kunnen uitdraaien. Pesticiden zou je misschien wel in moeten delen naar verschillende middelen.

**U heeft bij pesticiden veel tijd gezegd, maar het kost weinig moeite, dus tijd en moeite zijn toch niet altijd afhankelijk van elkaar.**

Ja goed, ik dacht een stap verder. Je moet ook de emissiefactor uitzoeken binnen deze scope. In dat geval gaat het natuurlijk veel tijd kosten, maar om naar de kwekerij te gaan om de gegevens op te halen hoeft niet veel tijd te kosten, want mensen weten wat ze gebruiken. Het is niet erg als je bepaalde groepen die minder dan 5% uitmaken van de CF meeneemt. Het is echter wel kwalijk als je groepen die meer dan 5% uitmaken van de CF niet meeneemt. Ander pestmanagement kost je misschien meer moeite, omdat dat niet altijd duidelijk is. De vraag is dan wat er wel en niet onder valt. Dat kost redelijk veel moeite, want dan moet je gaan vragen wat iemand precies heeft gedaan, terwijl deze groep niet onder een verplichte registratie valt. Pesticiden is bijvoorbeeld wel geregeld per wet, dat iedereen moet bijhouden wat hij/zij doet bij de gemeente of MPS. Brandstoffen, geïmporteerde warmte en elektriciteit kosten allemaal weinig moeite, want dat haal je gewoon van de factuur. Materialen om groei te begeleiden kun je gewoon nagaan, dus kosten weinig moeite net als verpakkingsmaterialen voor het eindproduct. Kapitaalgoederen kosten heel veel moeite, want daar ga je gewoon niet uitkomen, want dan moet je complete installaties inventariseren. Dat moet je echt pragmatisch zien aan te pakken en je afvragen of dat binnen de PAS 2050 ook gewenst is.
Praktische vragen

Wilt u iets toevoegen aan het interview?

Ik zou je als tip willen geven alles praktisch te houden. Ik heb me eerder verdiept in dit soort discussies over CO₂ e.d. en dat is gewoon uiterst gecompliceerd er zit geen enkele pragmatische inslag meer in. Het verandert natuurlijk heel snel in een politieke discussie.

U vindt dat er geen pragmatische aanpak meer mogelijk is?

Nee, op een gegeven moment gaat de discussie over wat je wel en niet meerekent. Als je het op de ene manier bekijkt is de emissie veel en op de andere manier weinig. Het moet gewoon helder zijn voor de mensen. Je koopt bijvoorbeeld een tomaat en daarmee veroorzaak je zoveel emissie extra, dat kan iedereen begrijpen.

Dus u wilt daarmee zeggen bepaal een CF op de makkelijke manier?

Het moet wel een beetje makkelijk blijven, ja.

Kent u iemand anders die ik zeker zou moeten interviewen voor dit onderzoek?

Nee, op dit moment alleen de mensen bij Blonk, maar die ken je. Kijk, er zijn waarschijnlijk ook certificeringbureaus zoals SGS Agrocontrol, volgens mij in Spijkenisse, die CFs goed moeten keuren. Die zou je ook nog eens kunnen benaderen.

Deze discussie rondom certificering komt met name uit Engeland. Hier is het allemaal begonnen met supermarkten die de CF wilden bepalen zoals TESCO. Daar zou je ook eens kunnen kijken hoe zij ermee omgaan, maar dat heeft weinig raakvlakken met dit interview, omdat je een systematiek wilt hebben, maar je kan ook vanaf de andere kant kijken wat zij er eigenlijk van verwachten.

Denkt u aan iemand specifiek?

Ik denk niet aan iemand specifiek, want ik heb daar geen contacten.

Als je de studies leest, zie je dat het is geïntroduceerd door die supermarkten, die hun product willen onderscheiden met een CF, welke zo laag mogelijk is.

En dan bedoelt u de mensen die deze onderzoeken hebben gedaan?

Bijvoorbeeld. Of de verkopers in zo’n supermarkt of het management, mensen die dat bedacht hebben. Volgens mij hield TESCO zich ermee bezig. Het meest bijzondere is dat dit soort mensen bedenken dat ze een CF willen en voor de rest denken ze er niet over na hoe het bepaald wordt. Iemand anders gaat bedenken hoe het bepaald moet worden en vervolgens weet eigenlijk niemand meer waar het over gaat. Zolang het eindresultaat maar een CF is, die lager is dan die van de concurrent.

Er moet natuurlijk een heldere standaard zijn, dat ieder bedrijf kan toepassen, waarbij duidelijk is wat er wel en niet onder valt zodat het ook onderling vergelijkbaar is.

Maar ik hoorde ook dat de certificeringbureaus in Duitsland ook weer allemaal andere standaarden hebben.

Ja dat kan heel goed, maar uniformiteit is natuurlijk op zijn plaats, anders heeft het totaal geen zin.
Maar u denkt toch dat het zin heeft om hen te interviewen, ondanks de verschillende standaarden?

Nou, ik denk het eigenlijk niet, maar dat moet je zelf natuurlijk even beoordelen.

Kent u kapitaalgoederenleveranciers of glastuinbouw bedrijven in Nederland, Spanje of Italië, die groenten, fruit of snijbloemen telen die mogelijk data willen leveren voor het tweede deel van mijn onderzoek in ruil voor een berekening van hun CF? Zo ja, kunt u mij hun contactgegevens geven?

Ja, dat denk ik wel ja. We hebben contactgegevens, maar die kan ik enkel geven na overleg binnen Agro Adviesburo.

Ik zal u hier nog eens naar vragen wanneer ik het transcript stuur.

We hebben contacten met de tuinbouwers van aardwarmteprojecten waarvan de boringen klaar zijn, maar deze zijn nog niet opgeleverd. Dit zijn de volgende bedrijven: Koekoekspolder, van der Bosch (2 bronnen), Duivensteijn die problemen heeft met gas, Almela die heeft problemen met olie en er is een bron geboord in Den Haag.

Heeft u literatuur met betrekking tot deze studie, die zou kunnen helpen voor dit onderzoek?

Niet andere literatuur dan die jij al hebt, denk ik, zoals PAS 2050 en literatuur die Blonk heeft geschreven, die heb ik gelezen. Ik denk dat je dan al heel wat bij elkaar hebt en daar staan ook al veel emissiefactoren in.

En de CF die u zelf heeft gemaakt is die openbaar?

Die is commercieel en die kan ik je daarom niet geven.

Dit was de laatste vraag. Hartelijk dank voor uw deelname. Als het transcript van het interview af is zal ik het naar u sturen, u kunt hierop commentaar leveren als u wilt. Wanneer het onderzoek klaar is, wat ik eind februari verwacht, zal ik u mijn verslag sturen.
A3. Data collection and calculation of CF for different groups

This appendix clarifies the development of the data collection Excel files in appendices A6 and A8. Furthermore it explains the way calculations were made to obtain the CF of the cases, of which the results are presented in appendices A7 and A9. An overview of the explained EFs can be found in appendix A12. The arrangement of this document is the same as the former formulated groups in Table 2. The document explains which data needs to be collected in order to determine a 100% CF to test the model. Moreover, it explains the data used and calculations made which were used to develop the 100% CF. A clear distinction is made when a calculation concerns the last mentioned case.

In order to be able to develop calculation and collection rules, it is assumed that the margin of error for large groups should be really small, whereas the magnitude of error is less important for small groups. This approach has been followed in order to have a small error in total and at the same time get a sense of the magnitude of groups which are not often studied before. The magnitude of many groups were not studied before, because they were assumed to be small. Therefore, it is justified to simplify CF calculations by making assumptions for groups which are assumed to play a subordinate role at the stage of developing the definition of a 100% CF.

A3.1. Seeds

Documentation for CFs for seeds is scarce. The most recent document which discusses the CF of seeds is focused on grains (Mombarg & Kool, 2004). However, because data of grain is the only data available concerning seeds at the moment, data regarding grains will be used for the calculations of the CFs. The value 14.8 MJ per kg seeds from Gaillard (Gaillard, 1997) will be used, since the accompanying study takes the most process steps into account, compared to the other studies mentioned by Mombarg and Kool. Furthermore, it uses the highest energy value, and therefore it is less likely to underestimate this group. The conversion factor used is 0.074 kg CO₂-eq per MJ, which results in an emission factor of 1.10 kg CO₂-eq per kg seeds. CO₂ is assumed to be equal to CO₂-eq, because references where the CO₂-eq factor is written are not available. This conversion factor is preferred over the factor which is based on solely natural gas, because basing the value on the chosen energy mix is more realistic than solely natural gas. It is assumed that transport is not yet included. Primary data to determine transport emissions according to Scholten et al. (Scholten, Hillerand, & Blonk, 2010) will be collected. A production loss of 0 is assumed. The emission factor of diesel is 3.731 kg CO₂-eq per kg which consist of upstream: 0.512 kg CO₂-eq per kg (density 0.84 kg/l) (Ecoinvent, 2007; diesel, at regional storage) and combustion: 3.220 kg CO₂-eq per kg (Gargand & Pulles, 2006). The emission factor of oil is 3.574 kg CO₂-eq per kg which consist of upstream: 0.452 kg CO₂-eq per kg (density 1.0 kg/l) (Ecoinvent, 2007; heavy fuel oil, at regional storage) and combustion: 3.122 kg CO₂-eq per kg (Gargand & Pulles, 2006). The emission factor of kerosene is 3.825 kg CO₂-eq per kg which consist of upstream: 0.506 kg CO₂-eq per kg (density ± 0.795 kg/l) (Ecoinvent, 2007; kerosene, at regional storage) and combustion: 3.319 kg CO₂-eq per kg (Gargand & Pulles, 2006). If only distance is known, default values from Blonk et al (2009) will be used. In case of unknown transport distances and density of the products, standard data from tables 4.2 till 4.4 from Ecoinvent can be used (Rolf Frischknecht et al., 2007, p.13-14) The data needed when own young plant material is produced is amount in kg of seeds and the producer and production location of seeds.
A3.2. Young plants
For young plants, the same problems as for seeds apply. In this case, only values for pot plants are available. The values which are used for heated greenhouses or tunnels are 640 MJ/1,000 plants and for non-heated greenhouses or tunnels 145 MJ/1,000 plants analysed by Sukkel, 2002 (Mombarg & Kool, 2004). The same conversion factor as for seeds is used, which results in 47.4 kg CO₂-eq per 1,000 plants for heated greenhouses and 10.7 kg CO₂-eq per 1,000 plants for non-heated greenhouses. It is assumed that transport is not yet included and it will be included in the same way as stated in the paragraph about seeds. The only difference is that a product loss of 5% is assumed for young plants (Scholten, et al., 2010). The study by Nienhuis and Vermeulen uses 565·10³ kg/ha cultivation, 2,500 kg/ha plant material and 39 kg CO₂-eq/1,000 kg tomatoes for young plant production, including inputs like fuels, fertilizer, and capital goods in the CF (Nienhuis & Vermeulen, 2008). This results in 8.8 kg CO₂-eq/kg plant material (39 * 565 / 2,500 = 8.8) for regular tomatoes with or without CHP and (46 * 500 / 2,500 = 9.2) 9.2 kg CO₂-eq/kg plant material for biological tomatoes. According to Sukkel, the variation in emission factor between different young plants is very large. It will strongly depend on the type of greenhouse (heated or non-heated), the kind of plants, size etc. However, no other studies regarding young plants are known. Therefore, the emission factor for tomatoes will be used for tomatoes and the values for pot plants for all other young plants (Sukkel, 2011).

The following data is needed: Are tomato or other products produced? If tomato is produced, is it biological produced or not? Furthermore in case of tomatoes the amount of plants in kg will be needed. If another product is produced the amount of plants will be questioned and if it concerns heated or non-heated production of young plant material. Furthermore the producer and production location are questioned to develop the 100% CF.

A3.3. Substrate
Emission factors of different types of substrate are collected from literature. This paragraph divides the different used EFs in two groups. The first group explains the EFs used to develop the 100% CF, while the second group defines the EFs to determine a 100% CF to test the model.

Development of 100% CF
For coco, the value 146 (431 * 0.339 according to table 3.3) kg CO₂-eq/ton substrate will be used which contains production only. Packaging material of substrate is included in the group packaging materials for raw input (Kool, 2011d).

Polyurethane has an emission factor of 4,460 (0.949 * 4700) kg CO₂-eq/ton polyurethane (Kool, 2011e).

Values for coco and stone wool (including packaging) have approximately the same emission factor (Kool, 2011c; Kool & Blonk, 2011). However, partitioning of the emission factors is not given in these documents and the emission factor is only mentioned per ha tomato production. Therefore it is assumed that the value for coco in Kool (Kool, 2011d) is equal to the emission factor of stone wool.

Transport will be included for all substrate types in the same way as in the group seeds. Packaging of substrate is included in the group packaging materials.
A 100% CF to test the model

For forteco grow bags (coco), the cradle-to-grave value 502 kg CO₂-eq/ton substrate will be used. Packaging material and transportation is included in this group (Kool, 2011d). For 1 ha tomato growing 6,000 Fortecco Grow Bags are used, which equals 9,000 kg or 90 m³. The cradle to gate CF is 3,883 kg CO₂ per ha tomato production in the Netherlands. The cradle to grave (16.4% higher): 4,520 kg CO₂ per ha tomato production in the Netherlands.

Polyurethane has an emission factor of 6.361 kg CO₂-eq/ton polyurethane (Kool, 2011e). For 1 ha tomato growing 2,700 kg of Polyurethane is used, which equals 90 m³. The cradle to gate CF is 12,740 kg CO₂ per ha tomato production in the Netherlands. The cradle to grave (34.8% higher): 17,174 kg CO₂ per ha tomato production in the Netherlands. If used as green roof (39.7% of the cradle to gate), the value will diminish to 5,058 kg CO₂ per ha tomato.

Values for coco and stone wool have approximately the same emission factor per ha (Kool, 2011c; Kool & Blonk, 2011). Stone wool has an emission factor of 919 kg CO₂-eq/ton, 3.714 kg (density: 46.4 kg/m³, 80 m³) Stone wool (light) is used, which represent a cradle to gate CF of 2916 kg CO₂-eq per ha tomato CF. The cradle to grave (17% higher): 3,412 kg CO₂-eq per ha tomato production in the Netherlands.

Coco has an emission factor of 544 kg CO₂-eq/ton, 6,500 kg (density: 81 kg/m³, 80 m³) Coco substrate light is used for 3,146 kg CO₂-eq per ha tomato. The cradle to grave (12.5% higher): 3539 kg CO₂-eq per ha tomato production in the Netherlands (Kool, 2011c, p.16).

Transport and packaging material is included in this group.

The kind of substrate and the consumption in ton/year or ton/ha/year is needed. Furthermore the density should be known and the lifetime of substrate. In addition, for the first group also producer and production location will be asked.

### A3.4. Fertilizer

(synthetic and mineral, such as nitrate, urea or sulphate based, P₂O₅, K₂O or lime and organic, such as such as manure, compost, mulch, co-products from industry)

For compost the EF of 0.163 CO₂-eq/kg will be used. This includes production process, transport and use (Dekker, Stilma, Geel, & Kool, 2009). For other organic fertilizer products only transport will be taken into account.

For phosphate an EF of 3.37 CO₂-eq/kg P is used ((0.646 * 1.00 + 0.00119 * 25.0 + 0.001 * 298) / (0.48 * 62 / 142) = 3.37) (Davis & Haglund, 1999; Appendix C. 16).

For potassium sulphate an EF of 0.53 CO₂-eq/kg K will be used, (Williams, Audsley, & Sandars, 2006).

EFs of the PDV project of Anton Kool will be used when available. In all other cases the following formula will be used. An emission factor of 7.41 + 298 * 44 * (VF * EF + 0.0075 + VF * 0.01) / 28 CO₂-eq/kg N/jaar will be used ((0.782 * 1 + 0.000806 * 25 + 0.0039 * 298) / 0.265) (Davis & Haglund, 1999; Appendix C. 12) + (VF * EF + 0.3 * UF + VF * Dep) * 298 * 44 / 28 (Scholten, et al., 2010, p. 25-27). The first part concerns production, the second part concerns the use of the fertilizer.
The values for VF depends on the kind of fertilizer used and EF depends on the fertilizer used and the soil (‘mineral’ is sand soil, whereas ‘organic’ soil is clay, compost or peat). When substrate is used, the value of organic soil will be used to prevent underestimation, since values for substrate are lacking.

Peat is classified under fertilizers, because it is not used in the form of a peat bale in the Netherlands and therefore cannot be classified as substrate. The only form for which it could be used in the Netherlands is to enhance nutrients in the soil or as an ingredient for potting compost (Gerven, Hendriks, Cuijpers, Twisk, & Grift, 2011). For peat the emission factor 802 kg CO₂-eq/ton peat is used, excluding transport and packaging (Kool, 2011a). The calculation was done as follows: determining the part which peat brought to the CF of peat casing: \[
851 \times 10^7 / (851 \times 10^7 + 12 \times 10^5 + 13.1 \times 2 + 136 \times 300 + 1.4 \times 146 = 0.63).
\]
With the help of this, the kg CO₂-eq/ton mushrooms, the contribution of peat will be calculated: \[0.63 \times 0.13 \times 1246 = 102 \text{ kg CO₂-eq/ton mushrooms}.
\]
By dividing this outcome by 107.4 kg CO₂-eq/ton peat, we know that 0.95 ton peat is needed to produce 1 ton mushrooms. Therefore, for an emission rate assumed 100%, the CO₂-eq/ton peat can be calculated as follows: \[107.4 + 33 \times 100 / (5 \times 0.95) = 802 \text{ kg CO₂-eq/kg peat} (Kool, 2011a).
\]
Transport is not included in these values and should therefore be taken into account separately for developing the 100% CF.

The following data is needed:

Kind of soil (when no substrate is used), fertilizer type, use in kg or ton per ha per year or kg or ton per ha per year, mass % N, P and K. In addition, for development of 100% CF also producer and production location will be asked.

**A3.5. External CO₂ fertilizer**

(from fossil origin or biogenic fuels)

The following equation will be used:

\[
(Rc / (Rc + Ro)) \times \text{tot CF/CO}_2 = EF
\]

Where:

\[
Rc = \text{Revenue if all kg external CO}_2 \text{ fertilizer will be sold by the supplier for the same price, as this grower paid for it. The unit is euro's per year.}
\]

\[
Ro = \text{Revenue of other products in euro per year of the supplying company in normal circumstances}
\]

\[
\text{Tot CF} = \text{total GHG emissions from firm}
\]

\[
\text{CO}_2 = \text{kg emissions in total emitted (potential sales)}
\]

The CF of the amount of sold CO₂ will be subtracted from this group. If there is a surplus from the external CO₂, the CO₂ surplus will directly be subtracted from the amount of purchased CO₂ before starting the calculations. If the CO₂ is produced at the farm, and thereafter sold, it will be allocated using economic allocation in the same way as stated in the above formula.
Transport emissions will not be measured in addition to these numbers. In case of a tube, calculation can be conducted per one metric ton. This means that 1,000 kg CO$_2$ is transported over a distance of one km. It is assumed that the value for natural gas tubes can be used, whereas old gas tubes are often used for such purposes. The EF is therefore 0.054094 kg CO$_2$-eq/ktm CO$_2$ (Ecoinvent, 2007). When a part of the total gas network is allocated to an average horticultural company the following estimation can be made for the year 2009. The horticultural sector consumes 122.9 of 1,500 PJ natural gas for approximately 5,850 horticultural companies in the Netherlands (CBS, 2010) Assuming a length of approximately 130,000 km natural gas tubes in the Netherlands an average horticultural farm could be allocated 1.8 km tube. It is assumed 40 ton CO$_2$ per ha is bought and therefore transported along the tubes. This results in a CF of transport of 3.8 kg CO$_2$-eq which is insignificant on a total of 20·$10^3$ kg CO$_2$-eq for transport (assuming 0.5 kg CO$_2$-eq/kg CO$_2$) and therefore transport is considered to be negligible.

However, purification (incl. absorbents) compressing and energy use for making distribution possible will be included. 0.04 kg CO$_2$/kg CO$_2$-eq (Scholten and Blonk, 2011) will be assessed to be above the mentioned EF.

When data is not available, a 0.5 kg CO$_2$-eq/kg CO$_2$ will be used, which is conform PAS 2050-1.

From experience of BMA it is known that data about other products from OCAP is not retrievable.

The following data is required:

<table>
<thead>
<tr>
<th>Data request</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of purchased CO$_2$</td>
<td>Kg</td>
</tr>
<tr>
<td>Price</td>
<td>Euro/kg</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
<tr>
<td>Quantity sold CO$_2$</td>
<td>Kg</td>
</tr>
<tr>
<td>Price of sold CO$_2$</td>
<td>Euro/kg</td>
</tr>
<tr>
<td>Data needed from supplier</td>
<td></td>
</tr>
<tr>
<td>Total amount of CO$_2$ produced</td>
<td>Kg</td>
</tr>
<tr>
<td>Revenue of all other products except CO$_2$ under normal circumstances</td>
<td>Euro</td>
</tr>
</tbody>
</table>

Table 10 Data required to determine the contribution of external CO$_2$ fertilizer to the CF

**A3.6. Pesticides**

(herbicides, insecticides, fungicides, biocides and soilfumigants)

Transport to the storehouse is included in the Ecoinvent database EFs for active ingredients in pesticides. Production and field emissions are included. Packaging is not included. Transport from storehouse to farm is not yet included, assumed is that 50% of all content is the active ingredient according to Ecoinvent. If the active ingredient is listed in Tab. 10.3 of Ecoinvent (Nemecek, Kagi, & Blaser, 2007, p. 102-103), the EF of the corresponding pesticide class will be used, if not “pesticide unspecified” will be used of the Ecoinvent database (Ecoinvent, 2007).

The data which is needed for the development of the 100% CF is the type of active ingredient, the amount of active ingredient in kg and producer and storehouse location of the pesticide.
A3.7. Other pest management
(nets, fences etc. and biological control such as plants and insects)

In the article of Oonincx the EFs of 5 different insects are determined. To not underestimate the CF of insects, the insect with the highest EF will be used which has a value of 4.00 g CO₂-eq/kg biomass per day (Oonincx, Itterbeeck, Heetkamp, Brand, & Loon, 2010). For plants the same values of young plant material will be used. Assuming no tomato plants will be used to control pest.

For other materials the EF of the input material which has the largest contribution in weight per product will be used. The following data will be used to determine the EF of these materials. First of all, production EFs will be collected from the Ecoinvent database, so 100% virgin material as an input is assumed. Transport from gate to grower will be determined when needed. For the waste management phase it is assumed everything will be burned with average heat and electricity recovery. Estimations about avoided emissions by incinerating the waste, as obtained by Roline Broekma from Blonk Milieu Advies, will be used. An avoided emission at incineration of electricity is 20% and an avoided emission at incineration of heat is 5% for the Netherlands according to Roline’s document written in 2010 (Broekema, 2010).

The incineration EF according to the chemical formula will be used minus calorific value (MJ/kg) *(avoided emission rate electricity * CF electricity + avoided emission at incineration heat * CF heat)

In formula: EF transport + EF Ecoinvent prod. + Incineration EF – (energy content material (MJ/kg) * avoided emission rate heat * EF gas) – (Energy content material * avoided emission at incineration electricity rate * EF electricity / 3.6)

EF gas = 0.060 kg CO₂-eq/MJ. The emission factor for heat consist of natural gas, high pressure, at consumer for the Netherlands from Ecoinvent (0.003022 kg CO₂-eq/MJ) + 56.7 ton CO₂/TJ (=0.0567 kg CO₂/MJ) for incineration of natural gas ("Monitoringseisen CO₂," 2011). The emission factor for electricity consist of 374 g CO₂/kWh for incineration (assumption: heat generation is negligible) (IEA, 2011b) + upstream emissions (=0.098 kg CO₂-eq/kWh (Ecoinvent, 2007; IEA, 2011a)) for the Netherlands. This results in 0.472 kg CO₂-eq/kWh for the EF of electricity. It must

---

10 The upstream emissions are calculated as follows: percentages of all different energy sources are multiplied by their accompanied upstream EF and added up together. The percentages of the energy mix in the Netherlands are as follows: Nuclear 3.87% Coal 24.89% Gas TAC 58.92% Oil 1.92% Hydro 0.09% and other renewable 10.31% (IEA, 2011a). Upstream emissions for these categories are 0.008 for nuclear (electricity, nuclear, at power plant), 0.004 for hydro (electricity, hydropower, at power plant) and 0.013 for other renewable energy sources (electricity, at cogen 6,400kWth, wood, allocation energy), all in kg CO₂-eq/kWh. To find upstream emissions for fuels which are combusted the total EF is needed to calculate the fraction of upstream, because upstream emissions are not available in kWh electricity, only EFs in MJ internal energy are provided by Ecoinvent. This results in 0.119 for coal (Hard coal mix, at regional storage 0.302 kg divided by conversion factor 25.5 MJ/kg. The outcome is divided by this outcome plus on site combustion of 0.096 MJ/CO₂ eq (Gómez et al., 2006, table 2.2) and afterwards this result (which is the fraction emission upstream) will be multiplied by the emission factor of electricity, hard coal, at power plant UCTE 0.109 (Natural gas, high pressure, at consumer 0.011479 MJ divided by conversion factor 1 MJ/MJ. The outcome is divided by this outcome plus on site combustion of 0.056 MJ/CO₂ eq (Gómez, et al., 2006, table 2.2) and afterwards this result (which is the fraction emission upstream) will be multiplied by the emission factor of electricity, natural gas, at power plant UCTE 0.64324 CO₂-eq/kWh). The result for Gas TAC is 0.109 (Natural gas, high pressure, at consumer 0.011479 MJ divided by conversion factor 1 MJ/MJ. The outcome is divided by this outcome plus on site combustion of 0.056 MJ/CO₂ eq (Gómez, et al., 2006, table 2.2) and afterwards this result (which is the fraction emission upstream) will be multiplied by the emission factor of electricity, natural gas, at power plant UCTE 0.64324 CO₂-eq/kWh). The result for Oil TAC is 0.112 for oil (heavy fuel oil, at regional storage 0.452 kg divided by conversion factor 40.2 MJ/kg. The outcome is divided by this outcome plus on site combustion of 0.078 MJ/CO₂ eq (Gómez, et al., 2006, table 2.2; Guidelines, , Table 2.2) and afterwards this result (which is the fraction emission upstream) will be multiplied by the emission factor of electricity, oil, at power plant UCTE 0.085852 CO₂-eq/kWh). The calculation is conducted in Excel by Groen (Groen, 2011). Adding the multiplication of the percentages of all different energy sources by their accompanied upstream EF results in: 3.87% * 0.008 + 24.89% * 0.0119 + 58.92% * 0.109 + 1.92% * 0.112 + 0.09% * 0.004 + 10.31% * 0.013 = 0.098 (Ecoinvent, 2007)
be mentioned that grey electricity has a little higher emission factor in practice, because in this case green electricity is already included into the production mix. However, the values from CE Delft are considered more reliable, because they are specifically focussed on the Netherlands and make a visible distinction between different kinds of electricity concerning only the Netherlands, instead of many countries in the world. This implies more specific and reliable values were used for calculation. The EF for grey electricity is used to value avoided emissions at incineration plants, which use this energy to produce electricity and heat. The corresponding EFs are 0.447 kg CO₂ eq/kWh (Bles & Wielders, 2011) and 0.060 kg CO₂ eq/MJ (Ecoinvent, 2007; “Monitoringseisen CO₂,” 2011).

Some incineration rates are already known, others should be determined by searching the chemical formula and calculating the carbon content of the product. For products which are made from trees it is assumed the life cycle of CO₂ is less than 100 years. Therefore an incineration EF of 0 will be used when a product is made out of trees.

The following data is required in which producer and production location is only of importance to develop the 100% CF.

<table>
<thead>
<tr>
<th>Data request</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>For usual products</td>
<td></td>
</tr>
<tr>
<td>Kind of material</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>Kg</td>
</tr>
<tr>
<td>Financial life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
<tr>
<td>For plants</td>
<td></td>
</tr>
<tr>
<td>Amount of plants</td>
<td></td>
</tr>
<tr>
<td>Heated or unheated production</td>
<td></td>
</tr>
<tr>
<td>Financial life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
<tr>
<td>For insects</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>Kg</td>
</tr>
<tr>
<td>Financial life expectancy</td>
<td>Days</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
</tbody>
</table>

Table 11 Data required to determine the contribution of other pest management to the CF

A3.8. Energy

(Gas, diesel, kerosene, propane, fuels from biogenic origin, imported heat, other electricity)

CHP

Allocation between useful energy in the form of heat and electricity takes place. The proportion of useful energy for electricity and heat will be determined and multiplied by the electricity: heat ratio as stated in PAS 2050 (BSI, 2008, p.23). For boiler based CHP systems (e.g. coal, wood, solid fuel) a ratio of 2.5:1 is assumed. For a turbine based CHP system (e.g. natural gas, landfill gas) a ratio of 2.0:1 is used.

The emissions of using fuels in the CHP can be calculated as follows. EFs for the upstream for different fuels can be found in the Ecoinvent database. Furthermore incineration for cogeneration processes can also be found in the Ecoinvent database and can be added to the number of the upstream emissions.

The avoided GHG emissions in CO₂ eq/MJ, arising from exporting the surplus of energy from the CHP to the grid, will be subtracted from the emissions of the corresponding CHP emissions. This CF of avoided emissions is determined by making use of average GHG emissions intensity of grid electricity and/or heat. The same values are used as in the group other pest management: 0.060 kg
Appendix 3 Data collection of CF for different groups

CO₂-eq/MJ as EF for heat (Ecoinvent, 2007; "Monitoringseisen CO₂," 2011) and 0.447 kg CO₂-eq/kWh (Bles & Wielders, 2011) for the EF of electricity. The production mix for CHPs and the trading mix have an equal EF. While CHPs influence mainly the Dutch trade mix, it would in principal be better to incorporate this value.

The grey electricity mix should actually be corrected for the supply of electricity from CHPs in horticulture, to avoid double counting regarding decreasing the CF for the avoided GHGes by supplying electricity to the grid from a CHP. However this is not possible at the moment, because data are lacking about which amount of electricity is supplied to the grid from greenhouse horticulture. According to Vermeulen 10% of the total electricity production in the Netherlands is generated by greenhouse horticulture in 2011 (see appendix A2). However this cannot be verified by literature. CBS Statistics only states values for the category agriculture and horticulture in the Netherlands, which fluctuates between 6% and 25% of total electricity production (CBS, 2010, Elektriciteit; productie en productiemiddelen). It does not state for which part greenhouse horticulture is responsible. Furthermore the trademix is used regarding the CHP instead of the production mix, which means data outside the Netherlands should also be taken into account. This double counting happens when EFs are used from literature, because CE Delft and IEA both take decentralized electricity production into account.

Moreover, it is not realistic to presume the mean EF of the production of electricity will be avoided when more electricity is supplied to the grid by CHPs. Therefore, it will also make a difference at what time electricity is supplied to the grid. During the peak-off hours mainly electricity generation from coal will be replaced and during peak hours electricity generated out of natural gas will be replaced (Blonk, Kool, Luske, & Ponsioen, 2009). During the pilot amounts of buying and selling electricity during off-peak hours (between 23 and 7 o’clock and during the holidays) were registered, but the grower told he would be one of the few growers to have this value available. The EF could be over- or underestimated depending on the proportion of peak and off-peak hours (In the research of Blonk underestimated, while in the case of the pilot overestimated).

In addition, the EF of electricity supplied by the grid might be under estimated, because the CO₂ reduction advantage which CHPs bring is accounted in total for electricity instead of sharing it with heat production regarding the EF of CE Delft. Therefore the EF of electricity supplied by the grid is estimated lower than would be the case if CO₂ emissions will be divided among useful heat and electricity (Bles & Wielders, 2011, p.10). However, this value from literature is the best there is and therefore it will be used.

Allocation

When heat or electricity is sold to any other company, allocation on the basis of the MJ ratio heat or electricity used regarding the total use of MJ heat or electricity will be used when allocation based on exergy is not possible. The net CF of electric and heat production from a CHP is needed in order to solve allocation issues like these or others. In addition, to deal with these kinds of allocation problems additional data about other energy sources needs to be known, because it is assumed that all heat sold at the farm is supplied out of a perfect mix of all own energy production. A surplus of electricity which is supplied to the grid is assumed to be allocated to all electricity producing equipment (e.g. CHP, PV cells) relating to the ratio of their CF concerning electrical output minus input plus their CF

11 To give an idea about the proportions of peak and peak-off hours: 6.4% of all electricity was supplied during peak-off hours and 68.1% was bought during peak-off hours of all imported electricity. From this it can be concluded that the mean differs tremendously compared to these data from the pilot. This means this method is highly sensitive and therefore must be used with great caution. In the report of Blonk, a proportion of 2/7 of electricity supplied in peak-off hours was assumed (Blonk, et al., 2009)
considering electrical input (per ratio in case of CHP), that is their net output. Therefore also the electrical input of energy generating equipment will be asked.

**Other energy sources**

Furthermore a boiler can be used. Therefore it is needed to ask the type of fuel and fuel use on a yearly basis. The use of geothermal heat and solar panels are also asked for allocation reasons. These data collection will also be used for capital goods in the case of solar panels and collectors. The document of TNO, written by researchers of TNO and WUR, about heat buffering, indicates this overview of other energy sources is complete (Janssen, Ruigrik, Ooster, & Wit, 2006).

**Imported heat**

The efficiency and energy source is needed in order to be able to calculate CO₂ emissions. Allocation between electricity and heat is calculated on the basis of exergy allocation. The Carnot factor is calculated with the formula \(1 - \frac{T_0}{T}\), where \(T\) is the temperature of the heat carrier and \(T_0\) is the lower surrounding temperature (in Kelvin). It is assumed that \(T_0 = 15^\circ\text{C}\) (Zeist & Scholten, 2011, p.10). The Carnot factor for electricity is 1. The efficiency for the generation of electricity and heat must be known in case of imported heat from CHPs. Electric or heat efficiency \(\eta\) is defined as the ratio between the useful electricity or useful heat output, in a specific time, and the energy value of the input in the same time period. The energy value of fuels can be found for instance in BINAS.

If this allocation on basis of exergy is not possible, allocation will be conducted by energy yield (efficiency) and an economical basis in the same way as in the paragraph External CO₂ fertilizer. In this case it is assumed that each MJ costs the same amount of money. If the EF of the origin cannot be determined, the EF of 0.060 kg CO₂-eq/MJ as EF for heat is used. For convenience, the questions about sold heat are stated in the same part of the data questionnaire.

**Imported electricity (use for acquiring geothermal energy, other electricity use, such as lighting, pumping etc.)**

A choice has been made to make a distinction between green and grey electricity in order to reward growers for choosing green energy. The emission factor for grey electricity is 0.447 kg CO₂-eq/kWh for the Netherlands, which includes incineration and upstream emissions (Bles & Wielders, 2011).

When green electricity is used the producer will be asked about the product mix. The CF will be calculated using the document of CE Delft, which states specific EFs for the Netherlands concerning renewable energy. In the energy mix capital goods that produce grey electricity are negligible (R. Frischknecht, H.-J. Althaus, C. Bauer, G. Doka, T. Heck, N. Jungbluth, D. Kellenberger, et al., 2007), just like the EFs of renewables are negligible compared to grey sources of energy generation.
The EFs stated in the CE Delft document are as follows (van de Vreede and Groot, 2010):

<table>
<thead>
<tr>
<th>Green energy source</th>
<th>Kg CO₂/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind (off-shore)</td>
<td>0.015</td>
</tr>
<tr>
<td>Wind (land)</td>
<td>0.012</td>
</tr>
<tr>
<td>Zon</td>
<td>0.077</td>
</tr>
<tr>
<td>Water (Nederland, rivier)</td>
<td>0.003</td>
</tr>
<tr>
<td>Water (Noorwegen, reservoir)</td>
<td>0.005</td>
</tr>
<tr>
<td>Biomass</td>
<td>0.001-0.144 (general)</td>
</tr>
<tr>
<td></td>
<td>-0.136 (best case)</td>
</tr>
<tr>
<td></td>
<td>2.036 (worst case)</td>
</tr>
</tbody>
</table>

Table 12 Emission factors for green energy sources for generation of electricity according to van de Vreede and Groot

Page 66-69 of the report of CML will be used to find specific data for biomass (Voet et al, 2008)

Conservative scenarios will be assumed, except when specific data of the producer states otherwise.

The following data is required:

<table>
<thead>
<tr>
<th>Data request</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td></td>
</tr>
<tr>
<td>Capacity</td>
<td>MW</td>
</tr>
<tr>
<td>Electricity use for generating this heat</td>
<td>kWh/ year</td>
</tr>
<tr>
<td>Life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Solar panels</td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>kWh</td>
</tr>
<tr>
<td>Type of PV cell: Multi-Si, a-Si, single-Si, CdTe, CIS, ribbon-Si</td>
<td></td>
</tr>
<tr>
<td>Flat roof, facade or slanted-roof</td>
<td></td>
</tr>
<tr>
<td>Laminated or panel</td>
<td></td>
</tr>
<tr>
<td>Integrated or mounted</td>
<td></td>
</tr>
<tr>
<td>Life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Solar collector</td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>M²</td>
</tr>
<tr>
<td>Life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Data for boiler</td>
<td></td>
</tr>
<tr>
<td>Type of fuel</td>
<td>M³</td>
</tr>
<tr>
<td>Amount of fuel</td>
<td>M³, l or kg</td>
</tr>
<tr>
<td>Origin of the fuel (country)</td>
<td></td>
</tr>
<tr>
<td>Life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Data for CHP</td>
<td></td>
</tr>
<tr>
<td>Electric input</td>
<td>kWh</td>
</tr>
<tr>
<td>Exported amount of electricity</td>
<td>kWh</td>
</tr>
<tr>
<td>Useful output of heat and electricity</td>
<td>kWh</td>
</tr>
<tr>
<td>Hours of operation</td>
<td>Hours</td>
</tr>
<tr>
<td>Type of fuel used</td>
<td></td>
</tr>
<tr>
<td>Amount of fuel</td>
<td>M³, l or kg</td>
</tr>
<tr>
<td>Electricity sales</td>
<td>kWh</td>
</tr>
<tr>
<td>Life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Biomass</td>
<td></td>
</tr>
<tr>
<td>Method of generation</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td></td>
</tr>
<tr>
<td>Origin (country)</td>
<td></td>
</tr>
<tr>
<td>Quantity</td>
<td>Ton</td>
</tr>
<tr>
<td>Energy yield</td>
<td>MJ</td>
</tr>
<tr>
<td>Other fuels</td>
<td></td>
</tr>
<tr>
<td>Amount of natural gas, diesel and oil</td>
<td>M³, kg or l</td>
</tr>
<tr>
<td>Data regarding heat</td>
<td></td>
</tr>
<tr>
<td>Amount of purchased heat</td>
<td>MJ</td>
</tr>
<tr>
<td>Price per unit</td>
<td>€/MJ</td>
</tr>
<tr>
<td>Temperature of purchased heat</td>
<td>°C</td>
</tr>
<tr>
<td>Origin (supplier)</td>
<td></td>
</tr>
<tr>
<td>Energy source</td>
<td></td>
</tr>
<tr>
<td>Quantity sold heat</td>
<td>MJ</td>
</tr>
</tbody>
</table>
Appendix 3 Data collection of CF for different groups

| Price of sold heat per unit | €/MJ |
| Temperature of sold heat    | °C   |
| Data from heat supplier     |      |
| Amount of heat in total produced | MJ |
| Revenue of all other products than heat in normal circumstances | € |
| Efficiency heat generation |      |
| Efficiency electricity generation |      |
| Data concerning imported electricity |      |
| Amount of imported grey electricity | kWh |
| Amount of imported green electricity | kWh |
| Producer green electricity |      |
| Data from green energy producer |      |
| Green electricity mix |      |

Table 13 Data required to determine the contribution of energy to the CF

A3.9. Packaging materials for raw material input

(foils, containers, pots, packaging material of consumables)

For this group, the same rules apply as for materials in the group pest management. The following data is only of importance to develop the 100% CF, since this group is excluded from the 100% CF ahead of the test phase.

<table>
<thead>
<tr>
<th>Data request</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials for raw material input</td>
<td></td>
</tr>
<tr>
<td>Packaging product</td>
<td></td>
</tr>
<tr>
<td>Kind of material</td>
<td></td>
</tr>
<tr>
<td>Weight of the products per year</td>
<td>Ton or kg</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
</tbody>
</table>

Table 14 Data required regarding the CF of packaging materials for raw material input to develop the 100% CF

A3.10. Materials for soil covering

(plastic foil etc.)

For this group, the same rules apply as for materials in the group pest management. The following data is required in which producer and production location is only of importance to develop the 100% CF.

<table>
<thead>
<tr>
<th>Data request</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials for soil covering</td>
<td></td>
</tr>
<tr>
<td>Product</td>
<td></td>
</tr>
<tr>
<td>Kind of material</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>Kg</td>
</tr>
<tr>
<td>Financial life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
</tbody>
</table>

Table 15 Data required to determine the contribution of materials for soil covering to the CF

A3.11. Materials to guide growth

(wires (steel, nylon), nails, tape, posts etc.)

For this group, the same rules apply as for materials in the group pest management. The following data is required in which producer and production location is only of importance to develop the 100% CF.
### A3.12. Packaging materials for the final product
(labels included)

For this group, the same rules apply as for materials in the group pest management except for financial life expectancy. The following data is required in which producer and production location is only of importance to develop the 100% CF.

<table>
<thead>
<tr>
<th>Data request</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials for packaging the final product</td>
<td></td>
</tr>
<tr>
<td>Product</td>
<td></td>
</tr>
<tr>
<td>Kind of material</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>Kg</td>
</tr>
<tr>
<td>Financial life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
</tbody>
</table>

Table 17 Data required to determine the contribution of packaging materials for the final product to the CF

### A3.13. Consumables for maintenance of capital goods
(non fuel oil, cleaning products, cooling agents, urea)

**Urea**

Urea is used to clean gases from a CHP in order to reduce NOx particles before the remaining CO2 will be supplied to the greenhouse. When urea is used to clean flue gases, the following reaction is taking place at temperatures between 950 – 1,000 °C:

\[
\text{CO}(\text{NH}_2)_2 + 2\text{NO} + O_{\text{isn}} \rightarrow 2\text{N}_2 + \text{CO}_2 + 2\text{H}_2\text{O}
\]

O_{isn} are formed radicals during incineration. In reality, the urea will be thermally cracked which results in the formation amongst others of ammonia. The generated ammonia reacts in the following way:

\[
4\ \text{NO} + 4\ \text{NH}_3 + O_2 \rightarrow 4\ \text{N}_2 + 6\ \text{H}_2\text{O}
\]

\[
6\ \text{NO}_2 + 8\ \text{NH}_3 \rightarrow 7\ \text{N}_2 + 12\ \text{H}_2\text{O}
\]

(Koster, 2010)

According to Peter Nijkrake from Codinox there is a linear relation of use of 2.5 litre urea solution (40% mass percentage solution) per hour per MW motor (CHP). No greenhouse gases will be emitted during this process. The density of this solution is 1.11 kg/l (Nijkrake, 2011). The people from Steuler support the statement of COdinox by saying that 2-2.5 litre urea solution per MWh is used (Wagner, 2011). Two different approaches can be followed in order to determine the CF of urea. The amount of litres urea solution can be asked or the power and hours of operation of a CHP can be asked.

---

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According to the estimation of Energy Matters, a CHP will be 4,050 hours in operation (Koolwijk & Schlatmann, 2011).

Kilograms urea/per year = hours of operation * 2.5 * density * 0.4 * power in MW of CHP.

Or Kilograms urea/per year = litres urea/year * density * 0.4

The pilot project should reveal which data collection is the most convenient approach. In order to obtain the amount of N in urea the kg urea will be multiplied by the mass percentage N in urea, which is 46.6%.

An emission factor of 3.49 CO₂-eq/kg N in urea/per year (cradle-to-gate) will be used (Kool, 2011b). Considering this all together indicates that urea is not always negligible in a CF of greenhouse products.

The following washing detergents are stated in the EcoInvent database:

“alkylbenzenesulfonate; carboxymethyl cellulose; DAS-1, fluorescent whitening agent triazinylaminostilben; esterquat, coconut oil and palm kernel oil; esterquat, tallow; ethoxylated alcohols (e.g. (AE11), palm oil, (AE3), coconut oil(AE3), palm kernel oil(AE3), petrochemical, (AE7), coconut oil, (AE7), palm kernel oil, (AE7), petrochemical, unspecified); fatty alcohol sulfate, (e.g. coconut oil, mix, palm kernel oil, palm oil, petrochemical); fluorescent whitening agent distyrylbiphenyl type; layered sodium silicate, SKS-6; polycarboxylates, 40% active substance; soap, sodium (e.g. metasilicatepentahydrate, 58%; perborate, monohydrate; perborate, tetrahydrate; percarbonate; tripolyphosphate, and zeolite (e.g. powder or slurry, 50% in H2O)” (Ecoinvent, 2007).

Their EFs vary between 0.23 and 22.3 kg CO₂-eq/kg detergent. Based on detergent sellers, it can be concluded that detergents probably will have a CF almost equal to 0, while 80 liter detergent per ha/per year will approximately be needed (Ecoprotecta, 2011), assumed cleaning is done twice a year. This is an indication that detergents will form a negligible amount of the CF.

Cooling agents
Commonly used cooling agents have very high EFs. Therefore the amount of kg cooling agents and the type of agent will be asked.

Oil
Oil is used to lubricate capital goods in order to reduce friction. Some of those oils can contain HCFC which have very high global warming potential. The amount of used oils should reveal if this CF is significant. The amount and type of oil will therefore be asked.

Other consumables
The following data is required in which producer and production location is only of importance to develop the 100% CF.

<table>
<thead>
<tr>
<th>Data request</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detergents</td>
<td></td>
</tr>
<tr>
<td>Type of Detergents used</td>
<td></td>
</tr>
<tr>
<td>Amount of detergent</td>
<td>Litres</td>
</tr>
<tr>
<td>Density of detergent</td>
<td>Kg/m³</td>
</tr>
<tr>
<td>Ingredients</td>
<td></td>
</tr>
<tr>
<td>Mass percentages of ingredient</td>
<td></td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
<tr>
<td>Cooling agents</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 3 Data collection of CF for different groups

<table>
<thead>
<tr>
<th>Type of cooling agents</th>
<th>Amount of cooling agent per year Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil used for maintenance</td>
<td>Producer and production location</td>
</tr>
<tr>
<td>Type of oil</td>
<td>Amount of oil used per year Kg</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>Amount of purchased urea or Power or Capacity and operational hours of CHP per year</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
</tbody>
</table>

Table 18 Data required to determine the contribution of consumables for maintenance of capital goods to the CF

A3.14. Capital goods 1

Production of the Greenhouse and all equipment inside and attached to the greenhouse (Greenhouses (incl. foundation, pavement, flooring and piling), plastic tunnels, cultivation grooves, CO2 installation, drainpipes, condense pipes, drip pipes, heat transport tubes, roof sprinklers, sprinkle installation (inside), lights, blinds installation,)

This data collection can be conducted by making use of an adjusted data sheet, made by Peter Vermeulen. Amounts of all specific sizes, types of material will be asked in order to calculate the total CF of the greenhouse with all things in and around it. However, it is concluded this is not feasible to do in this research, because too much data needs to be asked in order to calculate an accurate CF. Therefore the indicator glass in deck is developed which is assumed to contribute 10% to the total CF. Therefore the EF of glass is multiplied by ten and the weight of one m² of glass multiplied by the surface of glass in deck and hereafter multiplied by 0.07 to account for the life expectancy.

Therefore amount of glass in deck should be asked. The life expectancy rate is taken as given, because the indicator is also based on the life expectancies estimated by Vermeulen (P. C. M. Vermeulen, 2009).

A3.15. Capital goods 2

Production of machines, transport means on the farm and other energy using equipment (heat pump, pumps, aquifer, CHP, boiler, geothermal installation, aggregate, solar panels and suchlike, silo’s (as heat- or liquid CO2 storage), climate computer, flue gas purifier, gas and electricity pipes, fuel tanks, water tanks (including dirty water tank, filter and clean water tank), water basin, sorting installation, packaging line, seal installation, stacking machine, cooling installations, tiny means of transport)

From other capital goods, such as sorting machines, packaging lines, seal installation, stacking machine, cooling installation etc. the amount of kg machine will be determined. In this way the EF of industrial machines/kg from Ecoinvent can be used to determine the CF.

For capital goods belonging to the subgroup tiny means of transportation the amount of kg can be asked as well. The EF for agricultural machinery/ kg will be used in order to calculate this CF. A climate computer contributes not a lot to the CF, estimated on the values of PCs given in Ecoinvent. Therefore this subgroup will not be included in this group. Silo’s for storage are assumed to be from plastic. The value 146.1 kg CO2/m³ from Ecoinvent will be used to calculate this contribution. Liquid storage tank for chemicals, organics have an EF of 1,286.3·10³ per unit and will therefore be included. Gas and electricity pipes will not be taken into account, because it is not feasible to collect these data, furthermore the farmer is not able to influence this part of the CF. A hot water tank of 600 l has a EF
Appendix 3 Data collection of CF for different groups

of 658.46 per unit. However, upstream-production of minor components of the capital goods will be excluded, since they are considered to be negligible.

After the pilot was conducted the subgroups to obtain information from were limited to a minimum of six subgroups for the data request. For this group, the same rules apply as for materials in the group pest management. The following data is required in which producer and production location is only of importance to develop the 100% CF.

<table>
<thead>
<tr>
<th>Data request</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production of machines, transport means on the farm and other energy using equipment</td>
<td></td>
</tr>
<tr>
<td>Product</td>
<td></td>
</tr>
<tr>
<td>Kind of material</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>Kg or ton</td>
</tr>
<tr>
<td>Financial life expectancy</td>
<td>Years</td>
</tr>
<tr>
<td>Producer and production location</td>
<td></td>
</tr>
</tbody>
</table>

Table 19 Data required to determine the contribution of capital goods 2 to the CF

A3.16. Capital goods 3

Production of buildings, roads and other pavements and floor covering (boiler house, CHP house, geothermal house, cold store, fertilizer-water mixing room, process accommodation, office, canteen, changing room, loading and unloading space (dock shelter) road to the greenhouse, climate control room, pavements aside the greenhouse, floor covering of the buildings).

For every building except the office, changing room and canteen, the Ecoinvent database EF of a shed will be used which is 217.33 CO₂-eq/m².

For the office, changing room and canteen the m² will be counted. A model is made similar to the approach of Peter Vermeulen, but in this case for office rooms in the Netherlands based on the article by Blok e.a., 2009 (Blok, 2010), this model can be found in Appendix A4. The model assumes building materials travel on average 100 km (return distance) and the energy mix of Europe is used. This is plausible, because building materials used in the Netherlands are not always produced in the Netherlands. This model is fairly simplified. No detailed calculation for sub models have been conducted. Furthermore the real layout office plan could vary a lot from the model, which makes that the model has no great accuracy. However it is precise enough to give a good indication about whether and/or when the CF of buildings in greenhouse horticulture are significant. Piling is beyond the scope of these numbers. The precise effect for the total CF at this moment is unknown.

Road and parking place of the company will be 1.2839 CO₂-eq/m² annually according to Ecoinvent where construction and maintenance is included (Ecoinvent, 2007).

Therefore the surface of parking and roads are asked, the surface of all buildings except the office, changing room and canteen. In addition the surfaces of the rest of the buildings, the amount of floors and the kind of structure, internal partitioning and facade system are asked.

A3.17. Maintenance of all capital goods

This group includes maintenance for all 3 capital goods groups: new parts, third party maintenance, inspections and such like. There is no specific CF information on this subject. Therefore there will be assumed that the percentage of maintenance costs for all capital goods considering the product price
of the produced product will be equivalent to the ratio of CF maintenance of the CF of all capital goods for which data is collected. In formula: Maintenance in euro / revenues of product = CF maintenance_{cap1+2+3} / (CF subtotal + CF maintenance_{cap1+2+3}). In Ecoinvent can be viewed that maintenance can fluctuate tremendously amongst different capital goods. CF percentage fluctuate from 1.3% to 77.1%. By the article of Frischknecht is stated that a high level of maintenance compared to product price will indicate whether capital goods are important.
A4. Model for buildings (office, changing room and canteen)

The model can be obtained in this Excel file. On the left top corner values from the article of Blok of a standard office building are given. Together with the EFs from this article the model is obtained by proportional scaling. The yellow marked fields should be filled in with the data collected from the grower. In the green marked field the CF of the building, in which the office, canteen and changing room are situated, is provided once all the yellow fields are filled in correctly.

A5. Edited Excel sheet of Vermeulen

The edited Excel sheet of Vermeulen can be obtained here. The three columns which are marked red are added. These columns are added in order to gain insight in the relative contribution of the different subgroups for capital goods 1 (marked blue) and capital goods 2 (marked pink). In the tab “samenvatting” the overview of Table 3 can be found. Furthermore the absolute CFs of glass per ha are given and the calculation used for Table 4 can be viewed as well (P. C. M. Vermeulen, 2009).

A6. Data collection Excel sheet test cases

The data collection Excel sheet for the cases is provided here. This file differs from the file in appendix A8, because comments given during the pilot project were inserted. Furthermore, some groups are excluded from this data collection sheet or changed regarding to the former file, as a result of the adjustment of groups.

A7. Data collection results test cases

Unfortunately these results are missing, due to a lack of interest from growers in the Netherlands to supply all data requested in Appendix A6. The partly filled in confidential file from one grower can be viewed here.

A8. Data collection Excel sheet pilot

In the following link the confidential Excel sheet can be found for people who are permitted to view this confidential file. In the tab CF the calculations can be found for the absolute and relative results. The relative results are presented in appendix A9. People who don’t have approval to see the confidential file, can view the following file. This file is not filled in, while the confidential file is filled with data of the company.
A9. Results pilot

The relative result of the pilot can be viewed in Figure 8 and Figure 9. The result is presented in relative contributions for the groups which are defined to be approximately 100% in total. In Figure 8 the result will be given before final determination, while in Figure 9 the result can be viewed after determination of the approximately 100% CF and adjustment of groups. The absolute numbers of the CF can be viewed in the confidential file. In this file CF1 is the result before determination, while CF2 corresponds with the result after determination.

In Figure 8 the CF is presented divided in main groups. All groups smaller than 0.5% are added to form the group “other” in order to get a clear overview of the contribution of the different groups. The large groups external CO\textsubscript{2} fertilizer, fuels, imported electricity, packaging materials for the final product, capital goods 1 and maintenance add up to more than 95% of the approximately 100% CF. Capital goods 2 accounts 0.6% and fertilizer 1.5%, while the remaining groups account less than 0.5% per group. Usually the groups seeds, young plant material, substrate, fertilizer, pesticides, energy and packaging materials for the final product are taken into account.

In Figure 9 the CF all groups smaller than 0.5% are added to form the group “other” in order to get a clear overview of the contribution of the different groups. The large groups external CO\textsubscript{2} fertilizer, fuels, imported electricity, packaging materials for the final product, capital goods 1 and maintenance add up to more than 95% of the approximately 100% CF. Capital goods 2 accounts 0.7% and fertilizer 1.5%, while the remaining groups account less than 0.5% per group.

Figure 8 Relative contribution to the CF of the pilot with the initial division into groups
Figure 9 Relative contribution to the CF of the pilot after revision of the division into groups
A10. Data collection Min-max Excel sheet cases

The analysis of minimum and maximum values discussed in paragraph 3.4 is based on extensive research. This appendix will exactly explain how the minimum and maximum values are collected and calculated to transform them in the right unit to fit the EFs and to let the value correspond with the usage per ha. The result of this approach is presented in an convenient arrangement in Appendix A11. This arrangement could be seen as a summary of which the references are treated separately in this paragraph to make it a readable table.

Even though extensive time is devoted to this research it might be incomplete or excessive, due to a lack of information or time and because some combinations are unknown or assumed to be unrealistic. For example in KWIN only values for about 26 crops are given on which max and min values are based. Furthermore KWIN gives numbers of modern companies which are managed well under average circumstances (P.C.M. Vermeulen, 2010). As already discussed, it is assumed only companies which do well would be interested in a CF and it is assumed that higher values than the values given by KWIN will be unrealistic unless stated differently elsewhere. All emission factors which are used, are discussed in appendix A3 and arranged in appendix A12. Sometimes it is decided to split up groups into subgroups when there is an indication that this could make the analysis more detailed.

A10.1. Seeds
In KWIN only the example of radish is discussed, which has a maximum of about 2,500 seeds per square meter (P.C.M. Vermeulen, 2010). This number is multiplied by 10,000 to receive the amount of seeds per hectare. Afterwards the number is respectively divided by the number 100,000 (123Zaden.nl, 2012) and 130,000 (Wal), because this is the amount of seeds per kg seeds, in order to obtain the final result of the calculations.

A10.2. Young plant material
This group is divided into fruit and vegetables and cut flowers. In the first subgroup there is a maximum of 19.7 plants on a square meter and minimum of 1.6 plants per square meter. In the case of cut flowers there are maximum 403 flowers per square meter and the minimum is 1.5 plants per square meter (P.C.M. Vermeulen, 2010). These numbers are multiplied by 10,000 to obtain the amount of young plant material per hectare. Thereafter they are divided by 1,000 to get the unit 1,000 plants per ha. According to Wim in t Groen from wpk 2,500 km cooled transportation is the maximum distance young plant material travels. For the minimum transport distance 2 km cooled transport is assumed. For transport is assumed that one young plant weights the same as a tomato plant at the company for the pilot, because no data were available on this subject.

A10.3. Substrate
Several substrate producers were contacted. With a combination of the answers of Peter Sonneveld of Polyurethane, Hans de Vette of Forteco and Grodan combined with the studies of Kool on substrate the following calculations are made for the maximum and minimum values. 100 m³/ha and 60 m³/ha are the extremes for vegetables and fruit with a life expectancy of one year for the substrate (Vette,
2012). For cut flowers the values vary between 150 m\(^3\)/ha and 100 m\(^3\)/ha with a financial life expectancy of 3-5 years (Vette, 2012). Polyurethane yields the highest value, while coco and rock wool yield the lowest values. Peat as substrate is not applied in the Netherlands any more, but land is. Therefore the subgroup peat is seen as organic fertilizer and incorporated in that group. Rock wool gives the absolute minimum value by its weight/EF combination. For fruit and vegetables 100 m\(^3\)/ha and 60 m\(^3\)/ha (Vette, 2012) is multiplied by 30 kg/m\(^3\), the density of Polyurethane substrate (Kool, 2011e) and 46.4 kg/m\(^3\) respectively (Kool & Blonk, 2011), the density of rock wool. Thereafter it is divided by 1,000 to get the amount of substrate in tons. The same approach is used for cut flowers, only for this case 150 m\(^3\)/ha and 100 m\(^3\)/ha are divided by 3 and 5 years respectively (Vette, 2012) and multiplied by the densities of Polyurethane and rock wool respectively. Thereafter it is divided by 1,000 to obtain the amount of substrate in tons. The maximum and minimum transport ranges from 10 km as a minimum assumption with the help of maps till 200 km (Kool & Blonk, 2011).

### A10.4. Fertilizers

The extremes for fertilizer are researched by consulting an expert on fertilizers of Sosef. He is consulted about the highest values of fertilizers, focused on nitrogen, because of its relative high emission factors, will be. Tom de Haas of Sosef states that cucumbers and tomatoes need the most fertilizers. Assuming 30% of reuse of drain water 20 tons fertilizer will be used per ha for cucumber and 17 tons per ha for tomatoes, which equals 2000 kg and 1500 kg nitrogen per ha respectively. The fertilizers are calcium nitrate (15.5%), salpetre (13%) and ammonium nitrate (18%). The least a grower will use is about 250-300 kg nitrogen per ha, this is the case with the cut flowers like cymbidium and anthurium. This equals approximately 2500 kg per ha fertilizer. The fertilizers are calcium nitrate (15.5%), salpetre (13%) and magnesium nitrate (7%). Most producer locations are located in Europort, so the fertilizers should travel hundreds of kilometers (Haas, 2012).

The demand for fertilizers mainly depends on the soil and kind of crop used and can be determined by measuring the electrical transmittance of the soil. The electrical transmittance is an indicator of the amount of nutrients available for the crop to absorb. Vegetables that are botanically a fruit demand more fertilizers than ornamental flowers. In addition to this, the more drain water can be reused the less fertilizer is needed.

Compost is mainly used to enhance the organic compounds of the soil, the nutritive value is of secondary importance. However, WUR states that compost can be the main contributor to the nitrogen nutrients which the crops needs. This is mainly because, a maximum of 170 kg N per ha is allowed to have an animal origin. Organic compounds like compost remain to nourish biological crops. The highest number of compost per ha of a biological farm is 185 tons compost per ha (P.C.M. Vermeulen & Lans, 2010, p.14), therefore it is assumed to be the maximum. The rest of nutrients are assumed to have an insignificant contribution to the CF, because the EF of animal origin organic fertilizers is real low, as have been explained in appendix A3. The more compost is used the less synthetic fertilizer and peat will be needed. Maximum compost needed per year is 185 tons per ha per year, but in this case no synthetic fertilizer will be used. It is assumed that large amounts of compost are only used in case biological crops are cultivated.
A10.5. External CO₂ fertilizer
The optimum CO₂ dosage, depends on the costs and benefits which CO₂ fertilizing will bring. When there is more radiation, dosage will be more efficient. Furthermore, efficiency will decrease in case of more ventilation (Mate, 2012). Due to these circumstances, the demand for CO₂ is in summer four times the demand in winter or autumn (Vermeulen, 2011).

The exact statements of Vermeulen, do not seem to fit the Netherlands. The values are therefore multiplied by two, because from the pilot project and research from Blonk Milieu Advies on a company which uses geothermal energy, it is known that their CO₂ demand is about twice as high as Vermeulen states for the values of Koekoekspolder. Furthermore in literature higher values could not be found. The values for external CO₂ fertilizer are according to Vermeulen the following for Koekoekspolder. For a CHP the maximum demand is 100 Kg/hour/ha, with 1,000 of dosage hours, without CHP and boiler it will be 200 kg/hour/ha and 1,750 dosage hours and in case of geothermal application it is expected that there will be a demand of 100 kg/hour/ha for 1,000-1,200 hours (P.C.M. Vermeulen, 2011).

Besides, it could be there is no pipe to supply external CO₂. In that case all CO₂ should be generated by the boiler or CHP. In that case it is expected that more fuels will be used, but there will be more heat or electricity sold as well by those growers.

A10.6. Pesticides
Maximum values are hard to find, but values can be found for the crops which use most pesticides in active ingredient per ha (‘Gebruik van gewasbeschermingsmiddelen in de landbouw per gewas, 1995-2008,” 2010). If this table “28g” is compared with the other graph it seems that the values are probably not underestimated (‘Land- en tuinbouw cijfers “, 2011).

A10.7. Other pest management
For this calculation the calculation for the pilot study is used due to a lack of information provision by sellers. As a minimum all things not necessary for biological cultivation are left out of the minimum values, like pesticide spreaders.

A10.8. Energy
No data from practice were available for this analysis. Therefore it is chosen to mainly use the values of KWIN. These data are based on averages of well-managed, modern companies and are validated by tests on real locations (P.C.M. Vermeulen, 2010).

The absolute minimum of CF is the case of geothermal heat in combination with grey electricity which is in operation at one company at the moment. Other renewable energy sources limit CO₂ emissions less significantly (Velden & Smit, 2011). Moreover, remaining heat is not limiting CO₂ reduction as much as geothermal heat (Schepers & Buck, 2009). Only general average numbers are available in papers. Therefore the minimum and maximum values of KWIN are used. A distinction is made for four different categories. One is cold cultivation (< 25 m³/m² natural gas equivalent), which is at a minimum for radish and a maximum for lilies. In all cases fuels, electricity and electricity supply to the grid are taken into account. Another subgroup is warm cultivation by using a boiler. In
this case anthurium has the lowest CF, while lisanthus has the highest value. Furthermore there is the subgroup warm cultivation in combination with a CHP. Courgette is here at the minimum, while roses have the highest CF (P.C.M. Vermeulen, 2010). For geothermal heat, the exact values of the only grower which uses geothermal heat in combination with grey electricity, are taken. The worst case is assumed to use the most electricity known for this case. The calculations are as follows (((11.35 + 19.39) * 0.447)) * 10,000 and (((15.5 + 9.1) * 0.447) + (12.05 * 31.65 * (0.003222 + 0.068371))) * 10,000 in which 0.447 is the EF for grey electricity.

A10.9. Packaging materials for raw material input
Polyurethane uses the most packaging materials (0.076 kg/kg) when substrate is used, whereas stone wool uses the least (0.0164 kg/kg). Subgroups are made to distinguish the use of vegetables and fruit from cut flowers. Furthermore the rest of the packaging is determined by waste output, where paper and cardboard are distinguished from other waste like plastics. Only the information of the pilot project was available. Together with this grower it has been estimated that these numbers will not differ a lot from other growers per ha.

A10.10. Materials for soil covering
The minimum is set to zero, in case no foil is used. The maximum is set to the same amount as the pilot project, because the whole floor was covered and there is no material known for this purpose with a larger emission factor.

A10.11. Materials to guide growth
Again two subgroups are formed: fruit/vegetables and cut flowers. The minimum for cut flowers is determined by information from Wire weaving, a producer of flower gauze, which state that 4.25*10^{-3} kg iron is the minimum weight per m² for flower gauze used per year, where the maximum is 0.136 kg iron per year per m² which is used as flower gauze. The minimum for fruit and vegetables is set to 0, while the maximum is determined with the information of the pilot plus telephonic information from the company Deleco which sells materials to guide growth, by suggestion of the company Sosef, which stated 1,800 kg PP for clips and 168 kg PP for gregarious irons could be used. These high values combined is only possible in the case of tomatoes, because some of these elements like gregarious irons are only used in case of tomato cultivation.

A10.12. Packaging materials for the final product
The company Greenery suggested to call Prominent, which gave numbers for packaging materials for tomato, however by measuring packaging from the supermarket higher values could be found, hence those values were used as maximum. While minima and maxima are dependent on the output of yield, these numbers can be crop specific. Furthermore bottles are only used in the case of orchids, therefore a subgroup is made for orchids, flowers and vegetables/fruits. Table 134c ("Land- en tuinbouw cijfers ", 2011) is used to convert pieces lettuce into kg.

For flowers it has been assumed that flower covers are used to pack 10 flowers. The covers weight 5 grams per piece (FloraHolland, 2011, p.9) and are made of PE or PP (Packaging). Furthermore one cardboard box is used for 80 flower covers of 1.2 kg of cardboard each (FloraHolland, 2011, p.9). It
is assumed that for lettuce 250 mm from a role of LDPE foil: 250 mm/404 m/50 µm which weights 10 kg (Amercom) to pack small crops of lettuce. This is assumed to be the minimum, while packaging tomatoes is assumed to be the maximum in case of vegetables. The values gathered by telephone for boxes are combined with measurements with products from supermarkets.

**A10.13. Consumables for maintenance of capital goods**

Detergent is zero in case of the minimum value, while the values of the pilot project are assumed to be maximum values while no other values could be found.

The amount of lubricating oil is zero at its minimum and the maximum is determined by assuming the case of the pilot project, but with an adjustment for more operation hours (5,000 hours).

The amount of cooling agents is zero in case of no cooling, while it can become 30 kg per ha per 15 years. The cooling agent R410a has the highest possible EF in the Netherlands (ClimateQ, 2012).

The minimum use of urea is 0, in case no flue gas cleaning takes place. For the maximum is assumed that 700,000 clean CO₂ is needed (see subappendix A10.5). In this case 5,000 hours of use is assumed, while this is possible in the case of roses. The use of urea is calculated per year by multiplication of the hours of operation by 2.5 (amount of liters solution per MWh) and 0.4 (concentration of the solution) and the density of urea (1.11 kg/l) and the power in MW of a CHP.
A10.14. Capital goods 1
The proxy is determined by calculation of the highest value of all examples from Vermeulen and the pilot project. The data from the pilot project lie between the values of Vermeulen, therefore the highest values of Vermeulen will be taken as a maximum. The minimum is set as the minimum in the excel sheet of Vermeulen, excluding potplants, because they are left out of scope.

A10.15. Capital goods 2
In this group a distinction is made between cases with and without CHP. Calculation for minimum values are done based on a 23 ha farm, while minimum calculations are based on a 0.9 ha farm. In case of no scale advantages values of the pilot study and Vermeulen are used. Furthermore life expectancy are based on this information. Some equipment not required in some cases and is therefore excluded to calculate minimum values.

A10.16. Capital goods 3
The size of office buildings is based on the amount of employees per ha (Finder, 2012) and the amount of ha of the company (P.C.M. Vermeulen, van der Lans, & de Buck, 2004, p.102). With the model based on standardized offices the CF can be calculated, therefore the amount of squared meter calculated by these data should be devided in realistic shapes of buildings for minimum and maximizing the CF (Blokk, 2010). The surface of the sheds is calculated with the information of Vermeulen and the amount of ha. The size of parking lot and other pavements is indicated by parking numbers (Deege, 2010; Reumers, 2008)
A11. Data collection results min-max cases

Before determination the groups seeds, pesticides and transport was included. This confidential sheet gives the situation before those groups were excluded or adapted. This overview is put in the appendix, so formulas can be viewed. Furthermore the calculation of which groups need to be included or excluded can be seen in this file. Groups in red, which contribute less than 0.5% in a specific circumstance, can be viewed. Orange are the parts which do not contribute to the 95% CF, but contribute more than 0.5%, while green means the group contributes to the 95% CF.

After determination the min-max analysis is done again, since the 100% CF has changed, because multiple groups were adapted. This confidential file has the same features as the file mentioned above. The only difference is that the calculation for the quantitative model can be viewed on the right side of the sheet. Therefore it can be viewed where the numbers in the quantitative model originated from.

Both files are confidential, because absolute numbers based on the case study are used in several (sub)groups. When those numbers are known, numbers of the case study could be calculated with the help of the relative values which are perceptive for everyone.
### A12. Table of applied emission factors

<table>
<thead>
<tr>
<th>Description</th>
<th>EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (grey), corrected 2010</td>
<td>447 kg CO$_2$/(kWh (Bles &amp; Wielders, 2011, p.13))</td>
</tr>
<tr>
<td>Seeds (excluding transportation)</td>
<td>1.10 kg CO$_2$-eq/kg (Gaillard, 1997)</td>
</tr>
<tr>
<td>Diesel for transport*</td>
<td>3.731 kg CO$_2$-eq per kg (Ecoinvent, 2007; Gargand &amp; Pulles, 2006, diesel, at regional storage and combustion)</td>
</tr>
<tr>
<td>Oil for transport*</td>
<td>3.574 kg CO$_2$-eq per kg which consist of upstream: 0.452kg CO$_2$-eq per kg (density 1.0 kg/l) (Ecoinvent, 2007; heavy fuel oil, at regional storage) and combustion: 3.122 kg CO$_2$-eq/kg (Gargand &amp; Pulles, 2006)</td>
</tr>
<tr>
<td>Kerosene for transport*</td>
<td>3.825 kg CO$_2$-eq per kg (Ecoinvent, 2007; Gargand &amp; Pulles, 2006, kerosine, at regional storage and combustion)</td>
</tr>
<tr>
<td>Young plant material (excl. tomatoes) cultivated in heated greenhouses</td>
<td>7.151 kg CO$_2$-eq per 1,000 plants (Mombarg &amp; Kool, 2004; Sukkel, 2002)</td>
</tr>
<tr>
<td>Young plant material (excl. tomatoes) cultivated in non-heated greenhouses</td>
<td>10.7 kg CO$_2$-eq per 1,000 plants (Mombarg &amp; Kool, 2004; Sukkel, 2002)</td>
</tr>
<tr>
<td>Young plant material (regular tomatoes)</td>
<td>8.8 kg CO$_2$-eq/kg (Nienhuis &amp; Vermeulen, 2008)</td>
</tr>
<tr>
<td>Young plant material (biological tomatoes)</td>
<td>9.2 kg CO$_2$-eq/kg (Nienhuis &amp; Vermeulen, 2008)</td>
</tr>
<tr>
<td>Substrate coco * (excluding transportation)</td>
<td>146 kg CO$_2$-eq/ton substrate (Kool, 2011d)</td>
</tr>
<tr>
<td>Substrate polyurethane* (excluding transportation)</td>
<td>4,460 kg CO$_2$-eq/ton substrate (Kool, 2011e)</td>
</tr>
<tr>
<td>Substrate stone wool* (excluding transportation)</td>
<td>146 kg CO$_2$-eq/ton substrate (Kool, 2011c; Kool &amp; Blonk, 2011)</td>
</tr>
<tr>
<td>Substrate coco bags</td>
<td>302 kg CO$_2$-eq/ton substrate (Kool, 2011d)</td>
</tr>
<tr>
<td>Substrate polyurethane</td>
<td>6,361 kg CO$_2$-eq/ton polyurethane (Kool, 2011e)</td>
</tr>
<tr>
<td>Substrate stone wool</td>
<td>919 kg CO$_2$-eq/ton (Kool, 2011b; Kool &amp; Blonk, 2011)</td>
</tr>
<tr>
<td>Substrate coco</td>
<td>544 kg CO$_2$-eq/ton (Kool, 2011c, p.16).</td>
</tr>
<tr>
<td>Fertilizer: compost excl. transport</td>
<td>0.163 CO$_2$-eq/kg (Dekker, et al., 2009).</td>
</tr>
<tr>
<td>Fertilizer: Phosphate (excl. transport)</td>
<td>3.37 CO$_2$-eq/kg P (Davis &amp; Hagnud, 1999; AppendixC, 16).</td>
</tr>
<tr>
<td>Fertilizer: potassium sulphate (excl. transport)</td>
<td>0.53 CO$_2$-eq/kg K (Williams, et al., 2006).</td>
</tr>
</tbody>
</table>
| Fertilizer: Nitrate not provided by PDV project (excl. transport)          | 7.41 + 298 * 44 * (VF * EF + 0.0075 + VF * 0.011) / 28 CO$_2$-eq/kg N/haar will be used.  
  \( (0.782 * 1 + 0.0080/6 * 25 + 0.039 * 298) / 0.265) \) (Davis & Hagnud, 1999; AppendixC, 12) + (VF * EF + 0.3 * UF + VF * Dep) * 298 * 44 / 28 (Scholten, et al., 2010, p. 25-27) 
  = 11.4 kg CO$_2$-eq/kg N |
| Fertilizer: Peat (excluding transport and packaging)                       | 802 kg CO$_2$-eq/ton (Kool, 2011a)                                  |
| Ammoniumnitrate                                                           | 7.99 kg CO$_2$-eq/kg N (Kool, 2011b)                               |
| Bitterzout MgO                                                            | 0.2969 kg CO$_2$-eq/kg (Ecoinvent, 2007, magnesiumsulfate at plant, RER) |
| Calciumchloride flakes                                                    | 0.85342 kg CO$_2$-eq/kg (Ecoinvent, 2007, calcium chloride at plant, RER) |
| Borax Bo powder                                                          | 1.6475 kg CO$_2$-eq/kg (Ecoinvent, 2007, Borax, anhydrous, powder, at plant, RER) |
| Zincsulfate Zn powder Monohydrate                                         | 1.8083 kg CO$_2$-eq/kg (Ecoinvent, 2007, zinc monosulphate, ZnSO4.H2O, at plant, RER) |
| Inorganic chemical, unspecified                                           | 1.8585 kg CO$_2$-eq/kg (Ecoinvent, 2007, inorganic chemical)      |
| Monokaliumfersoate                                                        | 7.15 kg CO$_2$-eq/kg (0.646 * 1 + 0.001*719 * 25+0.001 * 298) / (0.48) |}

### Pesticides (excluding transport)

Several EFs of active ingredients are listed in Tab. 10.3 of Ecoinvent (Nemecek, et al., 2007p. 102-103) If the pesticide is not known or not mentioned in this table "pesticide unspecified" will be used of the Ecoinvent database (Ecoinvent, 2007): 7.8106 kg CO$_2$-
### Table 20 Emission factors of several products applied in this thesis

<table>
<thead>
<tr>
<th>Product</th>
<th>CO₂-eq/kg or m² or per MJ or per day</th>
<th>Reference(s)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other pest management: insects</td>
<td>4.00 g CO₂-eq/kg biomass per day</td>
<td>Oonincx et al., 2010</td>
<td></td>
</tr>
<tr>
<td>Other pest management: plants (heated)</td>
<td>47.4 kg CO₂-eq per 1000 plants</td>
<td>Mombarg &amp; Kool, 2004; Sukkel, 2002</td>
<td></td>
</tr>
<tr>
<td>Other pest management: plants (non-heated)</td>
<td>10.7 kg CO₂-eq per 1000 plants</td>
<td>Mombarg &amp; Kool, 2004; Sukkel, 2002</td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.060 kg CO₂-eq/MJ, consisting of production (Ecoinvent, 2007; natural gas, high pressure, at consumer for the Netherlands) and incineration (&quot;Monitoringseisen CO₂,&quot; 2011).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas burned in boiler at grower</td>
<td>0.071 kg CO₂-eq/MJ, consisting of production and incineration (Ecoinvent, 2007; natural gas, high pressure, at consumer for the Netherlands; natural gas, burned in boiler condensing modulating &gt;100kW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas burned in CHP at grower</td>
<td>0.078 kg CO₂-eq/MJ, consisting of production and incineration (Ecoinvent, 2007; natural gas, high pressure, at consumer for the Netherlands; natural gas, burned in cogen 1MWe lean burn) (Ecoinvent, 2007; natural gas, high pressure, at consumer for the Netherlands)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar collector</td>
<td>106.54 kg CO₂-eq/m² (Ecoinvent, 2009)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>3.49 CO₂-eq/kg N (Kool, 2011b)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Emission factors used before 100% CF was defined
## Table of applied emission factor

<table>
<thead>
<tr>
<th>Material</th>
<th>EF in CO₂-eq/kg excl. Incineration</th>
<th>Heat value (MJ/kg)</th>
<th>EF recovery of electricity (20%)</th>
<th>EF recovery of heat (5%)</th>
<th>EF incineration</th>
<th>Total EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>5.2974</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.0000</td>
<td>5.2974</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>0.13517</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.13517</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>1.0925</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.0000</td>
<td>1.0925</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>2.702</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.0000</td>
<td>2.702</td>
<td></td>
</tr>
<tr>
<td>LDPE</td>
<td>8.0191</td>
<td>28.0</td>
<td>0.695</td>
<td>0.084</td>
<td>2.9962</td>
<td>4.919</td>
</tr>
<tr>
<td>Nylon</td>
<td>2.8951</td>
<td>32.0</td>
<td>0.795</td>
<td>0.096</td>
<td>5.606</td>
<td>12.734</td>
</tr>
<tr>
<td>PE</td>
<td>4.8786</td>
<td>43.0</td>
<td>1.068</td>
<td>0.129</td>
<td>2.9962</td>
<td>4.694</td>
</tr>
<tr>
<td>Polyester</td>
<td>3.5138</td>
<td>27.0</td>
<td>0.671</td>
<td>0.081</td>
<td>2.2900</td>
<td>6.417</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>3.5584</td>
<td>40.0</td>
<td>0.993</td>
<td>0.120</td>
<td>3.1674</td>
<td>5.568</td>
</tr>
<tr>
<td>Steel</td>
<td>7.7876</td>
<td>0.0</td>
<td>0.0000</td>
<td>0.0000</td>
<td>3.5584</td>
<td></td>
</tr>
<tr>
<td>Undefined plastic</td>
<td>0.907735</td>
<td>31.0</td>
<td>0.795</td>
<td>0.096</td>
<td>2.7700</td>
<td>9.695</td>
</tr>
<tr>
<td>Cardboard to keep bees</td>
<td>15.3</td>
<td>0.380</td>
<td>0.046</td>
<td>0.02435</td>
<td>7</td>
<td>0.506</td>
</tr>
<tr>
<td>Cardboard and paper in</td>
<td>15.3</td>
<td>0.380</td>
<td>0.046</td>
<td>0.02462</td>
<td>2.333</td>
<td>0.60</td>
</tr>
</tbody>
</table>
### Appendix 12 Table of applied emission factor

<table>
<thead>
<tr>
<th>Material</th>
<th>Emission factor</th>
<th>Density (kg/m³)</th>
<th>CO₂e factor</th>
<th>Methane factor</th>
<th>Nitrous oxide factor</th>
<th>N₂O factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>rubbish bin*</td>
<td></td>
<td>120</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other waste*</td>
<td></td>
<td>150</td>
<td>0.00</td>
<td>0.000</td>
<td>0.50484</td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>1.9825 (Ecoinvent, 2007)</td>
<td>1.093</td>
<td>1.093</td>
<td>1.093</td>
<td>1.093</td>
<td>1.093</td>
</tr>
<tr>
<td>PLA</td>
<td>3.85 (Broekema, 2010)</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>PE</td>
<td>2.702 (same value as LDPE)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>PET</td>
<td>1.467 (Broekema, 2010)</td>
<td>2.290</td>
<td>2.290</td>
<td>2.290</td>
<td>2.290</td>
<td>2.290</td>
</tr>
</tbody>
</table>

*Emission factors used before 100% CF was defined*

Table 21 Emission factors of several materials applied in this thesis