EUPHOROS

DELIVERABLE 5.

Report on environmental and economic profile of present greenhouse production systems in Europe

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EUPHOROS DELIVERABLE 5

EUPHOROS: Reducing the need for external inputs in high value protected horticultural and ornamental crops

Report on environmental and economic profile of present greenhouse production systems

WP1 Environmental and economic assessment

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EUPHOROS DELIVERABLE 5

ABSTRACT

Deliverable 5 of the EUphoros project presents the environmental and economic assessment of the current situation in European greenhouses. An initial analysis of the resource requirements of existing greenhouse operations will help to both establish standards and identify potential “bottlenecks” associated with the different scenarios. With this purpose, four scenarios that are representative of the European geography have been considered: a) tomato crop in a multitunnel greenhouse in Spain; b) tomato crop in a glass greenhouse in Hungary; c) tomato crop in a Venlo greenhouse in the Netherlands; and d) rose crop in a Venlo greenhouse in the Netherlands.

In terms of the environmental assessment the bottlenecks associated with the different scenarios were identified and can be summarised as follows: fertilizers represent an important burden in all impact categories. For some scenarios the quantity of fertilizer applied is visibly high. Closed-loop irrigation systems should therefore be implemented. The manufacturing of substrate has an important environmental impact. Recycling used substrate and reducing the volume of substrate applied per plant were both to be strongly encouraged. Also, the consumption of energy in greenhouse heating for tomato and rose production and lighting for rose production is a major issue to be considered. With regard to to greenhouse structure, the large amount of steel in the frame was reflected in the results. Its environmental impact could be reduced by extending the life span of the greenhouse and by increasing productivity

In terms of the economic assessment, the total output, costs and net financial results were determined. The cost-benefit analysis reflected the following considerations: Equipment and labor were the highest cost components for the four scenarios; when cogeneration is not used, energy costs were very high in the Netherlands because of gas natural consumption therefore efforts in energy savings could reduce this item; and more efficiency in doses fertilizers could reduce fertilizers costs.

During the course of the project, the “tools” devised in the other work packages will be evaluated both for their environmental impact (the carbon footprint of the equipment, an impact assessment) and economic viability.

EXECUTIVE SUMMARY

Introduction

The **EUphoros** project aims to develop a sustainable greenhouse with a reduction of external inputs yet with high productivity and an efficient use of resources. Research institutes and companies from the main European countries specializing in greenhouse crop production participate in this project: The Netherlands, Spain, Italy, The United Kingdom, Hungary, Switzerland and Latvia.

One of the EUphoros Work Packages: Work Package 1 (WP1) deals with the environmental and economic sustainability of the greenhouse production system. An initial analysis of the resource requirements of existing greenhouse operations will help to both establish standards and identify potential "bottlenecks" associated with the different scenarios. During the course of the project, the "tools" devised in the other work packages will be evaluated both for their environmental impact (the carbon footprint of the equipment, an impact assessment) and economic viability, since only elements that positively contribute to the competitive strength of the enterprise were likely to be adopted by the end-users.

Within the framework of WP1 and as a result of completing Task **1.1: "Analysis of the resource inputs and cost-benefits of existing greenhouse operations",** Deliverable 5 of the **EUphoros** project presents an environmental and economic assessment of the current situation in European greenhouse production. This environmental and economic profile will be used as a reference for comparisons with potential improvements developed in the course of this project.

Methodology

The environmental analysis was conducted using the Life Cycle Assessment methodology as defined by the ISO 14040 standard. The economic assessment was based on a Cost-Benefit analysis.

The following phases were considered:

- Goal and scope definition
- Inventory
- Life Cycle Impact Assessment (LCIA) (in the environmental analysis)
- Cost-benefit analysis (in the economic assessment)
- Interpretation
- Sensitivity analysis (in the economic assessment)

The goal of the first year (**Task 1.1, WP1**) was to conduct an environmental and economic assessment of the current situation of greenhouse production in Europe and to identify the major sources of environmental and economic burdens.

The scope of the study was determined in order to achieve this purpose. Four scenarios that were representative of European geography were considered:

a) Tomato crop in a multi-tunnel greenhouse in Spain
b) Tomato crop in a Venlo greenhouse in Hungary
c) Tomato crop in a Venlo greenhouse in The Netherlands
d) Rose crop in a Venlo greenhouse in The Netherlands

The functional unit (FU) refers to the main function of the system analysed. Since the most important function in horticultural and ornamental crops is the production of vegetables and flowers, the functional unit chosen is the horticultural production of 1000 kg of tomatoes for tomato crops and 1000 stems for rose crops.

The system boundary defines the unit processes to be included in the product system, which is the model for life cycle greenhouse production. The system boundary was defined "up to farm level" including material disposal: neither post-treatments nor marketing processes were taken into account. Several processes were considered for the environmental analysis including raw materials; inputs and outputs in the manufacture of greenhouse components; the transport of materials; disposal processes; water, fertilizer and pesticide consumption; and lighting and heating.

For the economic analysis, costs and benefits were considered. The costs included were: planting material, water, fertilizers, pesticides and energy; labour and contractors; tangible assets (depreciation and maintenance); interest payments; and general costs. The benefits considered were yield (tomatoes/roses) and sales of electricity (Dutch situation).

The technical and economic data presented in the inventory were separately collected for each scenario. For this purpose, questionnaires were drawn up by the IRTA and Wageningen UR and sent to the responsible partners: the Experimental Station of Cajamar in Almería, Spain; Mórakert in Hungary; and Wageningen UR, in The Netherlands.

For the **inventory analysis** the crop production system was structured in several stages or processes in order to facilitate the study and interpretation of the results obtained. The stages considered were: the structure, auxiliary equipment, the climate system, fertilizers, phytosanitary treatments, waste and transport

Data from the inventory analysis were used in the **Life Cycle Impact Analysis** to evaluate the significance of potential environmental impacts. The impact categories selected for the environmental assessment were: one inventory indicator (water use); one energy flow indicator (Cumulative Energy Demand) and five impact categories (i.e. Abiotic Depletion, Global Warming, Air Acidification, Eutrophication and Photochemical Oxidant Formation). The inventory also served as the data source for the **Cost-Benefit Analysis** for the economic assessment. The cost-benefit analysis will show the economic implications of (different combinations of) input reducing options for the four greenhouse scenarios.

All these results were discussed during the **interpretation** phase to reach conclusions, explain limitations and provide recommendations to decision-makers.

Results

The main results and issues that could be improved were described for the reference situation relating to each scenario:

a) Tomato production under in a multi-tunnel greenhouse in Spain. A multi-tunnel greenhouse is an unheated passive system that needs little energy and inputs other than fertilizers and water. The main environmental burdens and cost components of the production system for this scenario were presented in Figures 1a, 1b and 2a.

- Structure: Structure was the main contribution to all the different impact categories except Eutrophication (Figure 1a).The large amount of steel in the frame was reflected in the results. Its environmental impact could be reduced by extending the life span of the greenhouse and by increasing productivity, which is low in Spain. Plastics also made an important contribution to the impact categories. Plastics made the largest contribution to Abiotic Depletion and Cumulative Energy Demand.

- Auxiliary equipment: Auxiliary equipment had a high environmental impact because of the consumption of electricity by the watering system and in the manufacturing of perlite. Electricity consumption included the consumption required by pumps and injectors to water the crop. This was the main burden in the Air Acidification, Eutrophication and Cumulative Energy Demand categories. Substrate processes include the manufacture of perlite and plastic bags as well as transport to the greenhouse; the manufacturing of perlite was the most significant. Substrate presented the highest contribution scores to the impact categories relating to Abiotic Depletion Potential and Global Warming Potential (Figure 1b).

- Fertilizers: fertilizer use entailed environmental impacts as a result of both manufacturing processes and emissions. Fertilizer application is an important process that the EUphoros project needs to examine in detail. An efficient balance of the two fertilizers and water is recommended. Emissions due to the use of fertilizers made a very high contribution to the Eutrophication category. With regard to the risk of eutrophication, it should be noted that the methodologies currently used to assess the amount of fertilizer reaching the aquifers were only approximate and subject to debate.

- In the economic assessment, tangible assets and labour were responsible for almost 60% of total costs. The cost associated with the structure of the greenhouse and other equipment amounted to almost 1/3 of the total cost. The variable costs of crop protection and energy were low (3-4%). Fertilizer costs amounted to 7% of the total costs (Figure 2a).

- For this scenario, a reduction in fertilizer use could potentially be used to create a high investment capacity, especially if inputs or emissions of fertilizers can be reduced by 50%. The question is whether halving fertilizer inputs would be realistic in terms of plant growth and development. Furthermore, halving the use of pesticides could offer a saving of nearly 0.9 €/m^2 of investment capacity.

b) Tomato production in a Venlo greenhouse in Hungary. The main burdens for this scenario were:

- Structure: The large amount of metal in the frame was reflected in the results which showed the highest burden for all the impact categories. In Hungary, greenhouses must be designed to bear the weight of snow. This makes it necessary to reinforce greenhouse frames. It may consequently be difficult to reduce the amount of metal in their frames. Nevertheless, more effort could be oriented in this direction in order to improve design and thereby reduce the amount of materials used and their environmental impact.
- Fertilizers. Fertilizers were an important burden in all impact categories. The quantity of product applied was visibly high. This is particularly clear when the use of fertilizers in Hungary was compared with tomato production elsewhere, where similar yields were achieved with much less fertilizer. Efforts should be made to reduce doses. This could be achieved by developing a better fertilization programme and by changing from an open-loop irrigation system to a closed-loop recirculation system. Emissions to water would then be significantly reduced, as would their contribution to the Eutrophication impact category.
- Climate system: environmental impacts were assessed considering two energy source options: the use of natural gas and the use of thermal water (Figures 1c and 1d). The former reflects the current situation in the Hungarian scenario and the latter was a supposition for the study. When using thermal water, the high scores in the climate system were due to electricity consumption. When considering natural gas for greenhouse heating, the contribution of the climate system to the Abiotic Depletion and Cumulative Energy Demand impact categories increased significantly. Unfortunately, the use of thermal water is not wide spread in Hungarian greenhouse production because of the economic investment necessary for its installation.
- In scenario 2, more cost components had a substantial effect on total costs: tangible assets, labour, fertilizers and energy. These cost components contributed 75% of total costs. It is noticeable that the cost of fertilizers was relatively high in comparison to tomato production in scenario 1 or 3. In scenario 2 the cost of crop protection (3%) was limited (see Figure 2b).
- The sensitivity analysis for the economic situation showed that fertilizer-reducing options were interesting. Halving inputs by 50% could be realistic, because in the reference situation the drain off water was not collected for re-use. Reducing geothermal water consumption also offers the possibility of reducing the energy demand of the greenhouse.

c) Tomato production in a Venlo greenhouse in The Netherlands. The main burdens were:
   - Climate system: results for this scenario without cogeneration showed that the climate system made the main contribution to the Abiotic Depletion, Eutrophication, Global Warming and Cumulative Energy Demand categories and was responsible for between 44% and 96% of the total impact (Figure 1e). The large amount of natural gas used to heat the greenhouse was the main reason for such high environmental impacts. The use of a cogeneration system to heat the greenhouse could significantly offset natural gas consumption and its environmental impact because of the large amount of electricity produced. The reduction in the environmental burden associated with the cogeneration process is discussed in this Deliverable.
   - Auxiliary equipment: the LCIA showed the importance of substrate contribution to the different impact categories. This is also one of the improvement targets of the Euphoros project. Process contributions were represented in Figure 1f. Substrate processes include the manufacture of rockwool and plastic bags as well as transport to the greenhouse. Rockwool manufacture was the most significant of the three.
   - The greenhouse production systems in The Netherlands were more capital intensive than those in Hungary and Spain. This is mainly due to higher levels of investment in greenhouse structure, climate systems and fertirrigation systems. Nevertheless, the difference between total outputs and total costs for all four scenarios was more or less the same.
   - Total costs mainly depended on natural gas consumption, tangible assets and labour. Energy accounted for 31% of total costs (Figure 2c). The costs attributable to fertilizers and crop protection were relatively small (1-2%).
   - Energy saving options could be very favourable in this scenario. By saving 10%-50% of energy, investment capacity would rise from 10 to 52 €/m^2. In scenario 3 halving the use of pesticide could also have an interesting influence on investment, as cold other cost reducing options (such as improving pest control). However, reductions in energy consumption can have a negative economic effect if cogeneration is used to produce heat and power at the farm level and the excess electricity is sold to the national grid.

d) Rose production in a Venlo greenhouse in The Netherlands. The main burdens were:
   - Climate system, even including cogeneration, this clearly made the highest contribution to all the impact categories with contributions of between 88% and 99% (Figure 1g). There were two reasons for such a high environmental impact: the consumption of natural gas to heat the greenhouse and the consumption of electricity for lighting (Figure 1h). In this scenario, although cogeneration helped to mitigate environmental impacts, it was not able to completely prevent them.

Cogeneration could not supply all the electricity needed for rose production, so a large amount of electricity had to be bought from the national grid.

- Energy, tangible assets and labour (see Figure 2d.) were also the main cost components for rose production, as they were for tomato production in The Netherlands. Together, these cost components accounted for 80% of total costs. In this scenario, a high volume of fossil energy (natural gas) was used, not only for heating but also for lighting (for electricity production using a heat-power generator). The cost of fertilizers and crop protection agents amounted to only 1-3% of total costs.
- For rose production in The Netherlands, an energy saving of 10%-50% entailed an increase in investment capacity from 23 to 118 €/m^2. Even so, a 50% energy reduction would be difficult to envisage because of the high energy input associated with lighting.

Conclusions

In terms of the **environmental assessment**, the bottlenecks associated with the different scenarios were identified.

The main conclusions for the four scenarios were:

Tomato production in Spain

- There is strong potential for increasing tomato yields in southern Spain. Technological improvements developed during the project will help to increase yield and thereby directly reduce the environmental burden per unit of produce.
- An efficient balance of both fertilizers and water is recommended, since a soilless system is an open system.
- The manufacturing of substrate (perlite) has an important environmental impact. Recycling used substrate and reducing the volume of substrate applied per plant were both to be strongly encouraged.

Tomato production in Hungary.

- With respect to geothermal heating, natural gas for heating significantly increases the contribution of the climate system to various impact categories (mainly abiotic depletion and cumulative energy demand). Energy saving is therefore needed in Hungary.
- Fertilizers represent an important burden in all impact categories. Compared with the other scenarios, the quantity of fertilizer applied is visibly high. Closed-loop irrigation systems should therefore be implemented.

Tomato production in The Netherlands.

- Greenhouse production in Holland is an efficient process in which most inputs were carefully considered. Nevertheless, this system requires intensive technology and intensive use of materials and energy.

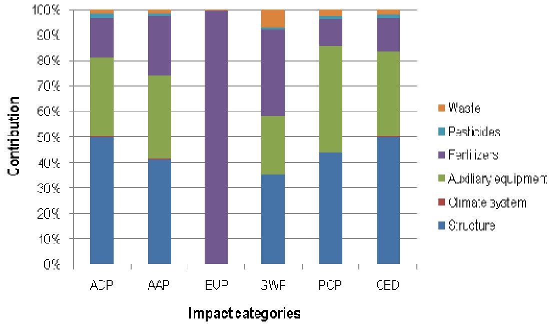
- Substrate represents an important burden because of the high energy consumption inherent to its manufacturing process. Finding better options for substrate recycling and manufacturing were particularly important for this scenario.

Rose production in The Netherlands

- The cumulative energy demand for this scenario is the highest amongst all the scenarios considered in this study. Energy saving is therefore a key factor.
- The plastic elements used in the watering system have a considerable environmental impact due to the large number of plants per unit of surface.

In terms of the **economic assessment,** the following conclusions or remarks can be made:

- the level of output, costs and investments differ between scenarios and is related to the specific performance of the reference greenhouse system in each scenario.
- greenhouse systems were more capital intensive in The Netherlands than in Hungary and Spain.
- in all the scenarios considered equipment and labour costs make a substantial contribution to total costs.
- energy costs were substantial in scenarios 4, 3 and 2 (36, 31, 11 % respectively).
- fertilizer cost is substantial in Hungary (19%) and relatively significant in Spain (7%).
- crop protection is not a very important factor in any of the scenarios, particularly when looked at from the cost point of view (1-4%). Finding ways to reduce the use of pesticides would be economically attractive, but represents a major challenge.
- reducing input costs will be particularly interesting for investment in energy saving (scenarios 2, 3 and 4) and fertilizer reducing (scenario 2) options.
- Reducing the use of pesticides is of some interest in terms of investment capacity in scenarios 2 and 3, but the risk of yield loss is much higher than in the case of reducing energy or fertilizer inputs.


Contribution
Impact categories
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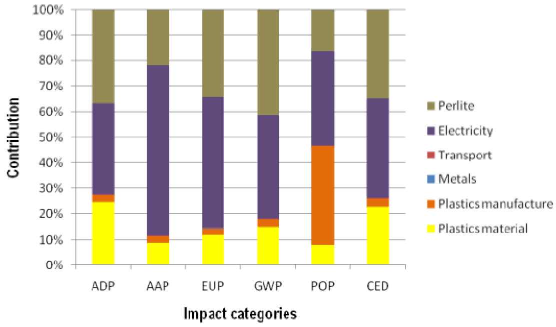
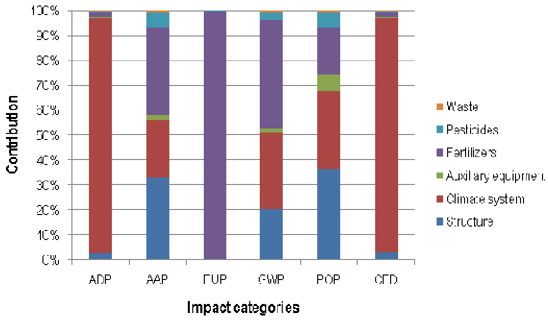
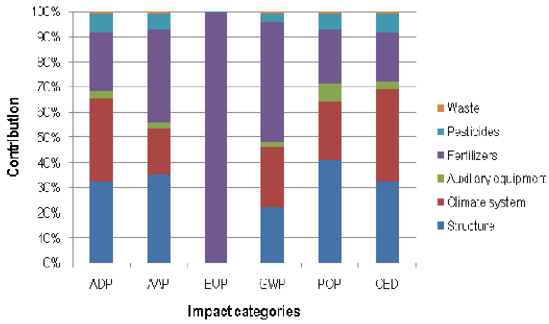
AAP
EUP
GWP
POP
CED
Waste
Pesticides
Fertilizers
Auxiliary equipment
Climate system
Structure


Contribution
Impact categories
ADP
AAP
EUP
GWP
POP
CED
Perlite
Electricity
Transport
Metals
Plastics manufacture
Plastics material

a)

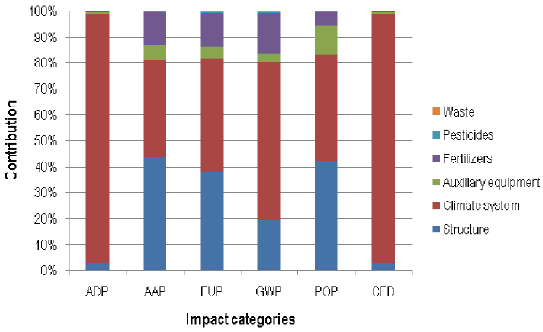
b)

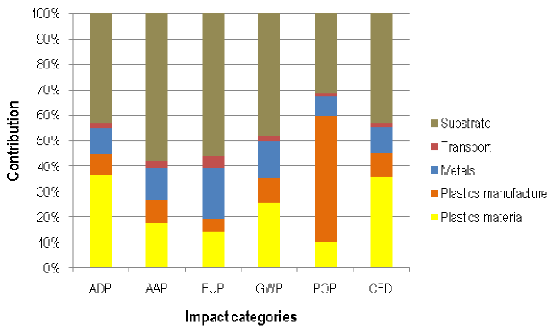

Contribution
Impact categories
Waste
Pesticides
Fertilizers
Climate system
Structure


Contribution
Impact categories
Waste
Pesticides
Fertilizers
Climate system
Structure

c)

d)

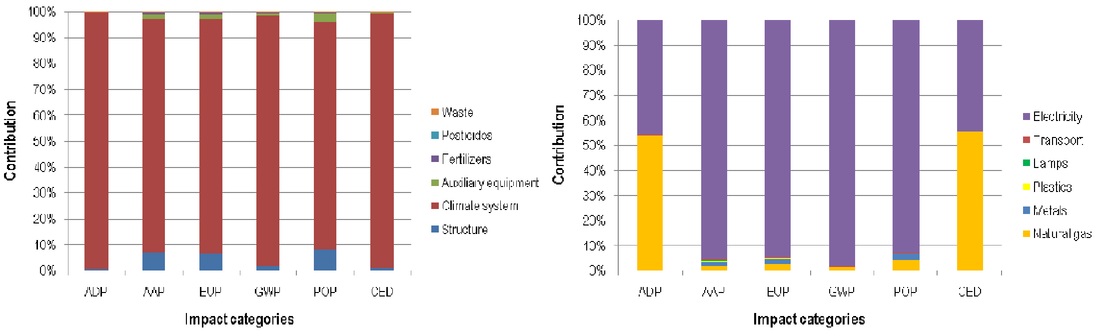

Contribution
Impact categories
Waste
Pesticides
Fertilizers
Auxiliary equipment
Climate system
Structure


Contribution
Impact categories
Substrate
Metals

e

)

f)



g

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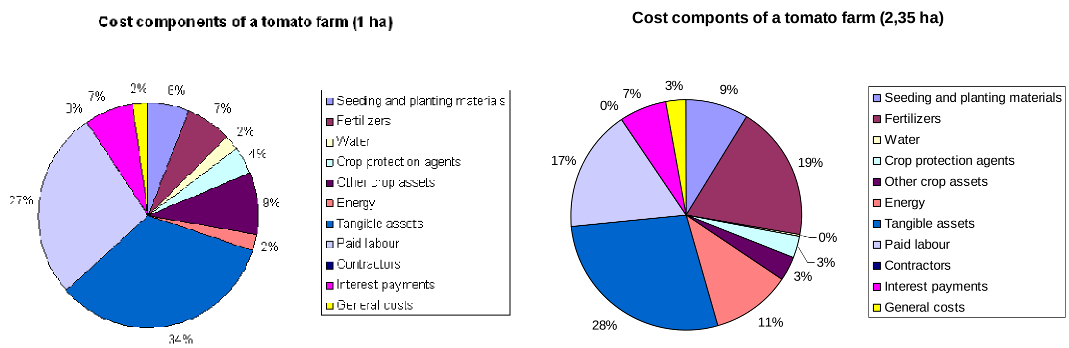
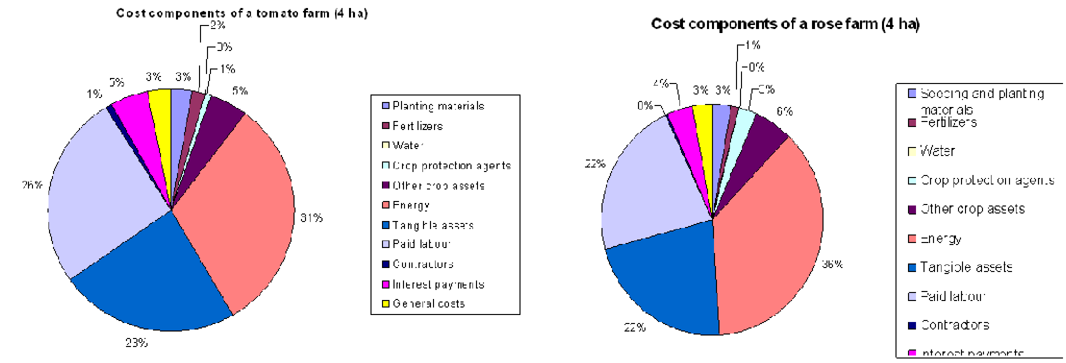
h)

*Figure 1. Stage contribution to impact categories for: **a)** scenario 1: tomato production in Spain; **b)** scenario 1: detail for auxiliary equipment; **c)** scenario 2: tomato production in Hungary with natural gas; **d)** scenario 2: tomato production in Hungary with thermal water. **e)** scenario 3: tomato production without cogeneration in The Netherlands; **f)** scenario3: detail for auxiliary equipment; **g)** scenario 4: rose production with cogeneration system in The Netherlands; **h)** scenario 4: detail for climate system. **Impact categories: ADP**, Abiotic Depletion Potential; **AAP**, Air Acidification Potential; **EUP**, Eutrophication Potential; **GWP**, Global Warming Potential; **CED**, Cumulative Energy Demand*



a)

b)



c)

d)

*Figure 2. Cost components of **a)** scenario 1: tomato in Spain; **b)** scenario 2: tomato in Hungary; **c)** scenario 3: tomato in The Netherlands and **d)** scenario 4: rose farm in The Netherlands.*

INTRODUCTION

In March 2008 the EU-project “Efficient use of inputs in protected horticulture” started, abbreviated as EUPHOROS. One of the work packages of EUPHOROS is the Environmental and economic assessment (WP1).

The objectives of WP1 were:

1. Environmental analysis of the current situation of greenhouse production in EU and identification of the major causes of environmental effects.
2. To assess the environmental effect of the tools (equipment, cultivation system, monitoring and management techniques) developed in this project.
3. To assess economic soundness (profitability) of the tools using a decision support tool.
4. Analysis of effect and economic soundness of the combinations of tools that will be implemented at the three test sites.
5. Indication of the possible advantages of organizing greenhouse enterprises into bigger units (greenhouse clusters) to minimize the environmental effect.

This deliverable presents the environmental and economic profile of representative greenhouses in Europe, identifying the main factors that affect environmental impact or economic aspects. This report was structured in two parts: Part I is the Environmental Assessment and Part II is the Economic Assessment.

In this analysis, the main factors responsible for the environmental impact of greenhouse production were established. These factors were processes that take part in the stages of the production system. This environmental profile of existing greenhouses will be used as a reference for comparison with future alternative greenhouse system designs with reduced inputs and emissions (subsequent tasks).

All relevant costs and benefits were quantified with respect to the resource inputs. These figures describe the reference greenhouse systems as basis for the evaluation of the designed greenhouse systems.

0. INTRODUCTION

PART I

1. ENVIRONMENTAL ASSESSMENT

Environmental assessment was conducted following Life Cycle Assessment methodology, LCA. As defined in ISO 14040 (ISO-14040 2006), LCA is a "compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle". The complexity of LCA requires a fixed protocol for performing and LCA study. Such a protocol was established by the International Standards Organisation (ISO-14040 2006). According to this normative, LCA studies comprise four phases that were iterative between them. The relationship between phases is illustrated in Figure 1.1. These phases were:

- Goal and scope definition,
- Inventory Analysis,
- Impact Assessment, and
- Interpretation

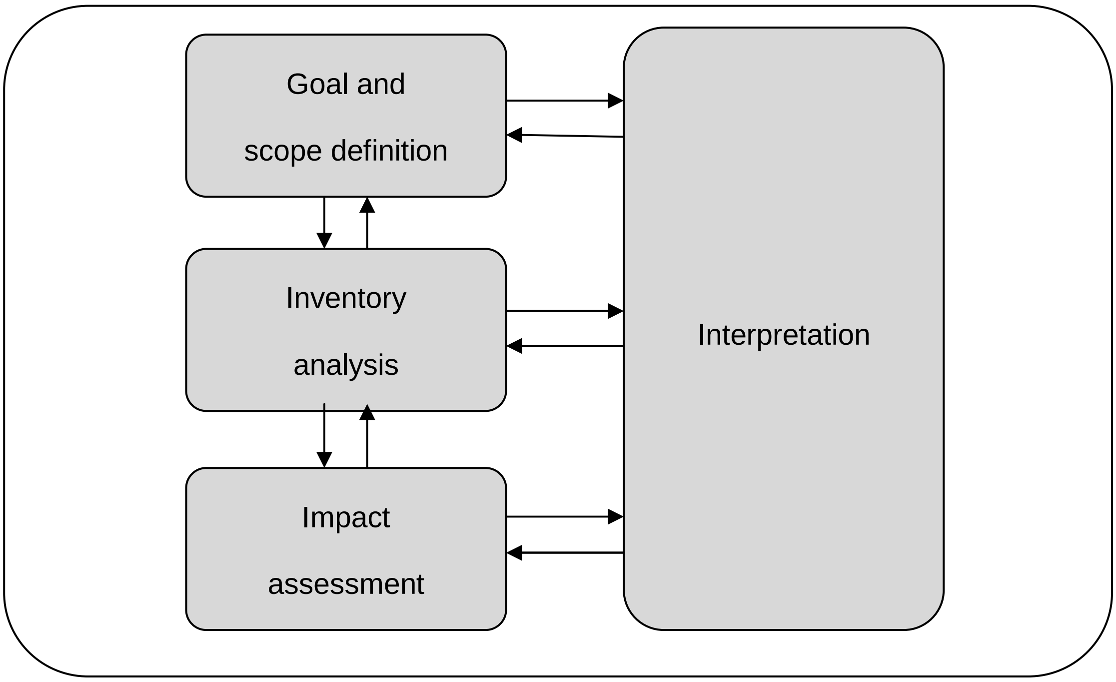


Figure 1.1 Methodological framework of LCA: phases of an LCA. ISO 14040 (ISO-14040)

1.1 Goal an scope definition

Goal: To assess four representative scenarios of greenhouse crops in Europe at the present moment. The reason for carrying out the study was to use these environmental profiles as a reference situation for comparison with alternative greenhouse system designs with reduced inputs and reduced emissions (subsequent tasks).

Scope: Four representative European greenhouse production scenarios were studied:

1) Tomato in multitunnel structure in Spain
2) Tomato in Venlo structure in Hungary
3) Tomato in Venlo structure in the Netherlands
4) Rose in Venlo structure in the Netherlands

Functional unit: The functional unit (UF) is the main function of the system analysed. A system may have a number of possible functions and the one selected for a study depends on the goal and scope of the LCA. In this case, since the most important function in horticultural and ornamental crops was the production of vegetables and flowers, the functional unit chosen was the horticultural production of 1000 kg of tomatoes for tomato crops and 1000 stems for rose crop. This choice gave us a reference to normalise all the system's input and output flows (ISO-14040 2006).

System boundary: LCA is conducted by defining product systems as models that describe the key elements of physical systems. The system boundary defines the unit processes to be included in the system. As the goal of this project was to improve production means (greenhouse), the **system boundary** was defined up to farm gates without considering post stages, such as commercialization but considering materials disposal. Therefore, the following life cycle stages and unit processes were taken into account:

- acquisition of raw materials
- inputs and outputs in the main manufacturing processes for Greenhouse infrastructure, Auxiliary equipment, Climate system, Fertilizers and Pesticides.
- transportation of materials
- production and use of fuels, electricity and heat
- crop production and greenhouse management (including water, fertilizers and pesticides consumption).
- recovery of used products or recycling
- disposal processes of waste and products
- additional operations such as lighting and heating

Impact categories selected: one inventory indicator (Water Use), one energy flow indicator (i.e. Cumulative Energy Demand) and five impact categories (i.e. Abiotic Depletion, Global Warming, Air Acidification, Eutrophication and Photochemical Oxidant Formation), were considered. Impact categories were defined by the CML (Guinée, Gorrée et al. 2002) and were selected for this study because of its relevance in agriculture and energy processes. Abiotic

Depletion and Global Warming were important indicators related to energy consumption. Emissions related to agricultural inputs, mainly fertilizers and pesticides, were important contributors to Global Warming, while ammonia and nitrate emissions from N-fertilisers were important to Acidification and Eutrophication. Photochemical Oxidant Formation is a category that may have important consequences on agriculture (i.e. ozone contamination).

Quality and origin of the data in the inventory: the broad system under study required a detailed data-collection process. Most of these primary data related to greenhouse dimensions, management and crop production were obtained from representative commercial greenhouses by the involved partners, i.e. Estación Experimental Fundación Cajamar, Spain, Mórakert Production Organization, Hungary and Applied Plant Research, the Netherlands. Therefore these data were considered as Own Experimental Data (OED). For the secondary data (reference database, RDB), database such as Ecoinvent (Frischknecht, Junblught et al.), ELCD (ELCD 2008) and LCAFoods (Nielsen, Nielsen et al. 2003) were used to complete the life cycle inventory.

The inventory questionnaires to be filled by the reference scenarios partners were prepared. These questionnaires consisted of excel sheets that were organized by listing the flows and relevant data for operating conditions associated to greenhouse crops. The intention was to obtain all the information about dimensions, materials, energy consumption, field operations, quantity of fertilizers and pesticides used, etc. for the four scenarios.

Figures considered were representative values and average for each of the four scenarios studied.

In order to simplify calculations and due to the fact that production was a variable with strong dependence on temporal and spatial factors, data were related to crop area as a first approach. In a second step, these data were related to functional unit (1000 kg tomatoes or 1000 rose stems).

The software tool used for the assessment was the SimaPro program version 7.1 (PréConsultants, 2008), only performing the compulsory phases of classification and characterization.

1. 2 Inventory analysis

Life Cycle Inventory (LCI) involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system.

The process of conducting an inventory analysis is iterative. As data were collected and more is learned about the system, new data requirements or limitations were identified. All the relevant data were collected and we considered that extra information in order to give more details woul not change significantly the sense of the present scenarios being assessed.

Stages and processes considered

Greenhouse crop production system was structured in several stages or processes to facilitate the study and interpretation of the results. Figure 1.2 showed the process flow diagram that outline all the unit processes to be modelled including their relationship.

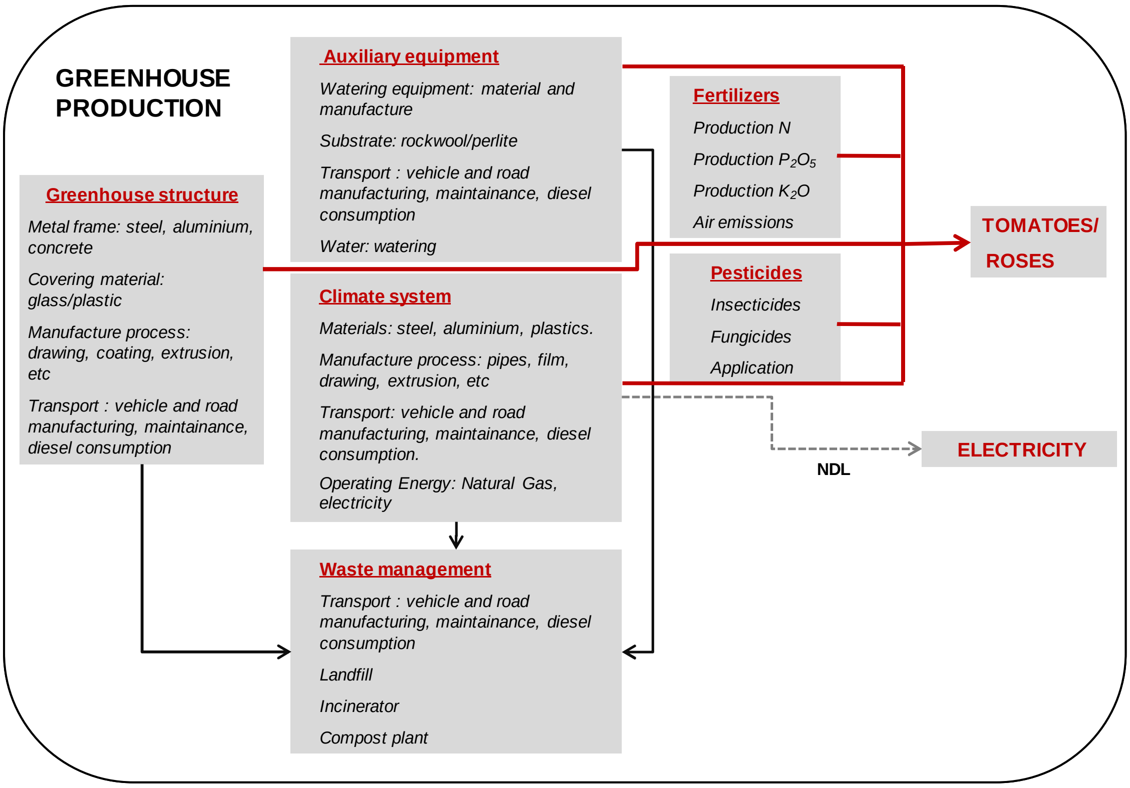


Figure 1.2 General flow diagram for greenhouse production

- **Greenhouse Structure characteristics**

Two types of structures were considered depending on the area of study: multitunnel greenhouse (Mediterranean, Spain) and VENLO greenhouse (Hungary and the Netherlands). In both cases, greenhouse structure consisted of a metal frame and a covering made of plastic film for multitunnel greenhouse in Spain and glass in VENLO greenhouses in Hungary and the Netherlands. Metals considered in all the structures were steel and aluminium. The metal production processes of steel and aluminium include the use of recycled scraps in a high proportion, 90% for steel and 100% for aluminium. Thus, we consider that metal production is based in recycled metal in the four scenarios. This assumption is considered for all the metal elements in the greenhouse, which were included in Structure, Auxiliary equipment and Climate system stages.

- **Auxiliary equipment**

The watering system begins at the well, channel or tank, which provides the water from the source to the water tanks and fertilizer tanks. Pumps and injectors supply fertilizers and water to the main pipe and this main pipe to the secondary pipes which finally distribute water to the crop. There were as many secondary pipes as plant rows. Each tomato or rose plant is watered by a dripper system composed by a micro tube, a pickaxe and a dripper. The plant rows run from side to side of the greenhouse, and were divided by a main path that allows labours operations.

Water for irrigation was included in the stage Auxiliary equipment. Electricity consumption for extraction and distribution pumps was also counted in the tomato crop in Spain. In the case of tomato crops in Hungary and the Netherlands and rose crop in the Netherlands, we assume that this electricity consumption is counted in the total amount of electricity consumption of the greenhouse and included in the Climate system stage.

- **Climate system**

Depending on each production system, Climate system can include heating system, cogeneration system, distribution equipment, thermal water, natural ventilation, CO_2 enrichment system, roof cooling and crop lighting.

Total electricity consumption for the greenhouse was also included in this section for Venlo scenarios (Hungary and the Netherlands). In tomato production in Spain, Climate system only includes the electricity for ventilators operation. Electricity consumption for the watering system is included in Auxiliary equipment stage.

These particular characteristics were described in the Climate system section of each scenario and can be consulted for more details.

- **Fertilizers**

Fertilizers use involves important environmental impacts, both by manufacturing processes and emissions produced by their application. It is also true that fertilizers emissions were a controversial subject that needs further study. There were different approaches and parameters to calculate the emissions. In this case, the reference choice was the one proposed by Bentrup for ammonia, NH_4^+ and dinitrogen oxide, N_2O-N (Brentrup and Küsters 2000) and Ausdley for nitrogen oxides NOx-N and NO_3^- emissions to water (Audsley 1997).

Ammonia emitted to air: kg NH_3-N per ha is 3% of the fertilizer N content kg per ha.

Nitrous oxide to air: kg N_2O-N per ha is 1,25% of the fertilizer N content kg per ha.

Nitrogen oxides to air: kg NOx-N per ha is 10% of N_2O-N.

It was considered that closed systems do not produce lixiviates. It was assumed that in case of flushing, this will be considered as a waste, without being thrown away to soil or aquifers.This was the situation for tomatoes and roses crop in the Netherlands. In the case of Spain and Hungary, the dripping watering system was not a closed one. Therefore, emissions to water were calculated.

In open systems and following the methodology proposed by Audsley [7], a balance between aported nutrients (N and P) and uptake by the plant, retention in the substrate and air emissions for N was calculated.

Nutrient uptake differs strongly among crops and is affected by growth stage, climatical conditions and ion composition of nutrient solution. Lixiviates of surplus also depends on characterisitics of the soil. Following the proposed methodology and using an average for different types of soil, a percentage of 30% of the N surplus was considered to reach aquifers (Audsley, 1997). Phosphorus can reach water aquifer as lixiviate or by runoff.

Runoff is not considered in greenhouse crops. For lixiviates, 0,09% of the surplus was taken as a reference. Therefore figures must be considered as a potential environmental impact, useful for this study.Nevertheless the real data will depend on an extense number of variables, out of the scope of this deliverable.

- **Phytosanitary treatments**

The reduction of plant-protective chemicals yet with high productivity and resource use efficiency is an important objective of the Euphoros project.

In this section, the amount of active ingredient of pesticides applied (specifically the environmental impact of manufacturing process) and the machinery for its application was considered. Toxicology of the emissions was not evaluated. This is a controversial aspect without general consensus about what methodology for calculations should be used in life cycle assessment studies. Therefore, for future improvements from other workpackages, quantity of total insecticides and fungicides from inventory phase was considered as a reference.

- **Waste**

All products, elements and devices taking part in the production system have a period of life after which can follow different options of waste management, such as reuse, recycling, incineration, delivery to landfill or compost plant. Only the main processes reported by each site were considered in this section, as it was discussed by the partners of the project in the meeting in Pisa, March 2009.

Waste management was studied grouping all materials in the greenhouse by their period of life (structure materials), by kind of materials (plastics, green biomass) or by its function (substrate). Thus, the following groups were organized:

- 15 years life materials: Steel, aluminium, concrete, glass, PC and cupper from structure, Climate system and Auxiliary equipment. Since most part of these materials take part of the frame, we can also name them “frame materials”.
- Plastics: PE, LDPE, PP, PVC, polyester and polystyrene. Plastic films such as the greenhouse covering or substrate bags were considered to have a life span of three years, while the others plastics (irrigation equipment, etc) were contempleted to last five years.
- Substrate: Rockwool and perlite lasted 3 years of useful life.
- Green biomass: Once the crop was over, it was estimated that plants were cut and let dry partially in the greenhouse. From previous experience it was assumed that 40% of the fresh weight of plants is transported to the composting plant

Materials that were directed to a recycling process were not considered as a phase of the production system. For the management of waste from cultivation, we used the “cut-off” method –defined by Ekvall and Tillman (Ekvall and Tillman 1997)- by which each system receives the burdens for which it is directly responsible. Under this method, there is no uncertainty in the case of the extraction of raw materials, production processes or transport, because these were all directly assigned to the system. In the case of waste disposal, such treatment is fully attributable to the system being studied; while for this waste which is recycled or reused, it is considered its burdens should be attributed to the system that will use it as a material source. Therefore, the process of recycling was included in the new material created in substitution of raw material in another system. We also made the assumption that the recycling company was going to the greenhouse to collect the materials. This was the reason why only transport and emissions for materials transported to landfill and incinerator were counted. In the case of green biomass, transport to the composting plant was considered part of the system because as far as we know it is usually done in this way.

- **Transport**

Transport considered delivery of materials and devices from its origin to the greenhouse. All transport was on road by lorry or van in the four sites under study.

Process of transport included vehicle and road manufacture and maintenance, as well as diesel consumption.

Fertilizers transport was not incorporated in this study. Usually growers can afford fertilizers from a near distributor. On the other hand, distributors usually receive fertilizers from other distributors and manufacturers from all over Europe and consequently it would have been difficult to track these data. Since fertilizers transport was not going to be improved in this study, it was decided not to include it.

Transport to market or auction was not also considered because commercialization was a process not included in the crop production system.

Allocation of flows and releases

One vegetable product (i.e. tomato or rose) was obtained for each scenario; therefore there was not any problem of allocation. Nevertheless, in the Netherlands scenarios, the heating system used a cogeneration process where electricity was obtained. The electricity produced exceeded the electricity greenhouse consumption and the surplus was transferred to the public grid. In this sense, two kinds of products were obtained: tomato or rose and electricity. In fact, the real situation was to consider both products, Therefore, and as a first approach, results presented here showed the production system considering the amount of electricity produced as an output and consequently as an avoided product. However and from a scientific and agronomic point of view, it was necessary to know the amount of energy required to operate the greenhouse. For this reason, calculations were also done without considering the electricity generation. A similar situation took place in Hungary scenario, using geothermal heat to operate greenhouses. Calculations of estimated energy demand were done to achieve these important figures.

1. 3 Life Cycle Impact Assessment

The impact assessment phase of LCA, LCIA, is aimed to evaluate the significance of potential environmental impacts using the LCI results. This process involves associating inventory data with specific environmental impacts categories and category indicators, thereby to understand these impacts. This phase also provides information for the life cycle interpretation phase.

In this phase the ISO 14040 (2006) defines the mandatory and optional elements. Mandatory elements include: 1) selection of impacts categories, category indicators and characterization models, 2) classification or assignment of LCI results to different impacts categories selected and 3) characterization or calculation of category indicator results. Optional elements were normalization, grouping and weighting. They involve calculation of results relative to the reference situation. In this way, such elements give a value of importance to the different environmental problems. The optional normalization and valorisation phases were excluded of this study because scenarios would be used as a reference themselves for the future development of the project. These phases entail a high degree of subjectivity since they considerably depend on local characteristics and they reduce the information contributed with regard to environmental impacts (Finnveden 1997; Bare and Gloria 2006).

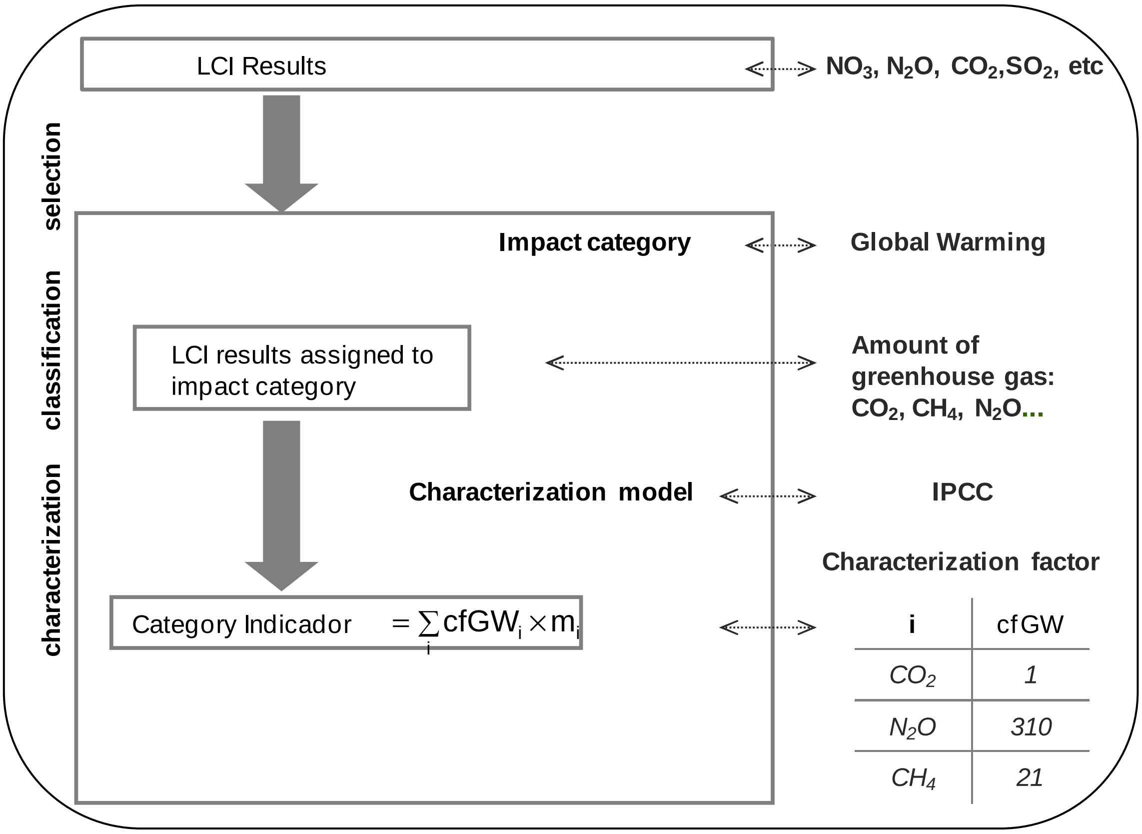


Figure 1.3 Diagram of LCIA phase. Adapted from ISO 14040 (2006)

Figure 1.3 outlines the classification and characterization elements of the LCIA with an example for the global warming category. In the LCI, a list of interventions were recorded and quantified including different inputs and outputs of the processes. From that list, a selection of different interventions (e.g. CO_2, CH_4, N_2O, etc) meaningful for the category chosen (e.g. Global Warming) was done. For a given impact category (e.g. Global Warming), a characterisation method comprises a category indicator (e.g. kg eq. CO_2), a characterisation model (e.g. IPCC (IPCC 2007)) and a characterization factor (e.g. 310 kg N_2O per kg CO_2)

derived from the model. By means of characterization factors, also named equivalent factors, the addition of the different interventions is possible to provide a total value.

The category indicator can be located at any point between the LCI results and the category endpoints (where the environmental effect occurs) in the cause-effect chain. Within this framework, two main schools of methods developed:

a) Midpoints categories: Classical impact assessment methods (e.g. CML (Guinée, Gorrée et al. 2002) and EDIP (Hauschild and Wenzel 1998)) which restrict quantitative modelling to relatively early stages in the cause-effect chain. The finality is to limit uncertainties and group LCI results in so-called midpoint categories, according to themes. Such themes were common mechanisms (e.g. climate change) or commonly accepted grouping (e.g. ecotoxicity).

b) Endpoints categories: Damage oriented methods such as Eco-indicator 99 (Goedkoop and Spriensma 2000) or EPS (Steen 1999), which try to model the cause-effect chain up to the endpoint, or damage, sometimes with high uncertainties. Damages can be correlated directly to areas of Protection, i.e. human health, natural resources (providing options for extraction) and natural environment (with significance not related to extraction).

The objectives of this study advised to select midpoints categories in order to reduce uncertainties in the comparison of improvements coming out from next advances in the project. The main characteristics of the different categories chosen were developed below. Moreover, the main substances that contributed to each category were listed in table 1.1.

- **Cumulative Energy Demand**, CED MJ eq

Cumulative Energy Demand aims to investigate the energy use throughout the life cycle of a good or a service. This includes the direct as well as the indirect uses; or grey consumption of energy due to the use of, e.g. construction materials or raw materials. The Cumulative Energy Demand is also widely used as a screening indicator to point out the priorities of energy saving potentials in their complex relationship between design, production, use and disposal. Furthermore, CED-values can be used to compare the results of a detailed LCA study to others where only primary energy demand is reported. Characterization factors were given for the energy resources divided in: non renewable, fossil and nuclear, renewable, biomass, wind, solar, geothermal and water.

- **Abiotic depletion**, ADP, kg Sb eq (Guinée, Gorrée et al.)

This impact category, depletion of abiotic resources, is concerned with protection of human welfare, human health and ecosystem health. This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic depletion characterization factor is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation.

- **Air Acidification**, AAP, kg SO_2 eq (Guinée, Gorrée et al.)

Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). The majors acidifying pollutants were SO_2, NO_x and NH_3. Acidification characterization factor for emissions to air is calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances (Guinée, Gorrée et al. 2002). AAP is expressed as kg SO_2 equivalents.

- **Eutrophication,** EUP, kg PO_4--- eq (Guinée, Gorrée et al.)

Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water and soil. Eutrophicatin characterization factor is based on the stoichiometric procedure of Heijungs (Heijungs, Guinée et al. 1992) and expressed as kg PO_4^{-3} equivalents

- **Global warming**, GWP, kg CO_2 eq (Guinée, Gorrée et al.)

Climate change can result in adverse affects upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases to air. The characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterization factors (IPCC 2007). Factors were expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide equivalents.

- **Photochemical oxidant formation,** POP, kg C_2H_4 eq (Guinée, Gorrée et al.)

Photo-oxidant formation is the formation of reactive substances (mainly ozone) which were injurious to human health and ecosystems and which also may damage crops. This problem is also indicated with “summer smog”. Winter smog is outside the scope of this category. Photochemical Ozone characterization factor for emission of substances to air is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene equivalents (Guinée, Gorrée et al. 2002).

- **Water use**, L

Nowadays, although research is advancing in the development of a method for assessing the environmental impacts of freshwater consumption (Milà i Canals, Chenoweth et al. 2009; Pfister, Koehler et al. 2009), there is not yet an agreement among the scientific community about how to handle this category. In this study and due to the relevance of water assessment in agriculture production, Liter of water was used as a rough indicator.

As far as there were not characterization factors for water and pesticides indicators only the inventory values were delivered. These values will be used as a reference for the future improvements that were being developed in the Euphoros project.

Table 1.1 Main contributing substances and units for each environmental impact category

Category		Units	Main contributing substances
Cumulative energy demand	CED	MJ	Coal, hard Gas, natural Oil Uranium

Abiotic depletion	ADP	kg Sb eq	Coal, hard Gas, natural Oil crude
Acidification	AAP	kg SO_2 eq	Ammonia Nitrogen oxides Sulphur dioxide
Eutrophication	EUP	kg PO_4^{---}eq	Ammonia Nitrogen oxides COD, Chemical Oxygen Demand Phosphate
Global warming 100a	GWP	kg CO_2 eq	Carbon dioxide fossil Dinitrogen monoxide Methane
Photochemical oxidation	POP	kg C_2H_4 eq	Carbon monoxide fossil Sulphur dioxide

1. 4 Interpretation

Interpretation is the phase of LCA in which the findings from the inventory analysis (LCI indicators, water and quantity of pesticides) and the impact assessment were considered. The interpretation phase delivers results that were consistent with the goal and scope definition, reaches conclusions, explains limitations and provides recommendations to decision-makers

The interpretation phase may involve the iterative process of reviewing and revising the scope of the LCA. This phase reflects the fact that the LCIA results were based on a relative approach, indicate potential environmental effects and were understandable, complete and consistent.

This section provides a first insight into the environmental hot spots in the life cycle of the four reference scenarios assessed, with recommendations to improve the processes which will reduce environmental impact. The information in this deliverable is the starting point for discussion and further research subjects where alternative possibilities of reuse, recycling and energy production will be analysed.

2. SCENARIOS

2.1 SCENARIO 1: TOMATO PRODUCTION IN SPAIN

2.1.1 GOAL AND SCOPE DEFINITION

This report describes the environmental impact of Protected Tomato Production in a multitunnel greenhouse in Spain. In order to perform the environmental impact assessment of this scenario, Life Cycle Assessment (LCA) methodology was applied. The study was structured in the compulsory phases of the methodology (Part I.1).

The goal of the study was the environmental analysis of the current situation of tomato greenhouse production in Spain and identification of the major causes of environmental impacts. In this LCA study, an analysis of the resource inputs of existing greenhouse operations was carried out.

The scope defined was the tomato greenhouse production (Part I. 1.2).

The Functional Unit selected was **1 t tomatoes (1000 kg tomatoes)**. A productivity of 16.48 $kg{\cdot}m^{-2}$ of tomato per campaign was taken into account.

2.1.2 INVENTORY ANALYSIS

Greenhouse tomato production system was structured in several stages or processes. Figure 1.2 showed the flow diagram of the production system for tomato crop in Spain, Part I, 1.2.

Figure 2.1.1 Multitunnel greenhouse in Spain

The greenhouse studied was an arched-roofed industrial steel-framed, multitunnel greenhouse. It was situated in Almería, in the Mediterranean coast.

More detailed information about the inventory data were provided in Annexes and can be requested to the coordinator.

2.1.2.1 Multitunnel Greenhouse Structure

Greenhouse Description

The greenhouse chosen as representative for scenario 1 was a tomato multitunnel production system. The main features of this greenhouse were (Annex 4.3, table 4.3.1):

- Surface: 19.440 m^2
- Ridge height: 5,8 m
- 18 spans
- Opening ventilator surface 7.776 m^2

Greenhouse Structure characteristics

Greenhouse structure was made of a steel frame and a plastic covering.

Figure 2.1.2 Multitunnel greenhouse with steel arched roof and plastic covering

Steel elements were posts, frame reinforcements, gutters, axes, profiles, ventilators and arches. High wire system to support the tomato crop was made of wire.

The covering, front walls and side walls were made of plastic: low density polyethylene for the covering and polycarbonate sheet for the walls.

There was also a great amount of concrete, coming from the foundations and a main path. The main path was 3 m wide.

Polyethylene was the plastic for soil mulching and insect proof screens.

The manufacturing processes for the structure materials were considered, including manufacture for steel and plastic elements (Frischknecht, Junblught et al. 2005). It was assumed that steel was manufactured from recycled steel scraps. A coating treatment was also taken into account.

All elements in the greenhouse were transported by lorry from an estimated distance of 605 k, which was the distance from the main steel factories to Almería.

(Annex 4.3, table 4.3.2).

2.1.2.2 Auxiliary equipment

In this section, the necessary elements for raising the crop were considered, including the distribution system for watering the crop, drainage installation, pipes to collect rain water, substrate and transport of these materials to the greenhouse.

The watering system consisted of a dripping and drainage installation.

Crop period was 9 months and density of plantation was 1,3 plants·m^{-2}, with 2 stems each.

All elements for the Auxiliary equipment were transported by lorry from an estimated distance of 5 km.

(Annex 4.3, tables 4.3.3 and 4.3.4).

Electricity consumption

Electricity consumption for pumps and injectors operation was considered. Based on own experimental data the amount of electricity for this watering work was 38,61 kWh·ton tomato^{-1}.

Figure 2.1.3 Tomato crop rows showing plastic floor

The electricity was obtained from public grid. Ecoinvent data (Frischknecht, Junblught et al. 2005) for Electricity production mix in Spain was used.

(Annex 4.3, tables 4.3.6 and 4.3.7).

Substrate

The substrate used was perlite in plastic bags. Bags were located on polystyrene benches. The bag size was (100x20x10) cm. Each bag contains three plants, 2 stems each.

Perlite was produced locally, 7 km from the greenhouse, and it was delivered by lorry.

(Annex 4.3, table 4.3.5).

Water consumption

Water consumption was considered including water for the crop and a surplus of 25% of leaching. The total amount of water was 4.748 $m^3 \cdot ha^{-1}$. The water use was 28,81 $l \cdot kg\ tomato^{-1}$.

2.1.2.3 Climate system

There was no heating system in this multi-tunnel greenhouse, so there was not any installation for this purpose.

In this section, only electricity consumption for opening and closing ventilators was taken into account. The working time of the gears was around 20 minutes per day. The electricity consumption was 50 kWh·ha, which was the same as 0.30 $kWh \cdot ton\ tomato^{-1}$.

(Annex 4.3, table 4.3.7).

2.1.2.4 Fertilizers

The total quantity of N, P and K was evaluated with independence of the type of fertilizers (see Part I, 1.2). The fertilizers used in this crop were:

The total amount of N, P and K applied to the crop was:

N	798,4	$kg \cdot ha^{-1}$
P_2O_5	220,8	$kg \cdot ha^{-1}$
K_2O	1.296,3	$kg \cdot ha^{-1}$

Uptake concentration of N was estimated from the study of Antón [18] and Sonneveld [19]. Phosphorus leaching was equal to zero due to the fact that surplus was retained by the substrate, Antón [18].

(Annex 4.3, tables 4.3.8 and 4.3.9).

2.1.2.5 Phytosanitary treatments

For this scenario Integrated Pest Management, IPM, was considered. Nevertheless, there was a lack of information about biological control process. Therefore, only the total amount of active ingredient was considered in this section. We have made a distinction between insecticides and fungicides. The use of machinery for its application to the crop was also taken into account. The quantities of pesticides estimated were:

Insecticides	3,77	$kg \cdot ha^{-1}$
Fungicides	28,48	$kg \cdot ha^{-1}$

(Annex 4.3, table 4.3.10).

2.1.2.6 Waste management

It was well known the variability of waste treatments from site to site, so, meanwhile the specific data were determined the following assumptions were estimated:

15 years materials:

- metal and polycarbonate: 100% was recycled and 0% was transported to landfill
- concrete: 50% was recycled and 50% was transported to landfill

Plastics (pipes, films, etc): 50% was recycled and 50% was transported to landfill.

Substrate (perlite and bags): 50% was recycled and 50% was transported to landfill.

Green biomass: 40% of fresh weight of plants was composted.

Transport burden for waste management destination and emissions of treatments were counted.

(Annex 4.3, tables 4.3.11 and 4.3.12).

2.1.2.7 Transport

The city of origin, means of transport and distance to the greenhouse were considered for all materials in the greenhouse.

(Annex 4.3, table 4.3.13).

2.1.3. LIFE CYCLE IMPACT ASSESSMENT

The significance of potential environmental impacts for tomato production under multi-tunnel greenhouse in Spain was presented in this section. Results from Life Cycle Inventory were used in order to calculate the environmental contribution to the impact categories selected (see Part I,1.3).

The values showed the contribution of the different processes to the impact categories selected. Detailed values coul be provided by request in Annex 4.3, tables from 4.3.14 to 4.3.19

2.1.3.1 Production system LCIA

LCIA for tomato production in a multitunnel greenhouse in Spain was represented in figure 2.1.4.

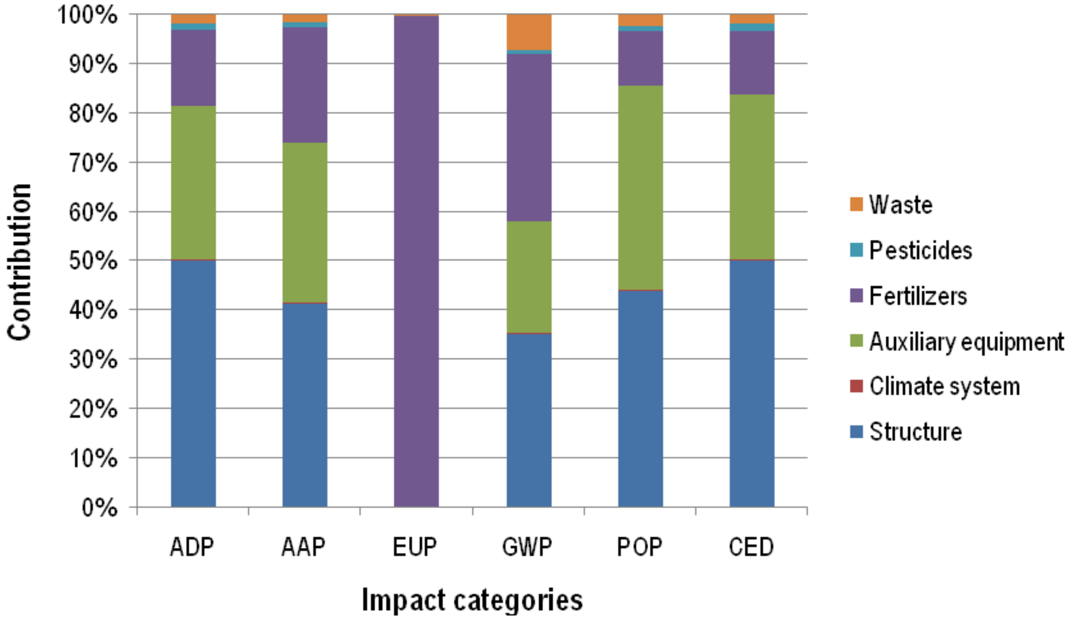


Figure 2.1.4 Stages contribution to impact categories for tomato production in Spain. Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand.

Life Cycle Impact Assessment results showed that Structure was the main contribution to all impact categories, with the exception of EUP, with percentages between 35,2% and 50,2% of the total.

Auxiliary equipment and Fertilizers were the second or third contributors depending on the impact categories. Auxiliary equipment was the second burden in ADP, AAP, POP and CED, with percentages between 31,2% and 41,2%; and the third for GWP with a percentage of 22,8%.

Fertilizers were the first burden in EUP, with a contribution of 100%. They were also the second burden in GWP with a percentage of 34,0%; and the third for ADP, AAP, POP and CED with percentages between 10,9% and 23,3%.

Pesticides and waste have low contributions with percentages between 0% and 7,2%.

Climate system contribution was negligible since all the values to impact categories were near to 0%.

2.1.3.2 Structure LCIA

Results for multi-tunnel greenhouse structure were represented in figure 2.1.5.

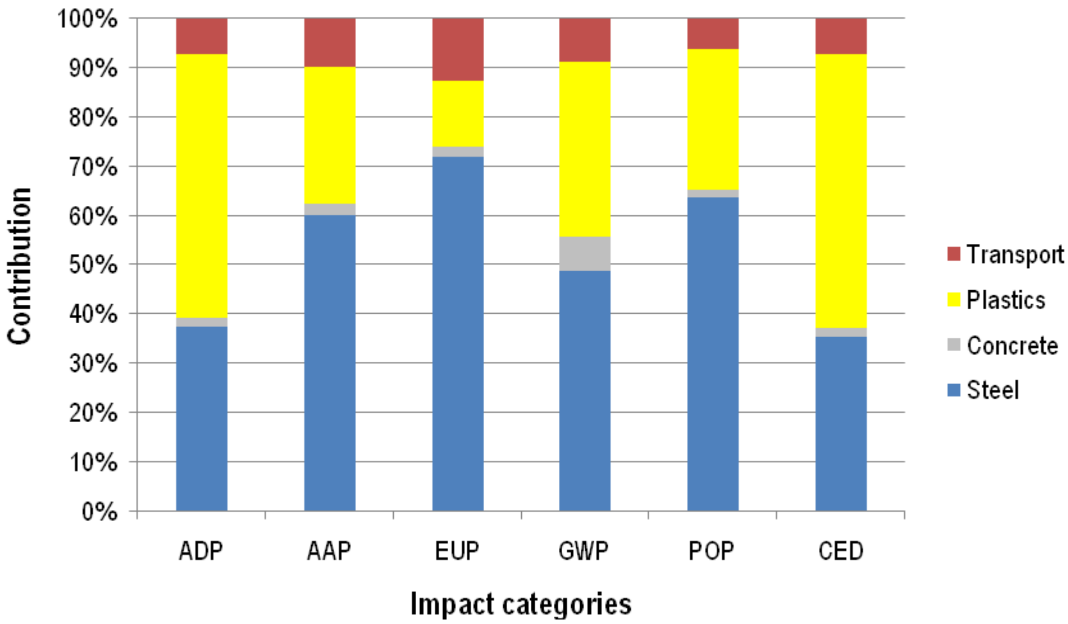


Figure 2.1.5 Structure materials contribution to impact categories for tomato production in Spain.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

Multi-tunnel greenhouse was a structure which consisted of a frame of metal and a covering of plastic. The high amount of steel in the frame was reflected in the results, which were the highest burden for the impact categories AAP, EUP, GWP and POP, with percentages between 48,7% and 71,8%. Steel was also de second burden in ADP and CED, with percentage of 37,4% and 35,2% respectively.

Plastics were also an important contribution to impact categories. It was the highest contribution to ADP and CED, with percentages of 53,7% and 55,6% respectively. The reason for such contribution was the high energy demand for the production of LDPE for the covering and floor of the greenhouse. For the rest of impact categories, plastics contribution percentages were between 13,3% and 35,4%.

Transport was the third contributor to all impact categories, with values between 6,1% and 12,7%. Structure materials arrive at the greenhouse by lorry, from a distance of 605 km.

Concrete contribution to impact categories have low values, between 1,7% and 6,9%.

2.1.3.3 Climate system LCIA

Climate system in this tomato production only included electricity consumption for opening the ventilators. That means a low value comparing to other aspects therefore there were no reasons to break down the process.

2.1.3.4 Auxiliary equipment LCIA

Auxiliary equipment LCIA showed the importance of electricity consumption and substrate contribution to all impact categories.

Processes contributions were represented in figure 2.1.6.

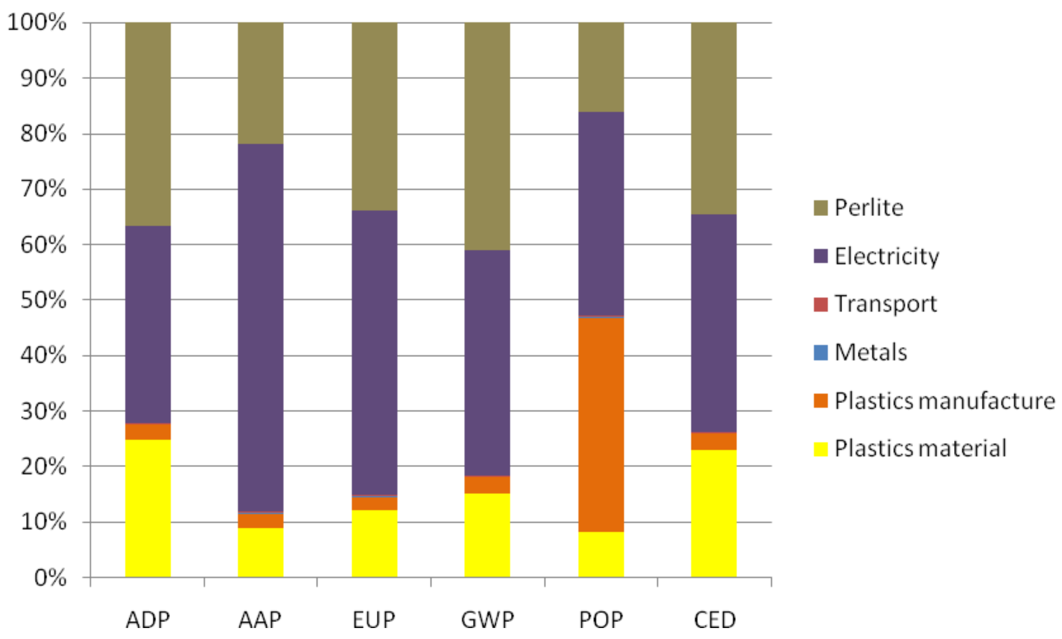


Figure 2.1.6 Auxiliary equipment processes contribution to impact categories for tomato production in Spain.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

Electricity consumption included the necessary one for pumps and injectors for watering the crop. It was the main burden in AAP, EUP and CED with percentages between 39,2% and 66,3%.

Substrate process included perlite manufacture, plastic bags manufacture and transport to greenhouse, being perlite manufacture the most significant of all of them. Substrate presents the highest contribution scores to the impact categories ADP and GWP, with percentages of 36,8% and 41,2% respectively.

Plastic manufacture was the main contributor to POP with 38,7%, due to the high impact of polystyrene layers manufacture.

Plastics contributions to impact categories had values between 11,6% and 46,9%.

Metals and transport contributions were not significant since all values were around 0%.

2.1.3.5 Fertilizers

Fertilizers use involved environmental impacts both by manufacturing processes and emissions due to their application to the crop. (Part I, 1.2).

Results obtained reflect that highest scores were for N fertilizers production for all impact categories, exept for EUP, with percentages between 52,3% and 66,0%. These results were represented in figure 2.1.7.

Emissions due to the use of fertilizers had a very high contribution to EUP, with a percentage of 95,2% of the total. This was due to emissions to water by leaching (Part I, 1.1). It was also a considerable burden in GWP with a 24,9% contribution mainly caused by emissions of dinitrogen monoxide to the air.

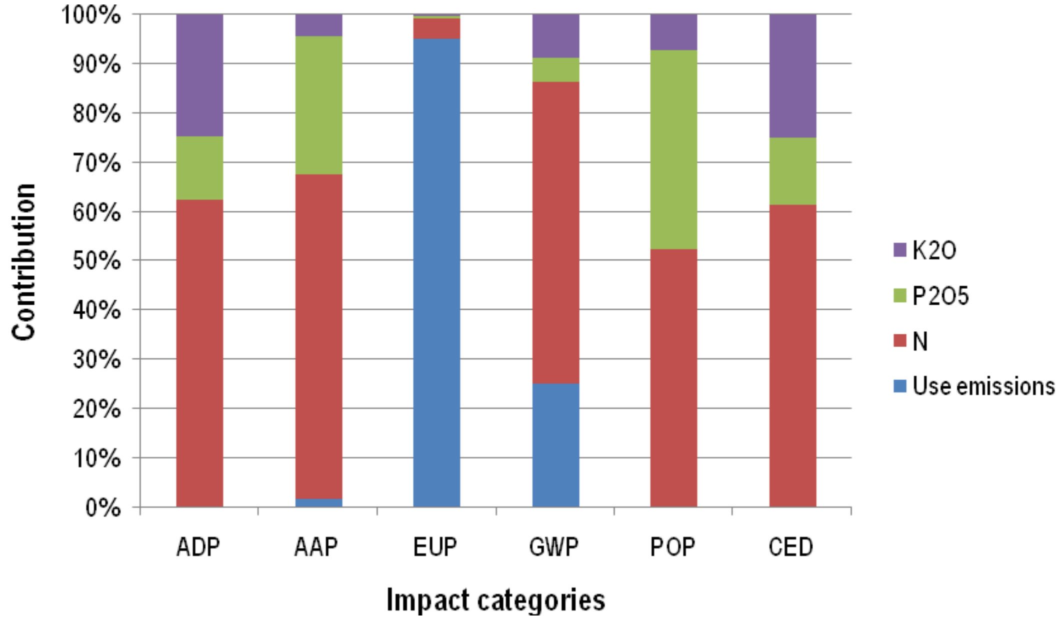


Figure 2.1.7 Fertilizers contribution to impact categories for tomato crop in Spain.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

2.1.3.6 Phytosanitary treatments

Pesticides results contribution was not significative with regard to the total contributions of the tomato production. Pesticides toxicity was not evaluated (see (Part I, 1.2).

2.1.3.7 Waste management

In this section waste materials management were considered, including transport to the disposal plant and emissions because of the specific treatment considered. It was assumed that concrete was the only 15 years useful life material that was rejected to the landfill, 50% of all the concrete material in the greenhouse. As well, it was considered that frame steel and walls polycarbonate were all recycled.

With these assumptions, green biomass transport was the main contribution to the impact categories ADP (70,5%), AAP (63,9%), POP (76,1%) and CED (71,0%). Thise high contributions were due to the fact that green biomass was transported every year at the end of the crop, meanwhile the rest of materials were transported depending on their useful life, which was superior to one year.

Plastics emissions at landfill were the highest contribution to EUP (56,7%) and GWP (80,8%).

2.1.4 INTERPRETATION

Tomato production in a multi-tunnel greenhouse in the Mediterranean coast of Spain was studied in order to quantify the environmental impact of this production process. This analysis of the present situation will be used as a reference and starting point to evaluate the reduction of burdens with the implementation of the new advances developed in the course of the Euphoros project.

Evaluation of the results for this scenario showed that the structure was the main contributor to nearly all impact categories, due principally to the relative high amount of steel in the frame and plastics of the covering and floor. The greenhouse structure had the heaviest environmental burden due to the fact that tomato production in unheated passive greenhouses is a process that needs little energy and small amounts of inputs besides fertilizers and water.

Since environmental impacts were referred to the amount of tomatoes produced per unit soil area along the useful life of the structure, an obvious way for reducing impacts could be by increasing the life span of the structure and by increasing productivity. In this assessment, a life span of 15 years was considered. This was in agreement with the European Code (CEN 2001) but it may be considered as an unrealistic figure: most growers extend the greenhouse life far from the accepted 15 years. Besides, increasing productivity with reduced inputs was a key factor in this EUPHOROS project. For the Spanish greenhouses, any technological improvement that (preferably) fit into the concept of the passive greenhouse will have a direct reduction on the environmental burden associated to the greenhouse structure.

Auxiliary equipment and Fertilizers had high contributions to impact categories. In the case of Auxiliary equipment, electricity consumption had most of the highest scores. The focus should be directed to the reduction of energy consumption and abiotic resources use. Although in Spain an important 21% of energy is produced by renewable energies, more efforts should be done in favor of more efficient processes and use of cleaner energies.

In this sense, the objectives of the Euphoros project investigating on energy (usage of solar energy, thermal storage, ventilation and renewable energies) could contribute to the improvement of energy consumption in tomato production. All these advances contributions will be analyzed in the next months.

Perlite manufacture was also of great relevance in Auxiliary equipment stage. Substrate could be also an area of progress due to the high environmental impact in the manufacturing process, for example, increasing recycling of the product in order to reduce the amount of new perlite manufacture. Improvement of substrate use is one of the objectives of the current Euphoros project (WP3).

For tomato production in Spain, Fertilizers application could be an important process to focus on in order to reduce its contribution to impact categories. Fertilizers were applied by fertirrigation in this tomato crop. Since water consumption was very high, fertilizers consumption became also high. Therefore, an efficient balance of both fertilizers and water should be recommended. Regarding the risk of eutrophication, it is worthy to note that current methodologies to assess the amount of fertilizers that reach the aquifers are approximated and debatable. This is an important subject that requires further analysis and that will be approached throughout the development of the EUPHOROS project.

Waste management depends strongly on the present governmental regulations of each country. Nevertheless, there is a European regulation that states that in 2020 EU countries should recycle 50% of paper, plastic and glass of all domestic waste, and 70% of no dangerous waste from construction and demolition. Recycling as much as possible of all materials coming from greenhouse production would obviously be an important development that should be achieved as soon as possible.

2.2 SCENARIO 2: TOMATO PRODUCTION IN HUNGARY

2.2.1 GOAL AND SCOPE DEFINITION

This report describes the environmental impact of Protected Tomato Production in a Venlo greenhouse in Hungary. In order to perform the environmental impact assessment of the scenario “Tomato production under glass greenhouse in Hungary” Life Cycle Assessment (LCA) methodology was applied. The study was structured in the compulsory phases of the methodology (Part I.1).

The goal of the study was the environmental analysis of the current situation of tomato greenhouse production in Hungary, and identification of the major causes of environmental impacts. In this LCA study, an analysis of the resource inputs of existing greenhouse operations was carried out. Scope and limits of the system were defined in Part I, 1.2 of this report.

The Functional Unit selected was **1 t tomatoes (1000 kg tomatoes)**. A productivity of 48 kg·m^{-2} of tomato per campaign was taken into account.

2.2.2 INVENTORY ANALYSIS

Greenhouse tomato production system was structured in several stages or processes. Figure 1.2 showed the flow diagram of the production system for tomato crop in Hungary. The greenhouse used as a reference was a steel and glass Venlo structure. It was situated near Mórahalom, in the South of Hungary, 150 km to Budapest.

More detailed information about the inventory data were provided in Annexes and can be requested to the coordinator.

Figure 2.2.1 VENLO greenhouse in Hungary

2.2.2.1 Venlo Greenhouse Structure

Greenhouse Description

The geenhoue chosen as representative for scenario 2 was a tomato Venlo production system. The main features of this greenhouse were:

- Surface: 23.552 m^2
- Ridge height: 5,2 m
- 32 spans
- Ventilator surface 5.299 m^2

Each span was built up by modules of two bays, 8m x 4m each module, and one next to the other to complete the greenhouse building.

(Annex 4.4, table 4.4.1).

Greenhouse Structure characteristics

Greenhouse structure was mainly made of metal and glass, with a frame of steel and aluminium.

Steel elements were girders, roof bars, stability braces, rails, posts, tie beams, foundations reinforcements, ventilators opening mechanisms and a high wire system to support the tomato crop.

Aluminium elements were gutters, ridges, bars and ventilators opening mechanism.

The covering, front walls and side walls were made of uncoated flat glass.

There was also a great amount of concrete, coming from the foundations and a main path 4 m width from side to side of the greenhouse.

Polyester was the plastic for floor material and energy screens. There was no insect proof screen.

Floor was made of polyester and polyethylene. Energy screens were made of polyester 1 mm of thickness.

The manufacturing processes for the structure materials were considered, including the manufacture of steel, aluminium, glass and polyester elements. In the case of metal a coating treatment was also taken into account.

All elements of the greenhouse were transported by lorry from an estimated distance of 2000 km.

(Annex 4.4, table 4.4.2).

Figure 2.2.2 Tomato greenhouse crop in Hungary. Picture showed the inside of the greenhouse with high wire system to hold tomato plants.

2.2.2.2 Auxiliary equipment

In this section, the necessary elements for raising the crop were considered, including the distribution system for watering the crop, substrate and transport of these materials to the greenhouse.

There was a dripping irrigation watering system without recirculation of water from drainage.

Crop period was 49 weeks and a density of 3,3 plants·m^{-2} was estimated.

All elements for the Auxiliary equipment were transported by lorry from an estimated distance of 2000 km.

(Annex 4.4 tables 4.4.3 and 4.4.4).

Substrate

The substrate used was rockwool in plastic bags. The bag size was (120 x 10 x 5) cm. The crop was characterized for double rows of bags along the greenhouse. Each bag contained four plants, 1 stem each.

(Annex 4.4, table 4.4.5).

Substrate was delivered to the greenhouse from an estimated distance of 15 km by lorry.

Water consumption

The total amount of water for the crop was 7.000 $m^3 \cdot ha^{-1}$ (data given by Mórakert).

Water use per plant was 14,58 $l \cdot kg\ tomato^{-1}$. It was considered a well as water source

Figure 2.2.3 Crop with double rows showing substrate bags with four plants each.

2.2.2.3 Climate system

This section included the thermal water distribution equipment, heat storage system, snow line, ventilator motors and fans for forced ventilation. Total electricity consumption for the greenhouse was also included in this section.

Climate system in this Hungarian scenario presented a particular characteristic, which required further comments. The energy source to heat the greenhouse was thermal water. Water was gained from a ground well and was at about 80ºC. Therefore, electricity was only needed to operate a pump in order to take up the water and provide it to the heating system. Water was distributed all along the greenhouses through the heating pipes. After the process, water was rejected to another well to the source from where it had been pumped previously. The use of thermal water in Hungarian greenhouses is not wide spread mainly because the initial investments for using thermal energy are very high. Most greenhouses use natural gas, wood or coal as energy source.

Thus, since not all greenhouses in Hungary use thermal water for heating, it was considered the need of calculating the supposed amount of energy to heat the greenhouse. An amount of natural gas was calculated applying the average temperatures of the area where the greenhouse was situated, the dimensions of the greenhouse and the expected temperature for the crop. The estimated value for natural gas consumption resulted in 93,3 $m^3 \cdot m^{-2}$.

For electricity energy production it was considered Electricity production mix Hungary (Frischknecht, Junblught et al. 2005).

Total electricity consumption for the greenhouse was 8,25 $kWh \cdot m^{-2}$ (data from Mórakert).

Climate system was transported to the greenhouse by lorry, from an estimated distance of 200 km.

Ventilators were not protected with insect proof screens.

(Annex 4.4, tables 4.4.6 to 4.4.9).

Figure 2.2.4 Greenhouse tomato crop showing overhead snow line

2.2.2.4 Fertilizers

The total quantity of N, P and K was evaluated with independence of the type of fertilizers (see Part I, 1.2).

The total amount of N, P and K applied to the crop was estimated:

N	9.090	$kg \cdot ha^{-1}$
P_2O_5	5.200	$kg \cdot ha^{-1}$
K_2O	13.953	$kg \cdot ha^{-1}$

The crop uptake needed to be known in order to make the balance of nutrients, as it was explained in paragraph 1.2. Since nutrient uptake values for Hungary were not available, data for tomato crops in the Netherlands [19] were used. So the uptake concentration were taken as 9.6 $mmol \cdot L^{-1}$ for N and 1.1 $mmol \cdot L^{-1}$ for P.

(Annex 4.4, tables 4.4.10 and 4.4.11).

2.2.2.5 Phytosanitary treatments

Integrated Pest Management, IPM, was considered for this scenario. Nevertheless, there was a lack of information about biological control process. Therefore, only the total amount of active ingredient was considered in this section. We made a distinction between insecticides and fungicides. The use of machinery for its application to the crop was also taken into account. The quantities of pesticides estimated were:

Insecticides 798 $kg \cdot ha^{-1}$

Fungicides 480 $kg \cdot ha^{-1}$

(Annex 4.4, table 4.4.12).

2.2.2.6 Waste management

Waste management was considered in base of the treatments that were applied to this Hungarian scenario:

15 years materials:

- metal: 100% was transported to landfill
- glass: 100% was recycled
- concrete: 70% was recycled and 30% was transported to landfill

Plastics (pipes, films, etc): 100% was recycled.

Substrate:

- Rockwool: 50% was recycled and 50% was transported to landfill.
- Plastic bags: 100% was recycled

Green biomass: 40% of fresh weight of plants was composted

Transport burden for waste management destination and emissions of treatments were counted.

(Annex 4.4, tables 4.4.13 and 4.4.14).

2.2.2.7 Transport

The means of transport and distance to the greenhouse were considered for all materials in the greenhouse.

(Annex 4.4, table 4.4.15).

2.2.3. LIFE CYCLE IMPACT ASSESSMENT

The significance of potential environmental impacts for tomato production under glass greenhouse in Hungary was presented in this section. Results from Life Cycle Inventory were used in order to calculate the environmental contribution to the impact categories selected (see Part I, 1.3).

(Annex 4.4, from table 4.4.16 to 4.4.24).

2.2.3.1 Production system LCIA

In this section, results from LCI were assessed for tomato production in Hungary. The environmental impacts to impact categories were assessed considering two options of energy source in Climate system stage: use of thermal water and use of natural gas. The first was the real situation in the Hungarian scenario assessed and the latter was a supposition for the study.

Structure, Climate system and Fertilizers were the stages with major contribution to impact categories. Results were analysed in more detail in this section.

- ***LCIA considering use of thermal water in Climate system***

Results for tomato production in Hungary, considering the use of thermal water in the Climate system stage were represented in figure 2.2.5.

Structure contribution to impact categories was between 0% and 40,6%. It was the highest contribution to POP, with a score of 40,6%.

Climate system contribution to impact categories was between 0% and 36,7%. It accounted for the major scores for ADP and CED, which were 32,8% and 36,7% respectively.

Fertilizers contribution to impact categories was between 19,3% and 100%. They were the highest burden for the impact categories AAP, EUP and GWP, with results of 37,1%, 100% and 48,1% respectively.

Due to the importance of previous stages mentioned, Auxiliary equipment, Pesticides and Waste contribution to impact categories were relative low in the global assessment with less than 8% of the total.

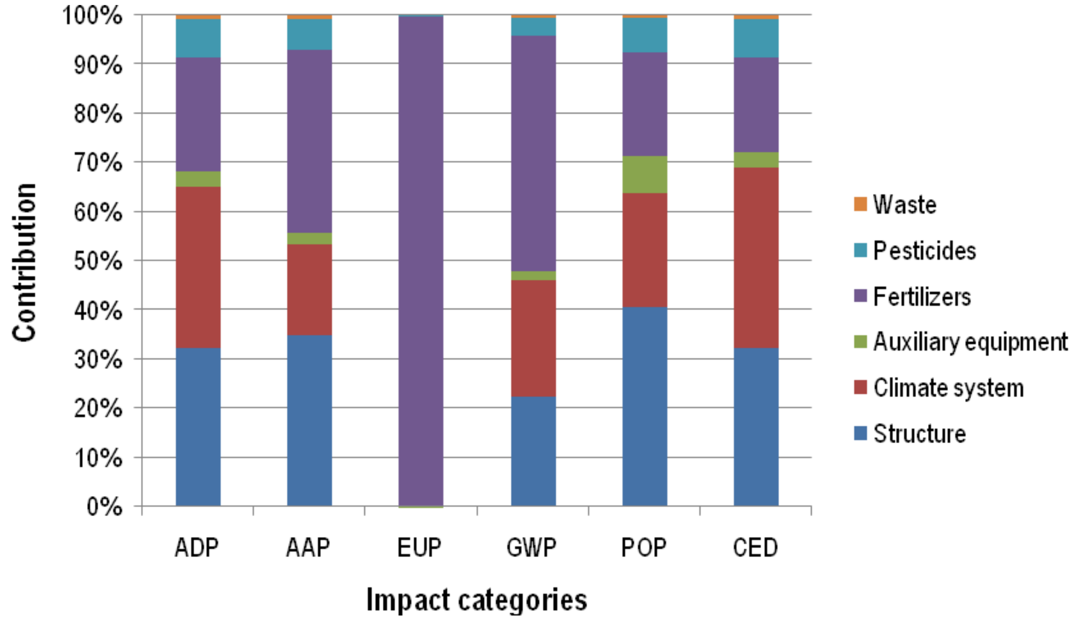


Figure 2.2.5 Stages contribution to impact categories for tomato production with thermal water in Hungary.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

- ***LCIA considering use of natural gas in Climate system***

Results for tomato production in Hungary, supposing the use of natural gas in the Climate system stage were represented in figure 2.2.6. Structure, Climate system and Fertilizers continued sharing the stages with major contribution to impact categories, but, as it was expected, Climate system stage contribution to ADP and CED was more significant.

Structure contribution to impact categories showed the highest contribution to POP, with a score of 36,4% of the total.

Climate system contribution to impact categories had the major scores for ADP and CED, which were 94,7% and 94,3% respectively.

Fertilizers contribution to impact categories was between 1,7% and 100%. They were the highest burden for the impact categories EUP, AAP and GWP, with results of 100%, 35,2% and 43,6% respectively.

Similar to when geothermal heating was considered, Auxiliary equipment, Pesticides and Waste contribution to impact categories was relative low in the global assessment with less than 6,1% of the total.

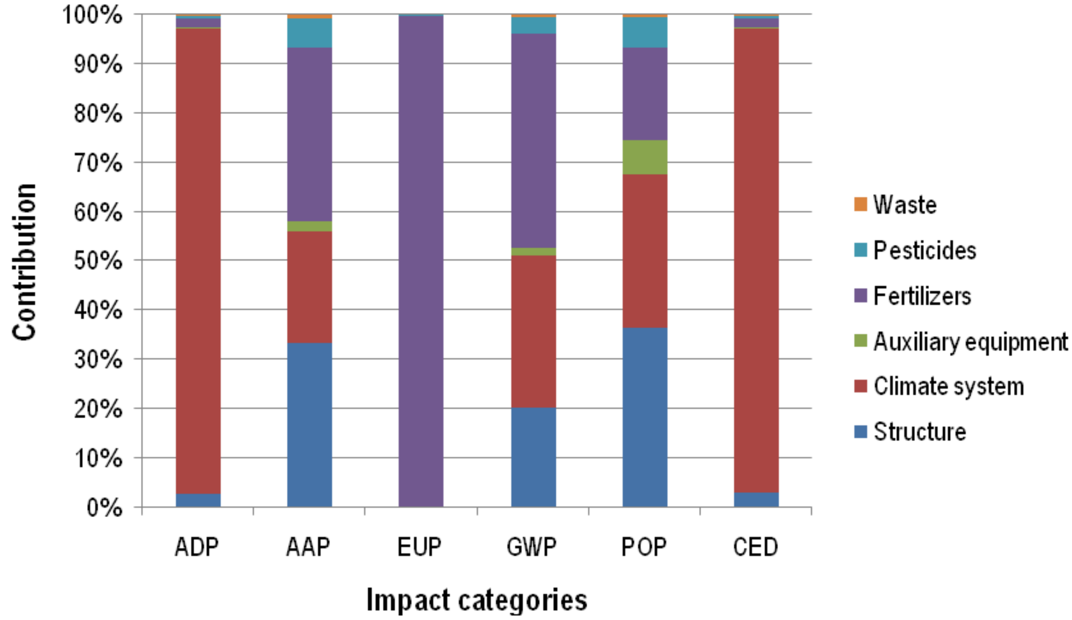


Figure 2.2.6 Stages contribution to impact categories for tomato production with natural gas in Hungary.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

2.2.3.2 Structure LCIA

Results for Venlo greenhouse structure in Hungary were represented in figure 2.2.7. The frame was mainly made of steel and aluminium. The large amount of metal in the frame was reflected in the results which showed the highest burden for all the impact categories with percentages between 49,4% and 62,1%.

Transport was the second burden for the impact categories AAP, EUP, GWP and POP, with percentages between 13,5% and 25,0%; and the third contributions to ADP and CED, with values of 17,8% and 18,2% respectively. These contributions would have also been the second magnitude to ADP and CED in case plastics materials and manufacturing processes were not summed up all together. These large scores were due to the fact that distance from origin of structure materials was 2.000 km.

Plastics processes were the second burden for the impact categories ADP and CED, with percentages of 23,4% and 23,6% respectively. The contribution of plastics to the rest of impact categories AAP, EUP, GWP and POP was between 10,1% and 14,9%

Glass contributions to impact categories were between 6,9% and 16,2%. After metal and transport processes, glass was the third burden in AAP and POP impact categories, with scores 16,2% and 11,5% respectively caused by the use of chemical compounds, mainly soda during the manufacture.

Concrete contributions to impact categories were low, with percentages between 0,6,% and 2,4%.

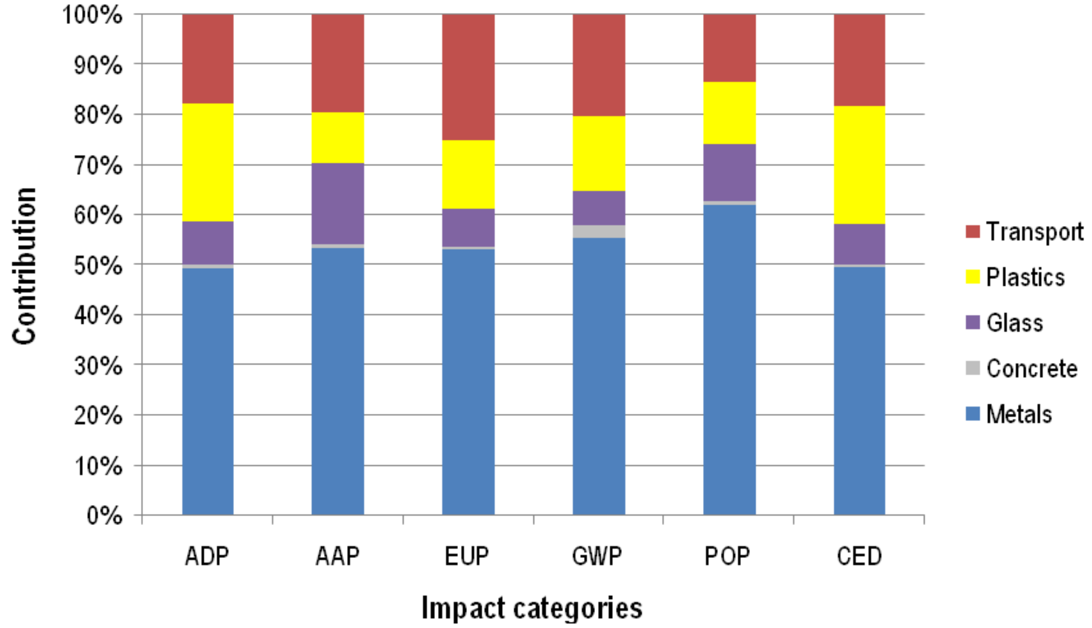


Figure 2.2.7 Structure materials contribution to impact categories for tomato production in Hungary.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

2.2.3.3 Climate system LCIA

- ***Considering heating system with thermal water***

Processes contributions to Climate system considering the use of thermal water for heating system were represented in figure 2.2.8.

Results showed clearly that electricity consumption was the main contribution to all impact categories. This amount of electricity corresponded to the total consumption of the greenhouse (Part I, 1.2). The scores of the contributions were between 50,6% and 89,4%. Electricity production mix in Hungary mainly depends on nuclear, natural gas and coal power plants. For more information about electricity production mix in Hungary, annex 4.4., table, 4.6 can be consulted.

Metals were the second contributor to impact categories, with scores between 9,0% and 46,5%. The high contribution of metal to EUP was due to the emissions of phosphate and nitrogen oxides to water because of furnace disposal in the production process of recycled steel.

Plastics contribution scores were between 0,6% and 1,3%. Transport contribution scores were between 0,5% and 2,1%.

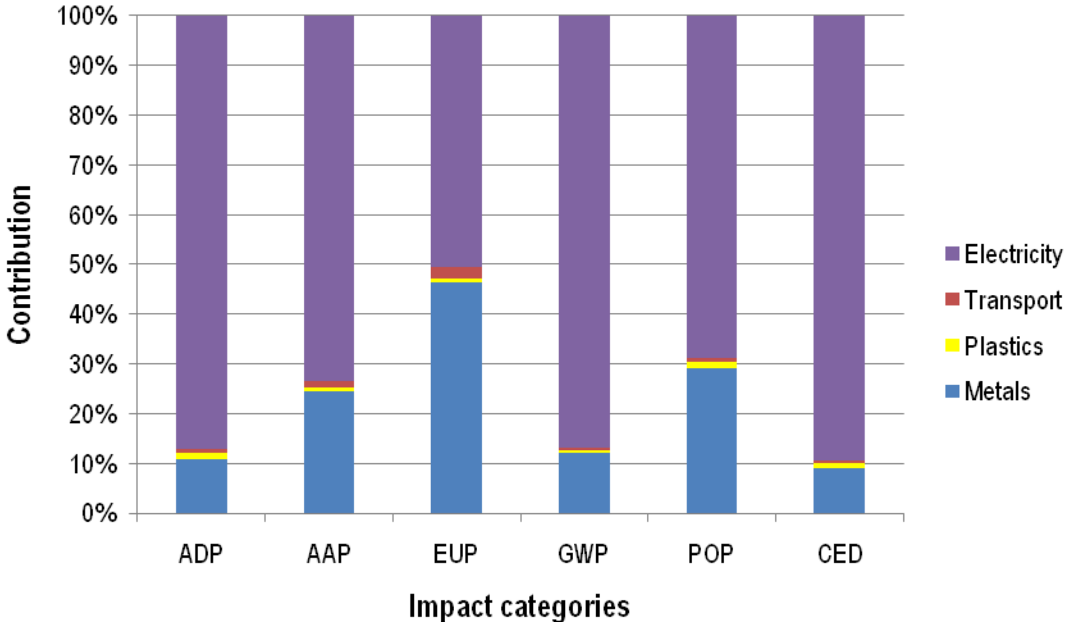


Figure 2.2.8 Climate system processes contribution to impact categories for tomato production with thermal water in Hungary.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

- ***Considering heating system with natural gas***

Processes contributions to Climate system considering the use of natural gas for the heating system were represented in figure 2.2.9.

As it was expected, results showed that natural gas and electricity consumption were the main contributors to all impact categories. They were the first or second contribution depending on the impact category selected.

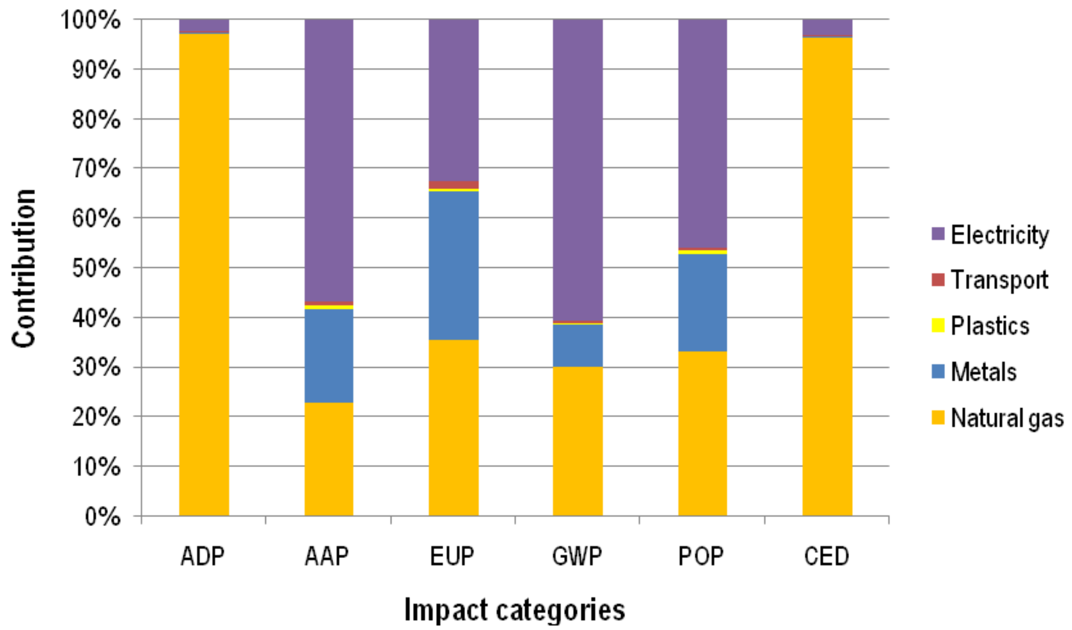


Figure 2.2.9 Climate system processes contribution to impact categories for tomato production with natural gas in Hungary.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

Natural gas was the main burden in ADP, EUP and CED, with scores of 97,3%, 35,4% and 96,5% respectively. For the rest of impact categories AAP, GWP and POP, scores were between 22,7% and 33,2%.

Electricity consumption was the main burden in AAP, GWP and POP, with scores of 56,8%, 60,7% and 46,0% respectively. For the rest of impact categories ADP, EUP and CED, scores were between 2,4% and 32,6%. The large contribution of electricity to GWP was due to carbon dioxide fossil emissions, which were more than twice the emissions produced by gas natural consumption. Two reasons caused these high emissions. Firstly, consumption included the total quantity of electricity for the greenhouse; secondly, in the electricity production mix in Hungary (table 4.4.6), 62% of the production uses carbon, oil and natural gas with the subsequent emissions of carbon dioxide.

Metals were the third contributor to all impact categories, with scores between 0,3% and 30,0%. Plastics contribution scores were between 0,03% and 0,86%. Transport contribution scores were between 0,01% and 1,39%.

2.2.3.4 Auxiliary equipment LCIA

Results for Auxiliary equipment LCIA were represented in figure 2.2.10. Results showed that Substrate and Plastics processes were the main contributors to impact categories.

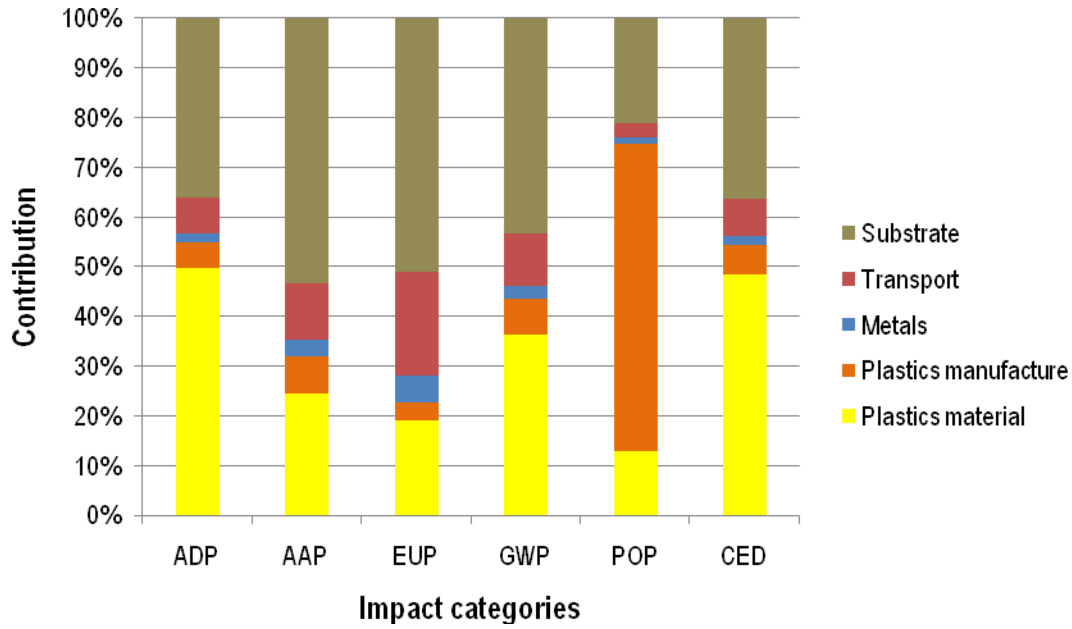


Figure 2.2.10 Auxiliary equipment processes contribution to impact categories for tomato production in Hungary.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

Substrate was the highest burden in AAP, EUP and GWP. The scores for these impact categories were 53,4%, 50,9% and 43,4% respectively. Substrate was also the second contributor to impact categories ADP, POP and CED, with scores of 36,%, 21,1% and 36,4%.

Plastic material production was the main burden in ADP and CED, with scores of 49,7% and 48,4% respectively. The rest of contributions to AAP, EUP, GWP and POP were between 13,0% and 36,4%.

Plastic manufacturing process was the first contributor to POP, with a score of 61,6%. Foaming expansion process for manufacture polystyrene substrate layers was the reason for such a high result because of emissions of pentane to air. For the rest of impact categories ADP, AAP, EUP, GWP and CED, scores were between 3,4% and 7,7%.

Metal environmental impact scores were between 1,4% and 5,4%..

Transport contribution scores were between 2,8% and 21,1%.

2.2.3.5 Fertilizers

Fertilizers use involved environmental impacts both by manufacturing processes and emissions (Part I, 1.2). Results obtained were represented in figure 2.2.11.

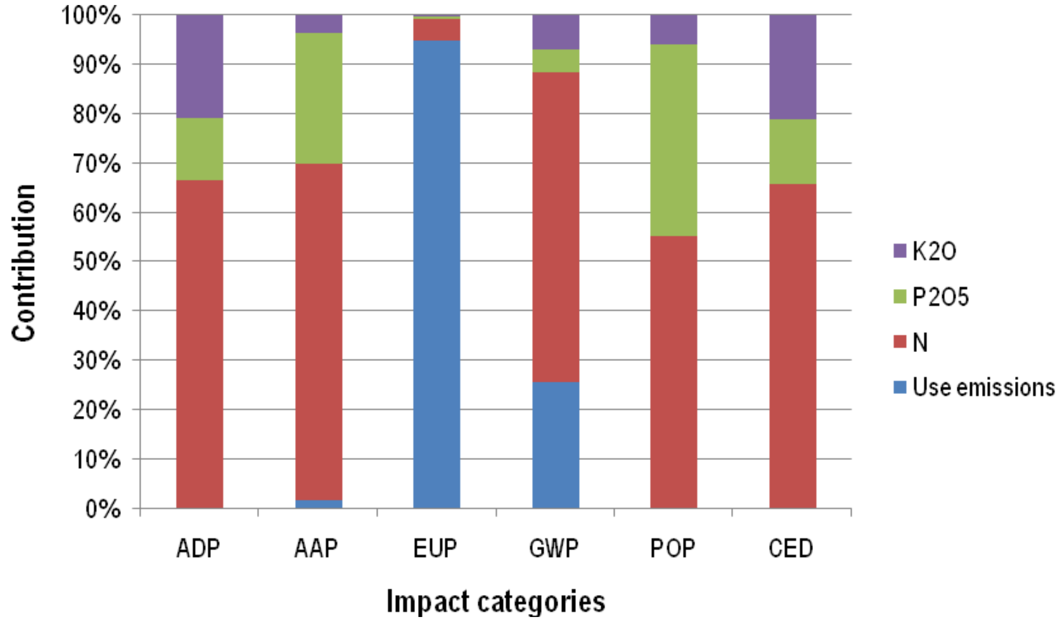


Figure 2.2.11 Fertilizers contribution to impact categories for tomato production in Hungary. Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

Results reflect that N fertilizers production had the highest scores for all impact categories exept for Eutrophication. The percentatges to impact categories were between 55,1% and 68,3%, For EUP was just 4,3%.

Contribution by use emissions stands out in EUP impact category, with 94,9% of the total. This high burden was the consequence of emissions to water by leaching, (Part I, 1.1).

Use emissions have also a considerable contribution to GWP, with a score of 25,5%, This result was mainly caused by emissions of dinitrogen monoxide.

2.2.3.6 Phytosanitary treatments

Pesticides contribution results were not one of the main burdens in regard of the total tomato production system. Nevertheless, results were, exept for EUP, between 3,6% and 7,9% of the total and this amount was much higher than it would be expected in this kind of tomato crop in Europe.

Pesticides toxicity was not evaluated (see (Part I, 1.2).

2.2.3.7 Waste management

In this section, LCIA waste management was studied according to the specific data received from Mórakert for this scenario. Waste management included transport to the disposal plant and emissions because of the specific treatment considered. Waste and recycling treatments data were represented in figure 2.2.12.

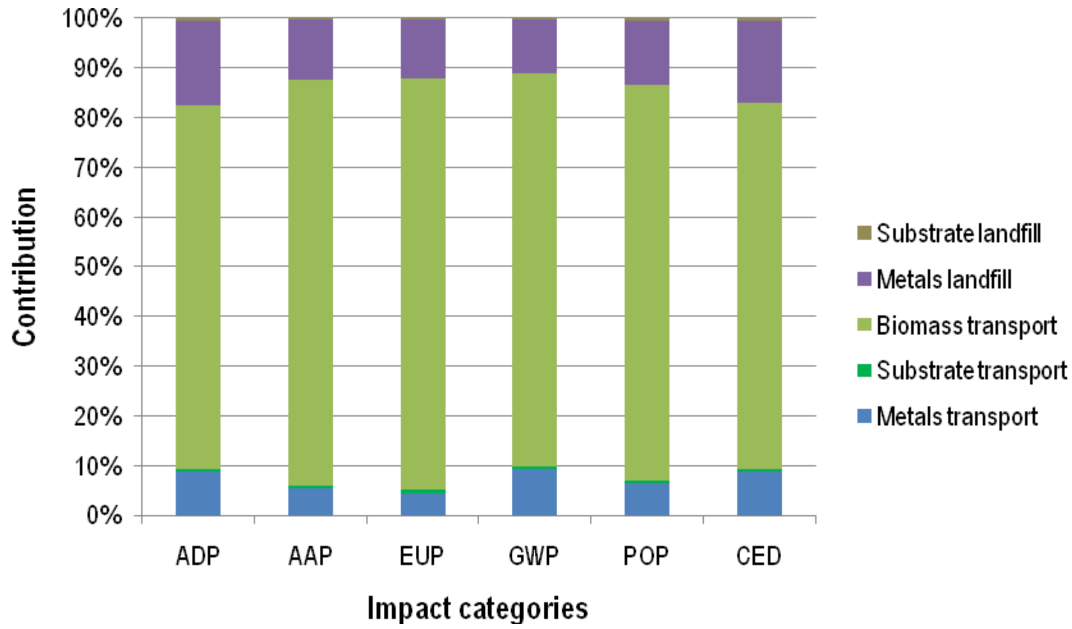


Figure 2.2.12 Waste management contribution to impact categories for tomato crop in the Hungary.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

Green biomass was 100% composted. Transport to the composting plant was the highest contributor to impact categories, with scores between 73,1% and 82,8%. This high contribution was due to the fact that was a transport carried out every year at the end of the crop. On the other hand, the rest of materials have to be transported depending on their useful life, which was superior to a year.

For frame materials, 100% of metal was rejected to landfill, 100% of glass was recycled and concrete was recycled in 70% and rejected to landfill in a 30%. Frame materials transport had contributions to impact categories between 4,5% and 9,3%. Metal and concrete emissions at landfill was a burden with contributions between 10,6% and 17,0%.

Substrate was 50% recycled and 50% transported to landfill. Contributions because of transport and landfill disposal were between 0,3% and 0,6%.

Plastics were 100% recycled, including substrate bags. Thus, no environmental impact has to be applied in this stage (see Part I, 1.2).

2.3.4 INTERPRETATION

Tomato production in a Venlo greenhouse in Hungary was studied in order to quantify the environmental impact of this production process. The analysis of the present situation will be the reference and starting point to evaluate the reduction of burden with the implementation of the new advances developed along the Euphoros project.

Evaluation of the results for this scenario showed that the stages Structure, Climate system and Fertilizers were the main contributors to impact categories, both considering thermal water or natural gas for the Climate system. Obviously, the magnitude of the contributions was different in one situation or another.

When using thermal water and not natural gas for heating the greenhouse, the high scores of Climate system were due to electricity consumption. Electricity production mix in Hungary depends principally on nuclear, natural gas and coal power plants. The use of renewable energies was practically zero. The EUPHOROS project cannot have an effect on the electricity production system in Hungary, but it can have consequences on the amount of energy used by the greenhouse production system. Energy saving was a subject to be developed in Workpackage 2.

When considering natural gas for heating the greenhouse, Climate system contribution to impact categories abiotic depletion and cumulative energy demand meaningfully increases. No doubt, the use of thermal water supposed great energy savings. Unfortunately, the use of thermal water was not widely spread in Hungarian greenhouses because of the economic investments necessary for the installation.

Structure greenhouse was another important environmental burden because of the high amount of metal. Greehouses in Hungary must be designed in order to be able to support the possible weight of the snow. This fact makes it necessary to reinforce the frame of the greenhouse and consequiently it may be difficult to reduce the amount of metal in the frame. Perhaps greater efforts should be done to improve greenhouse design or reduce environmental impact during the manufacture of these materials. However, these aspects were out of the scope of this project. The use of recycled steel instead of new steel was a less contamination process, but even this the consumption of energy in the manufacturing process continues being very high.

Fertilizers were an important burden for all the impact categories. Quantity of product applied was visibly high. This becomes particularly clear if the use of fertilizers in Hungary was compared with the other tomato production, where similar yield was achieved with much less fertilizers. Efforts should be done to reduce doses by developing a better fertilization program and by changing from an open-loop irrigation system to a closed-loop recirculation system. Emissions to water would be significantly reduced and consequently their contribution to Eutrophication impact category. Workpackage 3 was expected to help to improve the use of fertilizers. These aspects referring to fertilizers should be strongly taken into account in workpackages 6 (Integration and Evaluation) and 7 (Dissemination).

Substrate could be also an area of improvement due to the high environmental impact in the manufacturing process, for example, increasing recycling of the product in order to reduce the amount of new rockwool manufacture. Improvement of substrate use was one of the objectives of the current Euphoros project (WP3).

LCIA has also reflected that Auxiliary equipment was a significant burden due to the considerable use of plastic elements. Once more, further efforts should be done in order to reduce environmental impact of manufacturing processes. All of them were strongly dependent on energy. Thus, the focus should be directed to the reduction of energy consumption and abiotic resources use, in favor of more efficient processes and use of cleaner energies.

Pesticides contribution to impact categories has not important percentages of contribution compared with the rest of stages taking part in the tomato production system. Nevertheless, the results obtained reflect that they were higher that it should be expected for this kind of crop. Further efforts could be oriented to reduce the quantity of product applied.

2.3 SCENARIO 3: TOMATO PRODUCTION IN THE NETHERLANDS

2.3.1 GOAL AND SCOPE DEFINITION

This report describes the environmental impact of Protected Tomato Production in a Venlo greenhouse in the Netherlands. In order to perform the environmental impact assessment of the scenario “Tomato production under glass greenhouse in the Netherlands” Life Cycle Assessment (LCA) methodology was applied. The study was structured in the compulsory phases of the methodology (Part I, 1).

The goal of the study was the environmental analysis of the current situation of tomato greenhouse production in the Netherlands and identification of the major causes of environmental impact. In this LCA study an analysis of the resource inputs of existing greenhouse operations was carried out. The scope defined was the tomato greenhouse production (Part I. 1.2).

The Functional Unit selected was **1 t tomatoes (1000 kg tomatoes)**. A productivity of 56,5 $kg{\cdot}m^{-2}$ of tomato per campaign was taken into account.

2.3.2 INVENTORY ANALYSIS

Greenhouse tomato production system was structured in several stages or processes. Figure 1.2 showed the flow diagram of the production system for tomato crop in the Netherlands, Part I, 1.2.

Figure 2.3.1 VENLO greenhouse in the Netherlands

The greenhouse used as a reference was a steel and glass Venlo structure. It was situated near Wageningen. More detailed information about the inventory data can be provided by request.

More detailed information about the inventory data were provided in Annexes and can be requested to the coordinator.

2.3.2.1 Venlo Greenhouse Structure

Greenhouse Description

The greenhouse chosen as representative for scenario 3 was a tomato Venlo production in the Netherlands. The main features of this greenhouse were:

- Surface: 40.000 m^2
- Ridge height: 6,76 m
- 25 spans
- Ventilator surface 3.776 m^2

The Venlo greenhouse described has 25 spans. Each span was built up by modules of two bays, 8m x 5m, and one next to the other to complete the greenhouse building.

(Annex 4.5, table 4.5.1).

Greenhouse Structure characteristics

Greenhouse structure was mainly made of metal and glass, with a frame of steel and aluminium.

Figure 2.3.2 Venlo greenhouse with steel frame showing inside energy screen

Steel elements were girders, roof bars, stability braces, rails, posts, tie beams, foundations reinforcements, ventilators opening mechanisms and a high wire system to support the tomato crop. Aluminium elements were gutters, ridges, bars, ventilators opening mechanism and energy screens. The covering, front walls and side walls were made of uncoated flat glass.

There was also a great amount of concrete, coming from the foundations and a main path 4m width from side to side of the greenhouse.

Polyester was the plastic for floor material and screens (energy and darkening screens). There was no insect proof screen.

The manufacturing processes for the structure materials were considered, including manufacture for steel, aluminium, glass and polyester elements. In the case of metal a coating treatment was also taken into account.

All elements for the greenhouse were transported by lorry from an estimated distance of 55 km.

(Annex 4.5, table 4.5.2).

2.3.2.2 Auxiliary equipment

In this section, the necessary elements for raising the crop were considered, including the distribution system for watering the crop, substrate and transport of these materials to the greenhouse.

The watering system was closed and there was recirculation of water from drainage.

Crop period was 49 weeks and a density of 1,25 plants·m^{-2} was estimated.

All elements for the Auxiliary equipment were transported by lorry from an estimated distance of 200 km.

(Annex 4.5, tables 4.5.3 and 4.5.4).

Substrate

The substrate used was rockwool in plastic bags. Bags were located on polystyrene benches. The bag size was (132 x 10 x 7) cm. Each bag contained three plants, 2 stems each.

Substrate was delivered to the greenhouse from an estimated distance of 185 km by lorry.

(Annex 4.5, table 4.5.5).

Water consumption

Water consumption was considered as the main transpiration value of the crop for this inventory. The total amount of water for the crop (transpiration) was 7.944 m^3·ha^{-1}. (Hortimed 2001-2003).The water use per production was 14,06 l·kg tomato^{-1}.

Figure 2.3.3 Crop rows showing two stems per plant

2.3.2.3 Climate system

This section included the heating system, the cogeneration system, the distribution equipment, the heat storage system and CO_2 system. Total electricity consumption for the greenhouse was also included in this section.

There was a high consumption of natural gas for the heating system. The use of a cogeneration system allows the production of electrical energy at the same time than thermal energy.

For electricity energy production it was considered Electricity production mix Netherlands (Frischknecht, Junblught et al. 2005).

Total electricity consumption for the greenhouse was 10 $kWh \cdot m^{-2}$. Cogeneration system produced 178 $kWh \cdot m^{-2}$, much more than the necessary for the greenhouse and consequently the surplus of electrical energy can be discharged to the public grid.

Climate system was transported to the greenhouse by lorry, from an estimated distance of 55 km.

Ventilators were not protected with insect proof screens.

(Annex 4.5, tables 4.5.6 to 4.5.8).

Figure 2.3.4 Heating pipes along tomato rows

2.3.2.4 Fertilizers

The total quantity of N, P and K was evaluated with independence of the type of fertilizers (see Part I, 1.2). The fertilizers used in this crop were estimated:

N	1.688	$kg \cdot ha^{-1}$
P_2O_5	406	$kg \cdot ha^{-1}$
K_2O	1.855	$kg \cdot ha^{-1}$

(Annex 4.5, tables 4.5.9 and 4.5.10).

2.3.2.5 Phytosanitary treatments

In this section, it was considered the total amount of active ingredient with the distinction of insecticide and fungicide. The machine for its application to the crop was also taken into account.

The quantities of pesticides estimated were:

Insecticides	3	$kg \cdot ha^{-1}$
Fungicides	7	$kg \cdot ha^{-1}$

(Annex 4.5, table 4.4.11).

2.3.2.6 Waste management

It was well known the variability of waste treatments from site to site, so, meanwhile the specific data for this scenario were determined, the following assumptions were estimated:

15 years materials:

- metal and glass: 100% was recycled and 0% was transported to landfill
- concrete: 50% was recycled and 50% was transported to landfill

Plastics (pipes, films, etc): 50% was recycled and 50% was transported to the incinerator.

Substrate (rockwool and bags): 50% was recycled and 50% was transported to landfill.

Green biomass: 40% of fresh weight of plants was composted

Transport burden for waste management destination and emissions of treatments were counted.

(Annex 4.5, tables 4.5.12 and 4.5.13).

2.3.2.7 Transport

The city of origin, means of transport and distance to the greenhouse were considered for all materials in the greenhouse.

(Annex 4.5, table 4.5.14).

2.3.3. LIFE CYCLE IMPACT ASSESSMENT

The significance of potential environmental impacts for tomato production under glass greenhouse in the Netherlands was presented in this section. Results from Life Cycle Inventory were used in order to calculate the environmental contribution to the impact categories selected (Part I,1.3).

(Annex 4.5, tables from 4.5.15 to 4.5.22).

2.3.3.1 Production system LCIA

In this section, results from LCI were assessed for tomato production in the Netherlands. The environmental impacts to impact categories were assessed considering two options in Climate system stage: with cogeneration system and without cogeneration system. The first was the real situation in the Dutch scenario assessed and the latter was a supposition for the study.

- ***LCIA considering cogeneration in Climate system***

Tomato production in the Netherlands using a cogeneration system presents particular results in the LCA study that needs additional comments for its interpretation. The cogeneration system also produced a high amount of electricity that exceeds the electricity greenhouse consumption. The surplus of electricity was transferred to the public grid. Thus, there was an environmental benefit because all this energy was produced in parallel with the greenhouse heating. One may reach the paradoxical conclusion that the more natural gas was used by the cogeneration system the better for the environment. Since the generation of electricity was not the main function of the greenhouse, in order to better understandf the contribution of all stages taking part in tomato production, it was decided to conduct the LCIA without considering the environmental benefits of the cogeneration system.

- ***LCIA without considering cogeneration in Climate system***

LCIA results for tomato production without cogeneration in the Netherlands were represented in figure 2.3.5. Results showed that Climate system was the main contribution to the categories ADP, EUP, GWP and CED with percentages between 43,7% and 95,8% of the total. The high amount of gas natural for heating the greenhouse was the main responsible for such high environmental impacts for ADP and CED. For EUP and GWP, electricity consumption of the greenhouse was the cause of the environmental impact in Climate system stage because of emissions of NO_x in EUP and CO_2 in GWP in the process of electricity production (annex 4.5, table 4.5.7, electricity production mix in the NDL).

The main energy sources for electricity production in the Netherlands were natural gas (50%) and hard coal (20%). Emissions for the production of 1kWh of electricity produced by hard coal were between 5 or 6 times higher than for natural gas. Therefore, one of the reasons for the high contribution of electricity use to the environmental impacts was the combustion of hard coal.

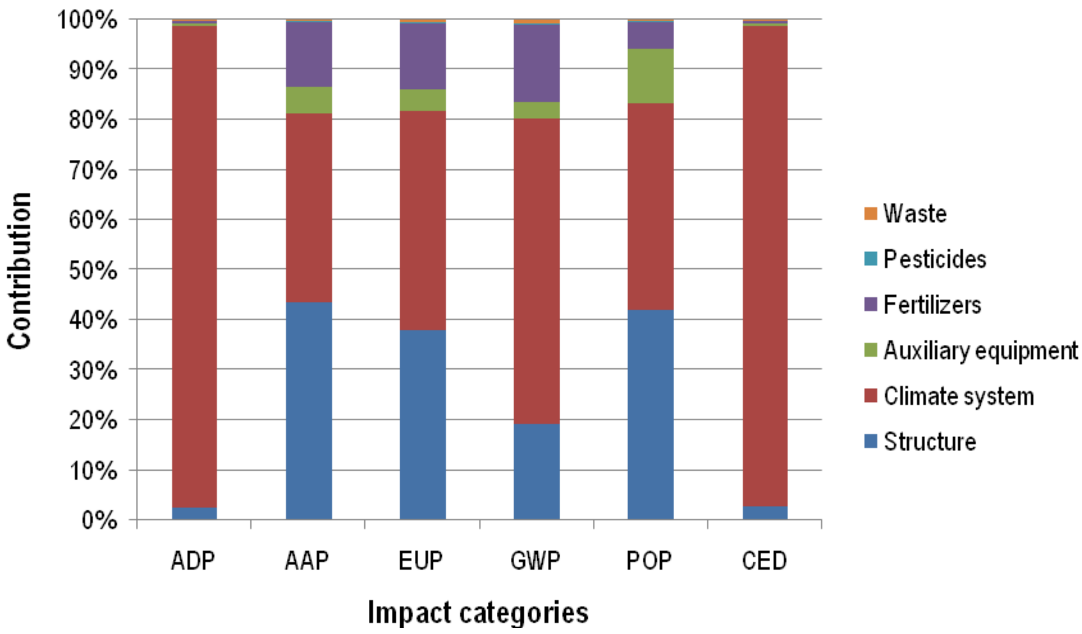


Figure 2.3.5 Stages contribution to impact categories for tomato production without cogeneration in Climate system in the Netherlands.
Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand.

Structure was the main burden for the impact categories AAP and POP, with percentages of 43,4% and 42,0% respectively. For these categories not only metal was a important contributor, also the glass manufacture. For this two impact categories Climate system was the second burden with percentages very close to those of structure, which were 37,7% for AAP and 41,3%.

Structure was the second burden for the impact categories ADP, EUP, GWP and CED, with percentages between 2,6% and 38,0%.

Fertilizers was the third burden in tomato crop production for impact categories ADP, AAP, EUP and GWP and Auxiliary equipment for POP and CED. Contributions to ADP and CED were negligible (0,68% and 0,65%) and the rest were between 10,9% and 15,8% of the total amount.

2.3.3.2 Structure LCIA

Results for Venlo greenhouse structure were represented in figure 2.3.6. The frame was mainly made of steel and aluminium. The high amount of metal in the frame was reflected in the results which were the highest burden for all the impact categories with percentages between 55,6% and 72,4%.

The second most important material in the structure contributing to impact categories was glass, with contributions to impact categories between 20,4% and 41,0%.

Plastics contribution to impact categories were much lower, between 1,8% and 5,3%.

Concrete contribution to impact categories was not relevant, between 0,6% and 2,8%.

Frame transport from origin to greenhouse had an insignificant environmental impact, with percentages between 0.6% and 1,5%.

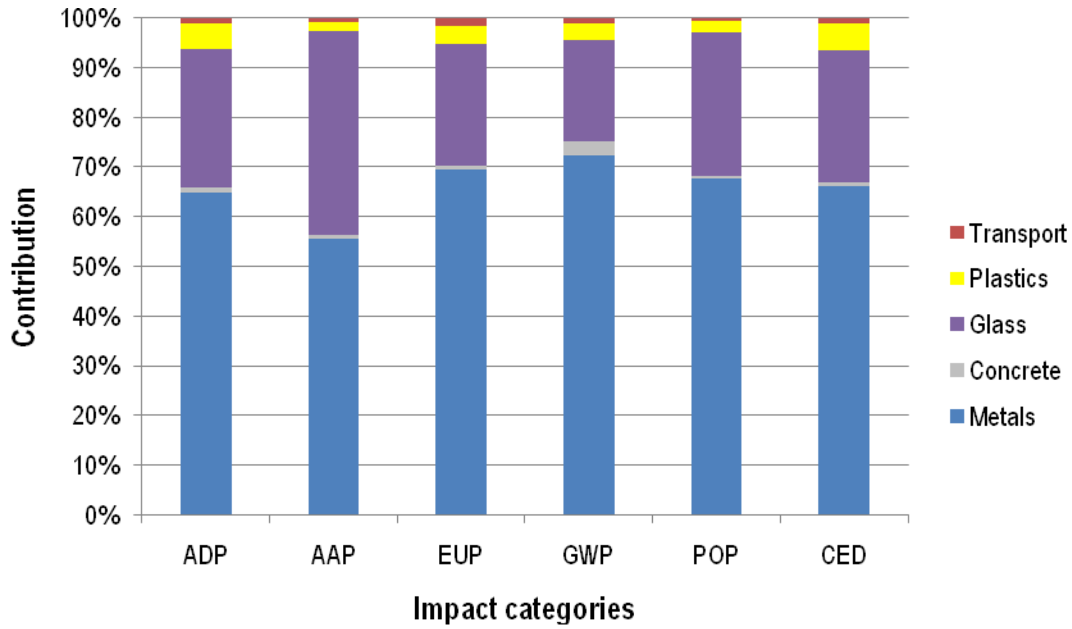


Figure 2.3.6 Structure materials contribution to impact categories for tomato production in the Netherlands.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand.

2.3.3.3 Climate system LCIA, without cogeneration

Processes contributions of Climate system were represented in figure 2.3.7. When cogeneration system was not included, the only consumption of natural gas was for heating the greenhouse. Natural gas was the highest burden in ADP and CED, with a percentage of 92% for both impact categories.

Electricity consumption of the greenhouse was the highest contributor to the rest of impact categories AAP, EUP, GWP and POP with percentages between 43,3% and 75,7% of the total impact. The impact to these categories corresponded to the emissions generated during the production of electricity at power plants (nitrogen oxides, sulfur dioxide, carbon dioxide principally). Electricity production mix in the NDL information was reflected in annex 4.5., table 4.5.7.

Metals from Climate system elements were the third burden in importance to impact categories AAP, EUP, GWP and POP, with percentages between 11,1% and 35,6%.

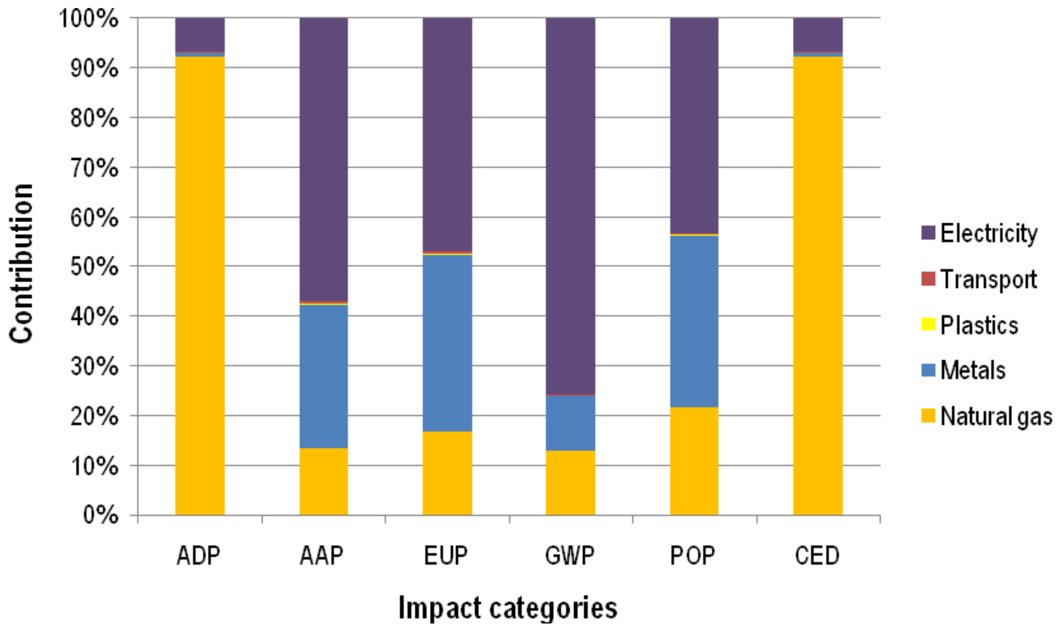


Figure 2.3.7 Climate system processes contribution to impact categories for tomato production without cogeneration system in the Netherlands.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand.

2.3.3.4 Auxiliary equipment LCIA

Auxiliary equipment LCIA showed the importance of substrate contribution to impact categories, which was also one of the objectives to improve in the Euphoros project. Processes contributions were represented in figure 2.3.8.

Substrate process includeed rockwool manufacture; plastic bags manufacture and transport to greenhouse. Rockwool manufacture was the most significant of the three.

Substrate presented the highest contribution scores for the majority of impact categories: ADP, AP, EUP, GWP and CED with percentages from 43% to 58%.

All plastic processes were organized in two groups, plastic materials and plastic manufacture. The former includeed all the processes for material production and the latter included the processes for producing the final elements Plastic manufacture was the main contributor to POP with 49,6%, due to the high impact of polystyrene layers manufacture.

Plastics contributions to impact categories had values between 5% and 49,6%.

Metals environmental impacts accounted for between 7,8% and 19,8%.

Transport contribution was not significant, 0,9 to 5,0%.

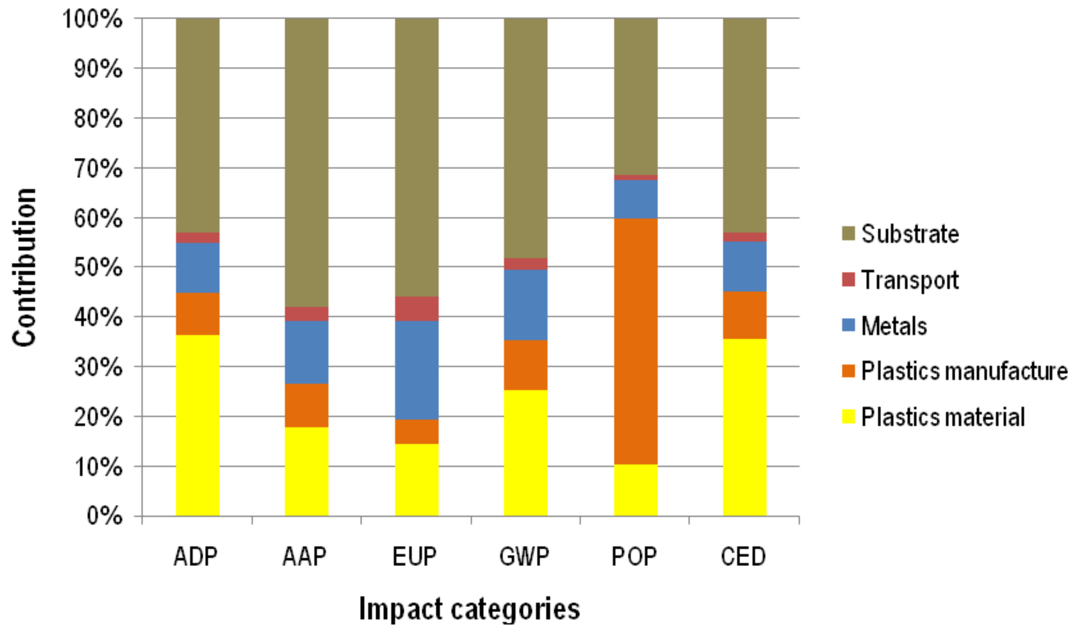


Figure 2.3.8 Auxiliary equipment processes contribution to impact categories for tomato production in the Netherlands.
Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand.

2.3.3.5 Fertilizers

Fertilizers use involved environmental impacts both by manufacturing processes and emissions in application. (Part I, 1.2).

Results were represented in figure 2.3.9.

Results obtained reflect that highest scores were for N fertilizers production for all impact categories, with high percentages between 65,9% and 88,3%.

Emissions because of application were also important for GWP, which accounted with a contribution of 26,7% mainly because of emissions of dinitrogen monoxide.

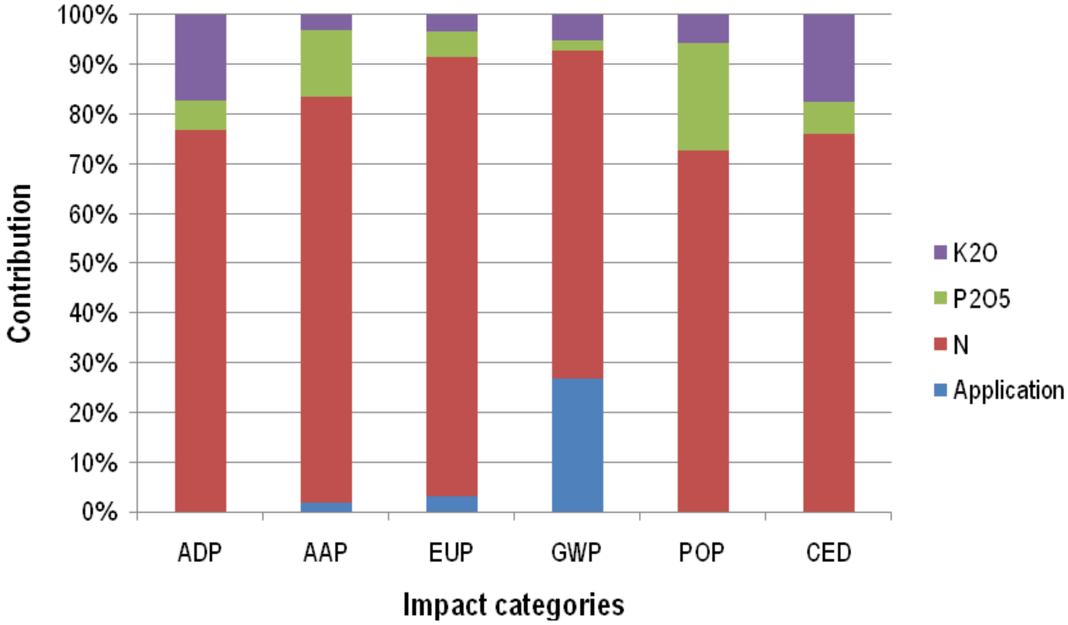


Figure 2.3.9 Fertilizers contribution to impact categories for tomato crop in the Netherlands. Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand.

2.3.3.6 Phytosanitary treatments

Pesticides results contribution was negligible with regard to the total contributions of the tomato production. Values were between 0,01% and 0,13% of the total. Pesticides toxicity was not evaluated (see Part I, 1.2).

2.3.3.7 Waste management

In this section waste materials management was considered, including transport to the disposal plant and emissions because of the specific treatment considered.

It was assumed that concrete was the only 15 years useful life material that was rejected to landfill, 50% of all the concrete material in the greenhouse. Moreover, it was considered that metal and glass were all recycled.

Biomass transport to the compost plant was the main burden for all the impact categories except for the GWP, with contributions between 49,2% and 71,6%. These high contributions were due to the fact that transport was carried out every year at the end of the crop; meanwhile the rest of materials were transported depending on their useful life that was superior to one year.

Plastics incineration accounted for the highest score for GWP (79,7 %).

Emissions due to concrete disposal at landfill were the second burden for the impact categories ADP (15,9) and CED (15,3%).

2.3.4 INTERPRETATION

The assessment about tomato production in the Netherlands was conducted in order to find out the most important burdens and the contributions to impact categories. Results will determine a reference situation in which the new advances developed in the current Euphoros project will be implemented and subsequently evaluated.

Results for this scenario demonstrated that Climate system was the main contributor to four impact categories, in two cases because of natural gas consumption for greenhouse heating, Abiotic Depletion and Cumulative Energy Demand, and in two others because of electricity consumption, Eutriphication and Global Warming. The use of a cogeneration system for greenhouse heating could compensate significantly the natural gas consumption environmental impacts because of the high amount of electricity produced. This electricity was a by-product that was used for other production processes different from greenhouse activities. Life Cycle Assessment considers electricity from cogeneration as a negative environmental burden that should be subtracted from the burdens associated to tomato production. At first sight, it could seem that the more natural gas was consumed the better for the environment because more electricity was produced. Nevertheless, under the perspective of the environmental improvement of agronomical production, efforts in this project should be addressed to the reduction of energy inputs in absolute terms.

Substrate came out as an important burden because of the high energy consumption in the manufacturing process. Euphoros project is focused on this subject in workpackage 3 and consequently better options for substrate recycling and manufacture are being evaluated.

Waste management depends strongly on the present governmental regulations of each country. Nevertheless, there is a European regulation that states that in 2020 EU countries should recycle 50% of paper, plastic and glass of all domestic waste, and 70% of no dangerous waste from construction and demolition. Recycling as much as possible of all materials coming from greenhouse production would obviously be an important progress that should be achieved as soon as possible.

LCA showed that greenhouse production in Holland is an efficient process in which most inputs are carefully considered. As a consequence, crop yield was notably high. Nevertheless the high yield was achieved through the use of intensive technology and intensive use of materials and energy. The Euphoros project may contribute to increase yield, (and therefore to reduce impacts per unit of kg produced) by using innovative techniques, such as new glass panels and innovative sensing and control elements. Also, results from Work Package two are expected to contribute to save energy, a key factor in greenhouse production in The Netherlands.

2.4 SCENARIO 4: ROSE PRODUCTION IN THE NETHERLANDS

2.4.1 GOAL AND SCOPE DEFINITION

This report describes the environmental impact of Protected Rose Production in a Venlo greenhouse in the Netherlands. Flower production is a very important economic, social and cultural activity in the Netherlands, being the centre of production for the European floral market.

In order to perform the environmental assessment of the scenario "Rose production under glass greenhouse in the Netherlands" Life Cycle Assessment (LCA) methodology was applied. The study was structured in the compulsory phases of the methodology (Part I, 1).

The goal of the study was the environmental analysis of the current situation of rose greenhouse production in the Netherlands and identification of the major causes of environmental impact. In this LCA study, an analysis of the resource inputs of existing greenhouse operations was carried out.

The scope defined was the rose greenhouse production (Part I, 1.2).

The Functional Unit selected was **1000 stems**. A productivity of 276 roses·m^2 per campaign was taken into account.

2.4.2 INVENTORY ANALYSIS

Greenhouse tomato production system was structured in several stages or processes. Figure 1.2 shows the flow diagram of the production system for tomato crop in the Netherlands, Part I, 1.2.

The greenhouse chosen as a reference for rose Venlo production system was a steel and glass Venlo structure. It was situated near Bleiswijk.

More detailed information about the inventory data were provided in Annexes and can be requested to the coordinator.

2.4.2.1 Venlo Greenhouse Structure

Greenhouse Description

The main dimensions of the greenhouse were:

- Surface 40.320 m^2
- Ridge height: 6,76 m
- 21 spans
- Ventilator surface 2.782 m^2

The Venlo rose greenhouse described had 21 spans. Each span was built up by modules of two bays, 9,6m x 5m, and one next to the other to complete the greenhouse building.

(Annex 4.6, table 4.6.1).

Greenhouse Structure characteristics

The greenhouse structure was mainly made of metal and glass, with a frame of steel and aluminium.

Steel elements were girders, roof bars, stability braces, rails, posts, tie beams, foundations reinforcements, ventilators opening mechanisms and a high wire system to support the rose crop.

Aluminium elements were gutters, ridges, bars, ventilators opening mechanism and energy screens.

The covering, front walls and side walls were made of uncoated flat glass.

There was also a great amount of concrete, coming from the foundations and a main path 4 m width from side to side of the greenhouse.

Polyester was the plastic for floor material and screens (energy and darkening screens). There was no insect proof screen.

The manufacturing processes for the structure materials were considered, including manufacture of steel, aluminium, glass and polyester elements. In the case of metal a coating treatment was also taken into account.

All elements for the greenhouse were transported by lorry from an estimated distance of 55 Km.

(Annex 4.6, table 4.6.2).

Figure 2.4.1 Venlo greenhouse with rose crop

2.4.2.2 Auxiliary equipment

In this section, the necessary elements for raising the crop were considered, including the distribution system for watering the crop, substrate and transport of these materials to the greenhouse.

The watering was a close system; and there was recirculation of water from drainage.

Crop period was 4 years. A density of 8,5 plants·m^{-2} was estimated.

All elements for the Auxiliary equipment were transported by lorry from an estimated distance of 200 km.

(Annex 4.6, tables 4.6.3 and 4.6.4).

Substrate

The substrate used was rockwool in plastic bags. Bags were located on polystyrene benches. The bag size was (132 x 10 x 7) cm. Each bag contained three plants.

(Annex 4.6, table 4.6.5).

Water consumption

The total amount of water for the rose crop was 9.025 $m^3 \cdot ha^{-1}$.The water use per plant was 3,27 l·$stem^{-1}$. Source of water was differentiated in its origin in rain water and surface water.

(Annex 4.6, table 4.6.6).

2.4.2.3 Climate system

This section included the heating system, the cogeneration system, the distribution equipment, the roof cooling, the heat storage system and the lighting system. Total electricity consumption for the greenhouse was also included in this section.

There was a large consumption of natural gas for the heating system. The use of a cogeneration system allowed the production of electrical energy at the same time than thermal energy.

For electricity energy production it was considered Electricity production mix Netherlands 2007 (Frischknecht, Junblught et al. 2005).

Total electricity consumption for the greenhouse was 633 kWh·m^{-2}. Cogeneration system produced 345 kWh·m^{-2}**.** Rose production supposed the use of lighting for growing the flowers which caused an elevated electricity demand. From the total electricity consumption, 54,5% corresponded to electricity generated by the cogeneration system and the 45,5% left comes from the public grid.

Figure 2.4.2 Lighting installation for rose crop

The artificial light for rose crop was produced by High pressure sodium (HPS) lamps.

Ventilators were not protected with insect proof screens.

(Annex 4.5, table 4.5.7 and annex 4.6, tables 4.6.7 to 4.6.9).

2.4.2.4 Fertilizers

The total quantity of N, P and K was evaluated with independence of the type of fertilizers (see Part I, 1.2). The fertilizers used in this crop were estimated:

N	1.163	$kg \cdot ha^{-1}$
P_2O_5	276	$kg \cdot ha^{-1}$
K_2O	1.280	$kg \cdot ha^{-1}$

(Annex 4.6, tables 4.6.10 and 4.6.11).

2.4.2.5 Phytosanitary treatments

In this section, the total amount of active ingredient was considered, without distinction between insecticides and fungicides. The machine for its application to the crop was also taken into account.

The quantity of pesticide applied to the crop was 42 $kg \cdot ha^{-1}$.

(Annex 4.6, table 4.6.12).

2.4.2.6 Waste management

It is well known the variability of treatments from site to site, so, meanwhile the specific data are determined for the site the following assumptions were estimated:

15 years materials:

- metal and glass: 100% was recycled and 0% was transported to landfill
- concrete: 50% was recycled and 50% was transported to landfill

Plastics (pipes, films, etc): 50% was recycled and 50% was transported to the incinerator.

Substrate (rockwool and bags): 50% was recycled and 50% was transported to landfill.

Green biomass: 40% of fresh weight of plants was composted

Transport burden for waste management destination and emissions of treatments were counted.

(Annex 4.6, tables 4.6.13 and 4.6.14).

2.4.2.7 Transport

The city of origin, means of transport and distance to the greenhouse were considered for all materials in the greenhouse.

(Annex 4.6, table 4.6.15).

2.4.3. LIFE CYCLE IMPACT ASSESSMENT

The significance of potential environmental impacts to the categories selected for rose production in the Netherlands is presented in this section. Results from Life Cycle Inventory were used in order to calculate the environmental contribution to the impact categories selected (Part I,1.3).

(Annex 4.6, tables from 4.6.16 to 4.6.24).

2.4.3.1 Production system LCIA

In this section, results from LCI were assessed for rose production in the Netherlands. In a similar way to scenario 3, the environmental impacts were assessed considering two options in Climate system stage: with a cogeneration system and without a cogeneration system. Results presented here are the real situation in the Dutch scenario assessed with cogeneration.

- ***LCIA considering cogeneration in Climate system***

Results of Climate system contribution to impact categories were represented in figure 2.4.3.

Clearly, Climate system including cogeneration accounted for the highest contribution to all impact categories with very high percentages between 88% and 99%. This was due to the high consumption of gas natural for the heating and the cogeneration system and the large consumption of electricity for the greenhouse, which was principally addressed for lighting the rose crop. In ADP and CED impact categories, Climate system had the highest contributions, with 98,8% and 98,6% respectively. The main burden was gas natural consumption.

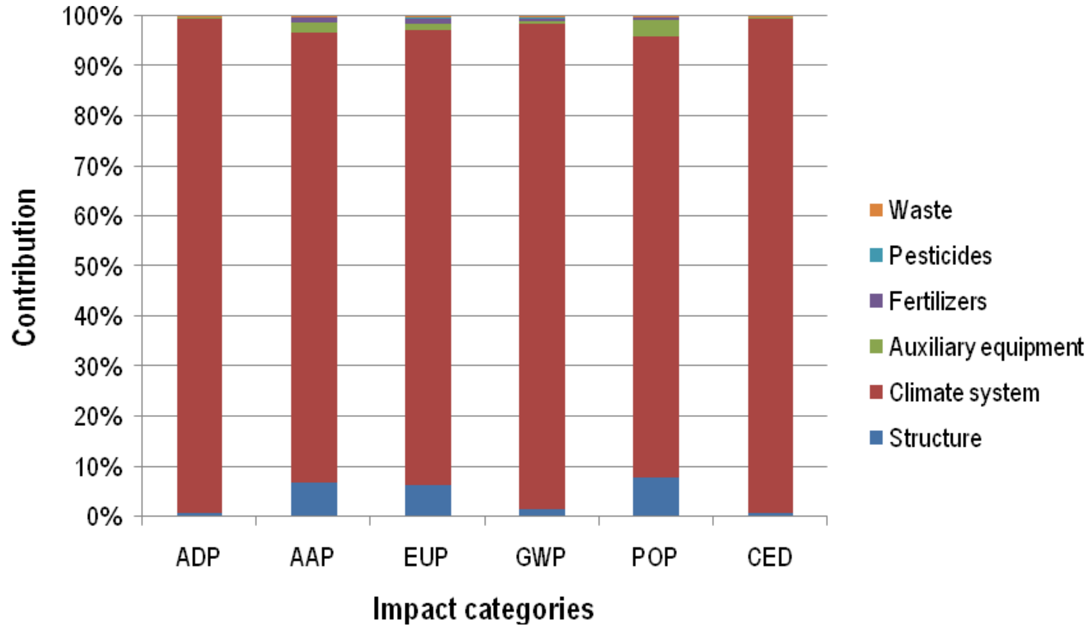


Figure 2.4.3 Stages contribution to impact categories for rose production with cogeneration system in the Netherlands.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand.

For the rest of impact categories AAP, EUP, GWP and POP Climate system contributions were between 88% and 97% and in these cases the main burden was electricity consumption. Structure was in a far second place and its contribution was mainly caused by metal.

2.4.3.2 Structure LCIA

Venlo greenhouse for rose crop was the same structure as scenario Venlo greenhouse for tomato crop. Therefore, conclusions described previously for tomato greenhouse structure could be applied for rose greenhouse structure. See NDL tomato report section 2.3.3.2.

The contributions to impact categories were represented in figure 2.4.4.

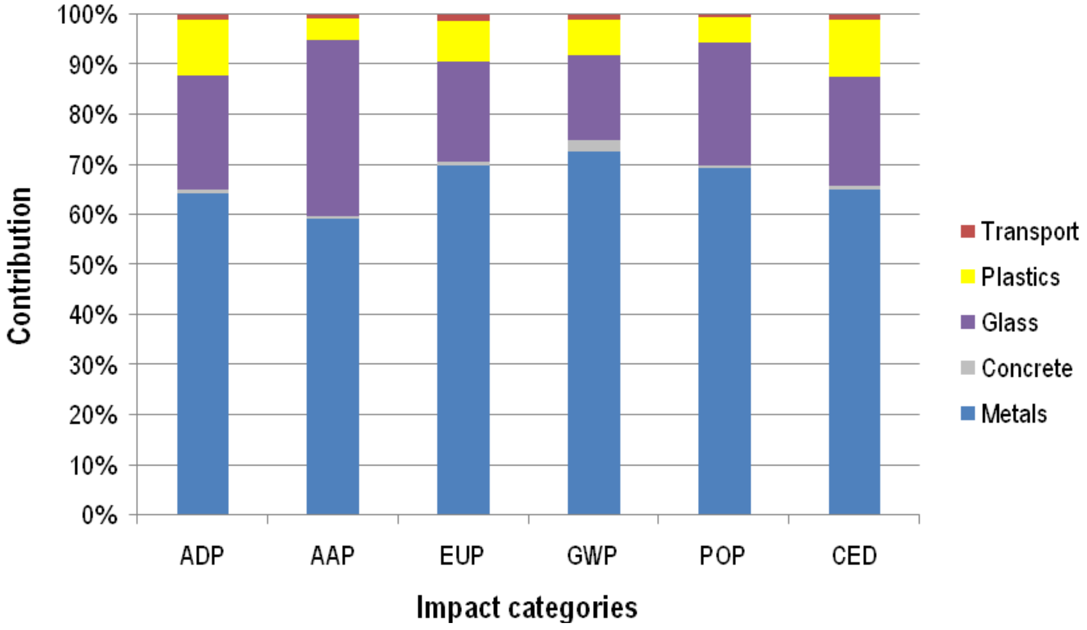


Figure 2.4.4 Structure processes contribution to impact categories for rose crop in the Netherlands.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

2.4.3.3 LCIA for Climate system with cogeneration

In this section, contribution of Climate system with cogeneration to impact categories was represented in figure 2.4.5.

Natural gas was the highest burden in ADP and CED, with 54,1% and 55,5% of the total percentage.

Electricity consumption was the highest burden for the rest of impact categories AAP, EUP, GWP and POP, with percentages between 92,4% and 97,9%. Electricity consumption was very high because of the use of lamps for lighting the crop.

The rest of processes of Climate system in rose crop had low contributions with percentages between 0,002% and 2,768%.

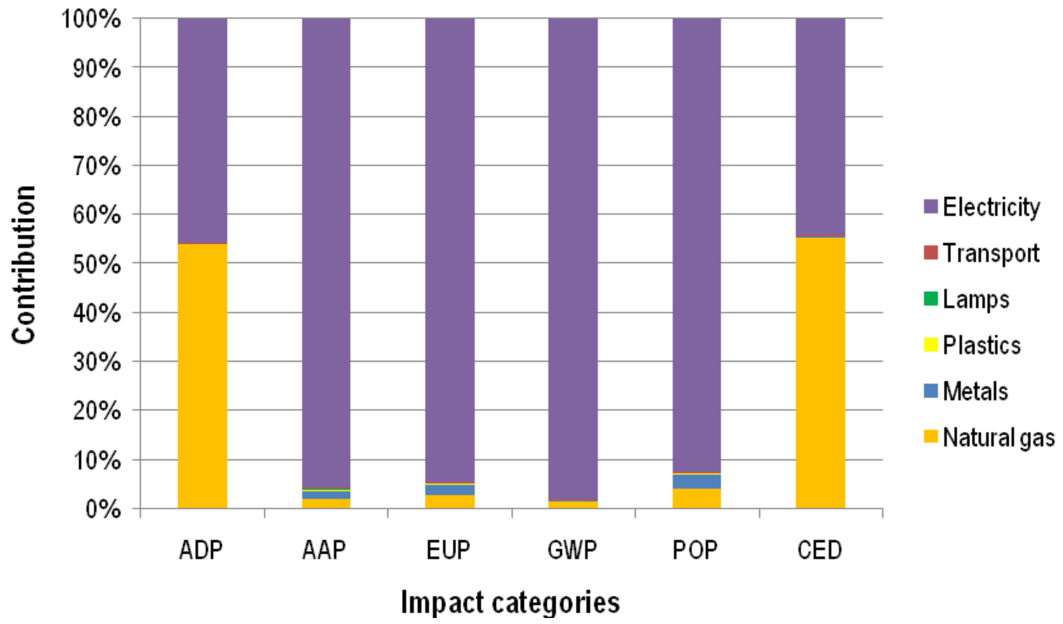


Figure 2.4.5 Climate system processes contribution to impact categories for rose production with cogeneration system in the Netherlands.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

2.4.3.4 Auxiliary equipment

In this section, processes contributions of Auxiliary equipment in rose crop in the Netherlands were represented in figure 2.4.6.

Substrate process included rockwool manufacture; plastic bags manufacture and transport to greenhouse, being rockwool manufacture the most significant of the three of them. Substrate was the highest contributor to all impact categories due to the energy consumed in the manufacturing process, with percentages between 45,3% and 68,1% of the total.

All plastic processes were organized in two groups, plastic materials and plastic manufacture. The former included all the processes for material production and had contributions between 13,4% and 39,2%. The latter included the processes for producing the final elements and the contribution percentages were between 5,6% and 36,6%.

Metal elements in Auxiliary equipment was the fourth burden for the impact categories, with percentages between 4,2% and 9,0% of the total amount.

Transport of Auxiliary equipment had not a relevant contribution to impact categories, with percentages between 0,4% and 1,9%.

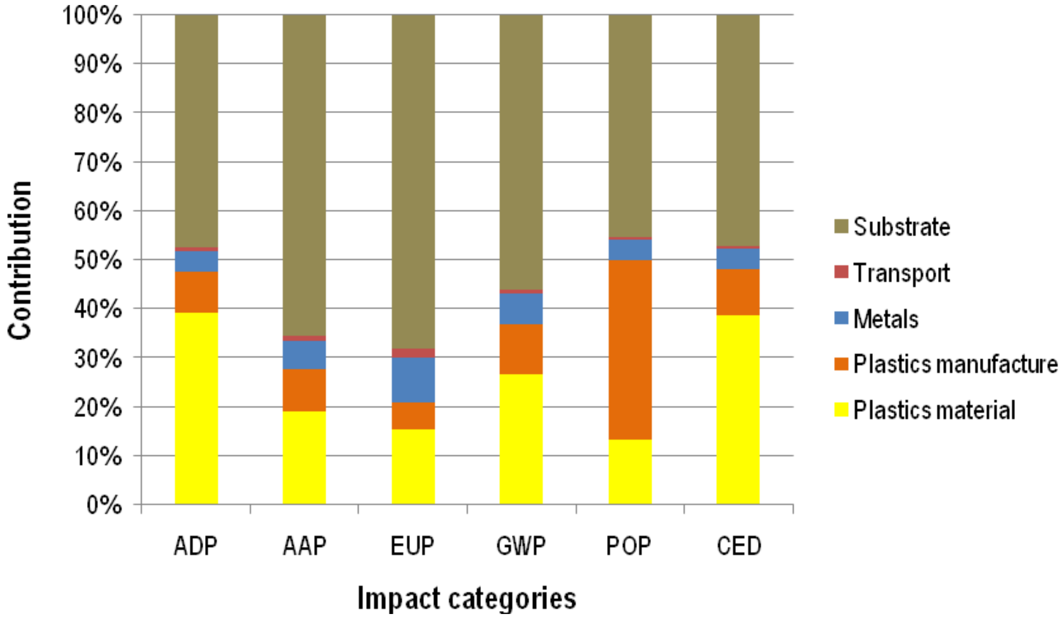


Figure 2.4.6 Auxiliary equipment processes contribution to impact categories for rose production in the Netherlands.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand

2.4.3.5 Fertilizers

Fertilizers use involved environmental impacts both by manufacturing processes and emissions due to their application to the crop. (Part I, 1.2).

Results obtained reflect that highest scores were for N fertilizers production for all impact categories, with high percentages between 64,2% and 88,1%. These results were represented in figure 2.4.7.

Emissions caused by use of fertilizers presented a contribution of 28,7% in GWP mainly caused by emissions of dinitrogen monoxide.

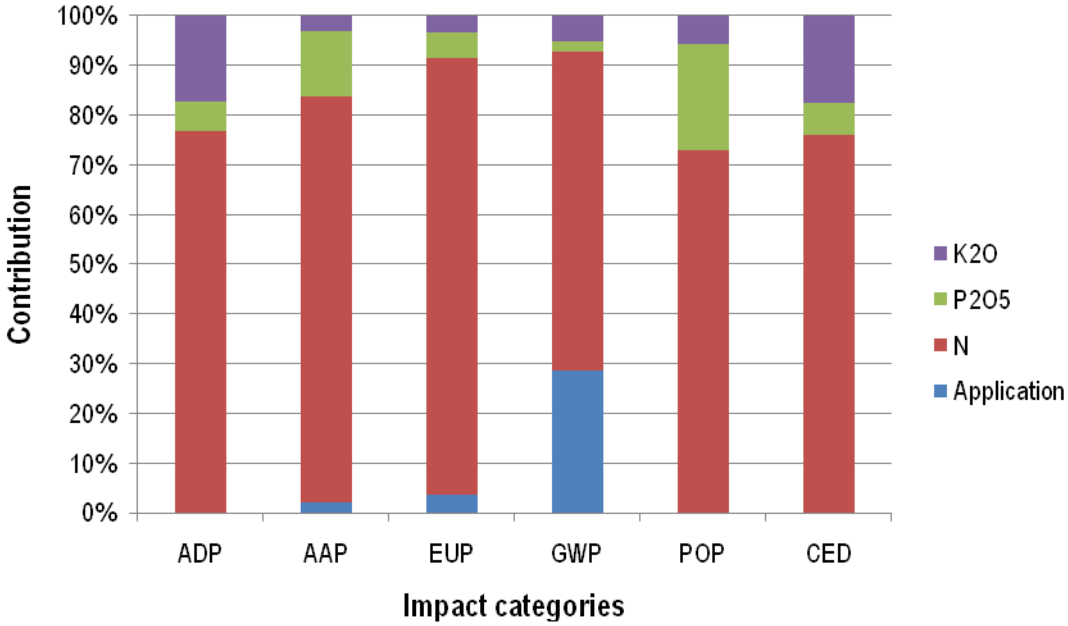


Figure 2.4.7 Fertilizers contribution to impact categories for rose production in the Netherlands.

Impact categories: ADP, Abiotic Depletion Potential; AAP, Air Acidification Potential; EUP, Eutrophication Potential; GWP, Global Warming Potential; CED, Cumulative Energy Demand.

2.2.3.6 Phytosanitary treatments

Pesticides results contribution to impact categories was negligible with regard to the total contributions of the tomato production. Pesticides toxicity was not evaluated (see Part I, 1.2).

2.4.3.7 Waste management

In this section waste materials management was considered, including transport to the disposal plant and emissions because of the specific treatment applied following criteria pointed out Part I, 1.2.

It was assumed that concrete was the only 15 years useful life material that was rejected to the landfill, 50% of all the concrete material in the greenhouse. As well, it was considered that metal and glass were all recycled.

Plastics incineration accounted for the highest scores for all the impact categories with percentages between 29,0% and 96,9%. The main contribution was for GWP with 96,9%. Concrete emissions at landfill were in second place with contributions between 0,82% and 24,8%.

2.4.4 INTERPRETATION

The LCA study for rose production in the Netherlands reflected the environmental impacts at the present moment. As in all the previous scenarios, this reference situation will be the starting point to evaluate the reduction of burdens with the implementation of the new advances developed in the course of the Euphoros project.

Evaluation of the results of rose production showed that Climate system was the main burden for all the impact categories studied. Two were the causes of such a high environmental impact: the natural gas consumption to heat the greenhouse and the electricity consumption to light the crop. In this scenario, although cogeneration process helped to mitigate environmental impact, finally it could not avoid it completely. Cogeneration process could not afford all the amount of necessary electricity so there was also a high supply from the electric grid.

Auxiliary equipment environmental impact could be reduced with the improvement of substrate manufacturing processes, another important point of focus of the present project (WP3).

Results also revealed that there was a considerable environmental impact produced by plastic elements of the watering system. Due to the high amount of plants per surface it was required a high number of drippers and consequently environmental impacts because of plastics increased. Objective of the present project was the reduction of carbon footprint of equipment therefore It could not be avoided to mention it.

LCA assessment is a methodology that allows finding out the potential burdens in a product system, their potential environmental impacts and consequently new opportunities for further investigation in order to reduce environmental damages.

PART II

3. ECONOMIC ASSESSMENT

This report contains the results of objective 1 of WP 1 and especially with respect to the economic assessment of the current greenhouse production. This objective has been achieved by developing task 1.1 Analysis of the resource inputs and cost-benefits of existing greenhouse operations (IRTA & PPO, with input from all other participants).

This economic report is part of deliverable 5 of the EUPHOROS project.

3.1 Scenarios

At the first meeting in Leiden (March 2008) it was decided to assess a reference greenhouse farm for four representative European scenarios:

1) Tomato in multitunnel structure in Spain
2) Tomato in Venlo structure in Hungary.
3) Tomato in Venlo structure in the Netherlands
4) Rose in Venlo structure in the Netherlands

These scenarios are the starting point to describe the production systems in terms of costs and benefits. The description is being done at that level of detail that objectives 3 and 4 of WP1 can be done successfully.

3.2 Economic analysis (partial cost-benefit analysis)

The economic analysis is focussing on a cost-benefit analysis. The approach is as follows:

- goal and system boundary definition
- inventory phase
- cost-benefit analysis
- interpretation
- sensitivity analysis

Goal and system boundary definition

The goal is to assess the financial results of four representative (reference) greenhouse systems under different conditions in Europe. These reference greenhouse scenarios are the starting point to calculate the economic soundness of the designed alternative greenhouse systems in task 1.2. The designed greenhouse systems are focussing on reduction of the inputs and emission of fossil energy/CO_2, crop protection agents and fertilizers. The financial situation of the four reference greenhouses will be the standard for evaluating the economic effects of the designed alternative greenhouse systems.

The system boundary is defined at farm level. This means that all cost and benefit effects of alternative greenhouse systems will be considered at farm level. The greenhouse farm can be seen as a black box with several inputs and outputs (see figure 3.1).

System boundary

Figure 3.1 System boundary of the cost-benefit analysis

The reference greenhouse systems are different in size in the four scenario's.

- 1 ha greenhouse area for tomato under multi-tunnel structure in Spain
- 2,4 ha greenhouse area for tomato under Venlo structure in Hungary
- 4 ha greenhouse area for tomato and rose under Venlo structure in the Netherlands

The following costs and benefits are considered:

- benefits: yield (tomatoes/roses), sales of electricity (Dutch situation)
- costs of planting material, water and fertilizers, pesticides (biological and chemical), energy, other crop assets, labor and contractors, tangible assets (depreciation and maintenance), interest payments and general costs (cost of waste, accountancy office, membership fees, etc.).

All costs and benefits of the reference greenhouse production systems are taken into account to be sure that the economic soundness (profitability) of the developed and tested tools can be judged sufficiently. For some tested tools only a partial cost-benefit analysis will be done, because not all cost components will change compared to the reference situation and therefore do not have to be considered.

Inventory phase

The technical and economic data about the four scenarios and the related reference greenhouse systems have been collected for each country separately (Spain, Hungary and the Netherlands). For this purpose a questionnaire is developed by IRTA and PPO (Greenhouse Horticulture) which contains the environmental and economic parts of the assessment.

For the Dutch situation data about the tomato greenhouse farm and the rose greenhouse farm is used according to the Quantitative Information for the Greenhouse Horticulture (Vermeulen 2008) and the Farm Accountancy Data Network of the AERI (Anonymous 2008). Mórakert has supplied information about a commercial greenhouse tomato farm for the Hungarian situation. Concerning the Spanish situation the technical and economic data about a tomato greenhouse farm was provided by the Experimental Station of Cajamar in Almería and from other literature (Fundación Cajamar 2008, Mesa *et al.* 2004).

(Partial) cost-benefit analysis

The cost-benefit analysis results in a net financial result. The absolute net financial results are of limited relevance, because the alternative greenhouse systems will be evaluated for the relevant cost and benefit components, the so called partial cost-benefit analysis. The partial cost-benefit analysis will show the economic effects of (combinations of) input reducing options in the four greenhouse scenarios. The partial cost-benefit analysis focuses on the improvements for each greenhouse scenario separately. A comparison of the net financial result of the reference or alternative greenhouse systems between the different countries is no part of the study.

Preliminary results of the partial cost-benefit analysis have been presented at the meeting in Pisa (Italy), March 2009. The final results are presented at the meeting in Warwick (England), September 2009.

Interpretation

The results of the cost-benefit analysis give insight in the reference situation for the four scenarios. Which cost components contributes most strongly to the net financial result or the profitability of the greenhouse system scenarios. Based upon the cost level of the inputs in the reference situation also the investment capacity is calculated in order to give an indication of the economic possibilities of alternative greenhouse systems/options to reduce inputs.

With respect to the developing and testing tools the (partial) cost benefit analysis will give insight in the profitability of the input reducing options in the different scenarios.

Sensitivity analysis

For the most relevant factors the effect will be determined of fluctuating amounts, levels or prices on the net financial result. The following relevant factors can be mentioned: production level, product prices, and energy prices changes in simulated or calculated reductions of the consumption of energy, pesticides and nutrients. The sensitivity analysis will be carried out for the tested tools in the different scenarios.

3.3 Starting points

In this paragraph some characteristics are shown of the reference greenhouse systems in the four scenarios. The greenhouse structures and cultivation systems are also illustrated with figures.

Scenario 1: Tomato in multitunnel structure in Spain

The data correspond to the situation in Almería:

Farm size: 10,000 m^2 greenhouse area

Greenhouse structure: plastic multitunnel (see figure 2.2)

Cultivation:

- crop period: 37,5 weeks (start: 15/9/2007; end: 04/06/2008)
- substrate bags with perlite (see figure 2.3)
- tomato production: 16,48 kg/m^2; average product price: 0,58 €/kg

Fertirrigation system:

- drippers
- no recirculation of drain water
- water from well

Climate systems:

- natural ventilation
- no additional heating
- no additional carbon dioxide enrichment

Crop protection: biological control, insecticides and fungicides

Labor:

- cultivation: 225 hours/1000 m^2

Figure 3.2 Multitunnel greenhouse

Figure 3.3 Tomato cultivation system

Scenario 2: Tomato in Venlo type structure in Hungary

Farm size: 23,500 m^2 greenhouse area

Greenhouse structure: Venlo type greenhouse (see figure 3.4)

Cultivation:

- crop period: yearrond/49 weeks (start: 06/12/2008; end: 15/11/2008)
- gutters with rockwool slabs (see figure 3.5
- tomato production: 46,3 kg/m^2, average product price: 0,79 €/kg

Fertirrigation system:

- drip irrigation

- no recirculation of drain water
- water from well

Climate system:

- geothermal water as energy source
- thermal water storage tank
- energy screen
- CO_2 distribution system

Crop protection: biological control, insecticides, fungicides and sulphur

Labor:

- cultivation: 1700 hours/1000 m^2 .

Figure 3.4 Venlo type greenhouse

Figure 3.5 Cultivation system

Scenario 3: Tomato in Venlo type structure in the Netherlands

Farm size: 40,000 m^2 greenhouse area

Greenhouse structure: Venlo type greenhouse (see figure 3.6)

Cultivation:

- crop period: yearrond/50 weeks (start: 15/12/2008; end: 01/12/2009)
- gutters with rockwool slabs (see figure 3.7)
- truss tomato production: 56,5 kg/m^2, average product price: 0,82 €/kg

Fertirrigation system:

- drip irrigation
- recirculation and disinfection (heating) of drain water
- rainwater tank

Climate system:

- heat boiler (incl. condenser)
- heat power co-generator with CO_2 clean up device
- heat storage tank
- energy screen
- CO_2 distribution system

Crop protection: biological control, insecticides and fungicides

Labor:

- cultivation: 950 hours/1000 m^2 .

Figure 3.6 Venlo greenhouse with covering washer

Figure 3.7 Tomato cultivation system

Scenario 4: Rose in Venlo type structure in the Netherlands

Farm size: 40,000 m^2 greenhouse area

Greenhouse structure: Venlo type greenhouse (see figure 3.8)

Cultivation:

- crop period: 4 year
- gutters with rockwool slabs (see figure 3.8)
- rose (Passion) production: 276 stem/m^2. average product price: 0,38 €/stem

Fertirrigation system:

- drip irrigation
- recirculation and disinfection (heating) of drain water
- rainwater tank

Climate system:

- heat boiler (incl. condenser)
- heat power co-generator with CO_2 clean up device
- heat storage tank
- energy screen
- CO_2 distribution system

Crop protection: insecticides, fungicides and sulphur

Labor:

- cultivation: 950 hours/1000 m^2 .

Figure 3.8 Rose cultivation system

The economic data of the reference greenhouse systems in the four scenarios are based upon an average of the prices and investments in the years 2007 and 2008. The current economic crisis and the effect on the price levels have not been taken into account. If for instance the current – vey low - product prices would be used in most scenarios no positive net financial result should be calculated. Beside the absolute net financial result is not the objective, but the economic effect of input reducing options compared to the reference situation in the separate scenarios. Moreover a comparison of the net financial result between the different scenarios is no part of the study.

3.4 Results

3.4.1 Economic results

Based upon the technical and economic data collected via the questionnaire, other statistic documents and personal information from the participants from Spain, Hungary and the Netherlands the total output, costs and net financial result are determined of the reference greenhouse systems in the four scenarios. The extended results are shown in annex 4.7 table 4.7.1 until 4.7.4. In this section a brief summary is given of the economic results of the reference greenhouse systems.

Table 3.1: Total output, costs and investments of the reference greenhouse systems in Spain, Hungary and the Netherlands (€/m^2)

	Scenario 1: **Tomato in multi tunnel** **(Spain/Almería)**	**Scenario 2:** **Tomato in Venlo greenhouse** **(Hungary)**	**Scenario 3:** **Tomato in Venlo greenhouse** **(the Netherlands)**	**Scenario 4:** **Rose in Venlo greenhouse** **(the Netherlands)**
Total output	9,6	34,8	58,3	112,4
Costs	9,0	34,7	58,3	113,5
Investments[1]	26	85	116	186

[1] Excluded investment in land area

Table 3.1 points out that the total output and total costs in all scenarios are more or less equal. Only for rose production in the Netherlands a negative net financial result is calculated, because of the strong competition on the European market. It can be noticed that there is quit a difference in the level of total output and total costs between the greenhouse systems in the different scenarios. Higher output goes together with higher costs of inputs.

The greenhouse production systems in the Netherlands are more capital intensive than those in Hungary and Spain respectively (see table 3.1). This is mainly due to higher investments in greenhouse structure, climate systems and fertirrigation systems.

3.4.2 Cost components

An important question is which cost components contribute substantially to the total costs in the different scenarios. In figures 3.9–3.12 an overview is given of the shares of the individual cost components. In the second place the effect of the costs for nutrition, crop protection and climate control (energy consumption) are shown, because these inputs are focus in view of alternative options.

Figure 3.9 points out that in scenario 1 (tomato in multitunnel greenhouse) the cost components tangible assets and labor contribute to almost 60% of the total costs. The cost of greenhouse structure and other equipment amounts to nearly 1/3 of the total costs. The variable costs of crop protection and energy are low (3-4%). Fertilizers costs amounts to 7% of the total costs.

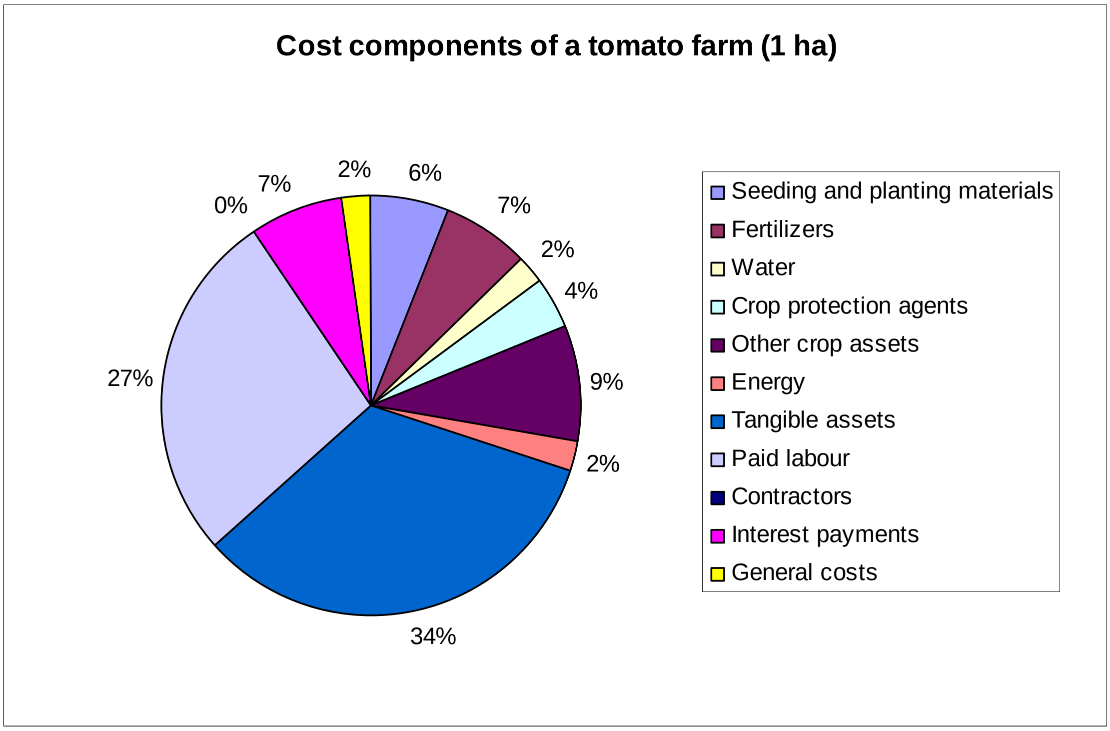


Figure 3.9 Cost components of tomato farm in multitunnel greenhouse (Spain - Almería)

In figure 3.10 the shares of the cost components are shown for a tomato greenhouse in Hungary (scenario 2). In scenario 2 more cost components determine the total costs substantially: tangible assets, labor, fertilizers and energy. These cost components contributes to 75% of the total costs. Noticeable is that the costs of fertilizers are relatively high in comparison to the tomato production in scenario 1 or 3. In scenario 2 the costs of crop protection (3%) is limited.

In scenario 3 (tomato in Venlo greenhouse in the Netherlands) three cost components mainly determine the total costs (see figure 3.11). These components are: energy (natural gas), tangible assets and labor. The costs of fertilizers and crop protection have a limited size (1-2%).

Energy saving options can be very favourable in scenario 3, because of the high cost level. On the other hand energy consumption reduction can have negative economic effect, because a co-generator produce heat and power on farm level at the same time and the electricity is sold to the public grid.

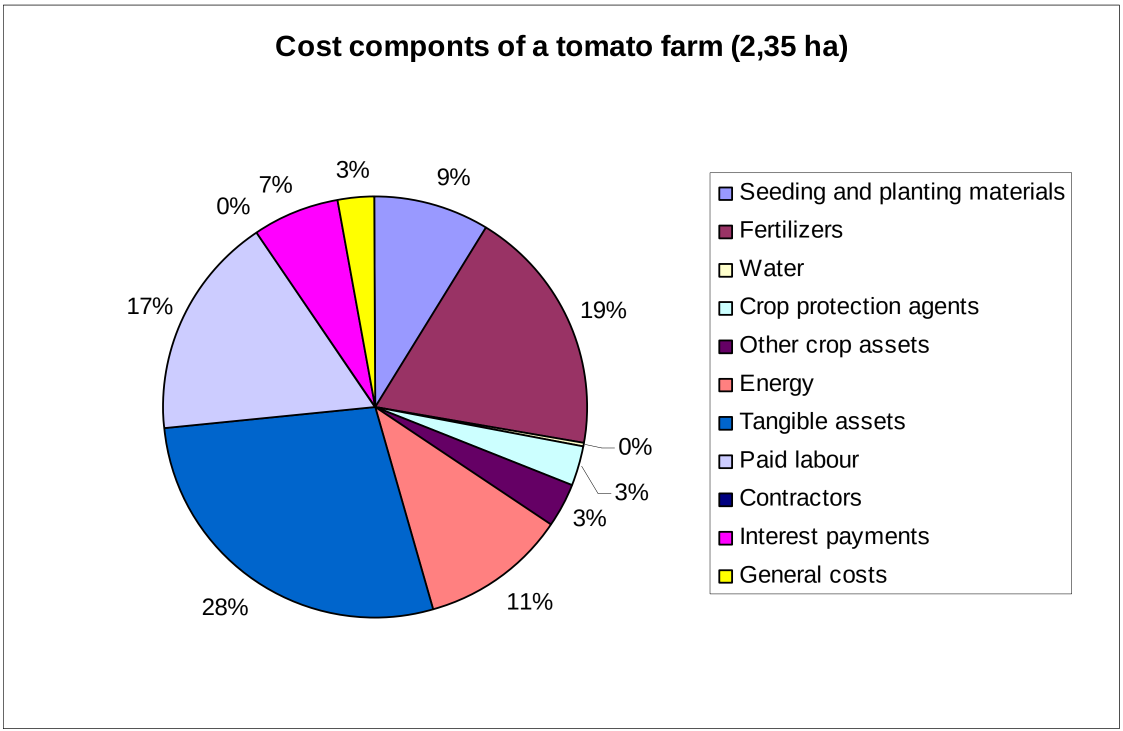


Figure 3.10 Cost components of tomato farm in Venlo greenhouse (Hungary)

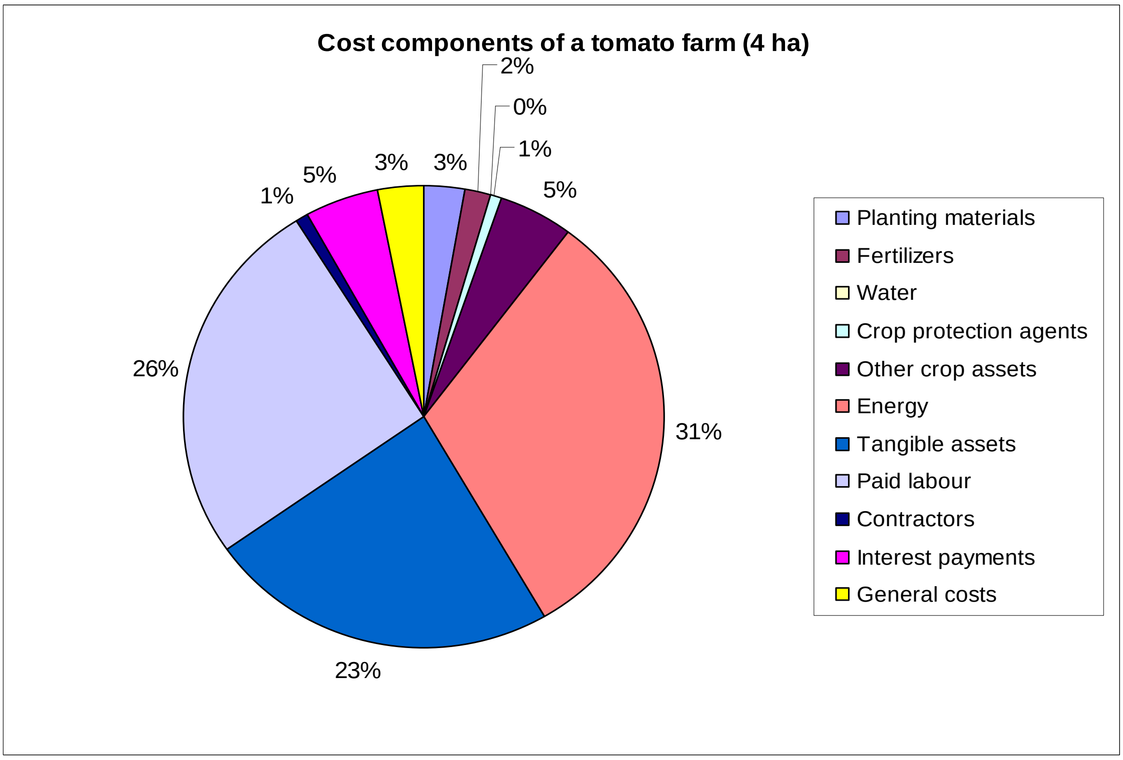


Figure 3.11 Cost components of tomato farm in Venlo greenhouse (the Netherlands)

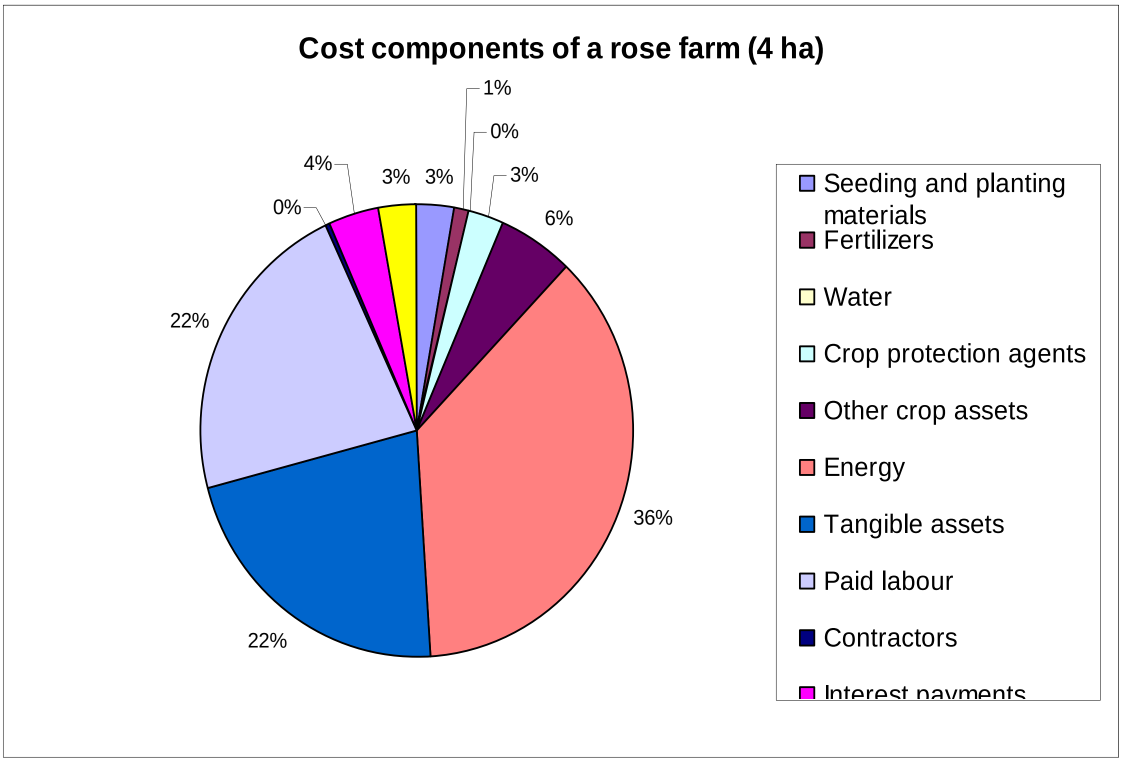


Figure 3.12 Cost components of rose farm in Venlo greenhouse (the Netherlands)

In scenario 4 concerning the rose production the same cost components mainly determine the total costs as for the tomato production in the Netherlands: energy, tangible assets and labor (see figure 3.12). These cost components together has a share of 80% of the total costs.

For rose production a high volume of fossil energy (natural gas) is used, not only for heating but also for lighting (for electricity production by a heat power generator). The costs of fertilizers or crop protection agents amount to 1-3% of the total costs.

In table 3.2 a summary is given of the most important cost components in the four scenarios. Moreover the costs of inputs are shown, where this project is focussing on: fossil energy, fertilizers and crop protection agents.

Table 3.2: Summary of the relevant cost components of the reference greenhouse systems in Spain, Hungary and the Netherlands (in %)

Cost component	Scenario 1: Tomato in multi tunnel (Spain)	Scenario 2: Tomato in Venlo greenhouse (Hungary)	Scenario 3: Tomato in Venlo greenhouse (the Netherlands)	Scenario 4: Rose in Venlo greenhouse (the Netherlands)
Equipment	33	28	23	22
Labor	27	17	26	22
Plant material	6	9	3	3
Energy	2	11	31	36
Fertilizers	7	19	2	1
Crop protection	4	3	1	3

Table 3.2 shows that the costs of equipment and labor contribute considerably to the total farm costs in all scenarios. With respect to the costs of energy, crop protection and fertilizers it pointed out that there are typical differences between the three countries. In the Netherlands the costs of energy are more than 30% of the total costs, whereas in Hungary this is about 10% and in Spain 2% (no additional heating). In Hungary on the contrary the comparative costs of fertilizers (19%) are substantially higher than in the Netherlands and in Spain (1-2% respectively 7%), because of the open cultivation system (no recirculation of drain water). The costs of crop protection vary between 1% and 4% of the total costs in the four scenarios.

The results in table 3.2 point out that from an economic point of view the best perspectives to reduce the environmental effect seem to be for energy saving options in the Netherlands and Hungary and for fertilizer or nutrient emission reducing options in Hungary and in Spain. Reduction of pesticide use unfortunately doesn't trigger the grower much, because of the low costs, although it is a big public issue. Furthermore the target to reduce pesticide use can have a great negative effect on the yield when plagues or diseases can not be managed sufficiently.

3.4.3 Economic opportunities of input reductions

To get an idea which economic opportunities input reductions can have a economic analysis is carried out. Calculated is what the economic effect will be of 10% or 50% reduction of the costs of energy, fertilizers or crop protection agents. This economic effect is expressed as the investment capacity. This is the amount what growers could invest in options (techniques, etc.), by which the annual costs of these options is equal to the cost reductions (see table 3.3).

Table 3.3 shows that a reduction of the costs of energy, fertilizers or crop protection can create in some cases a high investment capacity. For scenario 1 (tomato in multitunnel in Almería) reduction of fertilizers seems to have some perspectives, especially when the input or emission of fertilizers can be reduced by 50%. The question is if halving the input of fertilizers is realistic with respect to plant growth and development. Halving the pesticide use can offer nearly 0,9 €/m^2 of investment capacity.

In scenario 3 en 4 (tomato and rose in Venlo greenhouse in the Netherlands) energy saving options offer the best perspectives. For tomato the investment capacity varies from 10-52 €/m^2 and for rose from 23-118 €/m^2. For rose (scenario 4) 50% of energy reduction is doubtful, because of the necessary energy input for lighting. In scenario 4 also halving of pesticide use can be interesting to invest in reducing options (techniques or extra pest control).

In scenario 2 (tomato in Venlo greenhouse in Hungary) especially fertilizer reducing options are interesting. Halving the inputs by 50% could be realistic, because in the reference situation the drain water is not being collected for re-use. Also reduction of geothermal water consumption offers perspectives by decreasing the energy demand from the greenhouse.

The figures shown in table 3.3 can support the partners in the other work packages (WP2, WP3 and WP4) to select the most promising input reducing options of energy, pesticides or fertilizers for the implementation phase on each test site.

Table 3.3: Investment capacity of input reducing options for the reference greenhouse systems in Spain, Hungary and the Netherlands (in €/m²) [1]

Scenario 1: Tomato in multitunnel greenhouse in Spain

Cost component	Reduction in costs		Investment capacity	
	10%	50%	at 10%	at 50%
energy	0,02	0,11	0,12	0,61
fertilizers	0,06	0,30	0,30	1,50
pesticides	0,04	0,18	0,18	0,88

Scenario 2: Tomato in Venlo greenhouse in Hungary

Cost component	Reduction in costs		Investment capacity	
	10%	50%	at 10%	at 50%
energy	0,38	1,91	2,2	10,9
fertilizers	0,69	3,45	3,4	17,2
pesticides	0,12	0,58	0,6	2,9

Scenario 3: Tomato in Venlo greenhouse in the Netherlands

Cost component	Reduction in costs		Investment capacity	
	10%	50%	at 10%	at 50%
energy	1,83	9,15	10,5	52,3
fertilizers	0,09	0,45	0,5	2,3
pesticides	0,05	0,25	0,3	1,3

Scenario 4: Rose in Venlo greenhouse in the Netherlands

Cost component	Reduction in costs		Investment capacity	
	10%	50%	at 10%	at 50%
energy	4,13	20,66	23,6	118,1
fertilizers	0,12	0,58	0,6	2,9
pesticides	0,30	1,50	1,5	7,50

[1] For the annual costs of equipment (sum of depreciation, maintenance and interest) the following percentages have been used to convert the costs of reduction to the investment capacity:

- energy 17,5%
- fertilizers and crop protection: 20%.

3.5 Discussion and conclusions

3.5.1 Discussion

- **Reference greenhouse systems**

In four scenarios a reference greenhouse system is described in terms of output, costs and investments. Although there is a big difference in practice concerning performance of greenhouse systems, the reference system is a reasonable good reflection of the greenhouse production systems in each scenario (country). A representative reference system is a good instrument for evaluating the economic effects of input reducing options for implementation in practice.

- **Economic analysis**

The cost-benefit analysis will be used to compare input reducing options with the reference greenhouse system in each scenario (country) which input reducing options will have good prospects looking from an economic point of view. The potential input reducing options will differ per scenario, so a comparison of the scenarios (or countries) is therefore not the focus of this study.

3.5.2 Conclusions

The following conclusions or remarks can be made:

- the level of output, costs and investments differ between the scenarios and is related to the specific performance of the reference greenhouse system in each scenario.
- greenhouse systems are more capital intensive in the Netherlands than in Hungary and Spain respectively.
- in all scenarios the costs of equipment and the costs of labor have a substantial contribution to the total costs.
- the costs of energy are substantial in scenario 3 (31%), scenario 3 (36%) and in scenario 2 (11%).
- the costs of fertilizers is substantial in scenario 2 (19%) and to some extent in scenario 1 (7%).
- crop protection is not a very important factor in all scenarios looking from costs point of view (1-4%). This requires a big challenge to find options for pesticide use reduction which are economic attractive.
- input costs reduction will be especially interesting for investments in energy saving options (scenario 2, 3 and 4) and in fertilizer reducing options (scenario 2).

pesticide use reduction offer to some extent an investment capacity in scenario 4 and scenario 2, but the risk of loss of yield is much higher than that of input reduction of energy or fertilizers.

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