Report on economic & environmental profile of new technology greenhouses at the three scenarios

Juan Ignacio Montero[1]
Assumpció Antón[1]
Marta Torrellas[1]
Marc Ruijs[2]

[1]IRTA, Biosystems Engineering. Carretera de Cabrils, km 2. 08348 Cabrils, Barcelona, Spain
[2]Wageningen UR Greenhouse Horticulture. PO box 644, 6700 AP Wageningen, the Netherlands

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EUPHOROS DELIVERABLE 13

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

Report on Economic & Environmental Profile of new technology greenhouses at the three sites

WP1 Environmental and economic assessment

Coordinator:	J. I. Montero
Authors: Environmental part:	M.A. Antón M. Torrellas IRTA. Centre de Cabrils. Biosystems Engineering Cabrils, Spain
Economic part:	M. Ruijs PPO (WUR Greenhouse Horticulture) Bleiswijk, the Netherlands

SEVENTH FRAMEWORK PROGRAMME

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INDEX

ABSTRACT

EUPHOROS project objective is the development of sustainable greenhouse production systems in Europe, with reduction of inputs and waste yet with high productivity and resource use efficiency. The environmental and economic assessment of present production systems in Europe was analysed by work package 1 and reported in Deliverable 5 (Montero et al., 2011; www.euphoros.wur.nl/uk). Results showed the main bottlenecks that could be improved to reduce environmental and economic impacts: energy consumption, greenhouse structure, fertilizers and substrate.

This report presents the third year work of workpackage1, which aim was to analyse the reduction of environmental and economic impacts of production systems with the implementation of new technologies developed in other work packages in the project. The scenarios selected for the study were: a) Tomato production in a multi-tunnel greenhouse in Spain; b) Tomato production in a Venlo greenhouse in the Netherlands; and c) Rose production in a Venlo greenhouse in the Netherlands. The main issues to reduce the impacts focused on: implementation of new energy saving cultivation methods, covering materials and close-loop irrigation system; reduction of substrate volume per plant, extension of perlite and greenhouse life span. Results were compared with greenhouse profiles described in Deliverable 5 and showed the magnitude of the environmental and economic impacts reduction.

In scenario a), a new type of greenhouse with improved ventilation alternative gave extra production of 14.9 kg·m^{-2}, total 31.4 kg·m^{-2}, reductions to impact categories equal or higher to 36% by the total production system to impact categories and the extra investment of 9.5 €·m^{-2} could be compensated within 5 years. With a closed-loop irrigation system, total production system reduced environmental impacts to eutrophication impact category by 48% and the economic analysis showed that investments to implement a closed fertigation system could be profitable. In scenario b) a new energy saving cultivation method reduced energy demand by 35% and environmental impacts by 20% to 31% to most impact categories but gave a negative balance of benefits and costs. A double glazed Venlo greenhouse with the new cultivation method made reductions of 55% of heating energy, between 30% to 40% of environmental impact to most impact categories and 3.40 €·m^{-2} energy costs. In scenario c) rose production alternatives were with a new plant material that gave 5% increase in yield. With diffuse glass and AR coating near a 5% of environmental impact reductions to impact categories and a positive economic effect was achieved. The alternative with reduction of substrate made also environmental impacts reductions around 5%. The economic effect was positive if a 5% increase of yield was considered.

From the analysis of alternatives in each scenario it can be concluded that higher environmental impact reductions can be achieved by reduction of energy consumption, increase of productivity or combination of several improvement alternatives. Economic results showed that in some cases reduction of inputs can be also interesting. More effort should be done to implement technological management improvements and further research should be oriented to analyse the feasibility of suggested alternatives.

EXECUTIVE SUMMARY

Introduction

This Deliverable 13 is a report on third year work of work package 1 (WP1) in the context of EUPHOROS project. This four-year research European project aims at developing sustainable greenhouse horticultural and ornamental production systems with minimal use of equipment and inputs yet with high productivity and resource use efficiency. Several work packages are dedicated to develop innovative tools and systems to reduce energy, water, fertilizers, pesticides consumption and waste by designing new, robust elements related to greenhouse coverings, equipment, cultivation systems and greenhouse monitoring and management. WP 1 is devoted to the environmental and economic analysis of greenhouse production systems representing in Europe. A first study was reported in Deliverable 5 describing the environmental and economic profile of several selected scenarios: tomato crops in a multi-tunnel and Venlo greenhouses and a rose crop in a Venlo greenhouse. Results identified the main environmental and economic bottlenecks in the production systems: energy consumption, structure and fertilizers. These environmental and economic profiles of existing greenhouses were used as a reference for comparison with alternative greenhouse system designs with reduced inputs and reduced emissions, and developed in subsequent tasks of the project.

Deliverable 13 describes the environmental and economic comparison of three scenarios analysed in Deliverable 5 with cleaner production alternatives. The scenarios selected were: a) Tomato production in a multi-tunnel greenhouse in Spain, b) Tomato production in a Venlo greenhouse in the Netherlands; and c) Rose production in a Venlo greenhouse in the Netherlands. Alternatives for improvement focused on reduction of fossil energy, equipment carbon footprint, fertilizer emissions and amount of substrate according to the main bottlenecks detected in the reference scenarios. Results showed the best options to reduce environmental impacts for each production system and their economic consequences and are the base for discussion at the last section of the report.

Materials and methods

The goal of the study was the environmental and economic comparison between reference horticultural production systems in Europe and several cleaner production alternatives.

Detailed information about reference production systems and the methodologies used for the study was reported in Deliverable 5 (Montero et al., 2011). Environmental and economic assessments were conducted for each reference scenario in that previous study and this report includes only the information and results necessary to make explanations understandable. The reader can consult Deliverable 5 at the project web site www.euphoros.wur.nl/uk (EUPHOROS, 2008-2012).

The objectives of the present study are in line with results obtained by the environmental and economic assessments of the reference scenarios. The same methodologies were used: Life Cycle Assessment for the environmental analysis and Cost-Benefit analysis for the economic assessment.

The scenarios selected for the study and a brief description of alternatives for improvement for each one of them is described as follows:

Scenario a, Tomato crop in a multi-tunnel greenhouse in Spain:

- Rational use of substrates and fertirrigation system: Reduction of substrate volume, extension of substrate life span, reduction of fertilizers doses.
- Extension of greenhouse life span
- Increase of renewable energy in electricity production
- Closed-loop irrigation system.
- New type of greenhouse with improved ventilation

Scenario b, Tomato crop in a Venlo greenhouse in the Netherlands:

- Energy saving cultivation method. Contains several steps in the cultivation techniques to obtain energy saving. These steps can be implemented successively.
- New type of greenhouse with double glazing.

Scenario c, Rose crop in a Venlo greenhouse in the Netherlands

- Greenhouse with diffuse glass and AR coating.
- Reduced volumes of growing media and increased plant density.

In life cycle assessment, the functional unit quantifies the main function of the production system and is used as a reference unit to relate inputs and outputs. Functional units selected were: 1 ton of classic tomatoes for tomato crops and 1000 stems for the rose crop. Dutch scenarios used a Combined Heat and Power (CHP) system for the production of heat and electricity. Different approaches are analysed in Deliverable 5. In the present environmental study, the energy allocation approach was used as scenario for the reference situation and alternatives for improvement.

In the cost and benefit analysis, all costs and benefits of the greenhouse production systems were taken into account to ensure that the economic soundness of the developed and tested tools could be judged.

Results

Life cycle impact assessment (LCIA) and cost-benefit analysis were conducted to know the significance of environmental and economic effects of alternatives for improvement. In this section, results for each scenario are presented in tables. In the environmental analysis, values indicate the amount (%) of reduction of environmental impacts in the total production system compared to the reference situation and per impact categories. Impact categories selected were one energy flow indicator and five midpoint impact categories defined by the CML2001 method v.2.04 (Guinée et al., 2002) (Table 1).

Table 1. Impact categories selected, name abbreviation and units

Impact categories	**Abbreviation**	**Units**
Cumulative energy demand	CED	MJ
Abiotic depletion	AD	kg Sb eq
Acidification	AA	kg SO_2 eq
Eutrophication	EU,	kg PO_4^{-3} eq
Global warming over 100 years	GW	kg CO_2 eq
Photochemical oxidation	PO	kg C_2H_4 eq

In order to facilitate comprehension, a colour code was used indicating a percentage range of environmental impact reduction.

%	Colour
<5	
5<10	
10<20	
20<30	
≥30	

Scenario a, Tomato crop in a multi-tunnel greenhouse in Spain

The main burdens in the reference situation were structure, auxiliary equipment and fertilizers (Table 2).

Major environmental impact reductions could be obtained by a combination of several individual alternatives in the best case alternative and with a new type of greenhouse (Table 3). In the first case, environmental impacts were reduced by 30.1% in the air acidification impact category; 22.7% to 28.7% in abiotic depletion, eutrophication, global warming and photochemical oxidation impact categories; and by 17.4% in the cumulative energy demand impact category. Major reductions, 10.2% and 15.3%, could be obtained in eutrophication impact category with 20% and 30% of fertilizer dose decrease, respectively. It is noticeable that the increase to 40% of renewable energy in the electricity production mix reduced contributions to air acidification by 12.7%. A reduction of 25% of substrate volume and extension of perlite life span to four years gave similar environmental impact reductions to impact categories and similar economic effects (Table 4).

With the implementation of a closed-loop irrigation system, water consumption and fertilizer doses were reduced. Consequently, fertilizer environmental impacts decreased, because of the reduction of emissions due to fertilizer manufacture and their application, Contributions to eutrophication impact category highly decreased because of reduction of nitrate emissions to water. Economic results in table 5 show that an investment in a closed fertirrigation system seems to be profitable. The payback period is within three year. If disinfestations of the nutrient solution is required to prevent spreading of diseases the financial result will be negative.

In the new type of greenhouse environmental impacts were significantly reduced (36% to 42.7%) because of a high increase of productivity. Results in table 6 point out that an investment in a new type multi-tunnel greenhouse with improved ventilation appears to be profitable. The extra investment can be earned back within 5 years under the assumptions.

Table 2. Stage contributions to selected impact categories (IC) per ton of tomato, for reference tomato production in a multi-tunnel greenhouse

IC	Unit	Total	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	kg Sb eq	**1.7E+00**	**7.8E-01**	1.1E-03	6.3E-01	2.0E-01	1.7E-02	2.3E-02
AA	kg SO_2 eq	**1.0E+00**	3.9E-01	1.5E-03	**4.2E-01**	2.1E-01	1.9E-02	1.2E-02
EU	kg PO_4^{-3}eq	**4.9E-01**	1.5E-01	2.7E-04	8.0E-02	**2.5E-01**	6.5E-03	3.9E-03
GW	kg CO_2 eq	**2.5E+02**	**8.8E+01**	1.5E-01	7.7E+01	8.2E+01	2.0E+00	3.1E+00
PO	kg C_2H_4	**5.4E-02**	2.0E-02	5.4E-05	**2.7E-02**	4.9E-03	1.2E-03	1.0E-03
CED	MJ	**4.0E+03**	**1.9E+03**	3.1E+00	1.6E+03	3.9E+02	4.1E+01	5.7E+01

AD, abiotic depletion; AA, air acidification; EU, eutrophication; GW, global warming; PO, photochemical oxidation; CED, cumulative energy demand

Table 3. Environmental impact reductions (%) versus reference situation per alternative and impact categories

	AD	AA	EU	GW	PO	CED
Fertilizers ↓ 10%	1.2	2.0	5.1	3.2	0.9	1.0
Fertilizers ↓ 20%	2.4	4.0	10.2	6.5	1.8	2.0
Fertilizers ↓30%	3.6	6.0	15.3	9.7	2.7	3.0
20 years greenhouse life span	5.2	6.3	6.3	5.6	6.4	5.2
Perlite 4 years life span	4.5	3.0	1.3	3.9	2.8	4.4
Perlite volume ↓ 5%	0.8	0.6	0.3	0.8	0.5	0.8
Perlite volume ↓15%	2.5	1.7	0.8	2.3	1.6	2.5
Perlite volume ↓25%	4.2	2.9	1.3	3.8	2.7	4.1
Perlite volume ↓35%	5.8	4.0	1.8	5.3	3.8	5.7
↑10% renewable energy	0.4	0.8	0.3	0.4	0.6	0.1
↑20% renewable energy	2.4	4.8	1.8	2.1	3.4	0.6
↑30% renewable energy	4.3	8.8	3.4	3.8	6.1	1.1
↑40% renewable energy	6.3	12.7	4.9	5.5	8.9	1.7
Best Case	22.7	30.1	28.7	27.6	22.8	17.4
Closed irrigation system	5.2	9.9	48.2	12.3	5.1	4.9
New type of greenhouse	42.6	38.8	36.0	39.3	41.8	42.7

Table 4. Effect of reduced substrate volume and life span on yearly costs of substrate bags (€/m²) 1)

Substrate bags (perlite)	units/ha	investment €/unit	investment total	depreciation %	maintenance interest %	costs €/m2	savings €/m2
reference cultivation system	4650	1,80	8370	33,3	7,5	0,34	-
option 1: 25% volume reduction	4650	1,42	6591	33,3	7,5	0,27	0,07
option 2: 4 year life span	4650	1,80	8370	25,0	7,5	0,27	0,07

1) Option 1: Price per litre substrate is about 5% higher than the standard substrate bag.

Table 5. Effect of closed fertirrigation system, quick test nutrient solution analysis and UV filtration on balance of benefits and costs and payback period (€/ha, year)1) 2) 3)

	extra investment	depreciation	maintenance interest	other var costs	fertilizer savings	balance benefit-costs	payback period
	€/ha	€/ha	€/ha	€/ha	€/ha	€/ha	yr
Closed fertirrigation system	7500	750	565	1200	4650	2135	3
Closed fert.system + quick test	8300	910	625	810	4650	2305	3
Closed fert.system + quick test + UV filtration (desinfestation)	23300	3270	1750	810	4650	-1180	9

1) Variable costs: chemical (12x) and phytopathological (2x) analysis
2) Variable costs: chemical (2x) and phytopathological (2x) analysis and reagents.
3) Fertilizers savings: nutrients and waterconsumption.

Table 6. Effect of new type multi-tunnel greenhouse with improved ventilation on benefits and costs in comparison with reference tomato production system (€/m2)and pay-back period of extra investment (years)

Benefit-cost component, economic indicator	**Difference with reference system**
Yield	9.10
Variable costs	4.45
Fixed costs	3.05
Total costs	7.50
Net financial result	1.60
Payback period of extra investment (year)	5

Scenario b, Tomato crop in a Venlo greenhouse in the Netherlands

The main burden in the reference situation was climate control system, because of the high amount of natural gas to heat the greenhouse (Table 7).

It is noticeable the high reductions of environmental impacts in the two alternatives for improvement as both had significant reductions of natural gas consumption (Table 8). A new saving cultivation method made reductions between 20% and 31% to all impact categories. In spite of the substantial energy savings, the balance of benefits and costs was negative because of the reduction of sales of electricity to the public grid (Table 9).

The new type of greenhouse with double glazed cover and new energy cultivation method had environmental impacts equal or higher than 30% to most impact categories. It is remarkable the low reduction to eutrophication impact category (6%). Eutrophication is an impact category where emissions from electricity production are a high burden. For this impact category, the effect of a 155% electricity consumption increase in the alternative scenario is much higher than the effect of reducing 55% natural gas consumption. Economic results showed that the balance of extra benefits and extra costs results in an investment capacity of 27 €/m2 for the double glazed and AR cover. The investment capacity is very much dependent on the energy price (Table 10).

Table 7. LCIA results per FU, for a tomato greenhouse crop in the Netherlands, with energy allocation of natural gas in CHP

IC	Unit	Total	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	kg Sb eq	**1.5E+01**	3.4E-01	**1.5E+01**	1.4E-01	9.9E-02	1.6E-03	3.3E-03
AA	kg SO_2 eq	**2.9E+00**	3.0E-01	**2.4E+00**	8.8E-02	1.1E-01	1.8E-03	2.3E-03
EU	kg PO_4^{---}eq	**7.2E-01**	9.7E-02	**5.8E-01**	2.1E-02	1.6E-02	6.1E-04	9.1E-04
GW	kg CO_2 eq	**2.0E+03**	5.3E+01	**1.9E+03**	1.4E+01	4.8E+01	2.0E-01	2.1E+00
PO	kg C_2H_4	**2.1E-01**	1.4E-02	**1.9E-01**	6.5E-03	2.2E-03	1.1E-04	7.6E-05
CED	MJ	**3.1E+04**	8.2E+02	**3.0E+04**	3.1E+02	2.0E+02	3.9E+00	7.9E+00

AD, abiotic depletion; AA, air acidification; EU, eutrophication; GW, global warming; PO, photochemical oxidation; CED, cumulative energy demand

Table 8. Environmental impact reductions (%) versus reference situation per alternative and impact categories

	AD	AA	EU	GW	PO	CED
Energy saving cultivation method	31.1	25.9	20.4	30.4	29.1	30.9
New type of glasshouse	38.8	29.9	6.4	38.0	39.9	38.7

Table 9. Effect of new energy saving cultivation method on investments, yearly costs of investments, energy costs and balance of benefits and costs in comparison with the reference tomato production system (€/m2).

Component	*Difference with reference system (€/m2)*
Investment	1.20
Yearly costs of investment[1)]	0.10
Energy costs[2)]	0.45
Yield	-
Balance of benefits and costs	-0.55

1) Yearly costs: depreciation, maintenance and average interest.
2) Energy costs: balance of energy consumption and energy sales (electricity).

Table 10. Effect of double glazed greenhouse and new cultivation method on energy costs, production, balance of benefits and costs and investment capacity in comparison with reference tomato production system (€/m2)

Component	*Difference with reference system (€/m2)*
Energy costs[1)]	-3.40
Yield	-
Other costs	0.75
Balance of benefits and costs[2)]	2.65
Investment capacity[3)]	27

1) Energy costs: consumption of gas (-4.55 €/m2), electricity (0,75 €/m2) and CO_2(0.40 €/m2).
2) Excepting yearly cost of extra investment
3) Yearly costs of investment: 10% (depreciation: 7%, maintenance: 0,5% and average interest: 2,5%).

Scenario c, Rose crop in a Venlo greenhouse in the Netherlands

As in the previous Dutch scenario, energy consumption in the glasshouse was the main burden in the production system. In this rose production system, electricity consumption for crop lighting was the reason for the high environmental impacts. Natural gas consumption to heat the greenhouse was also a major burden (Table 11).

Table 12 shows the environmental impact reductions in the alternatives studied for this scenario. Diffuse glass alternative had moderate environmental impact reductions to all impact categories. Although the amount of electricity for lighting could not be reduced in this experiment, the benefit of higher productivity made a reduction of environmental impacts in the total production system. Reductions of substrate volume in combination with new plant material (extended propagation of synchronized rose cuttings) made similar environmental impacts reductions in the total production system. Nevertheless, it has to be mentioned that a 30% less of substrate in the rockwool slab made reductions of auxiliary equipment stage higher than 20.6% to all impact categories.

Both alternatives were attractive from an economic point of view as the balance of extra benefits and extra costs was positive considering an average extra production of about 5% (Tables 13 and 14).

Table 11. LCIA results per FU, for a rose greenhouse crop in the Netherlands, with energy allocation of natural gas in CHP

IC	Unit	Total	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	kg Sb eq	1.6E+01	8.7E-02	**1.6E+01**	7.5E-02	1.4E-02	1.3E-03	6.0E-04
AA	kg SO_2 eq	3.0E+00	7.2E-02	**2.8E+00**	4.8E-02	1.5E-02	1.5E-03	4.7E-04
EU	kg PO_4^{---}eq	1.7E+00	2.5E-02	**1.6E+00**	1.1E-02	2.3E-03	5.0E-04	3.1E-04
GW	kg CO_2 eq	2.1E+03	1.3E+01	**2.1E+03**	7.5E+00	6.7E+00	1.6E-01	1.1E+00
PO	kg C_2H_4	1.5E-01	3.4E-03	**1.4E-01**	3.0E-03	3.0E-04	9.0E-05	1.6E-05
CED	MJ	3.3E+04	2.1E+02	**3.3E+04**	1.7E+02	2.8E+01	3.2E+00	1.4E+00

Table 12. Total production system environmental impact reductions (%) versus reference situation per alternative and impact categories

	AD	AA	EU	GW	PO	CED
Diffuse glass covering	4.7	4.6	4.5	4.7	4.6	4.7
Substrate volume ↓30%	4.8	5.1	4.9	4.8	5.1	4.8

Table 13. Effect of diffuse and AR coated glass on costs and benefits in comparison to the reference glass type (€/m2) and payback period of extra investment (years)

Component	*Difference with reference system (€/m2)*
Yield	5.25
Sales costs	0.20
Crop labour	0.60
Yearly costs of equipment	1.10
Total costs	1.90
Balance of benefits and costs	3.35
Payback period (years)	4

Table 14: Effect of reduced volume of growing media (SPU) and new plant material on costs and benefits in comparison to the reference production system (€/m2)

Component	*Difference with reference system (€/m^2)*
Yield	5.15
Sales costs	0.15
Crop labour	0.60
Costs of plant material [1]	3.05
Costs of growing media	-0.10
Total costs	3.75
Balance of benefits and costs	1.40

[1] Synchronized cutting in rock wool plug on a SPU rock wool block.

Conclusions

The environmental and economic analyses of alternatives for improvement served to reach the following conclusions:

For Scenario a, the most relevant results were:

- A new type of greenhouse structure with improved ventilation reduced the total environmental impact by 36% to 43% in the reference greenhouse according to the category under consideration. Major reductions were found in the structure and auxiliary equipment subsystems. This option appears to be economically profitable and can be recommended for Spanish growers.
- The reduction on the use of fertilizers (up to 30% that of the reference situation) produced up to 15 % reduction of the total impact. The reduction of fertilizers doses made the highest reductions to the Eutrophication category.
- Significant impact mitigation was achieved by a combination of actions such as the best case alternative.
- The implementation of closed-loop irrigation system is a relative easy way of ameliorating greenhouse sustainability provided the water quality allows closed–loop irrigation. The analysis showed important benefits mainly for the euthrophication category (48% reduction) but also for the global warming category (12% reduction). Economic results showed that the investment in a closed fertirrigation system seems to be profitable, with a payback period within three years. If disinfestation (prevent spreading of diseases) is required the financial results will be negative.

For scenario b the most relevant results were:

- Energy saving cultivation methods. Better management of energy had a very positive effect in most impact categories. The reduction in natural gas consumption in the energy saving scenario decreased significantly energy burdens in climate control system and consequently in the total production system. Global warming was one of categories that benefited more with 30% of environmental impact reductions from that of the reference scenario. The energy saving cultivation method has a negative balance of benefits and costs in spite of the substantial energy savings, due to the reduction of sales of electricity to the public grid. The decrease of energy sales turns out to be larger than the savings on energy consumption.
- A new type of glasshouse structure with double glazing and anti reflect coating had a very positive effect in most impact categories with 6% to 40% environmental impacts reductions respect the reference glasshouse. The lower effect was for Eutrophication category since more electricity was used in the management of the new glasshouse type. The reduction of gas consumption results into an energy saving of 3.40 €/m^2 in spite of the increase of consumption of electricity and CO_2. The balance of extra benefits and extra costs offers an investment capacity of 27 €/m^2.

For scenario c the most relevant results were:

- Diffuse glass produced a reduction of around 5% in most impact categories. This was due to the increase in yield associated to the more uniform light level under the diffuse glass. From and economic point of view, an investment in diffuse and AR coated glass is very attractive.

- The reduction in substrate volume for rose crops leads to interesting impact mitigation in the auxiliary subsystem. The global effect of the substrate volume reduction was nearly 5% reduction of environmental impacts. Economic results showed out that a reduced volume of growing media in combination with new plant material can result in a positive balance of benefits and costs (1.40 €/m^2). This option is attractive both from economic as well from environmental point of view.

1 INTRODUCTION

The overall aim of four-year EUPHOROS project is to develop sustainable greenhouse horticultural and ornamental systems that minimize the use of external inputs and emissions to the environment, yet with high productivity and resource use efficiency. The issues focused on are the reduction of fossil energy, carbon footprint of equipment, water use, fertilizer emissions, plant protective chemicals application and full recycling of substrate. Several work packages are dedicated to develop innovative tools and systems to reduce energy, water, fertilizers, pesticides consumption and waste by designing new, robust elements related to greenhouse coverings, equipment, cultivation systems and greenhouse monitoring and management. 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.

The present study is in the context of EUPHOROS project work package 1 (WP1), which focuses on the balance between environment and economy, quantifying the reduction of resource input of each component of the project.

First task of WP1 (Task 1.1) was the environmental and economic assessment of current situation of protected crops in Europe to identify the resource requirements of the greenhouse operations and to establish an environmental and economic profile of representative greenhouses. The scenarios selected were: tomato crop in a plastic greenhouse in Spain, and in glasshouses in Hungary and the Netherlands, and rose crop in a glasshouse in the Netherlands. The detailed analyses were reported in Deliverable 5, entitled: *Report on environmental and economic profile of present greenhouse production systems in Europe* (Montero et al., 2011) and can be consulted at the web site www.euphoros.wur.nl/uk (EUPHOROS, 2008-2012). Results indicated the main environmental and economic burdens in the four scenarios. The main environmental burdens were energy consumption, structure and fertilizers. The best economic perspectives to reduce inputs were energy savings in glasshouses and reduction of fertilizers in Spain and Hungary. These environmental and economic profiles of existing greenhouses were used as a reference for comparison with alternative greenhouse system designs with reduced inputs and reduced emissions in subsequent tasks of the project.

This Deliverable 13 is the result of WP1 second work part (Tasks 1.2 and 1.3) and presents the environmental and economic assessments of several alternatives for cleaner production systems. The alternatives for improvement were chosen in order to reduce the main burdens identified in the environmental assessments conducted in first task of WP1. The issues focused on were the reduction of fossil energy, carbon footprint of equipment, fertilizer emissions and amount of substrate. Three of the reference scenarios were used for the study: the tomato crop in a multi-tunnel greenhouse in Spain and in a Venlo glasshouse in the Netherlands and the rose crop in a glasshouse in the Netherlands. Results of alternatives for improvement were compared with the reference situation to determine the amount of reduction of environmental impacts and identify the best options, together with the financial/economic consequences. Results are discussed in the report to suggest recommendations and implementation options. The feasibility of improvements will be tested for combinations of elements under greenhouse conditions, and to ensure that they are attractive for commercial growers.

2 MATERIALS AND METHODS

2.1 Goal and scope

The goal of the study (Tasks 1.2 and 1.3, WP1) was to conduct an environmental and economic assessment of several alternatives for the improvement of greenhouse production systems in Europe and to compare environmental and economic results to a reference situation. Environmental and economic assessments for the reference scenarios were conducted in Task 1.1 of WP1 and detailed information on the studies was reported in Deliverable 5 (Montero et al., 2011). The objectives of tasks 1.2 and 1.3 were in line with the results of environmental and economic assessments of the reference situation. A comparison between the scenarios under study was not conducted, as it is not an objective of EUPHOROS project.

The methodologies used were Life Cycle Assessment for the environmental analysis and Cost-Benefit analysis for the economic assessment.

Three production systems were used for the evaluation of improvements and the comparison with their reference situation. The scenarios to be studied were:

a) A tomato crop in a multi-tunnel greenhouse in Spain

b) A tomato crop in a Venlo greenhouse in the Netherlands

c) A rose crop in a Venlo greenhouse in the Netherlands

On a European level, greenhouse production systems differ technologically and economically due to different climate and market conditions and due to historical development.

A tomato crop in a multi-tunnel greenhouse on the coast of Almeria was the chosen scenario in the Mediterranean basin because Almeria has the largest concentration of protected crops in Spain, with nearly 30,000 ha of greenhouses. (EFSA-PPR, 2009). Nowadays there are about 170,000 ha of greenhouses and high tunnels in the Mediterranean basin. Nearly 90% of protected crops in Spain is devoted to vegetable crops; the rest being dedicated to ornamental (EFSA-PPR, 2009). Multi-tunnel greenhouses offer technological adaptation capacity with optimization of yields. Thus, from an environmental point of view, it would be better to assess potential cultivation improvements in a multi-tunnel greenhouse, with innovative developments and monitoring tools producing more efficient results in a high technology greenhouse.

In Northern cold-winter, such as the Netherlands, by far the majority of greenhouses are glasshouses (Pluimers, 2001). Greenhouse production in Holland is an efficient process in which most inputs are carefully considered and high yields are achieved. Nevertheless, intensive technology is used as well as intensive use of materials, and energy for heating and lighting.

The alternatives for improvement were selected to reduce the main burdens of the reference production systems, based on the innovative tools developed by other work packages. Other alternatives were suggested on the base of research studies and literature, such as reduction of volume substrate; current agricultural practices, such as extension of greenhouse and perlite life spans; and the current trend to fertilizer doses reduction and increase of renewable energy. From an economic point of view, the present project focuses on solutions for improved glass coatings and screens with the locally right combination of thermal insulation. The alternatives studied for each scenario were:

Scenario a, Tomato crop in a multi-tunnel greenhouse in Spain:

Production systems in the Mediterranean are very variable; therefore multiple alternatives for improvement were analyzed in this scenario order to go through the main issues of interest. The yield was considered 16.5 kg·m^{-2} as in the reference situation, except for new greenhouse alternative where a higher yield was achieved (31.4 kg·m^{-2}).

- Sensitive analysis with reduction of 5%, 15%, 25% and 35% of substrate volume. Substrate was one of the main burdens in the reference scenario.
- Reduction of fertilizers doses of 10%, 20% and 30%. In general, there is a tendency towards excessive fertilization in the Mediterranean area (Gallardo el al., 2009).
- Extension of substrate life span from 3 to 4 years. There are growers who extend perlite life span to four years and reduction of environmental impacts was calculated for this situation.
- Extension of greenhouse life span from 15 to 20 years. The reference scenario considered 15 years greenhouse life span according to the European Committee for Standardisation but growers usually extend greenhouse life span to 20 years.
- Increase of renewable energy to 40% in the national production mix, since this is the objective Spain claims will be achieved in 2020.
- A best case alternative considering a 25% reduction in volume of perlite, extension of life span of perlite to 4 years, a 30% reduction in volume of fertilizers, extension of greenhouse life span to 20 years and 40% renewable energy used in the production of electricity.
- Closed-loop irrigation system. This alternative was selected because the reference scenario had an open-loop irrigation system. Data about reduction of fertilizers doses and water consumption were obtained from a study at test site in Chiseina Uzzanese (Italy) conducted as part of the work of work package 3.
- New type of greenhouse with improved ventilation. The improvement of the climate in the prototype greenhouse allowed extending the crop period to 12 months (9 months in the reference scenario). The prototype greenhouse had small differences in dimensions and amount of materials, which were considered in the inventory.

Scenario b, Tomato crop in a Venlo greenhouse in the Netherlands:

Agricultural production systems in the Netherlands are quite homogeneous and are consistently defined. This is the reason why few alternatives for improvement were selected in comparison with the Mediterranean tomato production system. For the two alternatives studied, the yield was considered the same as in the reference situation, 56.5 kg·m-2.

- Energy saving cultivation method. The cultivation steps considered were controlled ventilation of moist greenhouse air by means of external air suction, extra screen and cultivation according to natural conditions. A reduction of 35% of heat demand and an extra energy screen were considered in the inventory.
- New type of greenhouse with double glazing. In this alternative the new cultivation method is analysed in combination with a double glazed greenhouse. There was

also controlled ventilation of moist greenhouse air by means of external air suction. Main changes in the reference inventory were: 50% of increase in the amount of glass, 55% of reduction of natural gas consumption in the climate control system and 155% increase of electricity consumption due to the use of forced ventilation to dehumidify the greenhouse.

Scenario c, Rose crop in a Venlo greenhouse in the Netherlands

As it was mentioned previously, agricultural production systems in the Netherlands are quite homogeneous and consistently defined and few alternatives for improvement were selected in the study.

- Diffuse glass covering. This alternative was studied because diffuse glass improves light distribution inside the greenhouse and according to an experiment conducted by WP6, an increase of 10% production can be expected, Groglass, another partner in the project, developed diffuse glass panes to be tested at the test site and provided data for the inventory. A 10 $kWh \cdot m^{-2}$ of electricity was considered for the glass coating process and a yield of 303.6 $roses \cdot m^{-2}$.
- Reduction of substrate. WP6 conducted experiments with 20% and 30% volume reduction in rockwool slabs. In both options, yield was considered 5% higher than in the reference situation: 290 $roses \cdot m^{-2}$.

2.2 Environmental description

The environmental analysis was conducted using LCA methodology, following the ISO 14040 standard (ISO-14040, 2006). The functional unit refers to the main function of the system analysed and is the reference unit for the inputs and outputs of the system analysed. Since the main function in horticultural and ornamental crops is the production of vegetables and flowers, a mass functional unit was chosen for the production systems: 1 ton of classic tomatoes for tomato crops and 1000 stems for the rose crop.

The system boundary was considered from raw materials extraction to farm gate, including material disposal, but not recycling processes, following the cut-off allocation procedure of Ekvall and Tillman (1997). Neither post-stages nor marketing processes were taken into account in the study, as the aim was to improve means of production. The processes considered for the environmental analysis included inputs and outputs in the manufacture of greenhouse components, transport of materials, materials disposal and greenhouse management (water, fertilizers, pesticides and electricity consumption).

The processes and flows included in the inventory to model the production system were described in detail in Deliverable 5 (Montero, 2011).

Dutch scenarios b and c used a Combined and Heat Power (CHP) system for the production of heat and electricity. This is a multifunctional process producing two co-products and allocation approaches were considered. Electricity produced was discharged to the public grid and two situations could be evaluated, with or without external interaction with another production system. If interaction were taken into account, the production of electricity at CHP would be an avoided burden in the Dutch electricity production mix. As interaction with another production system is not the goal of the study, energy allocation was applied. Detailed information about allocation approaches were explained in Deliverable 5 (Montero, 2011).

The SimaPro program version 7.2 was used for the environmental assessment only performing the obligatory phases of classification and characterization and without going through the normalization and weighting steps (ISO-14040, 2006).

The indicators and impact categories selected for the environmental assessment were: one energy flow indicator (cumulative energy demand, MJ) and five midpoint impact categories defined by the CML2001 method v.2.04 (Guinée et al., 2002): abiotic depletion (kg Sb eq), acidification (kg SO_2 eq), eutrophication (kg PO_4^{-3} eq), global warming over 100 years (kg CO_2 eq) and photochemical oxidation (kg C_2H_4 eq). These impact categories were selected because of their relevance in agriculture and energy processes. Abiotic depletion, global warming and cumulative energy demand are important indicators related to energy consumption. Emissions related to agricultural inputs, mainly fertilizers and substrate, are major contributors to global warming and cumulative demand potential because of the energy consumption in the manufacturing process, as well as energy consumption in heating and lighting. Ammonia and nitrate emissions from N-fertilizers are important contributors to acidification and eutrophication, respectively. Emissions contribution to photochemical oxidant formation may have significant consequences on human health, ecosystems and crops. Land use, water use and toxicity are other important impact categories in agriculture assessment, nevertheless they were not considered since there is no international consensus for their evaluation (Antón 2008; Berger and Finkbeiner, 2010).

2.3 Economic description

The economic assessment was based on cost-benefit analysis. The goal was to assess the financial consequences of the implementation of alternatives for improvement in the greenhouse systems.

The system boundary was defined at farm level, such that all costs and benefits of alternative greenhouse systems were considered at farm level. The greenhouse scenario can be seen as a black box with several inputs and outputs (Figure 2).

The following costs and benefits were considered:

- benefits: yield (tomatoes/roses), sales of electricity (Dutch situation)
- costs: planting material, water and fertilizers, pesticides (biological and chemical), energy, other crop assets, labour 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 were taken into account to ensure the economic soundness of the tools developed in the course of the EUPHOROS project. The objective was not the absolute net financial result but the economic effect of input reducing options compared to the reference situation in the different scenarios. The inventory included costs for greenhouse equipment, plant material, energy sources, electricity, fertilizers, crop protection and labour (employers and employees). A tangible asset is the component that contains the cost of depreciation and maintenance of the farm equipment. It does not include the interest costs. To get an idea of economic opportunities for input reductions an economic analysis was carried out. The effect of applying several of the cost-reducing alternatives for energy, fertilizers or crop protection agents was calculated and expressed as the extra net financial result, the payback period and/or the investment capacity.

2.4 Data collection

The broad system under study required a detailed data-collection process. Technical and economic data of the scenarios were collected for each country separately by a questionnaire developed by IRTA (Institute of Food and Agriculture Research and Technology) and PPO (Applied Plant Research, Wageningen UR Greenhouse Horticulture) in Task 1.1 of WPW. Detailed information on the production system and the economic data, representative of every process in the greenhouse is compiled in Deliverable 5 (EUPHOROS, 2008-2012; Montero et al., 2011).

Inventory analysis of greenhouses under consideration used data provided by the test sites, such as water consumption, fertilizers and pesticides doses and yield (primary data) and data from database, such materials manufacturing processes (secondary data).

The data for the tomato plastic multi-tunnel greenhouse in Spain were obtained by the Cajamar Experimental Station in Almeria and from the literature (Fundación_Cajamar, 2008; Mesa et al., 2004). For the Dutch situation, data on tomato and rose greenhouse farms were according to the Quantitative Information for Greenhouse Horticulture (Vermeulen, 2008) and the Farm Accountancy Data Network of the AERI. Improvements are suggested by the corresponding partners of the different WPs.

Secondary data were mainly obtained from Ecoinvent database version 2.2 (Ecoinvent, 2010).

The economic data for the reference greenhouse systems in the reference scenarios were based on an average of prices and investments in the years 2007 and 2008. The current economic crisis, and its effect on prices, was not taken into account: using the, very low, 2009 product prices would not give net financial gain in most scenarios.

For the present study, new data were incorporated according to the alternatives of improvement for each scenario and updated inventories were used for each assessment.

3 ENVIRONMENTAL ANALYSIS

This phase corresponds to the Life Cycle Inventory analysis (LCI) of the LCA and includes all the processes and flows considered in the production system. Manufacture of equipment and greenhouse elements included materials and processes such as drawing of pipes, coatings and plastic extrusion. Electricity consumption for greenhouse operations was included, and emissions released were calculated on the basis of the electricity production mix of each country. Transport processes to or from the greenhouse included vehicle and road manufacture, maintenance and diesel consumption.

In the environmental analysis, the flows and processes of the product system were structured in six stages to facilitate the compilation of data and assessment: structure, climate control system, auxiliary equipment, fertilizers, pesticides and waste management. Detailed data about the reference scenarios can be consulted in Deliverable 5 (Montero *et al.*, 2011). The main characteristics for each scenario are listed in Table 3.1. Dutch scenarios with energy allocation were used for comparison with alternatives for improvement (Table 3.2).

Table 3.1. Main characteristics of the three reference scenarios

	Scenario a) Tomato, multi-tunnel, Spain	**Scenario b) Tomato, Venlo, the Netherlands**	**Scenario c) Rose, Venlo, the Netherlands**
Structrure			
Surface (m^2)	19,440	40,000	40,320
Number of spans	18	25	21
Concrete (m^3·ha)	63	45	45
LDPE covering (kg·ha^{-1})	3,787		
PC walls (kg·ha^{-1})	1,707		
Steel (kg·ha^{-1})	76,994	109,829	133,922
Aluminium		28,110	31,399
Glass (kg·ha^{-1})		118,927	118,842
Crop			
Yield (kg·ha^{-1})	16.5 kg·m^{-2}·y^{-1}	56.5 kg·m^{-2}·y^{-1}	276 stems·m^{-2}·y^{-1}
Crop period	52 weeks	52 weeks	4 years
Crop density (stems·m^{-2})	2.5	2.5	8.5
Auxiliary equipment			
Substrate	Perlite	Rockwool	Rockwool
Substrate (kg·ha^{-1})	18,877	4,476	12,497
Substrate per plant (l)	10	5.22	2.14
Fertirrigation system	Drippers	Drippers	Drippers
	Open-loop	Closed-loop	Closed-loop
		Disinfection (heating)	Disinfection (heating)
Water source	Well	Rainwater tank	Rainwater tank
Water (l·m^{-2})	474.8	794	902
Water use	28.8 l·kg^{-1}	14.1 l·kg^{-1}	3.3 l·$stem^{-1}$
Fertilizers (kg·ha^{-1})			
N	798	1688	1163
P_2O_5	506	406	276

K_2O	1,562	1855	1280
Air emissions			
NH_3-N	24	51	35
N_2O-N	10	21	15
NO_x-N	1	2.1	1.5
Water emissions			
NO_3	359		
Pesticides (kg·ha^{-1})	32	10	42
Climate control system			
Climate system	Natural ventilation	Co-generation	Co-generation
Energy source	no	Natural gas	Natural gas
Lighting	no	no	yes
Energy screen	no	yes	yes
CO_2 enrichment	no	yes	yes
Waste			
Waste disposal emissions	Transport Landfill	Transport Landfill Incineration	Transport Landfill Incineration

Table 3.2. Energy consumption and production in scenarios b) and c)

	Scenario b		Scenario c	
Natural gas consumption at CHP	m^3·m^{-2}	m^3·ton tomato^{-1}	m^3·m^{-2}	m^3·1000 stems
Total, heating+electricity	64.7	1,145	101.7	368.5
Energy allocation, heating	41.7	738		
Energy allocation, electricity	23.0	407		
Electricity	kWh·m^{-2}	kWh·ton tomato^{-1}	kWh·m^{-2}	kWh·1000 stems
Greenhouse consumption	10	177	633	2,293
Produced by CHP	178	3,150	345	1,250
Surplus	168	2,973	0	0
Bought at public grid	0	0	288	1,043

In this study we considered the current agricultural practice for protected European crops, established as the starting point for the alternatives analysis. Several potential alternatives were analysed for reduction of environmental impacts. The majority of improvements were oriented to the agricultural practice according to each scenario: reduction of the volume of substrate and extension of its life span; reduction of the amount of fertilizers, extension of greenhouse life span and new cultivation methods. The purpose was to present feasible objectives that could be commonly applied by growers. Environmental and economic analyses were conducted comparing results from alternatives for improvement with the reference situation.

3.1 Alternatives for improvement:

New data for each alternative for improvement are detailed as follows for each scenario.

3.1.1 Scenario a, Tomato crop in a multi-tunnel greenhouse in Spain:

We considered the same yield as in the reference production system, 16.5 kg·m^{-2}, with the exception of new greenhouse, which good climate conditions increased yield to 31.4 kg·m^{-2}:

3.1.1.1 Reduction of substrate volume

Substrate was one of the main burdens in the reference system. A sensitive analysis with substrate volume reduction of 5, 15, 25 and 30% was conducted to calculate the potential environmental impacts reduction in the system. Reference system considered a substrate volume of 10 L·plant-^{2}. Substrate volume reduction could make root restriction in the crop. Nevertheless, several studies on this issue concluded that a reduction of substrate volume could be feasible without a significant loss of production (Ganea et al., 2002; Haghuis, 1990; Logendra et al., 2001).

3.1.1.2 Reduction of fertilizers doses

A sensitive analysis was conducted considering a reduction of fertilizer doses of 10, 20 and 30%.

In general, there is a tendency towards excessive fertilization in the Mediterranean area (Gallardo *et al.*, 2009). Even with a 30% reduction, the amount of fertilizers applied was within the range suggested for tomato crops (Muñoz *et al.*, 2008).

3.1.1.3 Extension of substrate life span

Extension of substrate life span from 3 to 4 years was considered as alternative. Currently there are growers who extend perlite life span to four years. In this option, four-year on the life span was also applied to plastic bags for substrate containment.

3.1.1.4 Extension of greenhouse life span

In the reference scenario greenhouse life span was considered 15 years according to the European Committee for Standardisation. It is usual practice to extend greenhouse life span to 20 years or even more. To give insight into this situation, calculations were made considering 20 years greenhouse life span in the inventory.

3.1.1.5 Increase of renewable energy in electricity production

The increased use of renewable energy in the production of electricity was another alternative taken into account. Although using renewable energy in the production system does not depend directly on growers, it affects the environmental impacts of the tomato production system because of the electricity consumption for the irrigation and climate control systems. The 2009/28/CE Directive of the European Parliament establishes compulsory objectives for every member state for using renewable energy in the European Union (EU), to be achieved by the year 2020 (European_Commission, 2009). As Spain claims that it will achieve its objective of 40% renewable energy in the production of electricity (Ministerio de Industria, Turismo y

Comercio, 2009), the progress towards renewable energy in the production of electricity was included in the sensitivity assessment.

Table 3.3 lists the share by technology for the production of 1 kWh of domestic electricity production in Spain, per kWh and percentage. Technologies included in the mix are thermal (grey), hydropower (blue), nuclear (yellow) and renewable (green). Columns on the right list the shares when considering 10%, 20%, 30% and 40% renewable energy in the sensitivity analysis, and the other processes were proportionally reduced.

Table 3.3. Electricity production mix, ES for the production of 1 kWh electricity in 2007 (Frischknecht et al., 2005) (kWh and %) and with 10%, 20%, 30% and 40% renewable energy

	Production mix		**Renewable energy**			
Materials/Fuels	**kWh**	**%**	**10%**	**20%**	**30%**	**40%**
Hard coal	0.243	24.37	23.5	19.2	14.9	10.5
Lignite	0.037	3.72	3.6	2.9	2.3	1.6
Oil	0.084	8.45	8.1	6.6	5.2	3.7
Natural gas	0.195	19.60	18.9	15.4	11.9	8.5
Industrial gas	0.004	0.40	0.4	0.3	0.2	0.2
Hydropower	0.127	12.70	12.70	12.70	12.70	12.70
Nuclear	0.228	22.80	22.83	22.83	22.83	22.83
Photovoltaic	0.0004	0.04	0.05	0.09	0.14	0.19
Wind	0.058	5.82	7.35	14.69	22.04	29.38
Cogeneration	0.021	2.07	2.61	5.22	7.82	10.43

3.1.1.6 A best case alternative

From previous alternatives, a best case was studied with a 25% reduction in volume of perlite, extension of life span of perlite to 4 years, a 30% reduction in volume of fertilizers, extension of greenhouse life span to 20 years and 40% renewable energy used in the production of electricity. A 25% reduction in volume of perlite was chosen among the possible options because other studies previously cited concluded that it could be feasible. A 35% could require future investigation.

3.1.1.7 Closed-loop irrigation system

Fertilizer emissions to water could be significantly reduced by the implementation of a closed irrigation system. The potential environmental impacts of this alternative were studied. For this purpose, the elements and materials for the implementation of a closed-looped irrigation system were taken into account, as well as the corrected water and fertilizer amounts. A closed irrigation system was implemented at test site in Chiesina Uzzanese (Italy). The experiment was conducted as part of the work of work package 3, devoted to water, fertilizers and substrate management. Results of the experiment on these three parameters were used for calculations in this alternative. Data referring to materials and electricity consumption were adjusted in the reference scenario. A tank and two pumps of steel were included. Water supply was reduced by 21% and electricity consumption was adjusted accordingly, subtracting 21% as 21% less water was used and adding electricity consumption for recirculation water. The new data in the inventory were:

- Increase of amount of steel in auxiliary equipment: 478%
- Decrease water consumption: 21%

- Decrease of amount of fertilizers: 35% N, 20% P, 17%K
- Irrigation system electricity consumption decrease: 17%

3.1.1.8 New type of greenhouse with improved ventilation

A new type of multi-tunnel greenhouse with improved ventilation was studied. The prototype greenhouse where experiments took place was a six-span multi-tunnel greenhouse, with ridge oriented North-South. Each span was 8 m wide and 20 m long, with a gutter and ridge heights of 4.5 m and 6.9 respectively. Therefore the roof slope was 30º. Each span had double roof vents 1.9 m wide and all the greenhouse perimeter had sidewall vents 3 m high opening from the ground level. The usual management for truss tomato in the area was changed with wires to train the crop at a height of 3.70 m. The long cycle crop management in the new type of greenhouse made a significant increase of yield due to the improvement of the climate. New data considered in the inventory to conduct LCIA were:

- Amount of steel: 8 kg·m-2
- Growing crop period: 1 year
- Yield: 31.4 kg·m-2

3.1.2 Scenario b, Tomato crop in a Venlo greenhouse in the Netherlands:

3.1.2.1 Energy saving cultivation method

The new energy saving cultivation system contains seven steps to obtain more than 50% of energy saving. For the tomato production system the steps analysed were: controlled ventilation of moist greenhouse air by means of external air suction, extra screen and more intense screen use and cultivation according to natural conditions. The light interception by the extra screen (in open position) was compensated by the better greenhouse climate conditions. These steps result in a reduction of the energy demand and the following points were taken into account:

- Heat demand was reduced by 35%.
- Electricity production at CHP was reduced by 35%. Because of the lower heat demand a smaller heat power co-generator was required with lower gas consumption, but consequently less electricity was produced and could be sold to the public grid. This scenario considered energy allocation of natural gas in climate control system, therefore electricity production was not taken into account neither its reduction in the alternative.
- Extra energy aluminised screen.
- The production and product quality remained the same (56.5 $kg \cdot m^{-2}$).

3.1.2.2 New type of glasshouse

In this alternative the new cultivation method is analysed in combination with a double glazed greenhouse. The double glazed Venlo greenhouse differs from the reference production system in the following points:

- Double glazed cover means the increase in 50% in the amount of glass. The reference greenhouse cover had panels 4mm thick. The double glazed cover has 2 panels 3mm thick, with AR coating in three sides and one low energy coating in one inside.
- In this new type of greenhouse the frame is adapted to support the extra weight of the glass, with an increase of steel 6.7% and aluminium 3.3%.
- Controlled ventilation of moist greenhouse air by means of external air suction and a regain unit to regain 75% of the perceptible heat.

The calculations result in the following energy effects in comparison with the reference system:

- 55% reduction of natural gas consumption
- 155% increase of electricity consumption
- Yield was considered as in the reference scenario 56.5 kg·m^{-2}, due to a negligible light transmission loss under double glazed anti reflexion treated greenhouse cover in comparison with a single glazed greenhouse cover.

3.1.3 Scenario c, Rose crop in a Venlo greenhouse in the Netherlands

Alternatives in rose production system were combined with synchronized rose cuttings. The big advantage of synchronized cuttings is that they will produce rose stems earlier after transplanting than the traditional rose because they have and extended propagation period. The average production over four years will increase by 5%. Yield was considered 290 stems·m^{-2} in both alternatives.

3.1.3.1 Greenhouse with diffuse glass and AR coating

The experiment with diffuse glass was applied to a rose crop in a Venlo glasshouse and started at the research station of WUR Greenhouse Horticulture in Bleiswijk, the Netherlands, in 2010. The diffuse and AR coated glass panes are placed in the greenhouse side walls and in the greenhouse cover. Diffuse glass improves the light distribution inside the greenhouse but decreases total light transmission. An AR (anti reflecting) coating can compensate this loss of light transmission. Due to the better light distribution, a 5% higher production was found. The experiment itself is described more extensively in WP6).

Tempered horticultural glass had the following light specifications in the reference situation:

- Tempered glass light transmission was 83%

- Light transmission at crop level was 62%.

The diffuse, tempered and AR coated glass had the same specifications. Diffuse glass itself resulted in a lower total light transmission due to the haze factor, but the AR coating compensated this light loss completely. Overall the light transmission of the diffuse, tempered and AR coated glass was similar to that of the standard tempered horticultural glass (Deliverable 19).

The production of diffuse glass panes were developed by Groglass, one of the partners in the project. In consultation with the company, electricity consumption for the glass coating process was estimated 10 $kWh \cdot m^{-2}$. This value of electricity consumption was introduced as input in the inventory, as well as:

- Electricity consumption for lighting was the same as in the reference situation.
- Yield increased by 5% (290 $stems \cdot m^{-2}$).

3.1.3.2 Reduction of substrate volume and increased plant density

A cultivation system is being tested with reduced volume of the growing media rockwool. This cultivation system called SPU (Solitair Production Unit; Grodan) is being tested in combination with synchronized rose cuttings. For the sake of this study only the effect of reduced volumes of the growing media will be evaluated. Other components of the cultivation system, like number of drippers, are kept to be equal to the reference system.

Substrate volume reduction tests started at Bleiswijk, the Netherlands, in 2010. Two variants of rockwool slabs are being used with a reduction of 20% and 30% volume of substrate. Substrate volume considered in the reference system was 2.14 $L \cdot plant^{-2}$. These amounts of volume reduction were applied to the reference system inventory data to calculate the corresponding environmental impacts.

In both options it is assumed that the rose crop will produce the same quality as in the standard cultivation system, with increase of 5% yield.

3.2 Results

A life cycle impact assessment (LCIA) was conducted for each alternative for improvement to know the significance of their potential environmental impacts. Results are presented in this section and compared to the selected scenarios reference situation. LCIA of reference production systems were analysed in detail in previous tasks of the project and can be consulted in Deliverable 5 (Montero, 2011). Results of the scenarios reference situation showed that structure, climate control system, auxiliary equipment and fertilizers were major contributors. The alternatives for improvement were selected to analyse the magnitude of their environmental impact reduction and compared to the reference scenario, which was established as 100%. To give insight in the significance of alternatives environmental impacts reduction, reference production systems contributions to impact categories are given at the beginning of each scenario section, per total production system and stage.

A colour code indicating the range of environmental impact reduction is used in tables to facilitate the comparison of alternatives results with the reference situation.

%	Colour
<5	(orange)
5<10	(yellow)
10<20	(light green)
20<30	(green)
≥30	(dark green)

3.2.1 Scenario a, Tomato crop in a multi-tunnel greenhouse in Spain

The main results in the reference situation for a tomato crop in a multi-tunnel greenhouse in Spain were included at the beginning of this section to facilitate the comprehension of alternatives for improvement life cycle impact assessments.

3.2.1.1 Reference situation

The main burdens in the reference scenario a), tomato crop in multi-tunnel greenhouse in Spain, were structure, auxiliary equipment and fertilizers (Table 3.4). Structure accounted for major contributions to abiotic depletion, global warming and cumulative energy demand impact categories; auxiliary equipment to air acidification and photochemical oxidation and fertilizers to eutrophication.

Table 3.4. Stage contributions to selected impact categories (IC) per ton of tomato, for reference tomato production in a multi-tunnel greenhouse

IC	Unit	Total	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	kg Sb eq	**1.7E+00**	**7.8E-01**	1.1E-03	6.3E-01	2.0E-01	1.7E-02	2.3E-02
AA	kg SO_2 eq	**1.0E+00**	3.9E-01	1.5E-03	**4.2E-01**	2.1E-01	1.9E-02	1.2E-02
EU	kg PO_4^{-3}eq	**4.9E-01**	1.5E-01	2.7E-04	8.0E-02	**2.5E-01**	6.5E-03	3.9E-03
GW	kg CO_2 eq	**2.5E+02**	**8.8E+01**	1.5E-01	7.7E+01	8.2E+01	2.0E+00	3.1E+00
PO	kg C_2H_4	**5.4E-02**	2.0E-02	5.4E-05	**2.7E-02**	4.9E-03	1.2E-03	1.0E-03
CED	MJ	**4.0E+03**	**1.9E+03**	3.1E+00	1.6E+03	3.9E+02	4.1E+01	5.7E+01

AD, abiotic depletion; AA, air acidification; EU, eutrophication; GW, global warming; PO, photochemical oxidation; CED, cumulative energy demand

3.2.1.2 Reduction of substrate volume

Table 3.5 shows the results of 5, 15, 25 and 35% substrate volume reduction compared to the reference scenario. Auxiliary equipment and waste were the stages affected by substrate volume reduction. It is notable that AD, GW and CED impact categories had the highest environmental impacts decrease because perlite manufacture is very energy dependent, as these impact categories. When the substrate volume was reduced by 35%, the auxiliary equipment contributions to AD, GW and CED decreased by 14% to 17% and the production system contributions by 5% to 6%.

Table 3.5. Contributions of substrate volume reductions versus the reference situation (%) to impact categories (IC), per production system and auxiliary equipment and waste stages

		Total production system				Auxiliary equipment				Waste			
IC	**Ref.**	**5%**	**15%**	**25%**	**35%**	**5%**	**15%**	**25%**	**35%**	**5%**	**15%**	**25%**	**35%**
AD	100	99.2	97.5	95.8	94.2	97.9	93.6	89.3	85.0	99.1	97.3	95.5	93.7
AA	100	99.4	98.3	97.1	96.0	98.6	95.8	93.0	90.2	99.1	97.3	95.5	93.8
EU	100	99.7	99.2	98.7	98.2	98.5	95.5	92.4	89.4	99.2	97.5	95.8	94.1
GW	100	99.2	97.7	96.2	94.7	97.5	92.6	87.7	82.8	99.2	97.5	95.9	94.3
PO	100	99.5	98.4	97.3	96.2	98.9	96.8	94.7	92.6	99.2	97.6	96.1	94.5
CED	100	99.2	97.5	95.9	94.3	98.0	93.9	89.8	85.8	99.1	97.3	95.6	93.8

3.2.1.3 Extension of substrate life span

Results for extension of substrate life span from three to four years are listed in Table 3.6 and compared to the reference situation, for production system and auxiliary equipment and waste stages. Contributions to impact categories were slightly lower than with 25% reduction of perlite volume because life span extension affected not only perlite but also plastic bags for its containment and transport to the greenhouse and final disposal. As in the previous case, energy dependent impact categories, abiotic depletion, global warming and cumulative energy demand, had the highest reductions and were between 11% and 13% in the auxiliary equipment, and between 3.9% and 4.5% in the production system.

Table 3.6. Contributions of perlite life span extension versus the reference situation (%) to impact categories (IC), per product system and auxiliary equipment and waste stages

IC	**Reference**	**Total production system**	**Auxiliary equipment**	**Waste**
AD	100	95.5	88.5	95.4
AA	100	97.0	92.6	95.5
EU	100	98.7	92.1	95.7
GW	100	96.1	87.3	95.9
PO	100	97.2	94.4	96.0
CED	100	95.6	89.0	95.5

3.2.1.4 Reduction of fertilizers doses

The fertilizer stage included processes directly related to the amount of product applied to the crop, such as manufacture, emissions to air and emissions to water due to their application. For this reason, contributions to all the impact categories were reduced by the same proportion as the reduction in the amount of fertilizer in the fertilizer stage. A 10% reduction of fertilizers decreased contributions to the global production system by 0.89% to 5.1% depending on the impact category (Table 3.7). A 20% reduction decreased contributions by 1.8% to 10% and with a 30% reduction of fertilizers, by 2.7% to 15%. Eutrophication impact category had the highest contributions in the reference situation because of emissions to water, since there was an open-loop irrigation system. Consequently, reduction of fertilizers doses made the highest reductions to this impact category.

Table 3.7. Contributions of reduction of fertilizer volume versus the reference situation (%) to impact categories, in the production system and fertilizers stage

IC	Reference	Total production system			Fertilizers		
		10%	20%	30%	10%	20%	30%
AD	100	99	98	96	90	80	70
AA	100	98	96	94	90	80	70
EU	100	95	90	85	90	80	70
GW	100	97	94	90	90	80	70
PO	100	99	98	97	90	80	70
CED	100	99	98	97	90	80	70

3.2.1.5 Extension greenhouse life span

Extension of greenhouse life span to 20 years reduced environmental impacts of the structure and waste management stages. Since structure was one of the principal burdens in the product system, this was the stage where the major reductions to all the impact categories were obtained, with percentages of between 10.8% and 20.5%. The total production system contributions to impact categories were reduced by 5.2% to 6.4% (Table 3.8).

Table 3.8. Contributions of greenhouse life span extension versus the reference situation (%) to impact categories (IC), per production system and structure and waste stages

IC	Reference	Total production system	Structure	Waste
AD	100	94.8	89.1	96.1
AA	100	93.7	83.0	96.6
EU	100	93.7	79.5	97.3
GW	100	94.4	84.1	97.1
PO	100	93.6	83.2	98.5
CED	100	94.8	89.2	96.3

3.2.1.6 Increase of renewable energy in electricity production

Table 3.9 shows contributions when considering 10%, 20%, 30% and 40% of renewable energy in the production system. It is noticeable the high reduction of contributions in the climate control system as only electricity consumption for operating ventilators was included. Auxiliary equipment major reductions were in air acidification and eutrophication impact categories. Electricity consumption by the irrigation system made the major contributions for these impact categories in the reference situation (60% and 58%).With 40% of renewable energy in the production of electricity there was a 4.1% reduction in the auxiliary equipment contribution to cumulative energy demand, and between 16% and 32% in the other environmental impact categories.

Table 3.9. Contributions of increase of renewable energy versus the reference situation (%) to impact categories (IC), per production system and climate control and auxiliary equipment stages

		Total production system				Climate control system				Auxiliary equipment			
IC	**Ref.**	**10%**	**20%**	**30%**	**40%**	**10%**	**20%**	**30%**	**40%**	**10%**	**20%**	**30%**	**40%**
AD	100	99.6	97.6	95.7	93.7	96.5	79.7	62.9	46.0	98.9	93.9	88.8	83.7
AA	100	99.2	95.2	91.2	87.3	96.6	80.1	63.6	47.1	97.9	88.1	78.2	68.3
EU	100	99.7	98.2	96.6	95.1	96.7	80.9	65.1	49.3	98.1	88.9	79.7	70.6
GW	100	99.6	97.9	96.2	94.5	96.6	80.0	63.5	47.0	98.8	93.3	87.7	82.2
PO	100	99.4	96.6	93.9	91.1	96.6	80.1	63.6	47.1	98.8	93.2	87.6	81.9
CED	100	99.9	99.4	98.9	98.3	99.2	95.4	91.5	87.7	99.7	98.4	97.2	95.9

3.2.1.7 A best case alternative

This best case alternative, with a 25% reduction in volume of perlite, extension of life span of perlite to 4 years, a 30% reduction in volume of fertilizers, extension of greenhouse life span to 20 years and 40% renewable energy used in the production of electricity, was found to give an 17 to 30% reduction of contributions to the impact categories (Table 3.10). High contribution decreases by the production system were because of the addition of improvement in stages, as in auxiliary equipment, where three alternatives were considered at the same time. A very significant reduction could be achieved in acidification impact category, mainly because of the use of renewable energy in the electricity production mix. Pesticide stage made the same contributions as any alternative for improvement related to crop protection was applied.

Table 3.10. Contributions of a best case alternative versus the reference situation (%) to impact categories (IC), per production system and stage

IC	**Reference**	**Total production system**	**Structure**	**Climate system**	**Auxiliary equipment**	**Fertilizers**	**Pesticides**	**Waste**
AD	100	77.3	89.0	46.0	64.1	70.2	100.0	88.1
AA	100	69.9	83.0	47.1	55.6	70.3	100.0	88.7
EU	100	71.3	79.5	49.3	56.9	70.1	100.0	89.7
GW	100	72.4	84.0	47.0	60.2	70.0	100.0	89.9
PO	100	77.2	83.2	47.1	72.4	70.2	100.0	91.5
CED	100	82.6	89.2	87.7	77.2	70.1	100.0	88.5

3.2.1.8 Closed-loop irrigation system

Table 3.11 shows the contributions of the production system with the implementation of a closed-loop irrigation system, compared to the reference situation. It is noticeable the decrease of fertilizer contributions to all impact categories. With the implementation of a closed-loop irrigation system, water consumption and fertilizer doses were reduced. Consequently, fertilizer environmental impacts decreased, because of the reduction of emissions due to fertilizer manufacture and their application. Contributions to eutrophication impact category were mainly produced by nitrate emissions to water in the reference system. With a closed-loop irrigation system there were no lixiviates and nitrate emissions to water were avoided, making a significant decrease. Contribution to global warming impact category was reduced because of lower emissions of dinitrogen monoxide to air.

The adjustment of water consumption made decrease electricity consumption by the irrigation system, which compensated the electricity consumption for water recirculation. Consequently, auxiliary equipment contributions to impact categories decreased.

The significant reductions of fertilizer contributions made high reductions of the production system in eutrophication and global warming impact categories, as these were the impact categories in the reference situation where fertilizers made major impacts,

Table 3.11. Contributions of production system with a closed-loop irrigation system versus the reference situation (%) to impact categories (IC), per production system and auxiliary equipment and fertilizer stages

IC	Reference	Total production system	Auxiliary equipment	Fertilizers
AD	100	94.8	95.3	71.6
AA	100	90.1	90.2	70.1
EU	100	51.8	91.2	8.0
GW	100	87.7	94.8	67.1
PO	100	94.9	94.6	72.6
CED	100	95.1	94.7	71.7

3.2.1.9 New type of greenhouse with improved ventilation

Table 3.12 shows the effects of a new type of multi-tunnel greenhouse compared to the reference situation. Total production system and all stage contributions to impact categories decreased significantly. All impact categories had reductions equal or higher to 36% comparing to the reference situation. The high increase of yield was the main reason for such results as environmental impacts were calculated per tonne of production. It is important to mention that the increase in yield of this new greenhouse type was mainly based on the improvement of natural ventilation, so compared with the reference situation relatively small input intensification was needed. The increase of steel in the structure was very low in the new type of greenhouse (from 7.6 to 8 $kg \cdot m^{-2}$) and had little effect on results. Reductions in climate control system, fertilizer and pesticide stages were lower than in the other stages because inputs for these stages in the reference situation were accounted for a growing period of nine months and in the new type of greenhouse the growing period was 12 months: by improving ventilation it was possible to control the high temperatures during the summer which allowed year round production in the new greenhouse.

Table 3.12. Contributions of new type of greenhouse versus the reference situation (%) to impact categories (IC), per production system and stage

IC	Reference	Total production system	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	100	42.6	46.7	29.9	42.1	29.9	29.9	36.0
AA	100	38.8	46.2	29.9	36.9	29.9	29.9	35.6
EU	100	36.0	45.9	29.9	37.3	29.9	29.9	35.0
GW	100	39.3	46.4	29.9	41.6	29.9	29.9	35.0
PO	100	41.8	46.2	29.9	41.5	29.9	29.9	33.9
CED	100	42.7	46.7	29.9	41.6	29.9	29.9	35.8

3.2.2 Scenario b, Tomato crop in a Venlo greenhouse in the Netherlands

3.2.2.1 Reference situation

Table 3.13 shows the contributions to selected impact categories for a tomato crop in a Venlo greenhouse in the Netherlands. Energy allocation was used to determine the impact of using natural gas to heat the greenhouse. The climate control system was the major contributor to all the impact categories selected. The high amount of natural gas needed to heat the greenhouse was the main reason for the high environmental impacts. Structure was the second contributor in the production system in a very far position.

Table 3.13. LCIA results per FU, for tomato greenhouse crop in the Netherlands, with energy allocation of natural gas in CHP

IC	Unit	Total	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	kg Sb eq	**1.5E+01**	3.4E-01	**1.5E+01**	1.4E-01	9.9E-02	1.6E-03	3.3E-03
AA	kg SO_2 eq	**2.9E+00**	3.0E-01	**2.4E+00**	8.8E-02	1.1E-01	1.8E-03	2.3E-03
EU	kg PO_4^{---}eq	**7.2E-01**	9.7E-02	**5.8E-01**	2.1E-02	1.6E-02	6.1E-04	9.1E-04
GW	kg CO_2 eq	**2.0E+03**	5.3E+01	**1.9E+03**	1.4E+01	4.8E+01	2.0E-01	2.1E+00
PO	kg C_2H_4	**2.1E-01**	1.4E-02	**1.9E-01**	6.5E-03	2.2E-03	1.1E-04	7.6E-05
CED	MJ	**3.1E+04**	8.2E+02	**3.0E+04**	3.1E+02	2.0E+02	3.9E+00	7.9E+00

AD, abiotic depletion; AA, air acidification; EU, eutrophication; GW, global warming; PO, photochemical oxidation; CED, cumulative energy demand

3.2.2.2 Energy saving cultivation method

Table 3.14 shows production system, structure and climate control system contributions to impact categories compared to the reference situation with a new energy saving cultivation method. Scenarios consider energy allocation approach at CHP, therefore only natural gas for heating the greenhouse is entered as an input and not electricity production at CHP.

It is notable the reduction of environmental impacts of the climate control system and the production system. Climate control system made the major contributions in the reference situation because of the natural gas consumption for heating the greenhouse. Therefore, the reduction in natural gas consumption in the alternative scenario decreases significantly energy burdens in climate control system and consequently in the total production system. Energy reduction use made lower reductions in eutrophication impact category because greenhouse electricity consumption is also a considerable contributor to this impact category.

Lower contribution reductions of climate control system to eutrophication impact category were achieved because greenhouse electricity consumption, with major contribution to this stage, remained the same and consequently made a higher relative contribution.

The use of an extra energy screen increased burdens in structure stage due to the additional input of aluminium, manufacturing processes and transport to the greenhouse. The increased contributions were not noticeable in the total production system because it was highly compensated by the reduction of energy burdens in the climate control system.

Table 3.14 .Contributions of energy saving cultivation method versus the reference situation (%) to impact categories (IC), per production system and structure and climate control system stages, with energy allocation of natural gas at CHP

IC	Reference	Total production system	Structure	Climate control system
AD	100	68.9	105.3	67.6
AA	100	74.1	103.9	68.3
EU	100	79.6	105.6	74.0
GW	100	69.6	105.1	67.6
PO	100	70.9	105.0	67.1
CED	100	69.1	105.6	67.6

3.2.2.3 New type of glasshouse

Table 3.15 shows the contributions of new type of greenhouse alternative to impact categories, by the production system, structure and climate control system compared to the reference situation. As in the previous alternative, results are for energy allocation approach at CHP.

A 55% reduction of natural gas consumption in the alternative scenario had a high environmental improvement effect. Contribution decreases by the production system and climate control system were very significant for all impact categories but for eutrophication, between 30% and 40% in the first case and between 39% and 46% in the second. Eutrophication is an impact category where emissions from electricity production are a high burden. For this impact category, the effect of a 155% electricity consumption increase in the alternative scenario is much higher than the effect of reducing 55% natural gas consumption.

The increase of glass and metal in the new type of greenhouse was an additional burden in the structure stage making higher contributions to all impact categories. As in the reference situation, metal and glass and their manufacturing processes were major burdens in structure stage.

Table 3.15. Contributions of a new type of greenhouse versus the reference situation (%) to impact categories (IC), per production system and structure and climate control system stages, with energy allocation of natural gas at CHP

IC	Reference	Total production system	Structure	Climate control system
AD	100	61.2	117.8	59.2
AA	100	70.1	125.0	60.9
EU	100	93.6	112.3	90.1
GW	100	62.0	118.8	59.1
PO	100	60.1	119.2	53.9
CED	100	61.3	116.7	59.1

3.2.3 Scenario c, Rose crop in a Venlo greenhouse in the Netherlands

3.2.3.1 Reference situation

Table 3.16 shows the contributions to selected impact categories for a rose crop in a Venlo greenhouse in the Netherlands. Energy allocation was used to determine the impact of natural gas use to heat the greenhouse. The climate control system was the major contributor to all the impact categories selected. The high amount of electricity to light the crop was the main reason for the high environmental impacts. Natural gas consumption was also a major contributor in climate control system stage.

Table 3.16. LCIA results per FU, for rose greenhouse crop in the Netherlands, with energy allocation of natural gas in CHP

IC	Unit	Total	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	kg Sb eq	1.6E+01	8.7E-02	**1.6E+01**	7.5E-02	1.4E-02	1.3E-03	6.0E-04
AA	kg SO_2 eq	3.0E+00	7.2E-02	**2.8E+00**	4.8E-02	1.5E-02	1.5E-03	4.7E-04
EU	kg PO_4^{---}eq	1.7E+00	2.5E-02	**1.6E+00**	1.1E-02	2.3E-03	5.0E-04	3.1E-04
GW	kg CO_2 eq	2.1E+03	1.3E+01	**2.1E+03**	7.5E+00	6.7E+00	1.6E-01	1.1E+00
PO	kg C_2H_4	1.5E-01	3.4E-03	**1.4E-01**	3.0E-03	3.0E-04	9.0E-05	1.6E-05
CED	MJ	3.3E+04	2.1E+02	**3.3E+04**	1.7E+02	2.8E+01	3.2E+00	1.4E+00

3.2.3.2 Diffuse glass and AR coating

Table 3.17 shows the contributions of the production system with the implementation of a diffuse glass covering compared to the reference situation.

Although there was an increase of burdens in the structure stage due to the electricity consumption for the diffuse glass coating, it was partially compensated by the increase of 5% yield. All the remaining stages (climate system, auxiliary equipment, fertilizers, pesticides and waste) had equal decreases because they were only affected by the increase of yield.

Table 3.17. Contributions with diffuse glass covering versus the reference situation (%) to impact categories (IC), per production system and system stages, with energy allocation of natural gas at CHP

IC	Reference	Total production system	Structure	Remaining subsystems
AD	100	95.3	106.0	95.2
AA	100	95.4	103.2	95.2
EU	100	95.5	110.0	95.2
GW	100	95.3	105.1	95.2
PO	100	95.4	101.8	95.2
CED	100	95.3	108.6	95.2

3.2.3.3 Reduction of substrate volume and increased plant density

Table 3.18 shows the contribution of the production system with volume substrate reductions compared to the reference situation. High contribution reductions were achieved in the auxiliary equipment because energy demand for rockwool manufacture decreased with lower inputs of substrate. Nevertheless, it is significant that these high contribution reductions in the auxiliary equipment made smaller effect in the total production system. This is due to the fact that auxiliary equipment contributions in the reference production system are lower than 2% so any change in this stage will make low variations in the total production system. Waste stage reduced its contributions because transport to landfill and substrate emissions at landfill decreased. Nevertheless, environmental impacts were reduced around 5% because of the benefit of 5% increased yield.

Table 3.18. Contributions with 20% and 30% substrate volume reduction versus the reference situation (%) to impact categories (IC), per production system and auxiliary equipment and waste stages, with energy allocation of natural gas at CHP

		Total production system		Auxiliary equipment		Waste	
IC	Reference	20%	30%	20%	30%	20%	30%
AD	100	95.2	95.2	84.0	78.4	86.8	82.6
AA	100	95.0	94.9	80.0	72.4	89.2	86.2
EU	100	95.1	95.1	80.5	73.2	93.0	91.9
GW	100	95.2	95.2	82.4	76.0	94.8	94.6
PO	100	95.0	94.9	82.7	76.4	89.1	86.0
CED	100	95.2	95.2	84.7	79.4	87.0	82.9

3.3 Discussion

The effect of the alternatives for improvement was analysed in the three scenarios and is summarised in this section. Results showed what alternatives could make major environmental impact reductions in the production systems. In this section, results are discussed for each scenario and several specific and general conclusions are presented.

3.3.1 Scenario a, Tomato crop in a multi-tunnel greenhouse

Alternatives for improvement in a tomato crop in a multi-tunnel greenhouse in the Mediterranean area focused on the main burdens described in the reference scenario: structure, auxiliary equipment and fertilizers. Results showed:

- Reduction of substrate volume and extension of perlite life span showed significant reductions in auxiliary equipment but had little effect in the total production system. A 25% reduction in volume of perlite or extension of its life span to four years gave similar results. Both substrate-use alternatives entail root restriction, so and adjustment to nutrients and water supply should be taken into account (Xu and Kafkafi, 2001). Studies on root restriction in horticultural practices concluded that a reduction of substrate volume is feasible without a significant lost of yield (Ganea et al., 2002; Haghuis, 1990; Logendra et al., 2001). Alternative local materials or other substrates such as coconut fibre or rockwool should also be studied in order to assess their contribution to environmental burdens in the tomato production system.
- Fertilizers analysis in the reference scenario showed their high environmental implication to the crop. Sensitivity analysis of volume fertilizer doses showed major reductions in contributions to eutrophication impact category. A 30% reduction of fertilizers volume is feasible and highly recommended. This is within the suggested margins of fertilizers for tomato crops under Mediterranean climatic conditions, without causing any adverse effects on fruit yield or quality (Muñoz *et al.*, 2008). Moreover, progress should focus on the methodologies currently used to assess the amount of fertilizer reaching the aquifers as they are only approximate and consequently the contribution of fertilizers to eutrophication is debatable.
- Structure was a major contributor in the production system. Consequently, extension of greenhouse span had a considerable effect and contributions of total production system were reduced. This is a more realistic situation as most growers extend greenhouse life span to 20 years or even more. Since the FU for the environmental impacts was the amount of tomatoes produced per unit soil area during the life time of the structure, environmental impacts of structure could be reduced by extending the greenhouse life span. When life span was estimated as 20 years, the structure environmental impacts were reduced by 6% in the total production system. A longer greenhouse life span is possible, but this would require increasing the strength of the structure to withstand the extra loads (wind, snow, etc) over a longer period of time. This structural calculation is beyond the scope of this paper.
- The present study revealed how agricultural production can decrease environmental impacts by improvements in non-agricultural processes such as the increase of

renewable energy in the production of electricity. The gross electricity production in Spain will include 40% renewable energies in 2020 (Ministerio de Industria, Turismo y Comercio (Ministerio_Industria 2009), Efforts are oriented to increasing wind power and photovoltaic energy, so reducing the use of abiotic resources, and the impact of processes such as irrigation and ventilator operation, depending on electricity, will significantly decrease. Nevertheless, this alternative showed a moderate effect in the total production system as tomato crop in a mult-itunnel greenhouse has little energy requirements.

- The best case alternative showed the importance of combining the implementation of several alternatives to obtained better results. Reductions from 17.4% to 30.1% for the different impact categories can realistically be achieved.
- A closed irrigation system can reduce significantly contributions to all impact categories due to the following reasons:
  - Adjustment of fertilizers doses and mainly no nitrate emissions to water gave a 48.2% reduction of environmental impacts to eutrophication.
  - Reduction of 17% in electricity consumption by the irrigation system because of adjustment of water consumption which compensates electricity consumption for water recirculation - few input materials are necessary for the implementation of a closed-loop irrigation system
- The new type of greenhouse was the most effective alternative due to the following considerations:
  - There were very high reductions of environmental impacts because of the increase in yield. There is considerable scope to enhance yields in Spain at the present moment, and technological improvements to increase productivity such as this demonstrate that would directly reduce the environmental burdens per unit of produce.
  - Little increase of materials structure which had negligible effect in LCIA
  - It should be taken into consideration the effort to put in practice this new climate control management: technical training, time demanding, and update in new technologies in a traditional sector, among others. Surely growers will be encouraged by the possibility to obtain high yields.
  - Further research could focus to implement other crop management alternatives in this new type of greenhouse.

3.3.2 Scenario b, Tomato crop in a Venlo greenhouse in the Netherlands

Two alternatives focused on energy use reduction were studied.Both alternatives reduced contributions significantly to all impact categories due to the high decrease in energy consumption for heating the greenhouse.

- Energy saving cultivation method:

- Was found to be a very effective solution based mainly in cultivation techniques management.
- The total production system reduced environmental impacts more than 26% in all impact categories.
- Only an energy screen was necessary as a material input. Its contribution was highly compensated by energy use reduction.
- The effect of lower electricity production at CHP was not analysed because an energy allocation approach was used for calculations. Nevertheless, it can be expected that electricity production environmental impacts would increase in any other system where electricity is produced from a source with higher environmental impacts than natural gas.

- New type of greenhouse
  - As in the previous alternative, high environmental impact reductions could be achieved although results were not as uniform for all impact categories. Reductions were higher than 30% to all impact categories but for eutrophication, which was 6.4% because of the effect of the increase of electricity consumption.
  - This alternative required high extra inputs of electricity consumption for external air suction and a regain unit, and for double glass covering, which were compensated with the reduction of a 55% of natural gas consumption for heating the greenhouse. Reductions were lower for eutrophication impact category, because of the high effect of phosphate emissions to water due to the use of hard coal in the electricity production mix in the Netherlands.
  - It could be a controversial discussion to obtain a 55% reduction of energy use but at expense of such high increase of electricity consumption and glass for the covering. In spite of high contribution reductions for most impact categories, even higher than in the previous alternative, the implementation of this alternative would not be easy for most growers as it requires major changes in the greenhouse. An extra screen would be possible to implement in an existing greenhouse and energy use reduction could be started easily with the convenient cultivation method.

3.3.3 Scenario c, Rose crop in a Venlo greenhouse in the Netherlands

For this scenario the climate system was the major contributor to all the impact categories selected. Intensive use of electricity is needed to produce roses in The Netherlands and electricity consumption was the major contributor to the environmental impacts. Diffuse glass covering has an effect on the greenhouse light level, therefore diffuse glass was considered as an alternative for input reduction.

- Diffuse glass covering:
  - Yield increase close to 5% was an obvious benefit reducing environmental impacts of the production system and stages. In terms of environmental impact this increase in yield compensated the extra energy required for the production of diffuse glass

compared to standard glass. Environmental impacts were reduced around 4.6% to all impact categories.

- Since diffuse glass covering improves natural light distribution and therefore natural light use efficiency, it would have been possible to reduce the artificial lighting to achieve the same yield as for regular greenhouse glass. Nevertheless rose growers are not willing to accept a reduction in artificial lighting, therefore this option was not considered in our study.

- Reduction of substrate volume

  - This environmental analysis showed similar results as in substrate volume reduction in the multi-tunnel greenhouse scenario.

  - Lower use of substrate volume produced significant reductions in auxiliary equipment (20.6% in cumulative energy demand) but had lower effect in the total production system (4.8%). This kind of results would make difficult to convince growers to implement an alternative that gives little environmental improvements in the production system and on the other hand requires extra effort in agricultural practices. However, substrate volume reduction must be equally encouraged to move to more environmental friendly practices.

  - Among the scenarios under consideration rose production in The Netherlands does not offer too many opportunities for input reduction without severe implications on crop yield and quality. More effort should be done to reduce energy consumption by lighting. Such efforts can be oriented towards the use of more efficient energy sources (LED lights and using renewable energy in the production of electricity. Those studies are beyond the scope of this project.

4 ECONOMIC ANALYSIS

The economic effects of improvement options has been evaluated in comparison with the reference situation as reported in deliverable 5 (Montero et al., 2011).

In this section, the improvement options are analysed for scenario a (tomato in multi-tunnel greenhouse), b (tomato crop in Venlo greenhouse) and c (rose crop in Venlo greenhouse).

4.1 Alternatives for improvement and results

4.1.1 Scenario a, Tomato crop in a multi-tunnel greenhouse in Spain:

4.1.1.1 New type of greenhouse with improved ventilation and yield

The experiments at Estación Experimental de la Fundación Cajamar (EEFC, Almeria) took place in a six-span multi-tunnel greenhouse with ridge oriented North-South. The dimensions of each span are: width 8 m and length 20 m. The gutter height is 4.5 m and ridge height is 6.9 m, therefore the roof slope is 30º. Each span has double roof vents (width of the vents: 1.9 m) and the whole perimeter has sidewall vents of 3 m height which open from the ground level (see figure 4.1).

As cultivation system a long cycle was used (transplant of grafted plants in the middle of July and finish at the end of June next year) with a plant density of 3 stems/m^2 during autumn and spring and 2 stems/m2 during the winter time. The wires to train the crop were at a height of 3.70 m. Cultivation in the soil.

Figure 4.1. New type of multi-tunnel greenhouse with improved ventilation (EEFC, Almeria, Spain)

The new type of greenhouse has effect on different components of the cost benefit analysis. The technical and economic data were provided by EEFC, Almeria (Anonymus, 2010). The economic data were processed by WUR Greenhouse Horticulture to make it comparable to the reference situation (Montero et al, 2011). The differences with the reference situation are:

- Extra investment: 9,5 €/m2. This results in extra annual costs (depreciation, maintenance and interest) of 1,40 €/m2
- Extra production: 14,9 kg/m2 (total production 31,4 kg/m2);
- Extra yield: 9,10 €/m2;
- Grafted plant material: extra costs 0,50 €/m2;
- Higher consumption of fertilizers, water and crop protection: 0,55, 0,20 and 0,10 €/m2;
- Use of CO2 enrichment: 2,50 €/m2;
- Extra crop labour (related to the extra production): 1,50 €/m2;
- Extra management labour: 0,20 €/m2 and
- Extra sales/packaging costs (related to extra production/yield): 0,15 €/m2.

These changes lead to the following economic consequences (Table 4.1).

Table 4.1. Effect of new type multi-tunnel greenhouse with improved ventilation on benefits and costs in comparison with reference tomato production system (€/m2)and pay-back period of extra investment (years)

Benefit-cost component, economic indicator	*Difference with reference system*
Yield	9.10
Variable costs	4.45
Fixed costs	3.05
Total costs	7.50
Balance of benefits and costs	1.60
Payback period of extra investment (year)	5

The results in table 4.1 point out that an investment in a new type multi-tunnel greenhouse with improved ventilation appears to be profitable. The extra investment can be earned back within 5 years under the assumptions.

Although the production in the new type of multi-tunnel greenhouse almost doubles (=191%) in comparison with the reference system, the efficiency figures of fertilizer, crop protection or energy input will not differ much (efficiency expressed as cost of inputs per unit of production).

4.1.1.2 Closed irrigation systems

In the reference cultivation system in scenario 1 no drain water is collected for reuse. If a recirculation system will be implemented a major part of the drain water will not washed away. This means also reuse of fertilizers. The question is only how much fertilizers could be reused again. When 30% of the fertilizers could be saved a cost reduction of 0,20 €/m^2 (or 2000

€/ha,yr) could be realised based upon the figures in the reference situation (see Deliverable 5, (Montero et al., 2011)). A cost reduction of 0,20 €/m^2would result in an investment capacity of ca. 0,90 €/m^2 or 9000 €/ha.

At the test site in Italy (commercial greenhouse in ChiesinaUzzanese) a closed loop fertirrigation system in rock wool and a quick test for periodical nutrient solution analysis have been tested by UNIPI (see figure 4.2 (Incrocci, 2011).

Figure 4.2. Experiment with closed fertirrigation system on test site (UNIPI, Pisa, Italy)

The closed fertirrigation system reduced the use of water (21%) and nutrients (17 to 35%). Based upon the small scale test estimation has been made for a 1 ha greenhouse (see Table 4.2).

Table 4.2: Effect of closed fertirrigation system, quick test nutrient solution analysis and UV filtration on balance of benefits and costs and payback period (€/ha, year)1) 2) 3) 4)

	extra investment	depreciation	maintenance interest	other var costs	fertilizer savings	balance benefit-costs	payback period
	€/ha	€/ha	€/ha	€/ha	€/ha	€/ha	yr
Closed fertirrigation system	7500	750	565	1200	4650	2135	3
Closed fert.system + quick test	8300	910	625	810	4650	2305	3
Closed fert.system + quick test + UV filtration (desinfestation)	23300	3270	1750	1390	4650	-1760	11

1) Other variable costs: chemical (12x) and phytopathological (2x) analysis
2) Other variable costs: chemical (2x) and phytopathological (2x) analysis and reagents.
3) Fertilizers savings: nutrients and water consumption
4) Other variable costs include costs of UV desinfestation (electricity UV and pump and replacing lamps) for variant with UV filtration.

The results in table 4.2 show that an investment in a closed fertirrigation system seems to be profitable. The payback period is within three year. A portable spectrophotometer for quick analysis of the nutrient solution will make the results slightly better.

It is known that reuse of drain water can spread diseases with the risk of loss of production and yield. When the drain water would be treated by UV filtration to prevent the risks of spreading diseases the balance of benefits and costs will be negative (ca. -1760 €/ha). The payback period will increase strongly to about 11 years.

From economic point of view reuse of drain water could be interesting, but it depends on the risks of diseases for the specific crop. The costs of disinfestation could be seen as an insurance premium.

4.1.1.3 Reduced volume and increased life span of growing media (perlite)

In this part two options are analysed on the economic effects:

- reduction of substrate volume
- longer life span of substrate medium.

Reduction of substrate volume

In scenario 1 the reference cultivation system consists of a substrate bag with perlite, and a substrate volume of 10 L·plant^{-2}, which is intended to be used for three years (see figure 4.3 and Deliverable 5, Montero, 2011).

Figure 4.3. Tomato cultivation system (EEFC, Almeria, Spain)

As option a 25% reduction of substrate volume is assumed at which no negative effects will be expected for the growth and development of the tomato crop in the three cultivation years. Other components of the cultivation system, like number of drippers, are kept to be equal to the reference system.

The economic effects of reduced substrate volume in comparison with the reference cultivation system are showed in Table 4.3.

Table 4.3. Effect of reduced substrate volume and life span on yearly costs of substrate bags (€/m^2)1)

Substrate bags (perlite)	units/ha	investment €/unit	investment total	depreciation %	maintenance interest %	costs €/m2	savings €/m2
reference cultivation system	4650	1,80	8370	33,3	7,5	0,34	-
option 1: 25% volume reduction	4650	1,42	6591	33,3	7,5	0,27	0,07
option 2: 4 year life span	4650	1,80	8370	25,0	7,5	0,27	0,07

1) Option 1: Price per litre substrate is about 5% higher than the standard substrate bag.

Table 4.3 shows that the yearly savings of reduced substrate volume amounts to only 7 eurocents per m^2. A sensitivity analysis of the substrate price points out that the savings are not very much affected, because of the three year life span.

Extension of life span of substrate medium

In the standard cultivation system the substrate bags with perlite will be used for three years. A calculation has been made what the economic effect will be of a longer life span. When the substrate bags have a life span of 4 years instead of 3 years the savings of substrate media will amount to 7 eurocents per m^2 (see table 4.3). Also in this case the sensitivity to substrate prices are limited.

4.1.2 Scenario b, Tomato crop in a Venlo greenhouse in the Netherlands

In this part two energy saving options will be analysed:

- energy saving cultivation method
- double glazed Venlo greenhouse

4.1.2.1 Energy saving cultivation method

Within the new cultivation method the crop and the cultivation technique are the central point. The new energy saving cultivation system contains seven steps in order to obtain more than 50% of energy saving. Interesting for practice is that the steps can be implemented successively (Greenhouse as energy source;(Anonymus, 2009)).

For the tomato production system the following three steps have been analysed: controlled ventilation of moist greenhouse air by means of external air suction, extra screen and more intense screen use and cultivation according to natural conditions. These steps result in a reduction of the energy demand and the energy consumption. Figure 4.4 represent a figure and a photo of the controlled ventilation of moist greenhouse air by means of external air suction.

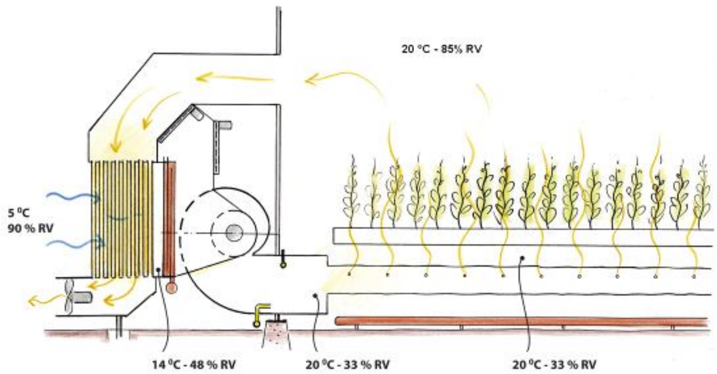

Figure 4.4. Controlled ventilation by means of external air suction (Zuiderwijk en Witzier, Bergschenhoek, The Netherlands)

Due to the new cultivation method the heat demand of the tomato production system will reduce with ca. 35% in comparison to the reference production system (1275 MJ/m^2> 825

MJ/m^2). Because of the lower heat demand a smaller heat power co-generator (electric capacity) is required with lower gas consumption, but also less electricity will be produced and can be sold to the public grid. For all variables a reduction of about 35% of the capacity or volume can be hold in comparison to the reference situation. The production and product quality will remain the same as in the reference production system. The light interception by the extra screen (in open position) will be compensated by the better greenhouse climate conditions (Ruijs et al., 2010).

The economic evaluation has taken into account:

- Investment in device to suck in external air and heat exchanger (6,- €/m^2)
- Investment in extra energy screen (4 €/m^2)
- Lower investment in heat power co-generator (7,5 €/m^2)
- No investment in fans (1.2 €/m^2)
- Lower gas consumption (35% of consumption in reference à 0.20 €/m^3)
- Lower electricity sales (35% of sales in reference à 65 €/MWh).

The results are shown in table 4.4.

Table 4.4. Effect of new energy saving cultivation method on investments, yearly costs of investments, energy costs and balance of benefits and costs in comparison with the reference tomato production system (€/m2)

Component	*Difference with reference system (€/m2)*
Investment	1.20
Yearly costs of investment[1)]	0.10
Energy costs[2)]	0.45
Yield	-
Balance of benefits and costs	-0.55

1) Yearly costs: depreciation, maintenance and average interest.
2) Energy costs: balance of energy consumption and energy sales (electricity).

Table 4.4 points out that the energy saving cultivation method has a negative balance of benefits and costs in spite of the substantial energy savings. An important factor for the negative result is the reduction of sales of electricity to the public grid. The decrease of energy sales turns out to be larger than the savings on energy consumption. The effect of varying energy prices is given in figure 4.5. In this figure the electricity price is set proportional to the gas price.

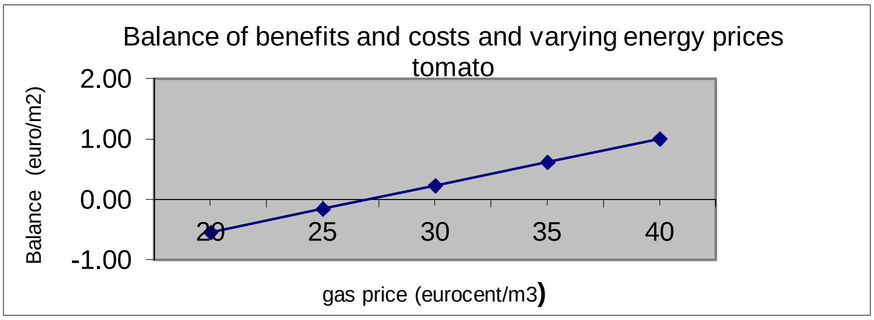

Figure 4.5. Effect of energy prices on balance of benefits and costs of new cultivation method for tomato production (€/m^2)

Figure 4.5 shows that higher energy prices are favourable for the attractiveness of the energy saving cultivation method. At a gas price of 27,5 eurocent/m^3 the new cultivation method becomes an economic interesting option.

In the cost-benefit analysis no effect of production or yield has been taken into account. Till now no significant improvement of production has been realised in research and in practice. When a production increase of at least 1% could be achieved the cultivation method would be profitable.

The Dutch government (Ministry of Economic Affairs, Agriculture an Innovation) stimulates sustainable greenhouse horticulture by subsidising growers who are willing to invest in sustainable production. The regulation Market introduction Energy Innovations gives an investment subsidy of 40% (www.agentschapnl.nl). In that case the new cultivation method will be profitable.

4.1.2.2 Double glazed Venlo greenhouse cover

In the previous paragraph the new cultivation method was analysed for a greenhouse with single glass. In this part the new cultivation method is analysed in combination with a double glazed greenhouse (see figure 4.6). In a simulation study the effects of different greenhouse covers on energy consumption, production and economics have been calculated (Poot et al., 2010). The new cultivation method under a double glazed Venlo greenhouse differs from the reference production system:

- Double glazed cover: three sides has a AR coating and one (inside) has a low energy coating;
- Controlled ventilation of moist greenhouse air by means of external air suction and a regain unit to regain 75% of the perceptible heat.

Figure 4.6. Double glazed greenhouse cover with AR coating (3 sides) and low energy coating (1 side)

The calculations result in the following energy effects in comparison with the reference system:

- 55% less gas consumption
- 155% more electricity consumption
- 10% more CO_2 enrichment.

Due to a negligible light transmission loss under double glazed greenhouse cover in comparison with Scenario b) Tomato crop in a Venlo greenhouse in the Netherlands a single glazed greenhouse cover no production effect has been taken into account.

The reduction of gas consumption results into an energy saving of 3.40 €/m^2in spite of the increase of consumption of electricity and CO_2. The investment of the double glazed AR coated greenhouse cover was unfortunately not available. Instead of the balance of extra benefits and extra costs the indicator investment capacity was calculated. The investment capacity is calculated as the balance of the extra costs and extra benefits divided by the percentage of the yearly costs of the investment (see table 4.5).

Table 4.5. Effect of double glazed greenhouse and new cultivation method on energy costs, production, balance of benefits and costs and investment capacity in comparison with reference tomato production system (€/m2)

Component	*Difference with reference system (€/m2)*
Energy costs [1)]	-3.40
Yield	-
Other costs	0.75
Balance of benefits and costs[2)]	2.65
Investment capacity[3)]	27

1) Energy costs: consumption of gas (-4.55 €/m2), electricity (0,75 €/m2) and CO_2(0.40 €/m2).
2) Excepting yearly costs of extra investment
3) Yearly costs of investment: 10% (depreciation: 7%, maintenance: 0,5% and average interest: 2,5%).

Table 4.5 shows that the extra investment in a double glazed greenhouse cover and a device for controlled ventilation of moist greenhouse air may amount at the most 27 €/m^2. The investment capacity is very much depending on the energy price. At a gas price of 0,25 €/m^3 the investment capacity will increase to 37 €/m^2; at 0,15 €/m^3 the investment capacity decreases to 15 €/m^2.

4.1.3 Scenario c, Rose crop in a Venlo greenhouse in the Netherlands

4.1.3.1 Greenhouse production system with diffuse glass and AR coating

At the research station of WUR Greenhouse Horticulture in Bleiswijk, The Netherlands, an experiment has been started in 2010 with diffuse and AR coated glass in a greenhouse with a rose crop. The diffuse and AR coated glass panes (from Europhoros partner GroGlass) were placed in the side walls and in the greenhouse cover (see figure 4.7). Diffuse glass improves the light distribution inside the greenhouse but decreases total light transmission. An AR (anti reflecting) coating can compensate this loss of light transmission. Due to the better light distribution higher production is to be expected.

Figure 4.7. Rose trial with diffuse and AR glass in cover (WUR Greenhouse Horticulture, Bleiswijk, The Netherlands)

In the experiment different diffuse and AR coated glass materials are studied. Furthermore the production of the glass panes for this experiment was more complicated than it would be for commercial purposes. For that reason a more realistic situation has been chosen for the economic evaluation. It is assumed that the diffuse, tempered and AR coated glass panes are produced in an on-going process.

In the reference situation tempered horticultural glass has the following light specifications:

- light transmission of tempered glass is 83%
- light transmission at crop level is 62%.

The diffuse, tempered and AR coated glass has the same specifications. Diffuse glass itself results in a lower total light transmission due to the haze factor, but the AR coating compensate this light loss completely. Overall the light transmission of the diffuse, tempered and AR coated glass is similar to that of the standard tempered horticultural glass (Deliverable_19_in_progress).

In consultation with an international trading organisation (Hogla, The Netherlands) a rough estimation has been made of the investments in diffuse and AR coated glass. Starting point for the assessment is a commercial greenhouse of ca. 4 ha. The investment in diffuse, tempered and AR coated glass is compared to other glass options (see table 4.6).

Table 4.6. Estimated investment in different glass type for greenhouse production (€/m2) 1)

Glass type	*Investment (€/m2)*
Horticultural glass, not tempered	3,5
Horticultural glass, tempered [2)]	6,5-7
Diffuse and tempered glass[3)]	11-12
Diffuse, tempered and AR coated glass [3)]	16-18

1) Source: Hogla. The Netherlands.
2) Glass type in reference production system.
3) Diffuse glass: type Vetrasol 503.

The installation of the diffuse and AR coated glass panes on the greenhouse structure seems not to be so much different from that of horticultural tempered glass. In that case no other extra costs are taken into account. According to the information of several manufacturers the life span and the maintenance costs of diffuse and AR coated glass types won't differ from that of the standard horticultural glass.

The extra yearly costs of diffuse and AR coated glass compared to the reference situation (horticultural glass, tempered) are mentioned in table 4.2.

Table 4.7. Investment and yearly costs of diffuse and AR coated glass and extra yearly costs in comparison to the reference glass type (€/m2)1)

					extra	extra
Glass type	Investment	Investment	yearly costs	yearly costs	yearly costs	yearly costs
	€/m2	€/m2	€/m2	€/m2	€/m2	€/m2
	min	max	min	max	min	max
Horticultural glass, tempered	6,50	7,00	0,65	0,70	-	-
Diffuse and tempered glass and AR coated	16,00	18,00	1,60	1,80	0,95	1,10

1) Yearly costs based on 7% depreciation, 0,5% maintenance and 2,5% average interest (total: 10%).

Table 4.7 shows that the application of diffuse and AR coated glass results in an increase of the costs with 0,95-1,10 €/m^2. This is an increase of the yearly costs of the greenhouse structure with 27,5-32%. The total costs of the greenhouse production system will increase with 0,8-1% (see Deliverable 5,(Montero et al., 2011)).

Another manufacturer and supplier of diffuse glass (Guardian; www.guardian.com) has also subsidised an experiment with diffuse glass at the Research Station in Bleiswijk. According to their latest information (September 2011) the extra investment in diffuse, tempered and coated glass is estimated at ca. 11 €/m^2.

From this point the extra investment in diffuse glass will be set at 11 €/m^2 and consequently the extra yearly costs will amount to 1.10 €/m^2.

In the experiment at Bleiswijk the effect of diffuse glass on production improvement has been studied (Deliverable_19_in_progress).

If the extra costs of diffuse and AR coated glass would be compensated by an extra yield, the production should increase with 1.3%. This is about 3.5 stem/m^2. In this calculation the following components have been taken into account: extra yield, extra costs of labour (picking and sorting) and extra cost of sales/packaging.

The experiment with diffuse glass at the Research Station in Bleiswijk was finished in September 2011. The first year production under diffuse glass was after one whole year more than 5% higher than the reference production system. Although the rose variety Red Noami was used in the experiment, the production effect will also be suitable for the rose variety Passion. If we made the assumption that the production increase of 5% can also be achieved in the full productive years (years 2-5) then the results will be as mentioned in table 4.3.

Table 4.8. Effect of diffuse and AR coated glass on costs and benefits in comparison to the reference glass type (€/m2)and payback period of extra investment (years)

Component	*Difference with reference system (€/m2)*
Extra yield	5.25
Extra sales costs	0.20
Extra crop labour	0.60
Extra yearly costs of equipment	1.10
Extra total costs	1.90
Balance of benefits and costs	3.35
Payback period (years)	4

Table 4.8 points out that an investment in diffuse and AR coated glass is very attractive. The payback period would be 4 years if the assumptions would be valid.

In this case the efficiency figures of fertilizers, water, energy and crop protection input will improve, because of the increased production. The inputs themselves will not change very much.

The higher production due to the improved light distribution under diffuse glass could make it possible to lower the light hours of artificial lighting. In that case the energy input would decrease.

4.1.3.2 Reduced volume of growing media (SPU) and new plant material

In the experiment with diffuse and AR coated glass (see 4.1) also a cultivation system is being tested with reduced volumeof the growing media rockwool. This cultivation system called SPU (Single Production Unit; Grodan) is being tested in combination with synchronized rose cuttings. For the sake of this study only the effect of reduced volumes of the growing media will be evaluated. Other components of the cultivation system, like number of drippers, are kept to be equal to the reference system.

In the reference system the substrate slab (100x12x7,5 cm) with rockwool (Grodan) is the standard. A variant is the slab 24 cm with the same substrate volume per plant. This means a substrate volume of 2,25 litre per plant or 18 litres per m^2(see table 4.9).

Table 4.9. Characteristics of growing medium in different rose cultivation systems1) 2)

	number/m2	length cm	width cm	height cm	litre/m2	pl/m2	litre/plant	reduction %
Standard								
Slab 12cm	2	100	12	7,5	18	8	2,25	-
Slab 24cm	1	100	24	7,5	18	8	2,25	-
Option								
SPU 24	4	24	20	7,5	14,4	8	1,8	20
SPU 20	4	21	20	7,5	12,6	8	1,575	30

1) Option SPU 24 is tested at WUR Greenhouse Horticulture in Bleiswijk. The option SPU 20 istested at a commercial greenhouse with roses.
2) Source: Grodan, The Netherlands.

The option SPU 24 – tested at Bleiswijk, The Netherlands - results in a substrate volume of 1,8 litre per plant or 14,4 litre/m^2 (see figure 4.8).This means a reduction of substrate volume of about 20%. The reduction of substrate volume can increase to about 30% with the SPU 20, which test started in 2010 at a commercial greenhouse with roses (see table 4.9).

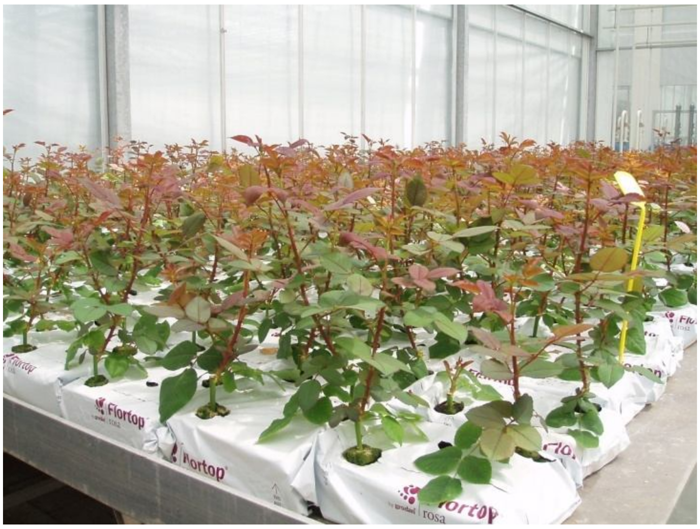

Figure 4.8. Rose trail with cultivation system SPU 24 and synchronized cuttings (WUR Greenhouse Horticulture, Bleiswijk, The Netherlands)

The reduction of substrate volume in the SPU option results in the following economic effects (see table 4.10).

Table 4.10. Investment, yearly costs and savings of growing medium in rose production systems (€/m2) 1) 2)

Variant	volume	price	investment	yearly costs	savings	reduction
	litre/m2	€/litre	€/m2	€/m2.yr	€/m2.yr	%
Slab 12/24 cm	18	0,13	2,38	0,60	-	-
SPU 24	14,4	0,14	2,00	0,50	0,10	16
SPU 20	12,6	0,14	1,75	0,44	0,16	27

1) Price of SPU is about 5% higher than the standard slab. Source: (Vermeulen, 2010).
2) Cultivation period of the rose crop is 4 years.

Table 4.10 shows that the reduction of substrate volume with SPU results in a saving of 0,10-0,16 €/m^2 depending on the SPU option. A sensitivity analysis of the substrate price points out that the savings (difference in yearly costs between the option and the standard cultivation system) are not very much affected, because of the four year cultivation period.

In the experiment in Bleiswijk the reduced volume of growing media (SPU) is combined with extended propagation of synchronized rose cuttings. Each SPU contains two synchronized rose cuttings which are placed in rock wool plugs. The plugs are sticked in the SPU block (see figure 4.8). Synchronized rose cuttings are treated in such a way that they will produce rose buds at the same time during the first year of the crop cycle. The synchronized cuttings are developed by WUR greenhouse Horticulture and are not available by commercial rose propagators.

The big advantage of synchronized cuttings is that they will produce rose stems earlier after transplanting than the traditional rose cutting because they have an extended propagation period. From an experiment of Grodan (personal information of E. Hempenius, 2011) it pointed out that in the first year an extra production of ca. 27% can be achieved. In the other productive years (2-4) no extra production is to be expected. This means that the average production over 4 years will increase by 4.9%.

The synchronized rose cutting with an extended propagation period has a higher price than the traditional plant material, but a lower royalty. The total price (or investment) of plant material is estimated at 26.3 €/m^2 in comparison to the traditional one (14 €/m^2). The extra price or investment of synchronized cutting plant material is 12.3 €/m^2 or an extra average year price of 3.05 €/m^2 (Vermeulen and García, 2008).

Due to the increased production in the first year of the crop cycle the costs of labour and the sales costs will also increase. The economic effects of SPU with synchronized cuttings are mentioned in table 4.11.

Table 4.11. Effect of reduced volume of growing media (SPU) and new plant material on costs and benefits in comparison to the reference production system (€/m2)

Component	*Difference with reference system (€/m2)*
Yield	5.15
Sales costs	0.15
Crop labour	0.60
Costs of plant material[1)]	3.05
Costs of growing media	-0.10
Total costs	3.75
Balance of benefits and costs	1.40

1) Synchronized cutting in rock wool plug on a SPU rock wool block.

Table 4.11 points out that a reduced volume of growing media in combination with new plant material can result in a positive balance of benefits and costs (1.40 €/m^2). This option is attractive both from economic as well from environmental point of view.

4.2 Discussion

The economic effect of alternatives for improvement was analysed in three scenarios. The results showed that in some cases reduction of inputs can be also interesting from an economic point of view. In this section some topics are discussed with respect to the results.

Cost-benefit analysis: The (partial) cost-benefit analysis proved to be a simple but useful method to analyse the economic effects of the different input reducing options. In some cases the difference in net financial result of the option in comparison with the reference production system could be calculated based upon experimental data. In other cases a simulation was conducted to assess the benefits and/or costs. Besides other economic indicators were calculated, like payback period and investment capacity.

Especially the investment capacity seems to be very useful. This indicator calculates the investment amount which growers should maximum pay, based upon the extra benefits and extra costs, without the yearly costs of investment. A lower investment amount will make the option attractive, while higher investments will result in negative financial results. This indicator has sometimes been used within the project to (pre)select input reducing options for testing on one of the test sites (Almeria/Spain, Bleiswijk/Netherlands and Pisa/Italy).

Experimental data: In the experiments at the test sites the alternatives for improvement were compared with a reference treatment. In many cases the reference situation in the tests was different from the reference production system described in deliverable 5 (Montero et al, 2011). In those cases the experimental data had to be processed to make them comparable to the reference production. In cooperation with the partners in this project the technical and economic data has been assessed. The processed data were checked with other literature if possible or available.

The conclusions will be discussed per scenario and specific alternative for improvement.

4.2.1 Scenario a, Tomato crop in multi-tunnel greenhouse in Spain

New type of multi-tunnel and improved ventilation

- This option appears to be profitable and can be recommended for Mediterranean growers. Although the extra investment amounts to 9.5 €/m^2 the balance of extra benefits and extra costs result in 1.6 €/m^2.
- The calculated payback period is 5 years.

Closed irrigation system

- The extra investment in a closed fertirrigation system amounts to 7500 €/ha and will increase to 8300 €/ha if a quick test for periodical nutrient solution analysis is supplemented.
- The balance of extra benefits and extra costs will increase with 2135 respectively 2300 €/ha, because of the high fertilizer and water savings. . In that case the investment seems to be profitable.

- The balance of benefits and costs will become negative (-1760 €/ha) when a disinfestation - UV filtration technique is being applied to prevent spreading of diseases.. In that case the investment will increase to 23.300 €/ha.

Reduced volume and increased lifespan of growing media

- A reduction of substrate volume or increased life span will improve the net financial results only slightly. The economic impact is limited because of the three year life span.

4.2.2 Scenario b, Tomato crop in Venlo greenhouse in the Netherlands

Energy saving method

- This energy saving option appear to be not so attractive (-0,55 €/m2), although the energy demand will decrease with 35%. The explanation for this result is the strong reduction of electricity sales to the public grid. The combined heat power installation produce much less electricity as in the reference situation. Higher energy prices are favourable for the attractiveness of the energy saving method.

Double glazed and anti-reflecting greenhouse cover

- When the energy saving method is combined with a double glazed cover, ant-reflecting coating and low energy coating the gas consumption will decrease with 55%. Despite the higher electricity and CO_2 consumption the balance of extra benefits and extra costs will result in an investment capacity of 27 €/m2. The investment is however sensitive to gas price fluctuations.

4.2.3 Scenario c, Rose crop in Venlo greenhouse in the Netherlands

Diffuse glass and anti-reflecting coating

- Under diffuse glass+AR the production will increase with 5% over the four year crop cycle. Taken into account an extra investment of 11 €/m2, extra costs of labour, etc. the economic results are very positive (3,75 €/m2). The payback period of the extra investment is 4 years. This new glass cover will have good prospects for rose production.

Reduced volume of growing media and new plant material

- A combination of reduced growing media and extended propagation of synchronized rose cuttings will increase the first year production by 27%. The plant material is more expensive because of the special treatment by which the production will come in flushes. All together it results in a clearly positive balance of extra benefits and costs.

5 CONCLUDING REMARKS

From the environmental and economic analysis of alternatives for improvement it could be concluded:

- Major reductions of environmental impacts where found in alternatives that reduced energy dependent processes. Some of these suggested alternatives have to be tested and demonstrated to prove their feasibility and acceptance by the growers.
- New type of greenhouse and energy saving cultivation method techniques, in scenarios a) and b) respectively, were found to be very efficient solutions and requiring few extra inputs. Particularly for greenhouse production in unheated greenhouses, new greenhouse structures with improved ventilation and light transmission make a better use of natural resources and produce more with little extra input.
- While single actions such the reduction of the use of nutrients are possible and produce by themselves a positive impact reduction, a combination of several alternatives is in many cases possible and should be implemented to obtain better results
- Alternatives with lower energy use reductions than others but only require simple changes of the greenhouse system should be encouraged to be implemented by growers, since they can give environmental benefits in existing greenhouses.
- Very important to disseminate results among growers to implement best profit of results. This is last task of the project and feedback from producers will be very useful in future progress towards more environmental friendly production systems
- Toxicology, water use and land use impact categories were not exploded in this study as there is no general consensus about the best methodology to be used for their evaluation. Further research should move towards the improvement of these methodologies with high interest from and agronomic point of view.
- The environmental and economic assessments of input reducing options show that for each scenario there are one or more possibilities to improve the sustainability of the greenhouse production system. For each scenario the best options will depended on the local conditions.

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