

Towards a low emission greenhouse horticulture

M.N.A. Ruijs
Wageningen UR
Agricultural Economics Research Institute
The Hague
The Netherlands

J.B. Campen and M.G.M. Raaphorst
Wageningen UR
Greenhouse Horticulture
Wageningen
The Netherlands

Keywords: sustainability, Dutch greenhouse horticulture, tomato crop, environmental topics, business concepts, energy and CO₂

Abstract

For the pilot crop tomato, business concepts of low emission greenhouses for the midterm (10 year) have been designed. The study is carried out in cooperation with innovators in the horticultural sector, suppliers and extension services. The business concepts are evaluated for different indicators in the field of planet and compared to the current situation. The focus is on the reduction of energy consumption and CO₂ emission for the cultivation with and without supplementary lighting. The energy concepts differ in the way the heat and power are produced or supplied on business level. The results show that the energy concepts without supplementary lighting have a lower environmental impact and have a better energy efficiency than the energy concepts with lighting. The energy concepts without supplementary lighting show that simultaneous production of heat and power on business level and the delivery of electricity to the public grid is most favorable looking at the energy use and CO₂ emission on national level. Second best is the conditioned greenhouse. In this energy concept solar energy is collected in summertime, stored and re-used in wintertime. Conditioned greenhouses have also good perspectives in reducing the use and emission of pesticides.

INTRODUCTION

In 2004, the Dutch Ministry of Agriculture, Nature and Food Safety has started the long-term research program 'Transition, Innovation and Knowledge Networks for Protected and Integrated Cultivation'. With different stakeholders from the greenhouse horticulture chain target visions were made for the long-term (25-30 years). The main question was how to realize that futuristic view. Against this background two transition pathways can be distinguished: from future to practice and from practice to future. In the transition pathway 'future to practice' the target visions has been translated into inspiration and transition points by means of back-casting (Aarts, 1998; Grin and Van de Graaf, 1996). These transition points are an obstacle in realizing the future visions. These transition points forms the starting point in designing and developing sustainable production systems for the mid-term (10-15 years). The pathway 'from practice to future' is working in the opposite way: from current practice towards an envisaged future. Pioneers are used as inspiring examples and pull in the transition process. Both pathways are visualized in figure 1 (Wijnands and Vogelesang, 2008).

In the present study the objective is to design and develop business concepts for greenhouse horticultural farms for the mid-term (10-15 years) with a low degree of

environmental pollution. For the pilot crop tomato business concepts have been designed and evaluated on different indicators on the field of planet. The focus in this paper is on energy and CO₂ emission.

MATERIALS AND METHODS

In cooperation between researchers of Wageningen University and Research Centre and representatives of the greenhouse horticulture industry the following approach for designing new business concepts has been used: 1) phasing of the cultivation process, 2) conditioning of the cultivation and 3) compartmenting of the production area. The phasing of the cultivation process forms the basis for analyzing the environmental problems per phase and for finding adequate solutions. The phasing of the cultivation process is the step in conditioning the cultivation circumstances: creating circumstances that are optimal for the production process and other business processes and in order to establish conditions that limit undesired emissions. The third step (compartmenting) makes it possible to optimize the conditions per cultivation phase.

The pilot crop tomato is chosen because of its dimensions in terms of CO₂ emission, use of pesticides and the increasing use of artificial lighting. As starting point for the design process three types of reference situations are defined due to the current variety of farm systems (farm size 7 ha):

1. a modern truss tomato farm (no artificial lighting);
2. a modern truss tomato farm with 25% surface area of conditioned and 75% of traditional cultivation (no lighting);
3. a modern truss tomato farm with artificial lighting (13,500 lux).

For each reference farm system one or more alternative energy concepts are defined, based upon early innovations in research and in practice. The energy consumption and the CO₂ supply of a greenhouse depend on the greenhouse climate, the outside climate, the crop and the set-up of the greenhouse, including the energy supply system. For this study the validated dynamic simulation model KASPRO is used (Zwart, 1996; Campen, 2008). The used specific conditions for the greenhouse climate are common for Dutch growers. The results are expressed in the following indicators: energy consumption (on local level: m³ gas/m² and kWh/m²; on national level: MJ/m²) and CO₂ supply/consumption (on local and on national level: kg/m²). The simulation model also makes it possible to calculate the dry matter production, expressed as photosynthetic production. Relative changes in photosynthetic production between the energy concepts are used to determine the physical production (kg/m²).

In table 1 a summary is given of the main indicators concerning the reference farm systems (base year 2006). The figures show that the conditioned greenhouse (farm system 2) has a lower consumption of natural gas as a consequence of collecting and storing solar energy. Nevertheless farm system 1 has the lowest (primary) energy consumption, as a result of the delivery of electricity to the public grid (during peak times). Farm system 3 (artificial lighting) clearly has a higher energy consumption. Although the production on farm system 3 is more than 15% higher than the other farm systems, it has the lowest energy-efficiency (higher energy consumption per unit of production). The CO₂ emission on local level (farm level) is the lowest for farm system 2 due to use of sustainable (solar) energy. When looking at the CO₂ emission on national level, farm system no. 1 has the lowest level of emission. The delivery of electricity to the public grid reduces the CO₂ production by

the power station. The pesticide use on farm system 3 is substantially higher, as a result of the higher level of pests under artificial lighting. In the conditioned farm system (no. 2) a lower pesticide use is reached by the better humidity control in the conditioned greenhouse compartment. The use of nutrients is related to the production level.

RESULTS AND DISCUSSION

The following alternative energy concepts have been evaluated:

1. truss tomato farm (no artificial lighting):
 - 1a) heat-power engine without minimum pipe temperature and no heat devastation;
2. truss tomato farm with 25% conditioned/75% traditional cultivation (no lighting):
 - 2a) heat-power engine and heat pump without minimum pipe temperature and 50% of conditioned cultivation area;
 - 2b) heat pump (electricity from the grid), without minimum pipe temperature and 100% of conditioned cultivation area;
3. truss tomato farm with artificial lighting (13,500 lux):
 - 3a) lighting with electricity from the grid and heating with the boiler;
 - 3b) lighting with gas-burned heat-power engine without delivery of electricity to the grid;
 - 3c) lighting and heating with electricity from the grid;
 - 3d) lighting and heating with electricity from a gas-burned heat-power engine.

Table 2 shows that the greenhouse farm without lighting and delivery of electricity to the public grid (1a) has the lowest input of total energy use (MJ primary/m²). The alternative systems with heating and/or lighting without fossil energy (gas) are not automatically an improvement from sustainable point of view (see 2b and 3c). For the case where electricity is supplied by a power plant in stead of producing it on the farm, the overall (primary) energy use is higher. When green electricity (from wind and solar) is used no fossil energy is needed. The use of artificial lighting requires a lot of energy (see 3a, ., 3d). Nevertheless farm system 3d results in a substantial reduction of the energy use and CO₂ emission in comparison to the reference system. The conditioned greenhouse farms (2a and 2b) have a low use of both fossil energy as well as primary energy use.

The production is stimulated by lighting and under conditioned cultivation (higher CO₂ levels during summertime). When the production is related to the (primary) energy use then farm system 1a has the best score, followed by system 2a and 2b (Table 2).

The best score on CO₂ emission at national level is reached at farm system 1a (Table 3). This is mainly due to the avoided CO₂ emission at the power station related to the delivery of electricity to the public grid. However the amount of supply of electricity to the grid is depending mainly on the energy prices and they can fluctuate frequently as recent years have showed. At farm level the CO₂ emission is substantially higher than system 2a, 2b, 3a, en 3c. Farm system 2a and 2b have both a low CO₂ emission at farm level as well as at national level. Table 3 shows that farm system 2b and 3c have to buy CO₂ in order to reach specific CO₂ levels in the greenhouse (see 2^o column). In almost all alternative farm systems the CO₂ emission is reduced. Only at farm system 3c and 3a the CO₂ emission increases in comparison the reference system, especially for system 3c (15%).

With respect to the use of pesticides only at farm system 2a and 2b a reduction is to be expected (12% and 24% respectively). This is mainly caused by the better pest management and humidity control in the conditioned greenhouse compartment.

In this study new business concepts of a tomato farm are evaluated from a sustainability point of view. At this moment the emphasis is on the planet aspects. Also attention is being paid to people and profit.

The delivery of electricity to the public grid has a positive effect on the energy use and CO₂ emission at national level. Also from economic point of view this development is positive, because it generates extra income and at this moment weakens the negative effects of higher gas prices.

The use of simulation models and expert judgments (in workshop) has resulted in an indication of the potential emission reduction on the different environmental topics. This indication will be directive for further research and development of energy and business concepts.

CONCLUSIONS

Farm system 1a has the lowest energy use and CO₂ emission looked at national level due to the fact that the electricity generated with a heat-power engine is supplied to the public grid. At local or farm level the energy use and CO₂ emission is the highest of the business concepts without artificial lighting.

Farm systems 2a and 2b have both on local level as well as on national level a low energy use and CO₂ emission, which is caused by the collection and storing of solar energy in an aquifer.

Farm systems with artificial lighting (3a, ..., 3d) have the highest energy use and CO₂ emission. Although the production increases by more than 3% (excepted at 3b) the energy-efficiency is substantially worse than the other farm systems.

From sustainable (planet) point of view the business concepts without artificial lighting score better than those with lighting. Farm systems 2a and 2b (conditioned greenhouses) have good perspectives looking at the different environmental objectives.

With respect to energy use and CO₂ emission new farm systems and energy concepts have great attention, mainly caused by the increased energy prices. At this moment a commercial farm with the farm system 2a is willing to invest in the further development of that energy concept. The research project will in that case support the grower by implementing and monitoring the system.

References

Aarts, W. 1998. Een handreiking voor Duurzame Technologische Ontwikkeling. 1e druk, SWOKA, Den Haag

Anonymus. 2007. LEI Farm Accountancy Data Network (LEI-FADN). LEI-WUR [AERI-WUR], Den Haag.

Campen J.B, Bot G.P.A. and Zwart H.F. de. 2008. Dehumidification of Greenhouses at Northern Latitudes. Biosystems Engineering, 86, 487-493.

- Grin, J. and Graaf, H. van de. 1996. Technology Assessment as learning. Science, technology and human values. vol. 20, no. 1, p. 72-99.
- Raaphorst, M, Nijs, L, Voogt, W. and Haaring, M. 2003. Quick Scan emissies. Intern rapport 41404517, Praktijkonderzoek Plant en Omgeving, Naaldwijk.
- Ruijs, M.N.A. 2006. Terugblik op innovaties op tomatenbedrijven; periode 1995-2005. Publicatie Onderzoeksprogramma Systeminnovatie beschermde teelten. LEI-WUR, Wageningen.
- Woerden, S.C. van. 2005. Kwantitatieve Informatie voor de glastuinbouw 2005-2006 [Quantitative information for greenhouse horticultural crops 2005-2006]. Publicatie Praktijkonderzoek Plant en Omgeving [Applied Plant Research Station], Naaldwijk.
- Wijnands, F.G. and Vogelesang, J.V.M. 2008 (in press). Two complementary transition pathways; Supporting strategies for innovation towards sustainable development in Dutch agriculture. PSG-WUR, Wageningen.
- Zwart, H.F. de. 1996. Analyzing energy-saving options in greenhouse cultivation using a simulation model. Phd-thesis, WUR, Wageningen.

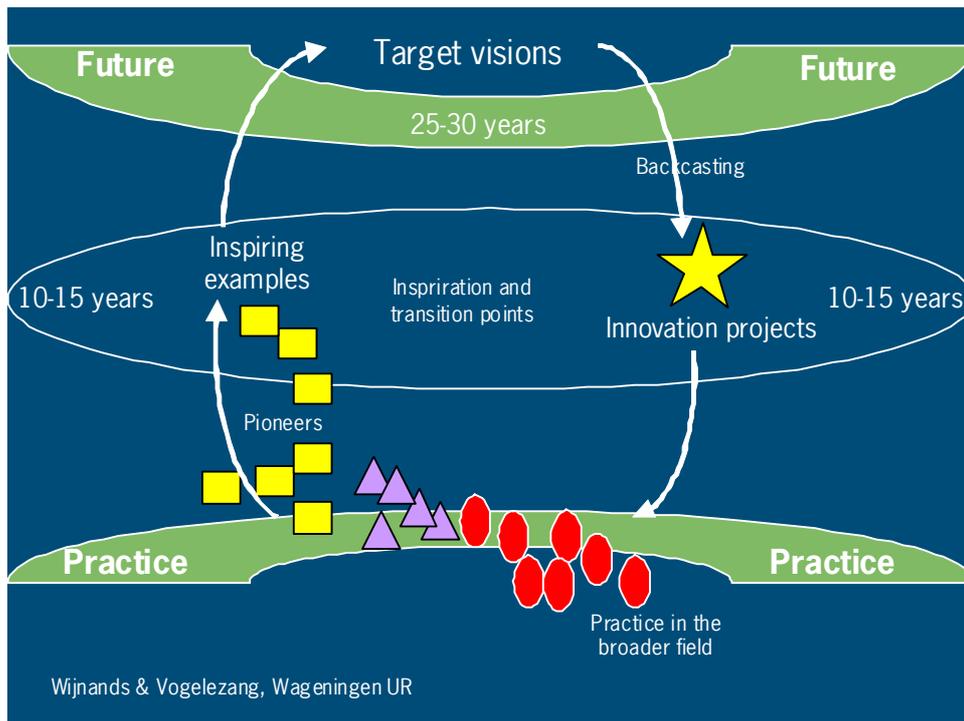


Figure 1: Illustration of the transition process to a sustainable agriculture.

Table 1: Main indicators about the reference farm systems for a truss tomato crop¹ with respect to environmental topics (base year 2006)

| <i>Reference farm system</i> | <i>Modern truss tomato farm (no lighting)</i> | <i>Modern truss tomato farm: 25% conditioned and 75% traditional cultivation (no lighting)</i> | <i>Modern truss tomato farm with lighting (13,500 lux)</i> |
|--|---|--|---|
| <i>Indicators</i> | <i>no. 1</i> | <i>no. 2</i> | <i>no. 3</i> |
| Energy supply system | Heat-power engine, boiler, heat storage and energy screen | Heat-power engine, heat pump, aquifer, boiler, heat storage and energy screen | Heat-power engine, boiler, heat storage, energy screen and lighting |
| Gas consumption (m ³ /m ²) | 77.8 | 30.0 | 107.3 |
| Electricity consumption (kWh/m ²) | 7 | 7 | 7 |
| Electricity delivery to public grid (kWh/m ²) | 242 | 7 | 193 |
| Energy consumption, incl. delivery to public grid (MJ primary/m ²) | 382 | 949 | 2703 |
| Production (kg/m ²) | 63.0 | 66.1 | 76.5 |
| Energy consumption per unit production (MJ primary/kg) | 6.1 | 14.4 | 35.3 |
| CO ₂ emission on local level (kg/m ²) | 138.5 | 53.4 | 191 |
| CO ₂ emission on national level (kg primary/m ²) | 21.4 | 53.4 | 151.9 |
| Pesticide use (kg active ingredient/ha) | 12.5 | 12.0 | 17.0 |
| Nutrient use N (kg pure nutrient/ha) | 1493 | 1566 | 1812 |
| P (kg pure nutrient/ha) | 437 | 459 | 531 |

¹ Modern truss tomato greenhouse farm of 7 ha

Sources: LEI-FADN, Quantitative Information for Greenhouse Horticulture Crops (Van Woerden, 2005), Greenhouse horticulture farm Themato and expert judgement of Wageningen UR Greenhouse Horticulture

Table 2: Energy balances and production of reference farm and alternative energy concepts for a truss tomato farm¹

| <i>Indicator</i> | <i>Gas use</i> | <i>Electricity use</i> | <i>Total energy use MJ primary/m²</i> | <i>Production</i> | <i>Energy-efficiency MJ primary/kg</i> |
|-----------------------|------------------------------------|---------------------------------------|--|-------------------|--|
| <i>System variant</i> | <i>m³/m²</i> | <i>kWh/m² ²</i> | | <i>kg/ha</i> | |
| 1 (ref) | 77.8 | -235 | 382 | 63.0 | 6.1 |
| 1a | 67.0 | -230 | 146 | 59.3 | 2.5 |
| 2 (ref) | 30.0 | 0 | 949 | 66.1 | 14.4 |
| 2a | 14.9 | 0 | 470 | 64.5 | 7.3 |
| 2b | 0 | 75 | 647 | 66.0 | 9.8 |
| 3 (ref) | 107.3 | -186 | 2703 | 76.5 | 35.3 |
| 3a | 33.1 | 195 | 2721 | 71.3 | 38.2 |
| 3b | 82.5 | 0 | 2611 | 76.5 | 34.1 |
| 3c | 0 | 362 | 3104 | 81.8 | 37.9 |
| 3d | 76.1 | -46 | 2008 | 73.5 | 27.3 |

¹ Modern truss tomato greenhouse farm of 7 ha

² Negative figure indicates that electricity is delivered to the grid

Table 3: CO₂ balances of reference farm and alternative energy concepts for a truss tomato farm¹ (kg/m²)

| <i>Indicator</i> | <i>CO₂ emission at local (farm) level</i> | <i>CO₂ purchase ¹</i> | <i>(Avoided) CO₂ emission by power station²</i> | <i>CO₂ emission (incl. avoided) at national level</i> |
|------------------|--|---|---|--|
| 1 (ref) | 138.5 | 0 | -117.1 | 21.4 |
| 1a | 119.3 | 0 | -111.2 | 8.1 |
| 2 (ref) | 53.4 | 0 | 0 | 53.4 |
| 2a | 26.3 | 26.1 | 0 | 26.3 |
| 2b | 0 | 28.4 | 36.4 | 36.4 |
| 3 (ref) | 191.0 | 0 | -39.1 | 151.9 |
| 3a | 58.9 | 0 | 94.1 | 153.0 |
| 3b | 146.9 | 0 | 0 | 146.9 |
| 3c | 0 | 28.4 | 174.6 | 174.6 |
| 3d | 135.5 | 0 | -22.2 | 113.3 |

¹ CO₂ emission of purchase is not taken into account, because this is attributed to the supplying branch.

² Negative figure indicates that emission is avoided.