REDUCING ENVIRONMENTAL IMPACT OF ENERGY USE IN TOMATO CULTIVATION IN THE NETHERLANDS: RESEARCH BY SYSTEMS ANALYSIS

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Abstract

Production in Dutch greenhouse cultivation requires use of energy, chemical biocides, fertilizers and water, and leads to the production of waste and artificial light sources in the environment. Systems analysis can be used to analyze the possibilities and consequences of sustainable development of Dutch greenhouse horticulture. This paper presents as a first step of such a study an analysis of energy use and CO_2 emission in Dutch tomato cultivation. This analysis aims at evaluating the cost-effectiveness of energy saving options. A model is developed which calculates gas use, CO_2 emission reduction and costs of energy saving options in tomato cultivation. Without application of energy saving options gas use is assumed to be 69 m^3/m^2. Model results indicate that the combi-condenser and the heat buffer are most cost-effective energy saving options and that gas use could be reduced to 47-49 m^3/m^2 at zero net costs. The associated CO_2 emission reduction relative to 1989/90 is 20-23%.

1. Introduction

In Dutch greenhouses vegetables, cut flowers and pot plants represent the most important crops. The total greenhouse area is about 10,000 ha and consists of circa 12,000 nurseries. The majority of the greenhouses is heated (92% of the area), mostly by using natural gas.

Dutch horticulture under glass aims at high production levels and excellent product quality. It is therefore based on high inputs of energy, chemical biocides and fertilizers (Poppe, *et al.*, 1995). Human activities such as energy use may have impact (e.g. global warming) on the environment as a result of environmental pressure (e.g. emissions of CO_2). Activities in Dutch greenhouse horticulture leading to environmental pressure are listed in Table 1.

Table 1: Activities in Dutch greenhouse horticulture and their impact on the environment.

activity	environmental pressure	environmental impact
- use of energy	- emission of CO_2, C_xH_y, SO_2, NOx	- climate change, acidification, smog depletion of fossil fuels
- use of chemical biocides	- emission of toxic and persistent substances	- dispersion of toxic elements: human toxicity and eco-toxicity
- use of fertilizers and water	- emission of nutrients	- eutrophication, desiccation
- production of waste	- disposal of waste	- soil, water and air pollution, depletion of resources
- supplementary lighting	- radiation of light	- nuisance

Environmental safe production is one of the challenges for greenhouse horticulture in the Netherlands. Several studies on environmental impact of Dutch greenhouse horticulture have been carried out focusing on for instance economic aspects (Velden, *et al.*, 1996) technical aspects of use of energy (de Zwart, 1996), biocides (Baas, *et al.*, 1996) and fertilizers (Sonneveld, 1996). Most of these are mono-disciplinary studies. The greenhouse sector, however, copes with a complex problem concerning both environmental and economic aspects. Therefore the method of systems analysis is used to quantify the possibilities for and consequences of sustainable development of horticultural production in greenhouses.

Systems analysis is a multi-disciplinary method to evaluate complex problems and involves several steps (Wilson, 1984; Checkland, 1979). The first steps include the problem definition and description of the objectives. Next, a model is developed and used for analyzing the system. Finally, scenario and optimization analysis are performed to gain insight into interactions within the defined system. Results of such a study may assist decision makers to find solutions to the problems Dutch greenhouse horticulture faces. Simultaneously, the study may lead to a deepening of the method of environmental systems analysis.

A preliminary systems analysis was restricted to energy use and CO_2 emissions in the Dutch tomato cultivation. The aim of the analysis was to improve insight in gas use, CO_2 emission and costs of technical energy saving options in Dutch tomato cultivation. This paper summarizes the analysis by presenting a description of the model and some preliminary results. A more detailed description can be found in Pluimers (1997).

2. Model description

A model has been developed calculating gas use, reduction of CO_2 emission and costs of energy saving options in Dutch tomato cultivation. The measures reducing energy use and CO_2 emission are divided into four groups; condensers (index j), screens (index k), CO_2 enrichment (index l), and wall insulation (index m). The options in each group are mutually exclusive which means that they are not applicable at the same time (e.g. a movable energy screen and a fixed energy screen). Combinations of options can be made by choosing an option from each group. From each group only one option can be selected, this may also be the 'no-option' (no condenser, no screen, no CO_2 enrichment options and no wall insulation). This leads to 144 different combinations of options.

Gas use (GU) is a function of GU_{ref} (gas use of 1995 for the situation without energy saving options) and a combination of energy saving options j, k, l and m (Table 2, Equation 1). The energy conservation factors ($f_{j..m}$) are based on Uffelen and Vermeulen (1994). If 'no-option' is applied f is zero. Reduction of CO_2 emission relative to the situation in 1989/90 (ER_{CO_2}) is equal to the reduction in gas use, because CO_2 emission is proportional to gas use (1.8 kg CO_2/ m^3 gas use; Amstel, *et al.*, 1994) (Table 2, Equation 2). The annualized costs (C) for options or combinations of options are calculated following the method of Blok and de Jager (1995) and consist of investment costs, fixed operation costs and variable costs (Table 2, Equation 3). The investment costs (Ian_i) are annualized by using an interest rate (q) and the economic lifetime of the option (t_i) which are based on Uffelen and Vermeulen (1994) (Table2, Equation 4). Fixed operation costs (FO_i) may comprise maintenance, insurance and administrative costs and are based on Uffelen and Vermeulen (1994) (Table 2, Equation 5). Variable costs (VO) depend on the yield reduction and reduction in natural gas consumption due to the option and the price of tomatoes and gas (Table 2, Equation 6 and 7). The yield reduction factors are also from Uffelen and Vermeulen (1994).

The model includes a reference hectare which represents Dutch tomato cultivation. Data of the year-round cultivation of 'round tomato' on substrate are used for the description of this hectare. The round tomato is the most commonly cultivated type of tomato in the

Netherlands and as a first approach it was assumed that this could represent Dutch tomato cultivation under glass. For the reference hectare 1995 data for gas use (GU_{ref}) and tomato production (Y_{ref}) for a situation where no measures to reduce gas use are applied (Table 3).

In addition, each single option can be analyzed by calculating its cost-effectiveness (CE_i) as the costs per % gas use reduction.

The analysis is performed for the reference case as described above. A sensitivity analysis is carried out by varying four important model parameters: gas price, interest rate, production and the availability of a subsidy (i.e. cases *a* to *g* in Table 4). In the analysis the gas use and CO_2 emission reduction and the costs after applying combinations of options are calculated for the reference case as well as for the alternative cases for the sensitivity analysis.

3. Preliminary results

In this section results of the analysis are presented. These include the cost-effectiveness of single options for the reference case (Table 3) and for cases of the sensitivity analysis (Table 4), the gas use after application of energy saving options and costs of energy saving options, and the gas use and CO_2 emission reduction for the reference case and other cases.

Results of model calculations show that in the reference case the most cost-effective single options to reduce gas use and CO_2 emission are the combi-condenser and the heat buffer (volume 80 m^3) (Table 3). For all types of condensers and heat buffers the calculated net additional costs are negative (this means that benefits exceed costs). Other options have positive net costs.

In all alternative cases (*a* to *g*, Table 3) the heat buffer and combi-condenser remain the most cost-effective options. There are two options for which in some cases the net costs are negative, while their costs in the reference case were positive. The use of a fixed screen is profitable when gas price doubles (to Dfl 0.45/m^3 gas) or a subsidy will be available (Dfl 1000/% gas use reduction). Secondly, the option of pure CO_2 becomes profitable when a subsidy will be available.

The calculated gas use (GU) ranges from $69*10^4$ m^3/ha (reference case) to $43*10^4$ m^3/ha and the costs of gas use reducing options vary between -15,000 and +40,000 Dfl/ha (Figure 1). Combinations 1 to 7 constitute the left border of the cloud of 144 points (Figure 1) and reflect the most cost-effective combination of options at that level of gas use. All seven combinations include a combi-condenser and a 80 m^3 heat buffer. Combinations 6 and 7 have negative net costs (C<0). The graph also indicates that difference in gas use between combination 1 to 5 is relative small compared to the costs involved.

For better readability the points 1 to 7 in Figure 1 are connected by a line. However, the seven points reflect independent combinations of options and only in some cases the difference between two adjacent points implies an application of one new option. Decreasing the gas use from point 7 to point 6 involves application of a fixed screen. Decreasing gas use from point 6 to 5 involves the application of a wall insulation screen. However, moving from point 5 to 4 the wall insulation screen changes into double glass in the wall and moving from point 4 to 3 the fixed screen is changed into a movable screen and double glass for wall insulation is changed into no wall insulation.

The minimum gas use (GU) where net costs are zero can be read for the reference case from Figure 1 where the graph crosses the x-axis. For all cases the minimum gas use at zero net costs is listed in Table 4. The maximum reduction of CO_2 emission is calculated using the minimum gas use relative to 1989/90 (i.e. the year to which policy targets relate). Cases *a* to *g* reveal that minimum gas use and maximum reduction of CO_2 emission where net costs are zero are relatively insensitive to the variation in the values of considered parameters. Table 4 illustrates that an increase in gas price will positively influence the cost-effectiveness of the technical options. If the gas price doubles (case b), all 7 combinations of options will become remunerative. The CO_2 emission reduction related to 1989/1990 can reach over 20% with the use of options with net zero costs.

Table 2: Model equations

$$GU = GU_{ref} * (1 - f_j) * (1 - f_k) * (1 - f_l) * (1 - f_m) \tag{1}$$

$$ER_{CO2} = (1 - (GU / (GU_{1989/90}))) * 100\% \tag{2}$$

$$C = \sum_{i=j}^{m} (Iani + FOi) + VO \tag{3}$$

where

$$Ian_i = \frac{I_i * q}{1-(1+q)^{-ti}} \tag{4}$$

$$FO_i = I_i * p_i \tag{5}$$

$$VO = (Y_{ref} - Y) * TP - (GU_{ref} - GU) * GP \tag{6}$$

$$Y = Y_{ref} * (1 - r_j) * (1 - r_k) * (1 - r_l) * (1 - r_m) \tag{7}$$

GU = gas use (m^3/ha)
GU_{ref} = gas use for reference hectare in 1995 = $69.1*10^4$ m^3/ha (Uffelen and Vermeulen, 1994)
$GU_{1989/90}$ = gas use for reference hectare in 1989/90 = $61.4*10^4$ m^3/ha (Uffelen and Vermeulen, 1994)
$f_{j..m}$ = energy conservation factor for option j, k, l and m (fraction of GU_{ref})
ER_{CO2} = CO_2 emission reduction % related to 1989/90.
C = total costs of the abatement measures (Dfl/ha)
Ian_i = annual investment costs of measure i (Dfl/ha)
FO_i = fixed operation costs of measure i (Dfl/ha)
VO = variable costs of the abatement measures applied (Dfl/ha)
I_i = investment costs of measure i(Dfl/ha)
q = 0.08, reflecting an 8% interest rate (Uffelen and Vermeulen, 1994)
t_i = lifetime of measure i (years)
p_i = fixed percentage of investment for maintenance of measure i (perunage)
Y = yield (kg/ha)
Y_{ref} = yield in reference hectare = $49*10^4$ kg/ha (IKC, 1994)
$r_{j..m}$ = yield reduction for option type j, k, l and m (fraction of Y_{ref})
TP = tomato price = 1.31 Dfl per kg (IKC, 1994)
GP = price of natural gas = 0.23 Dfl per m^3 (IKC, 1994)
i = measure j, k, l and m
j = type of condenser (no-, single (return net)-, single (seperate net)- and combi-condenser)
k = type of screen (no screen, fixed screen and moveable screen)
l = type of CO_2 enrichment (no CO_2 dosage, 80 m^3 heat buffer and 100 m^3 heat buffer)
m = type of wall insulation (no wall insulation, wall insulation screen, double glass in wall)

Table 3: Cost-effectiveness (costs (Dfl/ha) per % gas use reduction) of single options reducing gas use in Dutch tomato cultivation: calculated for cases *ref* and *a* to *g*.

		ref*	a#	b#	c#	d#	e#	f#	g#
Condensers	- single (return net)	-586	-931	-2106	-656	-512	-586	-586	-756
(type j)	- single (seperate net)	-463	-808	-1982	-542	-380	-463	-463	-637
	- combi	-677	-1022	-2197	-741	-610	-677	-677	-850
Screen	- fixed	408	63	-1111	373	444	409	408	-671
(type k)	- moveable	1868	1523	349	1743	1999	1765	1986	1677
CO_2 enrichment	- pure CO_2	2318	1972	798	543	2390	583	583	-497
(type l)	- heat buffer (80 m^3)	-690	-1036	-2210	-777	-598	-690	-690	-811
	- heat buffer (100 m^3)	-497	-842	-2018	-603	-385	-497	-497	-618
Wall insulation	- wall insulation screen	20603	20258	19084	19827	21396	20193	21066	20353
(type m)	- double glass in wall	4563	4218	3043	4328	4808	4317	4841	4414

* Reference case: gas use 1995 = 69.1*10^4 m^3/ha; gas price 1995 = 0.23 Dfl/m^3 ; interest rate = 8% ; tomato price = 1.31 Dfl/kg ; standard yield = 49*10^4 kg/ha; no subsidy.

\# Same as reference case except: a: gas price = 0.28 Dfl/m^3 gas; b: gas price = 0.45 Dfl/m^3 gas; c: interest rate = 6%; d : interest rate = 10%; e: production 10% lower; f: production 10% higher; g: subsidy of 1000 Dfl per % emission reduction.

Table 4: The minimum calculated gas use and related CO_2 emission reduction without additional net costs for different cases a to g.

changes in relation to reference case *)	minimum gas use (GU) (10^4 m^3/ha) for which costs (C) are zero	maximum CO_2 emission reduction for which net costs (C) are zero (% related to 1989/90)	Combinations of options #) with net zero costs (C < 0)
reference case	48	22	6, 7
a gas price = 0.28 Dfl/m^3	47	23	5, 6, 7
b gas price = 0.45 Dfl/m^3	43	30	all seven combinations
c interest rate = 6%	48	22	6, 7
d interest rate = 10%	49	20	6
e 10% production decrease	48	22	6, 7
f 10% production increase	49	20	6, 7
g 1000 Dfl subsidy per % emission reduction	47	23	5, 6, 7

* See Reference case Table 3.

\# The numbers 1 to 7 refer to the combination of options listed below Figure 1.

This preliminary analysis indicates that:

- under the assumptions made, the most cost-effective single measures to reduce the CO_2 emission in the Dutch tomato cultivation under glass are the combi-condenser and the heat buffer (volume 80 m^3).
- the combinations of options with least costs consist of a combi-condenser and a heat buffer (volume 80 m^3).
- model results indicate that gas use could be reduced from $69*10^4$ m^3/ha in the reference case to about $48*10^4 m^3$/ha ($43*10^4$- $49*10^4$ m^3/ha) by applying technical options where net additional costs are zero or negative. Associated CO_2 emissions reduce from $110.5*10^4$ kg CO_2/ha to $86.4*10^4$ kg CO_2/ha (20% reduction compared to 1989/90).

Further research could include an overview of measures to reduce environmental impact of greenhouse horticulture in the Netherlands and a description of sustainability indicators to quantify the environmental impact of present and future greenhouse horticulture. The research could be focused on the development of a model that can be used for calculating the costs and benefits of different emission reducing options for Dutch greenhouse cultivation. By using such a model, different scenarios and their consequences for the environmental impact of greenhouse horticulture in the Netherlands will be formulated and analyzed. A sensitivity analysis could be carried out for parameter values used in the model.

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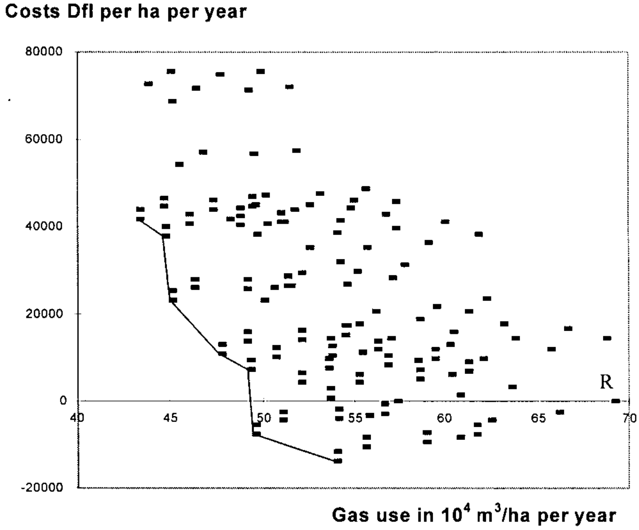

Figure 1 : The costs (Dfl/ha) of gas use reducing options in Dutch tomato cultivation under glass for 144 combinations of options (dots) and the most cost-effective combinations of options for the reference case (line; combination 1 to 7): $R = GU_{ref}$

1 = combi-condenser, movable screen, 80 m^3 heat buffer and double glass in wall.
2 = combi-condenser, movable screen, 80 m^3 heat buffer and wall insulation screen.
3 = combi-condenser, movable screen, 80 m^3 heat buffer and no wall insulation.
4 = combi-condenser, fixed screen, 80 m^3 heat buffer and double glass in wall.
5 = combi-condenser, fixed screen, 80 m^3 heat buffer and wall insulation screen.
6 = combi-condenser, fixed screen, 80 m^3 heat buffer and no wall insulation.
7 = combi-condenser, no screen, 80 m^3 heat buffer and no wall insulation.