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Combined Heat and Power (CHP) as a possible method for reduction of the CO_2 Footprint of Greenhouse Horticulture

热电联产作为减少温室园艺二氧化碳足迹的一种可能方法

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Abstract - **In recent years, the horticultural sector has been confronted with questions about the carbon footprint of its products. In greenhouse cultures, energy consumption is the main component of the CO_2 emission. To save energy, many Dutch greenhouse companies use CHP to heat their greenhouses. These growers may sell the superfluous electricity produced by the CHP to the national grid, thereby generating two products; the horticultural product, e.g. a tomato, and the electricity. The CO_2 emission of the electricity production should be deducted from the total CO_2 production of the CHP, in order to calculate the CO_2 emission that should be assigned to the production of the crop.**

To investigate the carbon footprint of a greenhouse production system to cases are compared: with and without a CHP system to heat the greenhouse. An example for grown tomatoes in The Netherlands is worked out. It shows the specific input factors and their impact on the CO_2 footprint. The functional unit used is kg CO_2 per 1000 kg product, and the system boundary is from seedling production until the delivery of product at the distribution centre of wholesalers or supermarkets.

The CO_2 footprint of the tomato crop grown without cogeneration is 55% higher than that of the crop grown without cogeneration and more than triple that of the conventional crop grown with CHP. The use of CHP is a way to reduce the CO_2 footprint for tomato growers.

Keywords - **CHP, sustainable greenhouse, greenhouse horticulture, carbon footprint, electricity production**

I. INTRODUCTION

Global heating as a result of greenhouse gasses (GHG) is a hot topic. The environmental impact of the modern horticulture sector is the subject of an increasing interest to the community. Wholesalers, supermarkets and consumer organisations therefore want insight into the GHG emission of their products, for both organic and conventional cropping methods. They plan to show the CO_2 footprint on their products, as an indicator of the impact on global heating by the production of their products. As a result, Carbon Trust, the UK Department for Environment Food and Rural Affairs (DEFRA) and the British Standards Institution (BSI) have developed a protocol for the calculations of the CO_2 footprint, the so-called PAS 2050 [2] [3]. This protocol is based on the methodology of the life cycle assessment (LCA) of the International Reference Life Cycle Data System [7]. In 2008, the Dutch Horticultural Board and the Ministry of Agriculture, Nature and Food Quality decided to start a pilot project to build a model to calculate the CO_2 footprint, so the sector can anticipate the answer to the potential question "What is the CO2 footprint of Dutch greenhouse production?" [1]. This model may be used by the members of the Dutch Horticultural Board to calculate the CO_2 footprint of their own production plant and is able to calculate the effects of changes in the production method (http://www.tuinbouw.nl/artikel/co2-footprint-berekenen).

During this study, it became clear that the use of cogeneration for the production of heat and electricity reduced CO_2 emissions, and consequently, the CO_2 footprint. Growers use co-generation to save costs and energy. In Dutch greenhouse horticulture in 2011, combined heat and power (CHP) systems which generated approximately 3000 MW of electric power were installed in a total area of 10,300 ha. Their annual electricity production is about 11,8 TWh. This electricity is partly used for artificial lighting, but most is sold to the national grid. The heat generated is used for heating the greenhouses. This decentralised cogeneration of electricity at greenhouses has benefits compared with central electricity production at normal power stations, where most of the heat is cooled and thus wasted. Organic crop production has to compete with this modern way of cropping with the use of CHP. This article calculates the CO_2 footprint of organic and conventional tomato cropping systems. Examples of the allocation methods for CHP are described and the impact on the CO2 footprint is shown.

II. MATERIALS AND METHODS

The CO_2 footprint of a greenhouse plant with and without combined heat and power generation (CHP) were compared. An overview of data for a tomato crop produced between mid-December and late November was used. Data were obtained from "Kwantitatieve Informatie voor de Glastuinbouw 2012-2013" (Quantitative information on greenhouse horticulture), a report that frequently contains overviews of the actual inputs, cost and yields for the main crops of the Dutch greenhouse horticulture [10]. Cogeneration is used to save energy, by avoiding energy waste, especially heat, at the central electricity plants. The relevant data are shown in Table 1.

TABLE 1. INPUT DATA OF TOMATO CROP PRODUCTION IN THE NETHERLANDS, 2013.

Input	Unit	Tomato	Tomato CHP
Production	$kg·m^{-2}·year^{-1}$	65.5	65.5
Electric power CHP	$MW·ha^{-1}$	0.0	0.6
Cogeneration	$hours·year^{-1}$	0	3560
Natural gas boiler	$m^3·m^{-2}·year^{-1}$	39.8	13.1
Natural gas CHP	$m^3·m^{-2}·year^{-1}$	0	58.5
Electricity	$kWh·m^{-2}·year^{-1}$	10.00	10.00
Electricity production	$kWh·m^{-2}·year^{-1}$	0.00	213.00
PE/PVC/PS	$kg·ha^{-1}·year^{-1}$	940	940
Pesticides	$kg·ha^{-1}·year^{-1}$	8.5	8.5
K_2O	$kg·ha^{-1}·year^{-1}$	1593	1593
N	$kg·ha^{-1}·year^{-1}$	1593	1593
P_2O_5	$kg·ha^{-1}·year^{-1}$	360	360

In the situation with the CHP system, the grower produced two different products; tomatoes and electricity. For assigning CO_2 emission from a central source to multiple objectives, three ranked allocation methods can be distinguished [2] [3]:

1. System reduction. The CHP production process was broken down into sub-processes: the electricity production and the heat production, and the allocation was based on energetic output. In the case of 40% electric and 50% thermal return of power, 1 m^3 natural gas (31.65 $MJ·m^{-3}$) produced 3.52 kWh (31.65/3.6*40%) electricity (Eq. 1). With a total return of 90%, 1 kWh of electricity was produced with (1/3.52) 0.284 m^3 of gas (Eq. 2). In practice, the electric return varied between 38% and 42% and the thermal return between 50% and 55%. So the CO_2 emission of the electricity was based on (40% / (40% + 50%) * 0.284) = 0.126 m^3 natural gas per kWh (Eq. 3).

$$P_e=E*C*S_e \quad (1)$$
$$G_t=1/P_e \quad (2)$$
$$G_e=(S_e/(S_e+S_h))*P_e \quad (3)$$

P_e= Electricity production kWh
E = Energy value natural gas (heat) $MJ·m^{-3}$
C= Conversion factor $kWh·MJ^{-1}$
S_e= Share electricity output %
S_h= Share heat output %
G_t= Total gas input CHP to produce 1 kWh electricity $m^3·kWh^{-1}$
G_e= Share electricity of gas input CHP $m^3·kWh^{-1}$

In horticulture, the CO_2 produced was also used in the crop production process. The electricity produced by the CHP in the greenhouse plant was used outside the greenhouse system and had an impact on the national electricity production. Because the electricity sold to the national grid is not recognized as a reduction in CO2 output by this allocation method, makes the system reduction allocation method a poor choice.

2. System expansion. This method is based on expanding the system to include the impact of displaced products. In the case of cogeneration, the electricity that would have been produced by the national grid (i.e. the avoided electricity) was displaced by the electricity that was produced by the CHP system and sold back to the grid (i.e. the replacement electricity). This allocation method was useful in the cogeneration cropping case. The system included the production of tomatoes and the production of replacement electricity. The emission of the replacement electricity was deducted from the total emission of the tomato crop and electricity production at the greenhouse plant, to calculate the emission level of the tomatoes.

3. Economic allocation. This allocation method was based on the economic return of the electricity and the crop. If, for example, in a tomato crop, the yearly returns are €50.00 per m^2 and the electricity returns are €12.50 per m^2, the share of the electricity in the gas consumption of the CHP will be 12.5/(50+12.5) = 20%. If you need 0.284 m^3 gas to produce 1 kWh, the electricity part will be 0.0568 (20% * 0.284) m^3. So for each kWh electricity supplied to the national grid, the CO_2 emission of the CHP can be reduced by the emission of 0.0568 m^3 gas. This method is very unstable and will give different CO_2 footprints throughout and over the years with a comparable input of energy. Because system expansion can be used, PAS 2050 doesn't allow use of the economic allocation method.

TABLE 2. CO_2 EMISSION OF ELECTRICITY PRODUCTION IN THE NETHERLANDS. (Based on [6] [8] [9]).

Electricity source	kg $CO_2·kWh^{-1}$ excl. pre combustion
Nuclear	0
Natural gas average	450
Oil	660
Coal	870
Import in Holland 2006	586
Production average Holland 2006	543

Looking at the replacement electricity production by CHP, the time of production is important. In The Netherlands, the electricity source is different at different times of the day and on different days of the week. There is a base load of electricity production that is supplied by long-lasting power plants such as those fuelled using coal or nuclear power. However, the daily fluctuation of electricity consumption is supplied mainly by gas combustion power plants. All these production methods have their own CO_2 emissions (Table 2).

In the case of tomato, the CHP is used for two purposes: 1) production of heat and CO_2 for crop production and 2) electricity as a co-product not used for the production of tomatoes. The electricity produced is sold to the national electricity grid. The electricity market in The Netherlands is divided into two main parts: base and peak hours. The peak hours Monday to Friday from 07:00 to 23:00, the hours with the highest electricity consumption. The base hours are from 23:01 to 06:59 weekdays and the 48 hours of the weekend. The peak hours have a high rate paid and the base hours have a low rate paid. Because the CO_2 demand by the (tomato) crop is also during the day, most of the growers use the CHP during daytime hours, both during the week peak time hours and the weekend base time hours with the low rate paid. The heat produced is used in the greenhouse directly or stored for the night in heat water storage tanks, except for the summer period when a portion of the heat cannot be used because the heat water storage tank is to small and is wasted.

Back to the question ‘what is the amount of avoided electricity?’ This question was answered by a panel of experts. Participants were a grower with a CHP, a PhD researcher on the energy market, a CHP specialist, an horticultural economist, a seller of electricity and two energy production specialists. The panel concluded that in The Netherlands, electricity delivered in the peak hours reduced electricity produced by gas-combusted electricity plants, and in the base hours, that produced by coal-combusted plants. In this case, it was simplified by calculating with 5/7 by gas- and 2/7 by coal-produced electricity, based on the number of days with and without peak hours, respectively. The so calculated avoided CO_2 emission was offset against the CO_2 emission of the gas used by the CHP. In situations where the amount of electricity that is delivered during peak and base hours is known, the real distribution can be used.

In the tomato crops without CHP, the allocation will be simply that all the CO_2 emissions will be due to the tomato production.

The CO_2 footprint looks at the effect on the GHG of all materials used during the whole production cycle. For all cases, the emission will be calculated for 1000 kg tomatoes. The system boundary of the life cycle assessment started with seedling production and the growth of the young plants, included their transport to the greenhouse and the fruit production at the greenhouse, and ended with the transport of the fruit to the gate of the distribution centre of the wholesaler or supermarket.

The main materials used during the seedling, young plant and fruit production periods were energy (gas and electricity), fertilizers, pesticides, plastics, rock wool, peat, etc. In these cases, the emission of the seedling and young plant production and transport is estimated at 10% of the emission for the fruit production.

An inventory in 2008 at a new tomato production greenhouse (11) gave the amount of materials used for greenhouse construction as shown in Table 3, with the average annual depreciation and percentage of recyclable materials at the end of its lifetime. PAS 2050 excluded the emissions of the production of these capital goods.

TABLE 3. MATERIALS USED IN GREENHOUSE CONSTRUCTION (TON·HA-1), THE AVERAGE DEPRECIATION (%) PER YEAR AND AMOUNT OF MATERIAL THAT MAY BE RECYCLED (%). (11)

	$ton \cdot ha^{-1}$	Average % depreciation	% recyclable
Concrete	109	7.0 %	90 %
Aluminium	37	8.1 %	90 %
Glass	119	7.0 %	90 %
Steel	196	8.2 %	90 %

III. RESULTS

The CO_2 emission of a tomato crop are compared in two cases: without and with the use of a CHP for heating of the greenhouse. The results are shown in Table 4 and Fig. 1.

TABLE 4. RESULTS OF CO_2 FOOTPRINT THE CALCULATIONS (KG CO_2 EQ·TON^{-1})

	Tomato	Tomato with CHP
Young plants	130	70
Gas boiler	1136	374
CHP[1)]	0	165
Electricity	98	98
Fertilizer	43	43
Materials	18	18
Transport	8	8
Total	1430	775

[1)] Gas CHP – electricity to national grid.

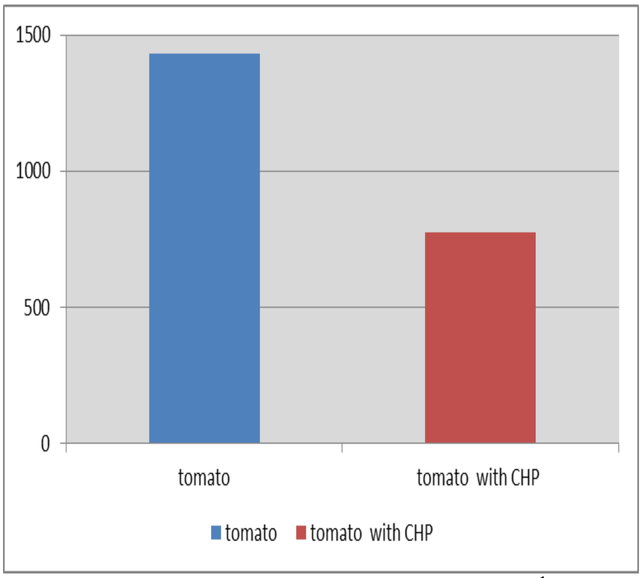

Fig. 1, Tomato crop: the CO_2 emission (kg CO_2 eq·ton^{-1}) of a crop with and without heating using a CHP system.

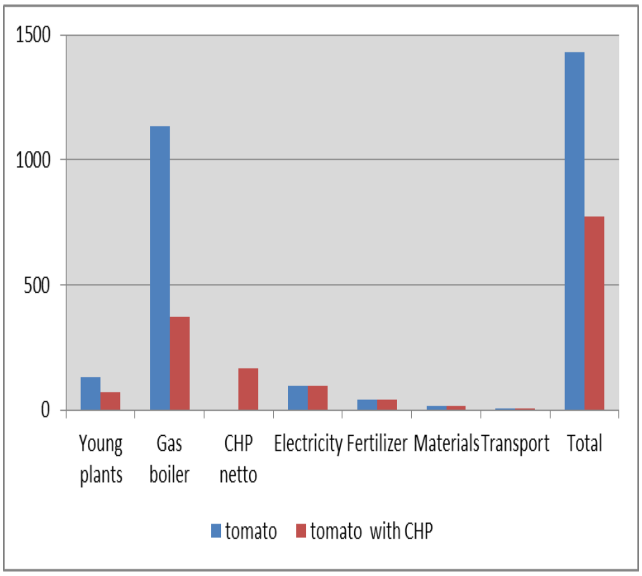

Fig. 2, Tomato crop: total and components of the CO_2 emission (kg CO_2 eq·ton^{-1}) of a crop with and without heating using a CHP system. (CHP netto = Gas CHP – electricity to national grid.)

The use of a CHP system lowers the CO_2 footprint of the crop by about 55%, due to the avoided production of electricity by power plants, for the tomato crop. So, the use of cogeneration has a positive impact on reducing the CO_2 emission of the community. The consumption of gas with CHP will be almost 50% higher than without CHP, due to the production of electricity for the national grid. However, because heat and CO_2 are used in the greenhouse production process, cogeneration results in an overall energy savings by avoiding electricity production in a central electrical production plant that generally wastes the generated heat. The final impact depends on the kind of electricity plant that the CHP-produced electricity replaces. Consequently, a greenhouse grower may decide to use cogeneration to lower his CO_2 footprint.

As shown in Fig. 2, the gas consumption is the greatest CO_2 emission component of greenhouse tomato production; without CHP in the tomato growing system it is 79%; and with CHP, it is 70%.

Energy savings and the use of green energy are the major components in the reduction of the CO_2 footprint of protected horticulture. The other factors that can be considered for a further reduction of the CO_2 eq. emission of a tomato are the use of fertilizers and the transport of the product to the distribution centre.

IV. DISCUSSION AND CONCLUSIONS

Greenhouse horticulture has to innovate their production system to lower the CO_2 footprint. Actually the greenhouse horticulture is quickly adapting new technologies, such as CHP, for its use. Other new energy systems already have been developed or will be developed, such as:

- Heat from CHP delivery by greenhouse growers to other companies and/or non-greenhouse partners, such as schools, swimming pools, etc.;
- Heat or CO_2 delivery by electricity or industrial plants to greenhouses;
- Use of geothermal heat; August 2014 10 wells in the Netherlands;
- Bio energy;
- Fermentation.

Greenhouse growers can choose from these options and look at the effects of the chosen option(s) on the CO_2 footprint for their production system.

Growers have to become aware that the community and wholesalers want insight into the production method of their suppliers and the impact of the production method on global warming and environmental burdens. The CO_2 footprint is said to be the indicator that wholesalers and supermarkets will use, explaining only part of the overall environmental impact of the production method used. Abiotic resource depletion, human, aquatic and terrestrial toxicity, acidification, eutrophication, deduction of stratospheric ozone depletion and photo-oxidants formation, etc., which are the other (sub)indicators of the LCA methodology, are not considered. For comparison studies, however, these other indicators should be considered to avoid any misinterpretation of the environmental effects of a specific growing system according to the International Reference Life Cycle Data System Handbook (ILCD, 2008).

There are a lot of databases with elements of the CO_2 eq emissions of materials that use different emission figures on the same materials. Using these different figures can have a high impact on the level of the CO_2 footprint. A widely accepted database which explains local differences in data will be necessary. In this study, the database Ecoinvent was used. (www.ecoinvent.ch) [4] [5]

The CHP case is one of many possible ways to use cogeneration in greenhouse horticulture. The potential CO_2 emission reduction depends on many specific factors. In this study, the most important factors were: electric and heat return of the CHP, number of hours with cogeneration, type of electricity production avoided (i.e. coal or nuclear vs. gas), amount of generated power in relation to the area of the greenhouse, and heat and CO_2 demand of the greenhouse. This CO_2 footprint method is an easy tool for growers to use to calculate the CO_2 emission of their own crop and production method. In this case study, the use of the CHP is based on the heat and CO_2 demand of the crop, to ensure the least possible heat wastage at the greenhouse plant. To achieve the illustrated reduction of CO_2 emissions using CHP, the investment and extra gas consumption have to be recouped by the returns from the electricity sales. In 2008, which had high prices for both base and peak time electricity delivery, growers let the CHP run extra hours to generate extra income. In 2010-2014, which had low electricity prices, growers stopped this extra use of cogeneration because the extra gas consumption would not have been recouped by the sale of electricity. Therefore, to realise a reduction of CO_2 emissions with cogeneration in horticulture, there needs to be a stable electricity market with fair prices.

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