

Lower global warming potential of cucumbers and lettuce from a greenhouse heated by waste heat

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ABSTRACT

Vegetable production in greenhouses is associated with a high global warming potential (GWP). By using alternative heat sources, the CO₂eq emissions are lowered. In Hinwil, Switzerland a promising project of the waste incineration plant KEZO and the vegetable producer Primanatura AG was started, where formerly unused waste heat is used to heat a greenhouse. As a consequence, the energy efficiency of the waste incineration plant increased, leading to an additional electricity generation of 110 kW. Cucumbers and lettuce from this greenhouse have a GWP of 0.178 and 0.453 kg CO₂eq per kg product. Considering credits from additional electricity production at the waste incineration plant, total emissions are -0.098 and -0.368 kg CO₂eq per kg of cucumbers and lettuce, respectively. Cucumbers and lettuce from fuel oil heated greenhouses have a GWP of 1.741 and 4.507 kg CO₂eq per kg product. A great potential exists for greenhouses using alternative heat sources.

Keywords: GWP, greenhouse, waste heat, waste incineration plant

1. An alternative way to heat a greenhouse

The cultivation of vegetables in greenhouses normally leads to high fossil energy consumption and therefore a high global warming potential (GWP) per kg product compared to non-heated production. However, in Switzerland certain vegetables are, due to climatic conditions, mainly grown in greenhouses. This is the case for cucumbers in summer and lettuce in winter. For both products, a considerable higher GWP is attributed to products from heated greenhouses compared to field-grown products (Jungbluth, 2000).

Therefore a great potential exists for alternative heating sources like wood pellets or district heating. In the year 2009 a promising project for a greenhouse heated with so far unused waste heat from a waste incineration plant in Hinwil, Switzerland was initiated. The waste incineration plant KEZO already produces electricity and maintains a district heating network for the nearby industry and households. However, there is still some hot steam with a temperature of about 55 °C left. This steam is too cold to be used in the district heating network and was therefore so far not used. It had to be chilled down actively by an air-cooled condenser to maintain the negative pressure needed for an efficient energy conversion. With the construction of the nearby greenhouse of Primanatura AG, an accepter for this waste heat was found. The system is shown in Figure 1.

The greenhouse project enhanced the energy efficiency of the waste incineration plant. Besides the utilisation of so far unused heat, the overall electricity production of the waste incineration plant could be increased. The net productivity improvement is credited to the following three effects: (1) the load of the ventilator of the air-cooled condenser can be decreased when heat is deducted by the greenhouse. This leads to an average economisation of 40 kW; (2) the productivity of the turbine is increased because the negative pressure of the off-steam is optimised. Therefore more energy is converted into electric power, leading to an average increase of productivity of 90 kW; (3) the waste heat needs to be pumped to the greenhouse. The pumps consume electric power, on average 20 kW. Overall, the productivity of the waste incineration plant is increased by 110 kW.

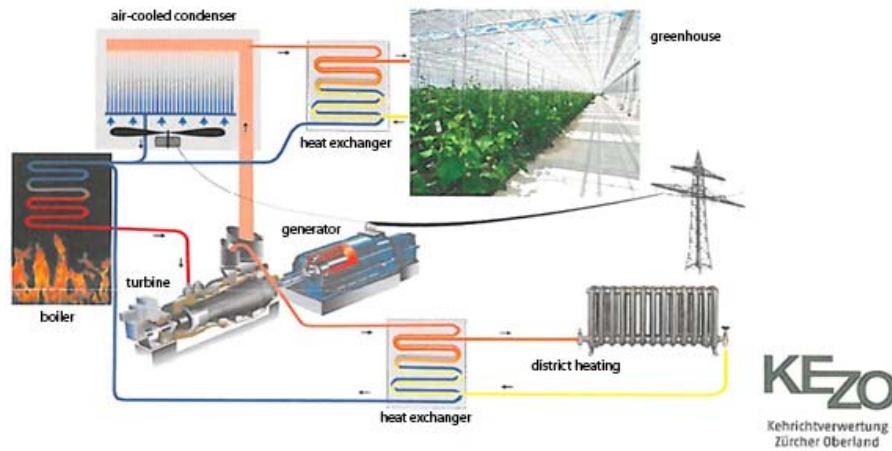


Figure 1. Heating system of the greenhouse

The objective of this study is a comparison of cucumbers and lettuce grown in the greenhouse of the Primanatura AG with cucumbers and lettuce grown in fuel oil heated greenhouses.

2. Methodology

2.1. Goal and scope

The goal of this study is to compare the global warming potential (GWP) of vegetables from a greenhouse heated with waste heat from a waste incineration plant to vegetables from a greenhouse heated with fuel oil. Therefore cucumbers, in Switzerland typically grown in greenhouses during the summer half-year, and lettuce produced in the winter months are studied.

All inputs such as seedlings, fertilizers and pesticides are considered as well as field processes, infrastructure, heat, electricity, other used materials, the transportation of the products to the point of sale and waste disposal. As the studied products cucumbers and lettuce are usually not cooked, no cooking processes are considered. Transportation from the point of

sale to the household is not considered as well, as it is highly depending on the individual behaviour of customers.

The system boundaries also include the heat and power production at the waste incineration plant.

The functional unit is 1 kg of cucumber or lettuce, respectively.

2.2. Data inventory

The primary data for the vegetable production and the greenhouse infrastructure are provided by the Primanatura AG. Additional data for conventionally heated greenhouses are taken from the guidance of the official reference method for nutrient balancing at farm level in Switzerland (agridea, 2008) and from Jungbluth (2000). Data for the heating system and the associated additional electricity generation are provided by the waste incineration plant KEZO. The most important data are summarised in Table 1.

For secondary data, the ecoinvent inventory V2.1 database is used (Swiss Centre for Life Cycle Inventories, 2009). Direct field emissions, mainly from fertilisation, are calculated according to Nemecek & Kägi (2007).

Table 1. Cucumber and lettuce production in greenhouses, overview

	Cucumbers	Lettuce
Yield	250 t / ha	40 t / ha
Vegetation period	200 days	95 days
Fuel oil (only for fuel oil heated greenhouses)	122500 L / ha	51000 L / ha
Electric power consumption	11550 kWh / ha	10972.5 kWh / ha
Additional power production at waste incineration plant (only for waste heat heated greenhouse)	132000 kWh / ha	62700 kWh / ha
Fertilizer		
N	300 kg / ha	80 kg / ha
P2O5	150 kg / ha	30 kg / ha
K2O	400 kg / ha	140 kg / ha
Transportation to point of sale		
Means of transportation	lorry	
Distance	80 km	
Packaging	Reusable plastic container (RPC)	

2.3 Allocation of the emissions from the waste incineration plant

In the ecoinvent database, heat and power from waste incineration plants are considered as emissions free. Three reasons are: (1) the main function of a waste incineration plant is the waste incineration itself. Electric power and heat are by-products; (2) heat is produced in any case. The overall emissions of the waste incineration plant would not be lower if the electric power and heat would not be used; (3) electricity and heat utilisation create only a small part of the income of the waste incineration plant. In this special case, the by-products electric power and heat can be considered as emission free (Doka, 2009).

2.4 Credits for additional electricity

The greenhouse heating system with waste heat increased the efficiency of the waste incineration plant. The additional electricity generation is only achieved due to the construction of the greenhouse, as there are no other possible accepters of this low temperature waste heat. Therefore the additional electricity is considered as a credit for the vegetable production. This additional electricity substitutes electricity that would otherwise have been produced from other sources. The substituted electricity is represented with the power production mix from the Union for the Co-ordination of Transmission of Electricity (UCTE). The UCTE is a predecessor of the European Network of Transmission System Operators for Electricity (ENTSO-E)¹. Switzerland's national grid company, Swissgrid, was a member of the UCTE and is now member of the ENTSO-E.

2.5 Impact Assessment

The global warming potential (GWP) with a time horizon of 100 years according to Intergovernmental Panel on Climate Change – IPCC (2007) was considered. The analysis was performed using the software EMIS (Environmental Management and Information System) developed by Carbotech AG (Dinkel, 2009).

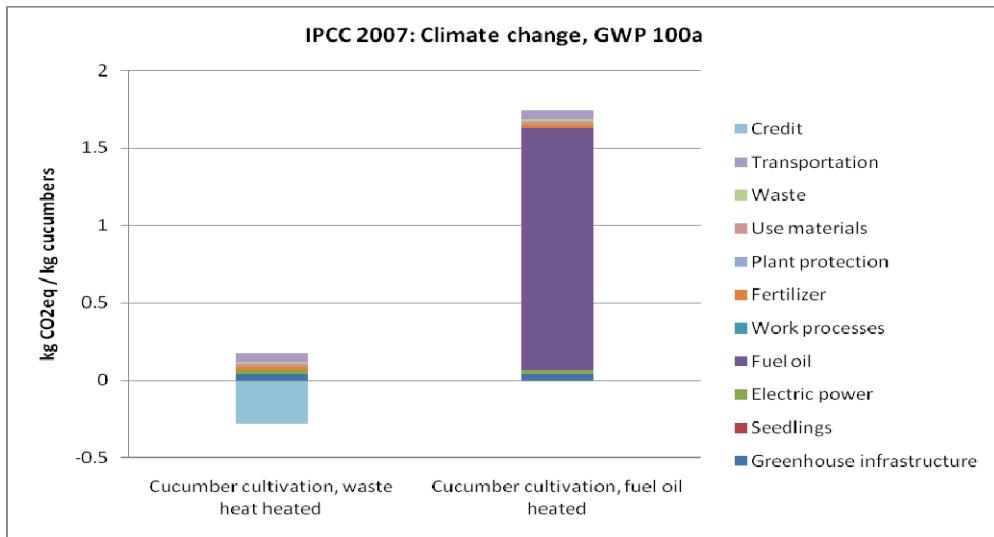
3. Results

3.1. Cucumber and lettuce production

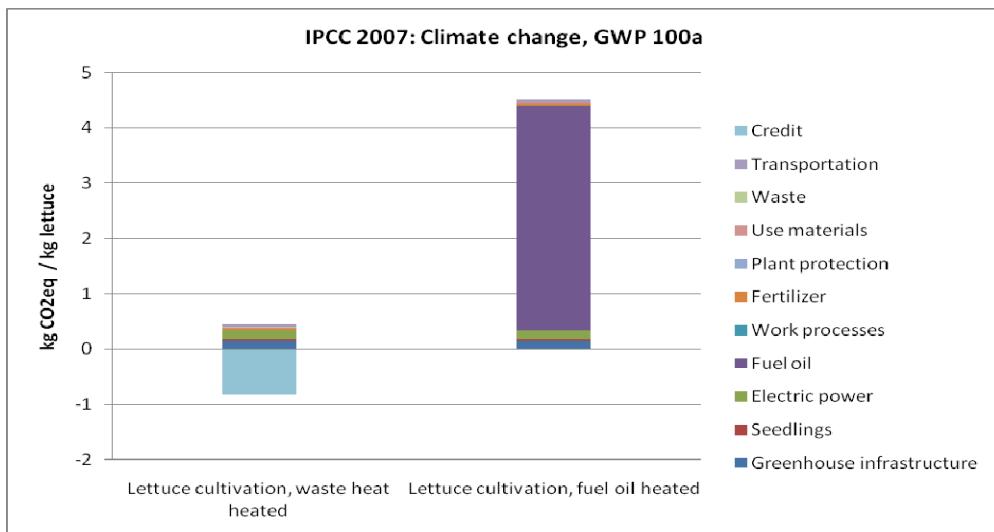
Figure 2 and 3 show a comparison of fuel oil heated and waste heat heated greenhouse production for cucumbers and lettuce, respectively. The results show that fuel oil is the main source for CO₂eq emissions of cucumber and lettuce production from fuel oil heated greenhouses. It is responsible for almost 90 percent of the total CO₂eq emissions of both products. In total, 1.741 kg of CO₂eq is caused per kg of cucumbers and 4.507 kg of CO₂eq is caused per kg of lettuce.

The cucumbers and lettuces from the greenhouse heated with waste heat cause considerable lower emissions. The largest source of emissions from the cucumbers derives from the transportation of the products to the point of sale, counting for 32 percent of the caused emissions. The greenhouse infrastructure is responsible for 21 percent of the emissions, followed by electric power (14 percent), the emissions from use materials (12 percent) and fertilisation (11 percent). All other processes cause less than ten percent of the total emissions from cucumbers produced with waste heat. Per kg of cucumbers 0.178 kg of CO₂eq is caused.

¹ Website of the ENTSO-E: <http://www.entsoe.eu/>

**Figure 2.** Global warming potential of cucumbers

The largest source of emissions from lettuces grown in the greenhouse heated with waste heat derives from the greenhouse infrastructure, counting for 33 percent of the caused emissions. The consumption of electric power, mainly needed for the heating water circulation, is responsible for 32 percent of the emissions, followed by the transportation of the products to the point of sale (12 percent). All other processes cause less than ten percent of the total emissions from lettuce produced with waste heat. Per kg of lettuce 0.453 kg of CO₂eq is caused.

**Figure 3.** Global warming potential of lettuce

3.2. Credits from additional power production

Due to the efficiency increase at the waste incineration plant, additional electric power of 0.574 kWh per kg of cucumber and 1.568 kWh per kg of lettuce is produced at the waste incineration plant. This leads to a credit of 0.276 kg CO₂eq per kg cucumber and of 0.820 kg CO₂eq per kg lettuce. The total CO₂eq emissions of cucumbers and lettuce result in negative emissions of -0.098 kg CO₂eq per kg cucumbers and -0.368 kg CO₂eq per kg lettuce.

4. Discussion – Climate neutral vegetable production?

Products from greenhouses heated with fuel oil have a very high GWP. For both, cucumbers and lettuce, fuel oil is responsible for about 90 percent of the total emissions. Products from the greenhouse heated with waste heat have a remarkably lower GWP, because no fossil fuels are used for heating. The heat from the waste incineration is considered as emission free in accordance with the allocation used within the ecoinvent database (Doka, 2009).

Credits for the additional electric power production at the waste incineration plant can be attributed to the products from the greenhouse, because the additional power wouldn't have been produced without the greenhouse project. The additionally produced electric power can be considered as emission free, as no additional emissions are generated at the waste incineration plant due to power production (Doka, 2009). Every amount of additionally produced electricity substitutes electricity from other sources. Considering this credits, the CO₂eq emissions per kg of cucumbers or lettuce become negative. In other words, all emissions caused by the vegetable production are compensated or even overcompensated by the avoided emissions from electricity production. Therefore the products from the greenhouse of the Primanatura AG can be considered as climate neutral.

5. Conclusion – Vegetable production increases electricity generation

The project realised by the Primanatura AG and the waste incineration plant KEZO in Hinwil, Switzerland, shows that alternative heating systems can improve the carbon footprint of vegetables from greenhouses remarkably. It clearly shows that there is a huge potential to improve greenhouse production systems by using alternative heating sources.

In the special case of the KEZO and the Primanatura AG, dissipating the waste heat even leads to an improved electricity generation. There is still room for further improvements. The KEZO assumes that the net improvement could be increased to more than 200 kW. Based on 8600 operating hours per year this sums up to more than 1,720,000 kWh of additional electricity per year, satisfying the needs of over 300 Swiss households².

² Based on an average need of 5,324 kWh per household (average consumption of the year 2008 according to the Swiss Federal Statistical Office).

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