International Journal of Sustainable Agricultural Research
2017 Vol.4, No.1, pp.1-8
ISSN(e): 2312-6477
ISSN(p): 2313-0393
DOI: 10.18488/journal.70/2017.4.1/70.1.1.8

REDUCTION OF THE CARBON FOOTPRINT IN AGRICULTURAL GREENHOUSES

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ABSTRACT

Climate change in the planet is currently creating many environmental, economic and social problems which are probably going to multiply in the near future. Reduction of greenhouse gases emitted from fossil fuels could result in the mitigation of greenhouse effect and the climate change. Agricultural greenhouses consume large amounts of energy mainly derived from fossil fuels, for the cultivation of various crops. Reduction of their carbon footprint is of primary importance to day. In order to investigate the possibilities of reducing their carbon footprint, the energy consumption during their operation has been estimated and the sustainable energy technologies which could be used for substitution of fossil fuels used have been analyzed. It has been found that a modern greenhouse located in Mediterranean region with a covered area of 1,000 m2 and a total annual energy consumption of 200 KWh/m2 emits 76,900 kg CO2 per year. Total elimination of their CO2 emissions could be achieved with the investment of 44,000 € in renewable energy technologies, including solid biomass for heating and solar-PV for power generation and resulting in lower energy cost during their operation. The payback time of the abovementioned investments has been estimated at 4.84 years.

Keywords: Agricultural greenhouses, Carbon footprint, CO2 emissions, Energy consumption, Energy saving, Renewable energy.

Received: 6 December 2016/ **Revised:** 5 January 2017/ **Accepted:** 13 January 2017/ **Published:** 21 January 2017

Contribution/ Originality

The study contributes in the existing literature regarding the improvement of the sustainability in agricultural greenhouses. It indicates the possibility of using various renewable energy sources instead of fossil fuels for covering their energy requirements resulting in zeroing their CO_2 emissions due to energy use in them.

1. INTRODUCTION

Agricultural greenhouses consume energy for heating, cooling, lighting, operation of various electric devices and transportation of the goods produced. Energy consumption, when generated from fossil fuels, is related with CO_2 emissions and climate change. Increase in the sustainability of greenhouses with the reduction of their carbon footprint is of primary importance to day promoted by various policies in many countries. Energy costs are the third highest cost for most greenhouse growers behind labour and plant materials. In a typical greenhouse heating energy represents 70-80 % of its total energy consumption, electricity represents 10-15 % and transportation fuel makes up the rest (Sanford, 2011). Reduction of the carbon footprint due to energy use in a greenhouse can be achieved with

a) Reduction of its energy consumption
b) Replacement of fossil fuels used with renewable energies

Since most of the energy used in modern greenhouses concerns their space heating it is of primary importance to decrease their heating energy which could be obtained with various ways. Renewable energy sources can be used for heating, for electricity generation and for transport fuels. Solid biomass and direct geothermal energy can be used in a cost effective way for covering all the heating requirements in a greenhouse (Vourdoubas, 2015). Grid electricity consumption can be offset annually from solar-PV electricity generated either in-situ or off-situ according to the net metering principle. The sharp decrease in the price of solar-PV panels in the last years has increased their attractiveness for power generation in various applications. Finally the replacement of transport fuels with bio-ethanol and biodiesel can be easily achieved reducing the CO_2 emissions due to their use.

The investigation of the possibilities of reducing the carbon footprint in agricultural greenhouses due to energy use in them will indicate the steps which should be taken for increasing their sustainability. In order to investigate this, the following will be examined

a) Energy consumption in greenhouses,

b) Possibilities of reducing energy consumption, and

c) Possibilities of replacing fossil fuels with renewable energies in heating , electricity generation and transporting

2. ENERGY CONSUMPTION IN AGRICULTURAL GREENHOUSES

Energy consumption in greenhouses depends on their construction, the local climate and the cultivated crop. A report has been published on the energy consumption in greenhouses with different constructions used for lettuce production in Serbia (Djevic and Dimitrijevic, 2009). The authors stated that direct energy consumption, including heating oil and electricity, corresponds approx. at 50 % of the total direct and indirect energy consumption, including fertilizers, irrigation water, pesticides and packaging material for the rest. Depending on the greenhouse construction, the energy consumption varied between 2.71 KWh/m^2 and 3.87 KWh/m^2. Energy inputs in greenhouses producing tomato in Turkey have been reported (Hatirli *et al.*, 2006) . The authors found that the total energy consumption was 2.96 KWh/m^2 and the share of heating fuel and electricity was approx. 50 % of the total energy consumed. More specifically the main contributors of total energy use were diesel (34.35 %), fertilizers (27.59 %), electricity (16.01 %), pesticides (10.19 %) and human power (8.64 %). Energy analysis in a greenhouse in Iran producing strawberries has been published (Banaeian *et al.*, 2011). The authors reported that the total energy consumption was 3.39 KWh/m^2. About 78 % of this was generated by diesel fuel, 10 % from chemical fertilizers and 4.5 % from electricity. Analysis of energy use in various greenhouses producing vegetables in Turkey has been reported (Canakci and Akinci, 2006). The authors have studied the cultivation of tomato, pepper, cucumber and eggplant in Antalya, Turkey (36°7'-37°26' north latitude and 29°17'-32°44' east longitude).They found that the energy consumed during their operation varied between 6.63-7.79 KWh/m^2. Wood fuel was used for heating corresponding to approx. 60 % of the total operating energy. The embodied energy in the greenhouses was estimated at 4.76 KWh/m^2 and the energy source requirements (including the embodied energy) varied between 12.71-13.88 KWh/m^2. An energy analysis in greenhouses producing vegetables in Antalya, Turkey has been reported (Ozkan *et al.*, 2004). The authors studied 88 greenhouse farms cultivating tomato, pepper, cucumbers and eggplants through the use of questionnaires. Total energy consumption varied from 3.74 KWh/m^2 for cucumbers to 2.28 KWH/m^2 for peppers. The highest energy input was for diesel oil, which was used for soil tillage, followed by fertilizers and electricity. Both diesel oil and electricity were corresponding approx. to 35-50 % of the total energy consumption. The authors reported that most greenhouses in Turkey are not heated except in the case of frost and their average vegetable productivity is three times lower compared with European greenhouses. The energy use patterns for greenhouses growing tomato and cucumber in Iran has been reported (Heidari and Omid, 2011). Total energy input has been estimated at 3.66-3.93 KWh/m^2. Among input energy sources diesel oil and fertilizers contained the highest energy, corresponding to 50-55 % and 21-24 % of total energy used. Electricity had a small share in the total energy consumption at 2-6 %. The authors collected data from 43 farmers and their results indicate that non-renewable energy sources have a share of 90-94 % in the total energy input. The relation between energy inputs and yield of greenhouse cucumber production in Iran has been reported (Mohhamadi and Omid, 2010). The authors analyzed 43 cucumber production greenhouses in the Tehran province and they found that 10.93 % of the total energy input was renewable and the rest was non-renewable. Energy analysis of a greenhouse used for flower cultivation in Crete, Greece (35°31' north and 24°1' east) has been reported (Vourdoubas, 2015) . The greenhouse was using solid biomass for heating and grid electricity for cooling, lighting and the operation of various electric devices. The indoor temperature was kept in the winter at not lower than 18 °Cand its total operating annual energy consumption, regarding the heating energy and the electricity used, was estimated at 328 KWh/m^2. The share of heat energy was 95.73 % while for electricity it was 4.27 % (Vourdoubas, 2015). A report on the energy consumption in greenhouses in the Italian peninsula has been published (Bibbiani *et al.*, 2016). The annual operating energy consumption, including heating fuel and electricity, was estimated at a wide range, 21-546 KWh/m^2, depending on the geographical location and the internal air temperatures. The authors stated that greenhouses in Italy have a total area of 6,000 ha. On average the share of heat consumed in the greenhouses is 96.6 % and of electricity 3.4 %.

Greenhouses used for vegetable production in mild climates which are not heated , or are heated only in cases of frost a few days a year, require much less operating energy compared with modern greenhouses in northern climates. According to various studies total direct and indirect energy use did not exceed 15 KWh/m^2 which is much lower than the energy used for heating in modern greenhouses. Their embodied energy is low as well as the energy used in fertilizers, for soil tillage and in various other operations. Therefore their carbon footprint due to energy use is low compared with greenhouses consuming large amounts of energy but their productivity is also lower.

3. ENERGY SAVING IN GREENHOUSES

An overview of reducing energy consumption in greenhouses has been presented (Sanford, 2011). The author reports that for new greenhouses structural considerations including type, shape and orientation affect their energy consumption. Different glazing materials with one or more layers also influence their energy behavior. Comparison of glazing material properties are presented in table 1.

Table-1. Comparison of glazing material properties

Material	% light transmission	U-value*	Life expectancy (years)
Glass			
single	88-93	1.1	25+
double	75-80	0.7	25+
Poly-ethylene film			
Single	87	1.2	3-4
double	78	0.7	3-4

*Lower U values result in less heat lost

Source: Sanford (2011)

According to Sanford (2011) other methods which can reduce energy consumption include

a) Sealing the greenhouse envelope

b) Creation of windbreaks in order to reduce wind speed, and

c) Insulation of the greenhouse envelope

About 80 % of the greenhouse heating occurs at night, so increasing the resistance to nighttime heat losses has a large impact on reducing heating costs. Thermal curtains or screens can be used for that which can reduce nighttime heat loss by about 50 %. The energy saving potential of greenhouse climate control has been reported

(Tantau, 1998). The author stated that the energy saving potential in a greenhouse with climate control is rather small and he suggests other possibilities for energy savings which are more efficient like thermal screens and double glazing. The effect of covering materials on energy consumption in greenhouses has been studied (Zhang *et al.*, 1996). The authors assessed different greenhouse covering materials and they found that a double polyethylene cladding consisting of an anti-fog thermal film for the inner layer and a standard PE film for the outer layer was the most energy efficient. They also found that the use of thermal screens in the greenhouse reduced the night heat losses by 23-24 %. Reduction of thermal radiation in glasshouses by thermal screens has been reported (Bailey, 1981). The author stated that thermal screens used in a glasshouse at night can reduce the loss of heat by between 35 and 60 %. They also discovered that a screen with a low emissivity upper surface and high emissivity lower surface gives high energy savings combined with reduced problems of condensation. Thermal screens consist of an effective way for reducing energy consumption in greenhouses. However due to high costs, their use is justified only in technologically advanced greenhouses.

Integration of waste and renewable energy to reduce the carbon footprint of locally integrated energy sectors has been reported (Perry *et al.*, 2008). The authors stated that successful strategies for integration of various energy systems from different processes located in nearby areas could result in significant CO_2 emissions reductions. The use of waste heat from a power plant for greenhouse heating in commercial applications in Germany has been reported (Bredenbeck, 1992). The author stated that the warm water from the cooling tower of the plant was able to maintain the indoor temperature of the greenhouse at 22 ^oC even with an outside temperature of -14 ^oC.

4. USE OF RENEWABLE ENERGY AND SUSTAINABLE ENERGY SOURCES FOR HEATING GREENHOUSES

In modern greenhouses most of the energy used is consumed for their heating. The main fuels used for that are either diesel oil or natural gas. Reduction of the heating energy used and/or replacement of fossil fuels with renewable fuels would result in the reduction of CO_2 emissions due to their heating. Various renewable energy sources have been used experimentally or commercially for that (Vourdoubas, 2016). Among them are solar energy, solid biomass, biogas, direct geothermal energy and ground source heat pumps. Solar energy has been used for heating greenhouses with passive and active systems. However it can cover their heating needs only partly. Solid biomass such as wood, wood products and residues have been used in many cases for covering all the heating needs of greenhouses. Biogas can also be used for heating but its use is limited so far. Direct geothermal fluids with temperatures between 40-80 ^oC can be used for covering all the heating needs of greenhouses. However the geothermal spring must be located near the greenhouse which would be heated. Low enthalpy geothermal heat pumps can also be used for heating and cooling greenhouses. They consume electricity and they are very efficient devices having high COPs. However they are expensive items of equipment and their use is rather limited. Co-generation systems using natural gas as fuel have been used commercially in greenhouses. The generated heat is used in the greenhouses and the co-produced power can cover their electricity needs while the surplus can be sent into the grid. Waste heat from various plants has also been used for heating greenhouses. Among renewable energy technologies used for heating greenhouses solid biomass and direct geothermal energy are technologically simple and cost effective (Vourdoubas, 2015). Renewable energy sources and sustainable energies which have been used so far for heating greenhouses are presented in Table 2.

Table-2. Use of renewable energy sources and sustainable energies for heating greenhouses

Energy source	Possibility of covering all heating needs	Commercial applications
Solar energy	No	Few
Solid biomass	Yes	Many
Biogas	Yes	Mainly experimental
Direct geothermal energy	Yes	Many
Ground source heat pumps	Yes , cooling needs as well	Mainly experimental and demonstration
Waste heat	Yes	Few
Co-generation of heat and power	Yes	Many

Source: Own estimation

5. USE OF SUSTAINABLE ENERGIES FOR POWER GENERATION IN GREENHOUSES

Sustainable energies can be used for power generation in greenhouses including:

a) Solar-PV energy,

b) Co-generation of heat and power, and

c) Fuel cells.

The generated power with these systems can cover the power needs of the greenhouses and sell the surplus electricity into the grid. The rapid decrease in the prices of photovoltaic cells allows their use for electricity generation in many applications including greenhouses. At the same time in many countries the net metering regulation permits generation of electricity in grid connected greenhouses in order to offset annually their grid electricity consumption. In the Mediterranean region and in areas with high solar irradiance (approx. latitude 35° north) annual solar electricity generation with PVs is approx. 1,500 KWh per KWp. Photovoltaic systems installed in greenhouses in Southern Italy have been reported (Sgroi *et al.*, 2014). The authors stated that due to the high feed-in tariffs offered the installation of solar-PV systems was very profitable.

The cost effectiveness of solar-PV applications in greenhouses has been reported (Sgroi *et al.*, 2014) indicating that it could be an alternative technology feeding electricity to them. Replacement of grid electricity in greenhouses, which is mainly generated with fossil fuels, with solar-PV electricity would result in the reduction of CO_2 emissions in them and the increase of their sustainability.

Co-generation of heat and power (CHP), is an efficient and eco-friendly method for providing energy in greenhouses. Natural gas is the most common fuel used for that and the efficiency of the process varies between 80-85 %. Biomass could also be used as fuel apart from gas. The heat produced can cover its heating needs and the generated power can cover its electricity needs selling any surplus into the grid. CHP technology is currently used in many large greenhouses. Electricity could also be generated in greenhouses with fuel cells. It could cover their power needs and it could possibly sell any surplus into the grid. Co-produced heat could cover their heating needs. However such commercial applications have not been reported so far. Sustainable energies which have been used for power generation in greenhouses are presented in Table 3.

Table-3. Sustainable energies which can be used for electricity generation in greenhouses

Energy source/technology	Possibility of covering all the electricity needs	Commercial applications
Solar-photovoltaic	Yes	Yes
Co-generation of heat and power /gas	Yes	Yes
Fuel cells/hydrogen	Yes	No, only experimental

Source: Own estimation

6. USE OF RENEWABLE TRANSPORT FUELS IN GREENHOUSES

Goods produced in greenhouses need transporting to the consumers sites. Usually transport fuel, mainly diesel oil, is consumed for that purpose. Replacement of diesel consumed in the trucks, based on fossil fuels, with biodiesel could zero CO_2 emissions due to transport fuel use. Therefore the reduction of the carbon footprint in greenhouses due to transport fuel is relatively easy without requiring capital investments in the greenhouse.

7. CASE STUDY OF A GREENHOUSE HAVING A LOW CARBON FOOTPRINT

In order to estimate the potential of carbon footprint reduction in a modern greenhouse with a covered area of 1,000 m^2, the following assumptions are made. The greenhouse is initially using grid electricity, diesel oil for its heating and diesel fuel for transport. Annual energy consumption in the greenhouse for heating is 150 KWh/m^2, for electricity 30 KWh/m^2 and for transport 20 KWh/m^2. In order to reduce its carbon footprint, solid biomass will be used for covering its heating needs. A solar-PV system will be installed providing all its electricity requirements with the net metering initiative. Finally biodiesel, instead of conventional diesel, will be used in the trucks transporting the good produced in the markets. The necessary annual quantities of solid biomass required have been estimated as well as the nominal power of the solar-PV system installed. An estimation of the capital and the operating costs of these two systems wasmade as well as the annual cost savings due to renewable energy systems. Finally the annual CO_2 emissions savings in the greenhouse due to changes in energy used have been estimated. It has been assumed that the solid biomass used for its heating results in zero CO_2 emissions. The energy consumed for its harvesting and its transport to the greenhouse has not been taken into account. It has also been assumed that the replacement of the conventional transport fuel with biodiesel has no additional cost. The results are presented in Table 4.

Table-4. Estimation of various parameters in a greenhouse using renewable energies instead of conventional fuels for covering its energy needs.

Area of the greenhouse	1,000 m^2
Energy consumed for heating	150,000 KWh/year
Electricity consumption	30,000 KWh/year
Transport fuel consumption	20,000 KWh/year
Heat content of solid biomass	4.6 KWh/kg
Efficiency of the solid biomass heating system	75 %
Annual quantity of biomass required	43,478 kg
Cost of solid biomass	0.12 €/kg
Annual cost of solid biomass	5,217 €
Size of the biomass boiler	200 KW
Electricity generated from the solar-PV system	1,500 KWh/KWp
Nominal power of the solar-PV required	20 KWp
Cost of the solar-PV system	24,000 €
Diesel oil used for heating initially	15,000 lt/year
Annual cost of diesel oil used for heating initially	7,800 €
Cost of grid electricity	0.25 €/KWh
Cost of grid electricity used initially	7,500 €
Installation cost of biomass boiler	20,000 €
Total installation cost of the biomass boiler and the solar-PV system	44,000 €
Annual maintenance cost of the biomass boiler and the solar-PV system	2,200 €
Annual maintenance cost of diesel boiler	1,200 €
Annual energy operating cost initially	16,500 €
Annual operating cost with the use of renewable energies	7,417 €
Annual savings in the operating cost	9,083 €
Annual CO_2 emissions initially due to grid electricity use	22,500 kg CO_2
Annual CO_2 emissions initially due to heating oil use	48,000 kg CO_2
Annual CO_2 emissions initially due to transport oil use	6,400 kg CO_2
Total annual CO_2 emissions initially	76,900 kg CO_2
Payback period for the investment in renewable energy systems	4.84 years
Necessary investments in renewable energy systems per annual CO_2 emissions savings	0.57 € per kg CO_2 saved annually

CO_2 emissions for diesel oil = 3.2 kg /lt

CO_2 emissions due to electricity use = 0.75 kg CO_2/KWh

The cost of a biomass boiler and a solar-PV system in the abovementioned typical greenhouse with covered area of 1,000 m^2 which could provide all the required energy for heating and electricity has been estimated at 44,000 €. Their use could replace diesel oil and grid electricity which were used initially and were emitting , together with the transport fuels used , 76,900 kg CO_2 annually.

8. CONCLUSIONS

Energy consumption in greenhouses depends on the type of construction, the climate conditions and the crop cultivated. In a typical greenhouse most of the energy used is related with its heating. Smaller amounts are used for electricity and for transporting the crops produced. Reduction of the carbon footprint due to energy use in a greenhouse could be achieved with a) Reducing the heat consumption by decreasing its heat losses , b) Replacing conventional fuels used for heating with renewable energies like solid biomass and/or geothermal energy , c) Offsetting the grid electricity used with solar-PV electricity and d) Replacing conventional transport fuels with bio-fuels. The necessary technologies to obtain this result exist and some of them are mature, reliable, cost effective and are being used currently on commercial scale. Investigation of the possibility of reducing the carbon footprint in a typical greenhouse with a covered area of 1,000 m^2 has shown that all its CO_2 emissions due to energy use could be eliminated with the use of mature, reliable and well proven renewable energy technologies. These technologies include solid biomass burning for heat generation and solar-PV panels for electricity generation. Solar energy and solid biomass could replace all the fossil fuels used initially in the greenhouse. With reference to the abovementioned greenhouse with covered area of 1,000 m^2, its annual energy consumption was 200,000 KWh and the investment cost of the renewable energy systems installed was 44,000 €. Annual CO_2 savings have been estimated at 76,900 kg, the decrease in the annual operation cost was 9,083 € and the payback period of the investment in the abovementioned renewable energy systems was 4.84 years. Therefore the increase of the sustainability and the reduction of the carbon footprint in agricultural greenhouses could be achieved with the use of mature and cost effective renewable energy technologies reducing or even eliminating the use of fossil fuels in them. Future construction and operation of a modern greenhouse using only renewable energies for covering all its energy requirements would give further insight into any problems which might appear and will prove the feasibility and the cost effectiveness of these technologies.

Funding: This study received no specific financial support.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

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