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Use of Low and Zero Carbon Energy Technologies in Agricultural Greenhouses

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Abstract

Climate change consists of a severe global environmental problem threatening the prosperity of our societies. Greenhouses utilize electricity and heat covering their energy needs while they mainly use fossil fuels and electricity derived by them. Heat energy has the highest share in the overall energy mix. The use of low and zero carbon technologies in agricultural greenhouses is presented in the current study. Solar energy, wind energy, biomass and geothermal energy can be used for heat and power generation in them. Various low carbon energy technologies including co-generation systems, heat pumps, fuel cells, district heating systems and low grade rejected heat can be also used for covering part or all of their energy needs. Many of these technologies are mature, reliable and cost-efficient while they are already used in greenhouses as well as in other sectors. They can replace fossil fuels reducing their carbon emissions due to energy use in them. Our results indicate that use of various reliable, mature and cost-efficient renewable and low carbon energy technologies in greenhouses can replace fossil fuels reducing or even zeroing the carbon emissions due to energy use in them.

Introduction

Climate change mitigation requires the replacement of fossil fuels with renewable energy sources as well as with low carbon emission fuels. European Union and many other countries are planning to become carbon neutral in the coming decades zeroing their net carbon emissions. Agricultural greenhouses utilize energy in various sectors including space heating and cooling, lighting and operation of various machinery and equipment. The most of them currently use fossil fuels and grid electricity while the use of benign energies is rather limited. Technological advances in various sustainable energy technologies allow their use in many sectors, including in greenhouses, since they are reliable, environmentally friendly and cost-efficient compared to conventional energy technologies. Use of benign energy technologies could offer economic benefits to greenhouse owners while they improve environmental sustainability contributing in the global effort for climate change mitigation. Their use could result in net zero carbon greenhouses according to the EU target for achieving a carbon neutral economy by 2050.

Aim of the current research is the presentation of various renewable energy technologies as well as low carbon energy technologies, which are used or could be used in the future for covering the heat and electricity requirements in agricultural greenhouses.

Energy Consumption in Greenhouses

Energy requirements in greenhouses depend on several factors including the local climate, the type of construction, the materials used, as well as the growth conditions and the temperature requirements of the cultivated crop. Energy is used in agricultural greenhouses for covering their needs in space heating and cooling, lighting and operation of electric equipment and machinery. The cost of energy, in some cases, could reach at 20-30% of the total production cost in greenhouses. In most modern greenhouses, heating energy has a share at approximately more than 90% in the overall energy consumption while the rest is electricity [1,2]. The operational energy use and the carbon emissions in greenhouses with tomato crop in different countries, according to published research, are presented in Table 1.

Table 1: Operational energy use and CO₂ emissions in agricultural greenhouses with tomato crop

Author/year	Crop	Energy consumption	CO ₂ emissions
Ntinis et al. 2016	Tomato, Europe	0.8-160.5 MJ/kg	0.1-10.1 KgCO ₂ per kg of tomato
Hatirli et al. 2006	Tomato, Turkey	5.34 MJ/m ² year	
De Gelder et al. 2011	Tomato, Netherlands	21.7 MJ/kg	
Canakci et al. 2006	Tomato and other vegetables, Turkey	23.8-28 MJ/m ² year	
Boulard et al. 2011	Tomato, France	31.6 MJ/kg	2.02 kgCO ₂ /kg

Source: Vourdoubas [3].

Use of Renewable Energy Sources and Technologies in Greenhouses

Various renewable energy sources could provide heat and electricity in greenhouses including:

- Solar energy
- Geothermal energy
- Solid and gaseous biomass
- Wind energy



Solar energy

Solar energy can provide heat, cooling and electricity in greenhouses [4,5]. Solar photovoltaic (Solar-PV) systems can generate electricity covering part or all of their requirements. Opaque or semi-transparent solar panels can be used in greenhouses covering their annual electricity needs according to net-metering regulations. Use of solar-PV systems can zero their net carbon emissions due to electricity use. Solar energy can be also used for heat production in greenhouses although its use is rather limited so far.

Geothermal energy

Geothermal fluids, when are available nearby the greenhouses, can cover all their heating needs in a cost-efficient way [6]. Low enthalpy geothermal fluids at around 45-60°C can be circulated inside plastic pipes located on the ground among the plants and heating the cultivated crop. Geothermal fluids, when available, are used worldwide for heating greenhouses. High efficiency heat pumps, utilizing the ambient heat and electricity can be also used for heating and cooling agricultural greenhouses. The installation cost of heat pumps is high and their use in greenhouses is rather limited to day.

Solid and gaseous biomass

Solid biomass is used by burning for heating greenhouses [2,7,8]. Use of local biomass is a cheap method for heating them although it results in emissions of smog, particulate matter and CO2. Biogas, if available, can be also used by burning for heating greenhouses. Biogas is a less polluting fuel than solid biomass while the CO2 emitted can be recycled inside the greenhouse for enriching the indoor atmosphere and assisting the growth of the plants.

Wind energy

When the wind potential and the mean annual wind velocity nearby greenhouses are high the wind energy can be used for electricity generation [9,10]. Wind turbines can be used for that while in many areas dominated by greenhouses the mean annual wind speed is high and attractive for electricity generation. Wind electricity has so far limited applications in greenhouses. Combined use of renewable energy technologies like solar-PVs and solid biomass burning as well as solar-PVs and ground source heat pumps can cover all the annual energy requirements in greenhouses.

Various renewable energy sources and technologies that can be used for heat and electricity generation in greenhouses are presented in Table 2.

Table 2: Use of renewable energy sources and technologies in greenhouses

Table with 4 columns: Energy source, Energy technology, Generated Energy, Current Applications. Rows include Solar energy (thermal, PV), Low enthalpy geothermal fluids, Solid biomass, Biogas, and Wind energy.

Use of Low Carbon Energy Technologies in Greenhouses

Various low carbon energy technologies can be also used in greenhouses providing heat, cooling and electricity including:

- a) Heat and power co-generation systems

- b) District heating systems
c) Heat pumps
d) Fuel cells
e) Waste heat recycle

Use of heat and power co-generation systems

Co-generation of heat and power (CHP), with various energy systems, is an attractive energy technology with overall efficiency at around 85-90% [11-13]. Natural gas is a preferable fuel while biomass can be also used in these systems. CHP systems can cover all the electricity requirements in the greenhouse selling any surplus into the grid. Co-generated heat can cover part or all of their heating needs while during the summer it could be used for space cooling in the greenhouse with thermal cooling absorption systems. CHP systems are mature, reliable and popular in large greenhouses due to their high energy and cost efficiency.

District heating systems

When greenhouses are located in areas with district heating systems they could use the hot water provided by the district heating system for heating their crops. The cost of greenhouse heating using the hot water from district heating systems is lower than the cost of individual heating systems while the energy investment regarding the installation of an individual heating system is saved.

Heat pumps

Heat pumps can provide heat and cooling in agricultural greenhouses [14,15]. They are very efficient energy devices with coefficient of performance at around 4-6 utilizing electricity and ambient heat. Although they are expensive equipment their use is increasing in many sectors due to their high efficiency. They can cover all the heating and cooling needs in greenhouses while their use is limited so far.

Fuel cells

Fuel cells are heat and power co-generation systems directly converting efficiently the chemical energy of a fuel, like natural gas or hydrogen, to heat and electricity [16]. Their installation cost is high and their use in various sectors is currently subsidized. Their efficiency in electricity generation is at around 40-50% while in heat production at 30-40%. Although they can cover the electricity and heating needs in greenhouses their use is limited so far.

Waste heat recycle

Low grade waste heat from various industries can be recycled and used for heating greenhouses particularly when they are located nearby the industries [17-19]. Promotion of circular economy favors the recycling of low-grade heat in various sectors including in greenhouses. It is a low-cost heating method and its use is attractive and preferable among other heating technologies. Various low carbon energy technologies used in greenhouses are presented in Table 3.

Table 3: Use of low carbon energy technologies in greenhouses.

Table with 4 columns: Energy source, Energy technology, Generated energy, Current applications. Rows include Solar energy, Low enthalpy geothermal fluids, Solid biomass, Biogas, and Wind energy.

Source: various authors



The Concept of Net Zero Carbon Emissions Greenhouses

Many countries have declared their will to zero their net carbon emissions in the coming decades as a necessary step for climate change mitigation. In this context the achievement of net zero carbon emission agricultural greenhouses due to energy use is important. Use of renewable energies as well as low carbon energy technologies for heat and electricity generation could assist in obtaining this target [3,20]. Depending on the site of the greenhouses and the local availability of various renewable energies they can be used efficiently providing heat and electricity to them. Many of the abovementioned benign energy sources and technologies are mature, reliable and cost efficient and they could be used for that. Technological improvements and increased R and D are expected to improve the attractiveness in other technologies in order to be used in the future. Various benign energy technologies, already used, providing heat and electricity in greenhouses zeroing their net carbon emissions are presented in Table 4.

Table 4: Benign energy technologies that could be used in net zero carbon emissions greenhouses

Energy Source	Energy Technology	Generated Energy	Current Applications
Solar energy	Solar-PV systems (opaque and semi-transparent)	Electricity	Few, increasing
Direct geothermal fluids	Heat exchange	Heat	Many
Solid biomass	Burning	Heat	Many
Biomass	Heat and power co-generation systems	Heat and electricity	Few
Biomass	District heating systems	Heat	Few
Low grade waste heat	Waste heat recycle and heat exchange	Heat	Few

Source: Own estimations

Discussion and Conclusions

The possibility of using sustainable energy technologies in greenhouses has been studied. Modern greenhouses consume large amounts of energy while heat has the main share in their total energy mix. They mainly use natural gas, oil and grid electricity derived by fossil fuels while currently the use of renewable energies is limited. Our results indicate that renewable energies and low carbon energy technologies can cover all the heating and electricity requirements in agricultural greenhouses replacing the use of fossil fuels in them. Many of these technologies are reliable, mature and cost-efficient while others can become soon attractive with technological improvements and innovations. Among renewable energies solar energy, solid biomass and low enthalpy direct geothermal fluids are already used in greenhouses. Among low carbon energy technologies co-generation of heat and power, district heating systems and recycle of low-grade waste heat are already used in them. Other benign energy technologies like heat pumps, fuel cells and wind turbines could be also used in the future. Use of sustainable energy technologies in greenhouses can offer economic benefits to growers while they reduce their environmental impacts. Our findings are important in the current era of climate change mitigation since they indicate that achievement of net zero emission greenhouses is technically and economically feasible. Future research should be focused in the design of net zero carbon greenhouses using various combinations of the abovementioned cost-efficient benign energy technologies.

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