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Overview of the Use of Sustainable Energies in Agricultural Greenhouses

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Abstract

Global concern on environmental problems like climate changes has altered our energy patterns promoting non-polluting renewable energies instead of fossil fuels. Technological advances in sustainable energy technologies allow their increasing use in all sectors of everyday life. Agricultural greenhouses utilize energy for heating, cooling and operation of various electric devices. The highest amount of energy used in greenhouses is consumed in heating them. Controlling crops growth conditions including temperature results in higher productivity and in better economic results. Various sustainable energies including renewable energies and high efficiency and low carbon energy technologies have been used in commercial scale and the technical and economic viability of others has been investigated in experimental scale. Among renewable energies solar energy, biomass and geothermal energy can be used in order to cover part or all of the energy requirements for heating, cooling and power generation of greenhouses. Energy efficient and low carbon technologies like co-generation of heat and power, heat pumps, fuel cells but also waste heat can be used also for energy generation in them. Governmental energy incentives for the promotion of sustainable energies like feed-in tariffs or net-metering allow the use of the abovementioned energy technologies for electricity generation in greenhouses offering additional economic benefits to the farmers. Use of the sustainable energies which are mature, reliable and cost effective in greenhouses results in mitigation of climate changes, use of local renewable energy resources instead of fossil fuels and better profitability of the cultivated crop.

Keywords: agricultural greenhouses, cooling, electricity, energy efficient technologies, heat, renewable energies, sustainable energies

1. Introduction

The necessity to cope with the severe problems of climate changes and the raise of the concentration of greenhouse gases in the atmosphere have increased the use of sustainable energy technologies in various sectors of daily activities. Low or zero carbon energy technologies for generation of power, heat, cooling and vehicle fuels include the use of various renewable energies as well as high efficiency energy technologies like cogeneration of heat and power, heat pumps and waste heat reuse. The majority of these technologies are currently mature, reliable and cost effective since technological innovations have reduced their cost and increased their economic attractiveness. Sustainable energies can find applications for energy generation in greenhouses covering part or all of their energy needs including electricity, heat and cooling. Usually greenhouses use grid electricity for lighting and operation of various electric devices and heating oil, fuel oil or gas for heating, contributing in CO_2 emissions in the atmosphere. Depending on the location and the type of the greenhouse, energy consumption may contribute more or less to the production cost of the crop, influencing the energy use in it. Mediterranean greenhouses are light structures with low energy consumption and low contribution of the energy cost to the final crop production cost. Governmental policies and various incentives play an important role in the promotion of sustainable energies use in agricultural greenhouses. Among renewable energies solar energy, solid biomass and geothermal energy have been used already in them. In some areas with high wind velocities, wind energy can be also used for power generation. Solar energy, wind energy and geothermal energy are site dependent and solid biomass should be produced nearby the greenhouse location, in order to minimize its transportation costs. Among energy efficient technologies cogeneration of heat and power, heat pumps, as well as waste heat recycle have been used in greenhouses and the emerging technology of fuel cells can be probably used in the near future. Successful incentives like feed-in tariffs and net-metering can promote the use of solar-PV energy, wind energy, and co-generation of heat and power in greenhouses offering the opportunity to the farmer to co-generate electricity additionally to crop production and to reduce or zero its electricity consumption cost. However, in some cases, the use of sustainable energies in greenhouses may require additional capital for the investments, which might not be available to the farmer and this fact limits the application of these technologies in them.

2. Solar Thermal Energy

Solar thermal energy can be easily used for heating greenhouses with various ways using active or passive solar heating systems. Solar heating of a greenhouse depends on its location and the climate conditions, the solar irradiance and its heating needs, but in general solar energy cannot cover all the heating needs of a greenhouse in a cost effective way. A survey of thermal performances of a solar system used for heating greenhouses in Morocco has been presented (Bargach et al., 2000). Solar flat plate collectors were used in order to heat water which afterwards was heating the greenhouse. Experimental results verified theoretical model simulation, obtaining satisfactory system efficiency. Worldwide evaluation of solar energy passive technologies used for heating greenhouses has been reported (Santamouris et al., 1994). They have classified the passive solar agricultural greenhouses in different categories like a) Passive solar using water storage, b) Passive solar with latent heat storage materials, c) Passive solar with buried pipes storage materials, d) passive solar with rock bed storage and e) Passive solar with other types of heat storage. They concluded that passive solar systems can be integrated into agricultural greenhouses in order to reduce their energy consumption for heating. In general these systems can increase the indoor temperature of the greenhouse at 2-12 °C compared with the minimum outdoor temperature. Design and operation of a low energy consumption passive solar agricultural greenhouse in Greece has been presented (Santamouris et al., 2004). They have constructed a 1 000 m^2 passive solar greenhouse with a mass storage wall located on the north side and a network of earth to air heat exchangers buried in the greenhouse. Operation for two years of the system has shown a 35% decrease of its heating requirements and an important reduction of its cooling needs during the summer. A survey and evaluation of various greenhouses heating technologies including solar flat plate collectors, ground source heat pumps and shallow solar ponds has been made (Setni & Sharma, 2008). They have concluded that performance of each system depends on the location, climate conditions and size of the greenhouse. Each heating system has advantages and limitations which should be taken into account. A review of energy storage applications in greenhouses by means of phase change materials has been presented (Kurklu, 1998). According to his findings, the most used phase change materials are based on salts hydrates, paraffins and polyethylene glycol.

3. Solar Photovoltaic Energy

Solar photovoltaic cells can be used for electricity generation in greenhouses covering part or all of their power needs and selling the excess electricity to the grid. Current decrease of photovoltaics prices has increased the attractiveness of solar-PV energy use in agricultural greenhouses. Use of semi-transparent photovoltaic films for Mediterranean greenhouses (simple structures covered with plastic films) as a sustainable technology has been reported (Marucci et al., 2012). The possibility of using semi-transparent PVs, which allow part of solar radiation to pass through them, in greenhouses in Crete-Greece has been examined (Vourdoubas et al., 2015). Their use can be combined with power generation in the greenhouse and the possibility of selling electricity to the grid. At the same time cooling requirements in the greenhouse are decreased. Use of solar PV cell assisted earth to air heat exchanger system for solar greenhouse has been reported (Yildiz et al., 2011). Assessment of the Italian energy policy through the study of a photovoltaic investment on greenhouse has been presented (Tudisca et al., 2013). The authors have analyzed a case study on a farm that has realized a grid-connected photovoltaic system on a greenhouse. They have reported that there are greenhouses in Italy which have invested in PV systems, taking advantage of the high feed in-tariffs offered by the government. However, these high feed-in tariffs have been reduced recently and with net-metering initiative farmers can use PVs in their greenhouses in order to save energy through self-consumption of the generated electricity. Feed-in tariffs and net-metering initiatives allow the farmers to become energy producers in their greenhouses having an additional income from energy generation. A network of small electricity producers can be created promoting distributed power generation. Future expectations of solar-PV use in greenhouses are high due to the decrease of their prices and the increase of the electricity prices.

4. Wind Energy

Many agricultural greenhouses are located in areas with high annual wind velocities where wind turbines can be installed generating electricity in a cost effective way. When the greenhouse is not connected to the grid, the generated electricity must be stored in batteries in order to be used effectively. In the case of grid connected greenhouses, generated electricity from the wind mill can cover various power needs of them. A greenhouse in Turkey which was heated with a hybrid system consisted of a solar assisted geothermal heat pump and a small wind turbine installed separately has been reported (Ozgener, 2010). Electricity generated by the wind turbine was covering though a small part of the annual electricity needs of the greenhouse. Therefore, in areas with high wind energy resources, wind turbines can cover part of the annual electricity requirements of agricultural greenhouses. However, the economic attractiveness of these systems should be investigated and proved for each case. An experimental installation of a small wind turbine in a greenhouse in Italy has been reported (Vox et al., 2008). The annual wind velocity in the installation site was low and the efficiency of the small wind mill was also low.

5. Solid Biomass

Various types of agricultural and forest residues and wastes can be used for heating agricultural greenhouses. Usually solid biomass is cheaper than fossil fuels and the heating system can cover all the heating requirements of a modern greenhouse. Solid biomass should be produced nearby the greenhouse location in order to avoid its transportation in long distance which usually is costly. A greenhouse located in Crete, Greece used for flowers cultivation which covers all its heating needs with olive Kernel wood, a locally produced byproduct of the olive oil producing industry has been reported (Vourdoubas, 2015). During its heating hot water of 50-55 °C was produced which was circulating inside plastic pipes placed on the ground of the greenhouse. The low price of olive kernel wood (approx. 0.1 €/kg) compared with its heating value (approx. 4 051 Kcal/kg) makes it very attractive compared with fossil fuels like fuel and heating oil. Its granular form facilitates its transportation and handling and it can be easily burnt in a proper heating system. Apart from olive kernel wood other types of solid biomass like the Kernels of various fruits including peaches or apricots can be used as an energy source for heating greenhouses. Solid biomass heating systems in greenhouses require proper treatment of the burnt gases, regular cleaning of the heat exchanger and disposal of the ash produced during burning. However, these problems are easily solvable. An economic and environmental assessment of the use of various renewable energies for heating greenhouses has been made (Vourdoubas, 2015). It is concluded that use of solid biomass and geothermal energy are very attractive and profitable options for heating greenhouses.

6. Biogas

Biogas which is generated in landfills, in municipal garbage processing plants or in sewage treatment plants can be used for energy generation in nearby located agricultural greenhouses. It is worth mentioning that CO_2 generated during biogas burning after its purification can be used for the enrichment of the greenhouse atmosphere in order to increase crops productivity. A soilless greenhouse with roses cultivation which used biogas produced in a nearby landfill for heat generation in order to cover the greenhouse heating requirements has been reported (Jaffrin et al., 2003). CO_2 produced during burning after proper purification can be supplemented inside the greenhouse. Application in two 300 m^2 plastic greenhouses has proved the technical feasibility of this technology. The authors have reported that the benefits due to the increased productivity of the crop because of the enrichment of the atmosphere with CO_2, are higher than the benefits obtained because of the cost reduction due to replacement of the fossil fuels used with biogas. An experimental greenhouse in Turkey which is heated with biogas produced with anaerobic digestion of dairy cow manure has been described (Esen & Yuksel, 2013). Temperature inside digestor was kept at 27 °C and the burnt biogas was heating the greenhouse keeping the indoor temperature at 23 °C. Biogas used as fuel in greenhouses can cover all their heating requirements.

7. Direct Geothermal Energy Heating

Geothermal energy is used today in agricultural greenhouses in order to heat them. Low enthalpy geothermal energy consists of a cheap and renewable energy source which can be used for heating greenhouses with rather simple technologies. The use of low enthalpy geothermal source in Northern Greece to heat a greenhouse with roses cultivation has been described (Bakos et al., 1999). Geothermal fluid temperature was 95 °C and the heating system was able to maintain an indoor temperature at 20 °C when the outdoor was 7 °C. In a second experimental greenhouse geothermal fluid temperature was lower, at 50 °C, maintaining an indoor temperature at 15 °C. Space heating was achieved with plastic tubes placed on the ground of the greenhouse where hot water was circulated inside them. Various cost effective renewable energy technologies for energy generation in greenhouses, like solar energy, solid biomass and geothermal energy have been presented (Campiotti et al., 2010). According to them direct geothermal energy heating technology is mature, site-dependent with a current installation cost 1 500-2 000 €/KWth (compared to 1 000 €/KWth for oil). CO_2 emissions are less than 0.1 gr/KWh. Mathematical modeling of geothermal energy heating in a greenhouse equiped also with a thermal curtain for energy saving has been presented (Ghosal & Tiwari, 2004). According to them indoor temperatures of 14-23 °C could be obtained using thermal curtain and flowing geothermal hot water through polyethylene tubes placed on the ground of the greenhouse.

8. Geothermal Cooling

Low enthalpy geothermal energy can be used for cooling greenhouses with earth to air heat exchangers. Soil temperatures few meters below the ground are almost constant all over the year and equal with the annual average air temperatures. During the summer when air temperatures can exceed 40-45 °C, temperatures below the ground are significant lower. A fiberglass greenhouse of 1 000 m^2 located in Greece where plastic buried pipes were placed underneath the greenhouse has been described (Santamouris et al., 1995). A ventilator was used to circulate the air from the upper part of the greenhouse to the air pipes and back again. During the summer when the ambient temperature was much higher than the soil temperature, the ventilator forced the hot air from inside the greenhouse to pass through the buried pipes, where it was partly cooled, and then to return inside the greenhouse with lower temperature. The opposite can happen during the winter, when this underground earth to air heat exchanger can rise the indoor temperature of the greenhouse. Authors have reported that this cooling and heating system can obtain lower and higher air temperatures of 3-5 °C compared to ambient, during summer and winter correspondingly.

9. Geothermal Heat Pumps

Heat pumps are very efficient energy devices which are used broadly in heating and cooling. Their coefficient of performance (C.O.P.) is high in the range of 2-4. That means that they produce 2 to 4 times more energy than the consumed electricity. Ground source heat pumps have higher C.O.Ps due to the fact that they operate more efficiently because of the almost constant temperature few meters below the ground. Use of heat pumps in an experimental greenhouse in Japan has been reported (Tong et al., 2010) and the authors have estimated C.O.Ps values between 3.3 and 5.8. Evaluation of a heat pump system for greenhouse heating in Australia has been reported (Aye et al., 2010). An air to water heat pump was used in a 4 000 m^2 greenhouse and the payback period of the system was estimated approx. to 6 years. This payback period was lower than those reported in previous evaluations. A ground-source heat pump combined with latent heat storage system for heating a greenhouse in Turkey has been evaluated (Benli & Durmus, 2009). Average heating C.O.Ps between 2-3.8 was obtained. The authors found that during January with ambient temperatures between -5 °C and -20 °C, ground temperatures were 5-7 °C making the operation of the heat pump more efficient. An experimental evaluation of using various renewable energy sources for heating a greenhouse in Turkey has been presented (Esen & Yuksel, 2013), including a ground source heat pump combined with a biogas system, concluding that heat pumps can have a leading role in Turkey in the future.

10. Co-Generation of Heat and Power

Cogeneration of heat and power is a very efficient energy generation technology obtaining an overall energy efficiency 75-90%. Different technological systems like gas turbines, steam turbines and diesel engines have been used for that. Since it is a low carbon energy technology which uses fossil fuels but generates low emissions of greenhouse gases, it is promoted in various sectors from E.U. policies (Directive 2008/8/EC). It is currently used in greenhouses for covering their heating needs, part of their power needs and selling the excess electricity to the grid. Various countries offer currently attractive feed-in tariffs for the electricity derived from CHP systems and sold to the grid. Cogeneration systems used in greenhouses are more attractive in northern European countries where greenhouses need heating almost all the year, than in warmer climate like Mediterranean countries (Garcia et al., 1998). Natural gas is the most popular fuel used in cogeneration systems and heat storage can improve the economics of such a system. Various cogeneration systems applications in greenhouses have been reported (Compernoll et al., 2011). They have implemented two case studies which prove the profitability of C.H.P. systems resulting also in positive environmental impacts. A C.H.P. in a greenhouse can 1) generate electricity which can be used in the greenhouse and the excess sold to the grid, 2) produce heat covering its heating needs, 3) Produce cooling with absorption cooling systems when the greenhouse needs cooling instead of heating and 4) Enrich the greenhouse atmosphere with purified CO_2 from the exit gases resulting in increasing productivity of the crop and improving its economics.

11. Waste Heat Recovery

Power plants as well as various other plants reject cooling water at temperatures which can be effectively reused for various heating purposes. Low enthalpy cooling water can be used for heating greenhouses covering all their heating requirements. Use of the water from the cooling towers of the large power plant in NiederauBen, Germany for heating commercial greenhouses has been reported (Bredenbeck, 1992). An area of 53 000 m^2 of greenhouses was heated with warm water at 30 °C during the winter, keeping the indoor temperature at 22 °C with ambient temperature at -14 °C. The heating system was using water to air heat exchangers with forced ventilation, properly controlled. The ratio of electricity used to gained heat energy varies from approx. 1:20 to 1:30 depending on temperatures of the cooling water, as well as the indoor and outdoor temperatures. Authors concluded that the use of waste heat for heating greenhouses is not so simple as it seems due to various financial and organizational problems. The possibility of using the cooling water of the power plant in Heraklion, Crete, Greece for heating nearby greenhouses used for cultivation of various vegetables like tomatoes, cucumbers, green papers and egg-plants has been presented (Vourdoubas et al, 1998). Maximum cooling water temperatures vary from 25 °C in the winter to 31 °C in the summer and the required minimum indoor temperatures in the greenhouses vary from 10°C-14 °C during day time and 8 °C-13 °C during the night.

12. Fuel Cells

Fuel cells can be used for cogeneration of heat and power in order to cover the energy requirements of agricultural greenhouses. Electricity generation efficiency of the fuel cells is approx. 50% and the overall efficiency including heat production is 80-90%. Modeling of a floriculture greenhouse in India equipped with solar- PV cells, an electrolyzer and a PEM fuel cell has been reported (Ganguly et al., 2010). Excess electricity generated from solar-PVs during peak hours after meeting the requirements of the greenhouse, can be used for hydrogen production with water electrolysis, which is consumed from the PEM fuel cell for electricity generation to cover electricity needs of the greenhouse during the low sunshine hours. This study has shown that such an integrated power system provides a viable option for powering stand-alone greenhouses in a self-sustained manner. The possibility of using fuel cells for providing energy in commercial greenhouses has been reported (Mulloney, 1993). According to him the benefits which are resulted from this application include a) Generation of electricity which can cover the greenhouse requirements and the rest can be sold to the grid if this is allowed. b) Heating the greenhouse as well as cooling it during the summer with absorption cooling systems c) Exhaust gases from the fuel cell can be used directly to greenhouse both for heating and for enriching the atmosphere with CO_2 in order to increase crop productivity. Renewable energies which can be used for energy generation in greenhouses are presented in Table 1 and low carbon technologies which can also be used for that are presented in Table 2.

Table 1. Renewable energies which can be used for energy generation in greenhouses

Energy source	*Generated energy*
Solar thermal	Heat
Solar- PV	Electricity
Solid biomass	Heat
Biogas	Heat
Direct geothermal	Heat
Ground heat (heat exchanger)	Heat and cooling
Wind	Electricity

Table 2. Low carbon energy technologies which can be used for energy generation in greenhouses

Technology	*Generated energy*
Cogeneration of heat and power	Heat and electricity
Fuel cells	Heat and electricity
Waste heat recycle	Heat

13. Benefits from the Use of Sustainable Energies in Greenhouses

The use of sustainable energies in agricultural greenhouses results in many environmental, social and economic benefits including:

a) Reduction of CO_2 emissions to the atmosphere due to the use of fossil fuels or to low efficiency energy technologies.

b) Increasing use of local renewable energy resources instead of fossil fuels which in many cases are imported.

c) Economic benefits to the farmers in the case that sustainable energies used are cost effective and reduce the production cost of the crop.

d) Possibility of creation of an additional income to the farmer in the case of using solar-PV energy or C.H.P. systems in the greenhouse and selling the electricity to the grid.

e) Increase of the employability and the local income from the exploitation of local resources like biomass and the operation of local companies installing and maintaining sustainable energy systems.

14. Conclusions

The effort to cope with global environmental challenges and climate changes has increased the use of non polluting energy resources including renewable energies and low carbon energy technologies. Recent improvements and innovations in these energy technologies have increased their reliability, maturity and their cost effectiveness. Therefore they can be used broadly for power generation as well as for heating and cooling. Modern agricultural greenhouses require energy in various operations and traditionally they use fossil fuels. However they can be replaced with sustainable energies, including solar energy, biomass, geothermal energy, heat pumps, cogeneration systems and reuse of waste heat. Depending on the case they can cover part or all of their energy needs in heating, cooling and electricity consumption. There are currently worldwide various commercial greenhouses using renewable energies and low carbon energy technologies. The technological viability of some others has been investigated and proved in experimental installations. Use of solar-PV cells or C.H.P. systems in grid connected greenhouses is combined with selling the electricity to the grid with attractive feed-in tariffs resulting in additional income to the farmers. The benefits of replacing conventional fuels in greenhouses with sustainable energies result in many environmental and economic benefits to the farmer and to the local society.

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