Possibilities of Using Renewable Energy Sources for Covering all the Energy Needs of Agricultural Greenhouses

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Abstract

Renewable energy sources are used worldwide for generation of heat, power and the production of vehicle fuels. They can cover all the energy needs of agricultural greenhouses with a cost effective way. Among renewable energies solar energy, biomass and geothermal energy can be used for providing heat, cooling and electricity to them. Production of various crops from agricultural greenhouses with zero CO_2 emissions due to energy use could make their products very attractive to environmentally conscious consumers and this could be an effective marketing tool. Agricultural greenhouses consume energy for heating and cooling as well as for lighting and operation of various machinery. Depending on the local climate greenhouses consume mainly energy for heating, approx 90-95% of the total annual needs and the rest for electricity. The abovementioned renewable energy sources can be used in a reliable and cost effective way for covering all their energy needs. Two greenhouses are presented where in the first use of solid biomass and solar PV energy and in the second use of low enthalpy geothermal energy and solar PV energy cover all their energy requirement s increasing their sustainability and reducing their CO_2 emissions due to energy use.

Keywords: biomass, cooling, electricity, geothermal energy, greenhouses, heat, renewable energy sources, solar energy.

1. Introduction

Use of renewable energy resources is of primary importance in order to cope with the climate changes which threaten the global growth and prosperity and create severe natural disasters in various countries all over the world. They are used for power and heat generation as well as for the production of biological fuels used in various vehicles. Costs for energy and biofuels production from renewable energy sources are decreasing so in many cases they compete with the cost of energy derived from fossil fuels. Use of renewable energies instead of fossil fuels has many environmental, social and economic benefits and results in mitigation of the greenhouse effect. They are currently used broadly for power and heat generation in buildings, in industry and in agriculture where successfully substitute fossil fuels. Greenhouses require heat and power for the production of various crops. The quantities of electricity and heat needed depend on the local climate, the greenhouse construction and the cultivated crop. In general it can be said that the most of energy used is consumed for their heating.

Among renewable energy sources solar energy, biomass and geothermal energy have been used for covering the heating needs of the greenhouses (Campiotti et.al., 2010 , Campiotti et.al., 2012 , Sethi et.al.,2008 , Vox et.al , 2008). Various experimental installations have been tested and many commercial greenhouses operate today using renewable energy sources instead of fossil fuels, like fuel oil , heating oil , LPG and natural gas, for their heating. Depending of the specific area, the local availability of the abovementioned renewable energy sources is an important factor for their use in greenhouses. However greenhouses apart from heating require electricity for lighting, cooling and operation of various electric devices (motors, valves, pumps, fans e.t.c.). Due to many technological improvements and breakthroughs the recent years the cost of electricity generated from solar-photovoltaic cells has been reduced substantially and competes with the cost of grid electricity.

Therefore PV cells can be installed and they can cover all the electricity needs of a modern greenhouse in a cost effective way (Carlini et.al., 2010, Marruci et.al., 2012 , Tudisca et.al., 2013). The use of renewable energy sources for covering all the energy needs of a greenhouse results in the production of crops with zero CO_2 emissions due to energy use. The production of green eco-friendly products like vegetables, fruits and flowers from greenhouses makes them very attractive to environmentally conscious consumers and offers them a competitive advantage related to the same products produced from conventional greenhouses. Currently the use of renewable energies in European greenhouses is very low and there is not any legal framework regarding their use in them (Campiotti et.al. , 2012) .

2. Solar Energy

Solar energy can be used in greenhouses for heating and power generation.

2.1. Solar Heating of Greenhouses

Solar heating can be achieved with storage of thermal energy which is collected during day time and it can be used when it is needed (Chikaire et.al., 2010) . Heat can be stored in water (Santamouris et.al., 1994), in various solutions with or without phase change (Kurklu , 1998) , in the soil or in a wall constructed in the north side of the greenhouse. Solar heating can increase few degrees (3-10 ^oC) the indoor temperature but it is difficult to cover all the heating needs of the greenhouse. However the cost of solar heating is low and this method can be combined with another heating system to cover all the heating needs of the greenhouse.

2.2. Solar Cooling of Greenhouses

Solar cooling in greenhouses can be obtained with a system of empty plastic tubes buried in the ground beneath them (Santamouris et.al., 1995, Yildiz et.al., 2011) . The tubes are connected with a fan which circulates air from inside the greenhouse through the plastic tubes which is cooled as it passes through the tubes since the temperature of the ground is relatively constant and lower in the summer than the inside temperature of the greenhouse.

2.3. Solar-PV Electricity Generation in Greenhouses

Solar energy can also be used for power generation in greenhouses with photovoltaic cells (Carlini et.al., 2010, Marruci at.al., 2012). Depending on the power needs of the greenhouse and the size of the PV system it can cover part or all of the electricity needs of it. Due to high cost of electricity storage in batteries it is preferable to use solar-PV cells connected with the electricity grid. In this case the PV system can be sized to generate annually the same amount of electricity as the greenhouse consumes. Since net-metering becomes a common practice in many countries solar-PV generated electricity can offset annually the grid electricity consumption of the greenhouse. Rapid fall of PV cell prices and the gradual increase of grid electricity prices result in increasing the attractiveness of the installation of solar-PV systems in agricultural greenhouses for covering all the power needs of them. Combination of PV cells generating electricity in greenhouses and partly used for water electrolysis for hydrogen production has been reported. Hydrogen can be stored and used later for power generation via fuel cells. This system offers the possibility of storing excess electricity in hydrogen instead of batteries but it is not currently economically viable (Ganguly et.al., 2010). Covering the greenhouse with semi-transparent solar-PV cells offers the possibility of electricity generation and simultaneously allowing solar irradiance to enter inside the greenhouse. Mono- and poly-crystalline as well as thin film solar cells are currently available but they have to prove their economic viability in the future. In table 1 the characteristics of various heating systems using renewable energies in the greenhouses are presented.

3. Biomass

Gaseous and solid biomass have been used for heating greenhouses. Biogas produced from landfills has been used in nearby greenhouses for covering their heating needs (Jaffrin et.al., 2003) . The flue gases after biogas burning contain CO_2 and they can enrich the atmosphere inside the greenhouse improving crops growth and productivity. Since biogas is produced from wastes (either from landfills, or from cattle wastes or from sewage treatment plants) its cost is low. Its heating value (5,000 Kcal/NM^3) is approx the half of heating oil and it can cover all the heating needs of the greenhouse. Apart from biogas, solid biomass in the form of agricultural byproducts and residues has been used for covering all the heating needs of greenhouses. Burning solid biomass results in hot water production with temperatures 40-55 ^oC which can be circulated in plastic pipes placed on the ground of the greenhouse.

Alternatively burning solid biomass can result in hot air production which can be circulated inside the greenhouse. In areas with cultivation of olive trees a byproduct of olives processing, the olive kernel wood, has been used successfully for heat generation in greenhouses (Vourdoubas , 1999) . Its high heating value which is estimated at 4,051 Kcal/kg combined with its good burning characteristics and its low price makes it an attractive alternative renewable fuel for heat production. Other types of woody biomass like peaches and apricots kernels or forest residues can be used also for heat generation in greenhouses. Due to high cost of solid biomass transport, greenhouses using solid biomass as fuel must be situated nearby the biomass production sites. In the case of biogas use for heating, greenhouses must be situated also nearby the biogas production sites in order to avoid biogas transport. Environmental impacts due to biomass use for heating greenhouses are local and unimportant. They are limited to burnt gases which can be processed (filtered and water washed) in the case of solid biomass. Small quantities of the produced ash can be disposed in a landfill site or it can be recycled as fertilizer in some tree cultivations. Environmental impacts from biogas use are negligible.

4. Geothermal Energy

Geothermal Energy can be used either directly or indirectly for heating greenhouses. Geothermal fluids with temperatures between 40-80 ^{o}C can be used directly for heating (Bakos et.al. , 1999) . Depending on the chemical composition of the fluid it can be either circulated in plastic pipes inside the greenhouse or it can be used with heat exchangers for heating water or air. The geothermal fluid after transferring its heat must be either processed to remove any pollutants which are contained in the fluid or rejected back into the ground. In order to avoid transport of the geothermal fluid and heat losses the greenhouses should be located nearby the geothermal spring. Depending on the heating needs of the greenhouse and on the flow rate and temperature of the geothermal fluid all the heating needs of the greenhouse can be covered. Low enthalpy geothermal fluids are used broadly today to heat greenhouses in various parts of the world. The cost of heat is low but the cost of pollutants removal in some cases may be high.

Geothermal energy can be also used indirectly with heat pumps for heating greenhouses (Ozgener et.al., 2007) . Low enthalpy ground source geothermal heat pumps are used for heating them. In these cases vertical or horizontal heat exchangers inside the soil are used. Recent technological improvements in these systems allow them to operate very efficiently obtaining C.O.P. in the range of 3-4 or even higher. Geothermal heat pumps can cover all the heating needs of the greenhouses during the winter and all the cooling needs during the summer. However their initial capital cost is high and they are capital intensive heating systems. Since the heat pumps consume electricity during their operation, the greenhouse heating cost in that case is higher compared with their direct heating with geothermal fluids. However among the advantages of geothermal heat pumps are the absence of any pollution during their operation and the easiness of automatic temperature control in the greenhouse. The most common used systems are ground to water heat pumps which produce heating water in the desired temperatures. Low enthalpy geothermal energy has been also used for partly heating and cooling greenhouses with an underground heat exchanger. In this case the soil underneath the greenhouse is excavated in depth approx. of two meters and empty plastic tubes are placed inside covered with the soil. The tubes are connected with a fan and the inside air of the greenhouse. The soil temperature is relatively stable almost equal with the yearly local average air temperature. The plastic tubes underneath the greenhouse behave like a heat exchanger. During the winter when heat is needed the aerator is forcing air through the plastic tubes which is partly heated and returns inside the greenhouse. During the summer when cooling is needed the hot air inside the greenhouse is circulated with the help of the fan inside the plastic tubes and being partly cooled returns back inside the greenhouse. The underground heat exchanger can partly cover the heating and cooling needs of the greenhouse utilizing the low enthalpy geothermal energy of the ground.

5. Energy needs of Greenhouses

Agricultural greenhouses use energy to cover their heating needs and to operate their electric equipments and machinery. They use energy for:

a) Space heating
b) Space cooling
c) Lighting
d) Operation of various equipments and machinery

Usually they use electricity, natural gas, LPG, heating oil and fuel oil. Conventional energy use results though in the emissions of greenhouse gases. Depending on the specific greenhouse and the cultivated crop they use more energy for their heating than for supplying electricity to various electric equipment. In many cases the required heat corresponds up to 90-95% of the annual energy needs. In order to reduce energy consumption in the greenhouses various energy saving techniques and systems can be used including thermal curtins, double plastic or glass cover or equipments of high energy class. In many cases the energy cost in the greenhouse contributes significantly to the final production cost of various crops. Therefore the decrease of this cost can increase the competitiveness of the produced vegetables or flowers.

Modern greenhouses are energy intensive agricultural systems and annual energy consumption of 300 KWh/m^2 has been reported. Apart from reducing their energy consumption the use of renewable energies is of primary importance in order to cover part or all of their energy needs. The use of renewable energies in the greenhouses must comply with the following criteria:

1) The energy systems must be reliable
2) They must be cost effective
3) The operation of the energy systems must not be complex.

Various renewable energies like solar energy, geothermal energy and biomass comply with those criteria and can be used in them (Vourdoubas , 2004). Use of renewable energies in the greenhouses results in the additional benefit of reducing the emmitted greenhouse gases due to energy use.

6. Use of Solar Energy and solid Biomass for Covering all the Energy requirements of a Greenhouse

Heat and electricity generation in a greenhouse can be obtained without the use of fossil fuels. In this case solid biomass can be used for space heating and solar – photovoltaic cells can be used to generate the power required in the greenhouse. The solar – PV system can be either connected with the electric grid or it can be autonomous and in this case batteries for storing electricity must be used. Burning solid biomass technology is a well known and reliable technology without presenting any serious problem. Therefore the combination of a solid biomass burning system for space heating and a solar – PV system for electricity generation can cover all the annual energy requirements of a greenhouse resulting in the production of crops with zero CO_2 emissions due to energy use. Data for sizing the necessary heating and power generation system are presented in table 3. It has been assumed that the solar – PV system will be interconnected with the electric grid and it will generate annually the same amount of electricity that the greenhouse consumes from it according to the net-metering initiative.

7. Use of Solar Energy and low Enthalpy Geothermal Energy with Heat Pumps for Covering all the Energy requirements of a Greenhouse

The heating and cooling requirements of the greenhouse can be covered with low enthalpy geothermal heat pumps and its power needs with solar-PV cells. Heat pumps are energy efficient devices and for a ground to water heat pump a COP of 3-4 can be easily obtained. Therefore for each KWh of electricity consumed 3-4 KWh of heat or cooling are produced. It is considered that the electricity needed for the operation of the heat pump will be generated from the solar-PV system, together with the electricity needed for the operation of other electric devices. The operation of the heat pump does not have environmental impacts in the site of the greenhouse compared with the operation of a solid biomass burning system which produces exit gases containing pollutants. However its cost is much higher compared with the cost of a solid biomass burning system which can cover only the heating needs of the greenhouse but not its cooling needs. In table 4 various parameters of a greenhouse covering all its energy needs with solar-PV cells and a geothermal heat pump are presented. It has been assumed that the heat pump covers all the heating requirements and not its cooling needs.

8. Comparison of the Two Previous Systems Covering all the Energy needs of the Greenhouses

Comparison of the two previous systems which cover all the energy needs of the greenhouses has been made regarding

a) The capital cost of the energy systems
b) The annual fuel cost of the two systems
c) Total annual CO_2 savings due to energy use
d) Local environmental impacts

The following assumptions have been made

- The capital cost of the solid biomass boiler is 80 Euros per KW
- The solid biomass cost delivered to the greenhouse (in the form of olive kernel wood) is 0.08 Euros per kg
- The cost of the solar-PV system is 1,400 Euros per KWp
- The cost of the ground source heat pump is 2,300 Euros per KW

The results of the estimation are presented in table 5

9. Conclusions

Modern agricultural greenhouses require significant amounts of energy in their daily operation. Although they use mostly conventional fuels recent advances in renewable energy technologies combined with the requirements for cleaner environment and mitigation of the greenhouse effect have changed the traditional energy use pattern towards increased use of renewable energy sources in cultivated crops. Greenhouses use mainly energy for their heating and small amounts of electricity for the operation of various electric equipment. Replacement of fossil fuels with renewable energy sources can be obtained without many difficulties. Solar energy, biomass and geothermal energy can be used today with cost effective technologies. Since greenhouses can cover all their energy needs with renewable energies they can zero their CO_2 emissions due to energy use and their ecological footprint. Two case studies have been examined related with the replacement of conventional fuels with renewable energies in agricultural greenhouses.

In the first solid biomass is used for covering all the heating needs and solar-PV electricity with an interconnected with the grid system for covering all the power needs. In the second low enthalpy geothermal energy with ground source heat pumps is used for covering all the heating needs of the greenhouse and solar-PV electricity with an interconnected with the grid system for covering all the power needs. In both cases there is an offsetting of the electricity consumed annually from the grid with the electricity fed to the grid from the solar PV system with the net-metering framework. Both systems are technically and commercially viable and reliable and can be used without any problems. The use of geothermal heat pump requires a larger solar – PV system to cover the electricity needs of the electric devices of the greenhouse including the electricity needs of the heat pump. In that case the overall capital cost of the heat and electricity generating systems is higher compared with the first case due to the fact that the cost of the solid biomass burning system is relatively low and the required solar-PV system in smaller. However local environmental impacts from the operation of the heat pump are negligible and the fuel cost is zero compared with the first case. In the solid biomass burning system exit gases are produced and they must be processed in order to minimize local environmental degradation.

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Table 1: Characteristics of Heating Greenhouses with Various Renewable Energy Sources

	Investment Cost	**Fuel Cost**	**Heating / Cooling**	**Cover of heating and cooling needs**
1.Solar-heat-storage	Low	0	Heating	Part of heating needs
2.Biomass-biogas	Low	Low	Heating	All
2. Biomass-solid	Low-Medium	Low-Medium	Heating	All
3.Geothermal fluids (40-80^{0}C)	Low	Low	Heating	All
3.Geothermal-Low enthalpy ground heat-buried tubes	Low	Low	Heating and Cooling	Part of the needs
3.Geothermal-low enthalpy ground heat pumps	High	High	Heating and Cooling	All

Table 2: Factors Influencing the use of Renewable Energy Sources in Greenhouses

1. Availability of the energy source
2. Capital cost of the energy system
3. Cost of the fuel and total operating cost of the energy system
4. Reliability of the energy system
5. Environmental impacts of the energy system

Table 3: Sizing a Biomass Heating System and a Solar – PV Power Generation System for Covering all the Energy Needs of an Agricultural Greenhouse

Surface of the greenhouse	1,000 m^2
Specific Electricity	14 KWh/m^2 year
Consumption of electricity	14,000 KWh/year
Specific heating needs	220 KWh/m^2 year
Heating needs of the greenhouse	220,000 KWh/year
Total energy requirements	234,000 KWh/year
Peak heating load	160,000 Kcal/h
Power of the heating boiler	185.8 KW
Efficiency of heating system	70%
Annual power generation from the PV system	1,500 KWh/KWp
Heating value of solid biomass	$4{,}051\frac{Kcal}{Kg}\left(4{,}70\frac{KWh}{Kg}\right)$
Nominal power of the PV system	9.33 KWp
Annual consumption of solid biomass	66.87 tons/year
Annual saving of heating oil	26.75 tons/year
Annual saving of CO_2 due to biomass use	85.60 tons/year
Annual saving of CO_2 due to solar-PV	13.85 tons/year
Total annual savings of CO_2	99.45 tons/year

- Conversion factors
- electricity 0,989 kg CO_2/KWh ,
- heating oil 3,2 kgCO_2/kg fuel

Table 4: Sizing of a low Enthalpy Geothermal Heat Pump for Heating and Cooling and a solar-PV Power Generation System for covering all the Energy needs of an Agricultural Greenhouse

Surface of the greenhouse	1,000 m^2
Consumption of electricity	14,000 KWh/year
Specific heating needs	220 KWh/m^2 year
Heating needs of the greenhouse	220,000 $\frac{KWh}{Year}$
Total energy requirements	234,000 KWh/year
Peak heating load	160,000 Kcal/h
Efficiency of heat pump	350 %
Power of heat pump	53.1 KW
Electricity consumption from the heat pump	62,857 $\frac{KWh}{Year}$
Electricity consumption for the operation of other electric devices	14,000 $\frac{KWh}{Year}$
Total electricity consumption	76,857 $\frac{KWh}{Year}$
Annual power generation from the PV system	1,500 $\frac{KWh}{KWp}$
Nominal power of the PV system	51.24 KWp
Savings of CO_2 emissions due to the use of the PV system	76.01 $\frac{tons\,CO_2}{Year}$

Conversion factor for electricity 0.989 kg CO_2/KWh

Table 5: Comparison of Two Systems covering all the Energy needs of Agricultural Greenhouses

	Use of solid biomass* and PV system	Use of geothermal heat pump and PV system
Capital cost (Euros)	27,926	191,990
Annual fuel cost (Euros)	5,350	0
Annual CO_2 savings (kg)	99,450	76,012
Local environmental Impacts	Due to burnt gases which must be processed	None

* Solid biomass use is considered to have neutral impacts to greenhouse effect