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Possibilities of Using Renewable Energy Sources for Covering All the Energy Needs of Hydroponic Greenhouses. A Case Study in Crete, Greece

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Abstract: Hydroponic greenhouses consume large amounts of energy in order to cultivate the desired crops. Usually they consume fossil fuels for heat production and grid electricity for the operation of various electric devices. The aim of the current work is the investigation of the possibility of using renewable energy sources for covering all the energy needs of a hydroponic greenhouse in Crete, Greece. This could be achieved with the combined use of solid biomass and solar electricity. Solid biomass and solar-PV technology are mature, reliable, well-proven and cost-effective technologies. Solar irradiance and solid biomass, in the form of olive kernel wood, are abundant in Crete and they are extensively used for energy generation. For a hydroponic greenhouse in Crete, Greece with a covered area of 1,000 m^2 and annual energy consumption of 245.5 KWh/m^2, the installation cost of the abovementioned renewable energy systems has been estimated at 42,380€ and the CO_2 emissions savings due to the use of solar energy and solid biomass at 104,725 kg CO_2 /year. The size of the solar-PV system has been calculated at 17 KWp and the annual consumption of olive kernel wood at 66.87 tons/year. Therefore the use of renewable energies instead of fossil fuels in hydroponic greenhouses results in economic and environmental benefits and it should be promoted in order to increase sustainability in agriculture.

Keywords: Crete; Energy; Hydroponic greenhouses; Renewable energies; Solar-PV energy; Solid biomass.

1. Introduction

Renewable energy sources have been used for heat and power generation in numerous cases. Due to their environmental, social and economic benefits, their use is increasing rapidly in buildings, in agriculture and in industry. At the same time some countries are ambitiously aiming to be transformed in the future to zero-carbon societies. Commercial greenhouses successfully using various renewable energy sources have been reported so far. Also some experiments have been constructed and operated using as yet non-proven renewable energy technologies in order to assess their technical, economic and environmental benefits and drawbacks.

An off-grid hydroponic greenhouse which covers all its energy needs from renewable energy sources has been reported by Ronay and Dumitru [1]. The authors stated a small hydroponic greenhouse with covered surface of 280 m^2 which was using a solar-PV system with storage battery for its power supply and solid biomass for its space heating. They also reported that the nominal power of the PV system was 2 KWp and the biomass consumption was 16 tons in a season. Energy aspects in a pilot hydroponic greenhouse with tomato crop in Canada have been reported by Otten , *et al.* [2]. The authors stated that energy savings of at least 30% could be obtained in the greenhouse by reducing the air temperature at 11^{o}C without rootzone heating. They also stated that the overall energy consumption in the greenhouse varied between 105-406 KWh/m^2 depending on the cultivating period. Energy saving techniques in hydroponic greenhouses with tomato crop have been studied by Morgan and O Haire [3]. The authors stated that increased yields were obtained when the root solution was kept at 25.5^{o}C and the air temperatures were kept during the day at 20^{o}C and during the night at 12.2^{o}C. Provided that the energy consumption for heating the root solution is low, the reduced air temperatures during the night would result in significant energy savings. Comparisons of land, water and energy requirements of lettuce grown using hydroponic versus conventional agricultural methods in Arizona, USA have been reported by Barbosa , *et al.* [4]. The authors reported that the energy consumption in the (hypothetical) hydroponic greenhouse was 1025 +_ 152 KWh/m^2 year, which is much higher than the energy consumption in conventionally produced lettuce. They also stated that the energy consumed in the greenhouse is due mainly to heating and cooling loads at 82.22%, the supplemental artificial lighting at 16.66% and the operation of circulating pumps at 1.12%. The high energy requirements for heating and cooling are due to the fact that on the site of the greenhouse, the average summer temperature is 34.7^{o}C and the winter 14.1^{o}C. Greenhouses located in more moderate climates require less cooling and heating energy. Supplementary artificial lighting is needed only for optimization of lettuce production and it is not used in most commercial greenhouses. However the estimations of the authors indicate that in hydroponic greenhouses the energy needed for the operation of the circulating pumps is very low compared with the energy required for heating and cooling. The use of wood biomass as sustainable energy for greenhouse heating in Italy has been reported by Bibbiani, *et al.* [5]. The authors stated that the energy consumption in greenhouses in Italy varies between 21-546 KWh/m^2 year according to different indoor air temperatures. Biomass is considered "greenhouse gas" neutral when converted to heat excluding the GHG generation during harvesting, transportation and pre-processing of raw materials. They also reported that CO_2 enrichment from the exhaust gas of biomass boilers is still challenging and expensive, considering that wood biomass boilers generate a higher volume of particulate matter and ash emissions than other fossil fuels. A techno-economic analysis of wood biomass boilers for the greenhouse industry has been presented by Chau, *et al.* [6]. The authors investigated the use of wood pellets and wood residues in a greenhouse boiler for heat generation. They proposed that an electrostatic precipitator could reduce the particulate matter in exit gases in acceptable levels similar as for natural gas. Economic analysis of a biomass boiler covering 40% of the annual heat demand in the greenhouse is very attractive resulting in high NPV. In the case that an electrostatic precipitator would be used to improve the quality of the gas effluent the NPV is lower but still positive. A hydroponic greenhouse for lettuce production in Alaska using geothermal heat and power has been reported by Karlsson and Werner [7]. The greenhouse had a covered area of 400 m^2 and it was using electricity generated from a geothermal fluid with temperature at 74^{o}C in Alaska. At the same time geothermal energy was used for heat production covering the heating needs of the greenhouse. Although annual outside temperatures vary from -50^{o}C to +35^{o}C it was proved that low enthalpy geothermal energy can sustain successfully the operation of the hydroponic greenhouse in Alaska covering all its energy needs. A review of various renewable and high efficiency energy technologies which could be used in greenhouses has been reported by Vourdoubas [8]. The author presented the use of solar energy, solid biomass, biogas, geothermal energy, fuel cells and co-generation systems which either have been used commercially or experimentally providing heat, cooling and electricity in greenhouses.

The aims of the current work are to investigate the possibilities of using renewable energy sources for covering all the energy needs of hydroponic greenhouses and to present a preliminary design of a hydroponic greenhouse located in Crete, Greece which uses various local and cost-effective renewable energy resources for covering all its energy needs.

2. Energy Use in Agricultural Greenhouses

2.1. General

Greenhouses utilize energy for covering their needs for the heating, cooling, lighting and operation of various electric devices. The amount of energy needed depends on climate conditions, the construction of the greenhouse and the cultivated crop. The largest amount of total energy consumption is utilized for space heating which could reach up to 95% or even more. In Italian greenhouses the energy used for space heating corresponds on average to 96.6% and only 3.4% is consumed for other reasons [5]. In areas with mild climate like Crete, Greece the cultivation of various crops like tomatoes or cucumbers does not require space heating. However in order to increase crops' productivity and product quality, automatic control of various parameters like indoor temperature is needed. This results in higher energy consumption and increased costs which is compensated from the higher yields and better product quality.

2.2. Energy Use in Hydroponic Greenhouses

Hydroponic greenhouses are usually highly automated production systems and many parameters in the cultivated crop are automatically controlled. In a hydroponic greenhouse using the nutrient film technique, recirculation of the solution is needed. Therefore additional energy is consumed in the operation of the recirculating pumps compared with an ordinary greenhouse. Estimations on the energy used in hydroponic greenhouses have been presented [4], indicating that the additional energy used for the recirculation of the solution is only a small percentage (1.12%) of the total energy used. As a result the largest amount of energy in hydroponic greenhouses is used for space heating maintaining the indoor air temperature and the temperature of the circulating solution at the desired levels.

3. Use of Renewable Energy Technologies in Greenhouses

Various renewable energy sources are currently used for energy generation in greenhouses. Other renewable energy technologies could be used in the future if technology improvements will increase their reliability and cost-effectiveness. Among renewable energies, solar energy, biomass and geothermal energy are already used for heat, cooling and electricity generation in greenhouses. Solar energy can be used both for heating and power generation. A study of a solar system used for heating greenhouses in Morocco has been presented by Bargach, *et al.* [9]. The solar system consisted of flat plate collectors which were heating up water. The produced warm water was used afterwards for heating the greenhouse. An assessment of solar passive technologies used worldwide for heating greenhouses has been presented by Santamouris, *et al.* [10]. The Italian energy policy through the study of a photovoltaic investment on a greenhouse has been assessed by Tudisca, *et al.* [11]. The authors stated that the farmers can take advantage of the net-metering initiative to install PV systems in their greenhouses in order to self-consume the generated electricity. Biomass can also be used for heat generation in greenhouses. A greenhouse located in Crete, Greece used for flower cultivation which covers all its heating needs with solid biomass has been reported by Vourdoubas [12]. The greenhouse was utilizing olive kernel wood, a local byproduct of the olive processing industry. A small experimental soilless greenhouse with flower cultivation which used landfill gas for heat generation has been reported by Jaffrin, *et al.* [13]. The authors stated that the recycling of exhaust gases for CO_2 enrichment of the indoor atmosphere resulted in its increased productivity and in many benefits. Low enthalpy geothermal energy consists of a cheap renewable energy source which could be used for heating greenhouses with rather simple technologies. The use of low enthalpy geothermal fluids in Northern Greece to heat a greenhouse with cultivation of roses has been described by Bakos, *et al.* [14]. Low enthalpy geothermal energy can be used for cooling greenhouses with earth to air heat exchangers as described by Santamouris, *et al.* [15]. Geothermal heat pumps are very efficient energy devices with COPs greater than 4-5. Although their cost is still high they can be used for covering all the heating and cooling needs of a greenhouse [16]. Therefore various renewable energies can be used in order to cover all the heating needs of greenhouses. The existing technologies are mature, reliable and cost-effective. Additionally the cost of PV systems is rather low today. Taking into account the net metering initiative, solar-PV energy can provide all the required electricity in a greenhouse. The use of various renewable energies for energy generation in greenhouses is presented in Table 1.

Table-1. Use of various renewable energy sources for heating greenhouses

	Energy source	**Generated energy**
1	Solar-thermal energy	Heat
2	Solar-PV energy	Electricity
3	Solid biomass	Heat
4	Biogas	Heat
5	Direct geothermal energy	Heat
6	Low enthalpy geothermal heat pumps	Heat and cooling

4. Towards 100% Renewable Energy Greenhouses

Replacement of the fossil fuels and electricity derived from fossil fuels with renewable energies could result in 100% renewable energy greenhouses regarding their operational energy use. In order to achieve that, two conditions must be fulfilled.

1) All fossil fuels must be replaced with renewable energies, and

2) The grid electricity used derived from fossil fuels must be offset by green solar electricity. This is allowed in many countries through the net-metering initiative.

Before replacement of the fossil fuels used with renewable energies, it is necessary to reduce its total energy consumption applying various energy-saving techniques and technologies. Possibilities of using renewable energy sources for covering all the energy requirements of greenhouses in Crete, Greece have been presented by Vourdoubas [12]. The author proposed two combinations of renewable energy technologies which could cover all their energy needs. The first combination includes the use of solid biomass and solar-PVs and the second the use of low enthalpy geothermal heat pumps combined with solar-PVs.

Solid biomass can replace fuel oil, heating oil or natural gas which are commonly used fuels for heating greenhouses. Burning solid biomass is a well-known technology which is mature, reliable and cost-effective. The capital cost of biomass burning systems is low. Local biomass resources like olive by-products and residues in Crete, Greece are widely used for heat production. Solid biomass is considered carbon neutral excluding the energy required for its collection, transport and pre-processing before its use. Unfortunately exhaust gases from biomass burning contain particulate matter and undesirable chemical compounds and they could not be used for enrichment of the greenhouse atmosphere with CO_2. The necessary filters and gas cleaning equipment are expensive and currently there are no commercial applications recycling the exhaust gases from solid biomass burning in order to enrich the greenhouse atmosphere with CO_2.

Solar-PV electricity can be used for generating the annually consumed electricity in the greenhouse. Proper sizing of the solar-PV system is necessary in order to ensure that it will generate the annual consumed grid electricity in the greenhouse achieving its offsetting. Therefore the combination of solid biomass and solar energy use in the greenhouse could cover all its energy needs resulting in a 100% renewable energy greenhouse. Assuming that solid biomass and solar energy are carbon neutral, the greenhouse could also be carbon neutral due to energy use.

Low enthalpy geothermal energy with ground source heat pumps could be used for heat and cooling generation in the greenhouse. Geothermal heat pumps are very efficient energy devices with COPs at 5-6 or even higher. They consume electricity generating 5 or 6 times more heat and cooling energy and they could cover all the heating and cooling needs in the greenhouse. Additionally to geothermal heat pumps, solar-PV electricity could be generated covering all the electricity requirements of the greenhouse including those for the operation of the heat pump as mentioned previously. Therefore the combination of geothermal heat pumps and a solar-PV system could cover all its energy needs, achieving the target of a 100% renewable energy greenhouse. In this case the greenhouse would also be carbon neutral since all the grid electricity used would be offset from green solar electricity. The renewable energy technologies which could be used in order to achieve a 100% renewable energy greenhouse in Crete, Greece are presented in Table 2.

Table-2. Renewable energy technologies which could be used in order to achieve a 100% renewable energy greenhouse in Crete, Greece

Renewable energy source	Generated energy	Characteristics	% cover of the energy needs	CO_2 emissions during the use of the energy source
Solid biomass	Heat	Low initial capital cost Low operation cost Reliable and mature technology	100% cover of the heating needs	Yes, due to biomass collection, transport and pre-processing
Low enthalpy geothermal energy with heat pumps	Heat and cooling	High initial capital cost Medium operation cost Reliable and mature technology	100% cover of the heating and cooling needs	Yes, due to electricity use from the heat pump
Solar-PV	Electricity	Medium initial capital cost Low operation cost Reliable and mature technology	100% cover of the electricity needs	No

5. Design Characteristics of A 100% Renewable Energy Hydroponic Greenhouse in Crete, Greece

A preliminary design of a hydroponic greenhouse in Crete, Greece which uses only renewable energy sources for covering all its energy needs has been implemented. Crete has high solar irradiance and the generation of solar electricity is attractive and cost-effective. Olive trees are extensively cultivated on the island resulting in high production of olive oil and olive kernel wood. Current prices for olive kernel wood are low compared with its heating value and its use is desirable and cost-effective. The proposed grid-connected greenhouse uses only solid biomass for space heating and solar-PV energy for electricity generation. The annual generated electricity from the PV systems will be equal with its annual consumption according to the existing net-metering regulations. The specific energy consumption of the greenhouse has been assumed to be the same as the energy consumption of a greenhouse in Crete used for flower cultivation [17]. However the required electricity will be increased for the operation of the circulating pumps as reported by Barbosa , *et al.* [4]. The covered surface of the greenhouse is 1,000m^2 and its energy consumption is 220 KWh/m^2 for space heating, 11.5 KWh/m^2 for the operation of the circulating pumps and 14 KWh/m^2 for the operation of various other electric devices. Therefore in the hydroponic greenhouse, heat would be produced with olive kernel wood and electricity would be generated with a solar-PV system installed near the greenhouse. The power and cost of the biomass boiler, the necessary quantities of the olive kernel wood used, its annual cost and the CO_2 savings due to biomass use have been estimated. Additionally the nominal power of the solar-PV system, its installation cost, and the CO_2 savings due to its use have also been estimated. The design characteristics of the hydroponic greenhouse are presented in Tables 3 and 4.

Table-3. Energy consumption in a hydroponic greenhouse in Crete, Greece

Covered area	**1,000 m^2**
Annual specific heat consumption	220 KWh/ m^2
Annual specific electricity consumption in the circulating pumps	11.5 KWh/ m^2
Annual specific electricity consumption in other electric devices	14 KWh/ m^2
Total annual specific electricity consumption	25.5 KWh/ m^2
Total specific annual energy consumption	245.5 KWh/ m^2
Annual heat consumption	220,000 KWh/ m^2
Annual electricity consumption	25,500 KWh/ m^2
Annual energy consumption	245,500 KWh/ m^2

Table-4. Characteristics of the renewable energy systems used for covering all the energy needs of a hydroponic greenhouse in Crete, Greece

Required olive kernel wood annually	66.87 tons/year
Cost of olive kernel wood (0.09 €/kg)	6,018 €/year
Heat content of the olive kernel wood	4.70 KWh/kg
Efficiency of the biomass heating system	70 %
Power of the biomass boiler	185.8 KW
Cost of biomass boiler	18,580 €
Annual CO_2 savings due to biomass use	85,600 Kg CO_2 /year
Nominal power of the solar-PV system	17 KWp
Annual power generation from the solar-PV in Crete	1,500 KWh/KWp
Installation cost of the solar-PV system (1,400 €/KWp)	23,800 €
Annual CO_2 savings due to solar-PV use	19,125 kg CO_2 /year
Total installation cost of the renewable energy systems	42,380 €
Annual cost of fuels (includes only the cost of olive kernel wood)	6,018 €/year
Total CO_2 savings	104,725 kg CO_2 /year

Conversion factors, heating oil 3.2 kg CO_2/kg of fuel , electricity 0.75 kg CO_2/KWh

6. Discussion and Conclusions

Solid biomass and solar energy are abundant in various areas and the technologies involved in using them for heat and power generation are mature, reliable and cost-effective. In Crete these technologies are already successfully used in many cases. Their combined use could result in covering all the energy needs of a modern hydroponic greenhouse. The design characteristics of such a greenhouse located in Crete, Greece have been presented, and the size of a solid biomass burning system and a solar-PV system have been estimated. The energy consumption of the above-mentioned greenhouse is in the same range of the reported energy consumption in greenhouses in Italy [5] but lower than the estimate for a hydroponic greenhouse in Arizona, USA [4]. However it is higher than the reported energy consumption of an independent autonomous energy hydroponic greenhouse in Romania [1] which used solar electricity and solid biomass for covering all its energy needs. The use of solid biomass for heat generation and solar energy for power generation results in agricultural production systems which are sustainable regarding their energy use. At the same time the above-mentioned sustainable energy systems are cost-effective, resulting in economic benefits to the farmers apart from the environmental benefits. Increased use of sustainable energy technologies in agriculture will increase its sustainability. In the future experimental and demonstration hydroponic greenhouses should be constructed in Mediterranean regions in order to prove the technical and economic viability of the proposed renewable energy technologies.

References

[1] Ronay, K. and Dumitru , C. D., 2015. "Hydroponic greenhouse energy supply based on renewable energy sources." *Procedia Technology,* vol. 19, pp. 703-707.

[2] Otten , L., Muller , P. G., Tiessen , H., Khosla , S., Rey , F., and Jackson , H. A., 1989. "Energy saving hydroponic greenhouse pilot project : energy aspects." *Canadian Agricultural Engineering,* vol. 31, pp. 147-152.

[3] Morgan, J. V. and O Haire, R., 1978. "Heated hydroponic solutions as an energy saving technique ISHS Acta Horticulturae 76 : Symposium on more profitable use of energy in protected cultivation." Available: http://www.actahort.org/books/76/76_24.htm

[4] Barbosa , G. L., Daiane, F., Gadelha, A., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., Wohlleb, G. M., and Halden, R. U., 2015. "Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. Conventional agricultural methods." *Int. J. Environ. Res. Public Health,* vol. 12, pp. 6879-6891.

[5] Bibbiani, C., Fantozzi, F., Gargari, C., Campiotti, C. A., Schettini, E., and Vox, G., 2016. "Wood biomass as sustainable energy for greenhouses heating in Italy." *Agriculture and Agricultural Science Procedia,* vol. 8, pp. 637–645.

[6] Chau, J., Sowlati, T., Sokhansanj, S., Preto, F., Melin, S., and Bi, X., 2009. "Techno-economic analysis of wood biomass boilers for the greenhouse industry." *Applied Energy,* vol. 86, pp. 364–371.

[7] Karlsson, M. G. and Werner , J. W., 2009. "Hydroponic greenhouse lettuce production in subarctic conditions using geothermal heat and power , Proc. IS on soilless culture and hydroponics , Eds.: A. Rodrigues-Delfin & P.F. Martinez." *Acta Hort.,* vol. 843, pp. 275-282.

[8] Vourdoubas, J., 2016. "Overview of the use of sustainable energies in agricultural greenhouses." *Journal of Agricultural Science,* vol. 8, pp. 36-43.

[9] Bargach, M. N., Tadili, R., Dahman, A. S., and Boukallouch, M., 2000. "Survey of thermal performances of a solar system used for the heating of agricultural greenhouses in Morocco." *Renewable Energy*, vol. 20, pp. 415-433.

[10] Santamouris, M., Balaras, C. A., Dascalaki, E., and Vallindras, M., 1994. "Passive solar agricultural greenhouses: A worldwide classification and evaluation of technologies and systems used for heating purposes." *Solar Energy*, vol. 53, pp. 411-426.

[11] Tudisca, S., Di Trapani, A. M., Sgroi, F., Testa, R., and Squatrito, R., 2013. "Assessment of Italian energy policy through the study of a photovoltaic investment on greenhouse." *African Journal of Agricultural Research*, vol. 8, pp. 3089-3096.

[12] Vourdoubas, J., 2015. "Overview of heating greenhouses with renewable energy sources. A case study in crete, Greece." *Journal of Agriculture and Environmental Sciences*, vol. 4, pp. 70-76.

[13] Jaffrin, A., Bentounes, N., Joan, A., and Makhlouf, S., 2003. "Landfill biogas for heating greenhouses and providing carbon dioxide supplement for plant growth." *Biosystems Engineering*, vol. 86, pp. 113-123.

[14] Bakos, G. C., Fidanidis, D., and Tsagas, N. F., 1999. "Greenhouse heating using geothermal energy." *Geothermics*, vol. 28, pp. 759-765.

[15] Santamouris, M., Mihalakakou, G., Balaras, C. A., Argiriou, A., Asimakopoulos, D., and Vallindras, M., 1995. "Use of buried pipes for energy conservation in cooling of agricultural greenhouses." *Solar Energy*, vol. 55, pp. 111-124.

[16] Tong, Y., Kozai, T., Nishioka, N., and Ohyama, K., 2010. "Greenhouse heating using heat pumps with a high coefficient of performance (COP)." *Biosystems Engineering*, vol. 106, pp. 405-411.

[17] Vourdoubas, J., 2015. "Possibilities of using renewable energy sources for covering all the energy needs of agricultural greenhouses." *Journal of Agriculture and Life Sciences*, vol. 2, pp. 111-118.