RENEWABLE ENERGY FOR GREENHOUSE AGRICULTURE

CAMPIOTTI C[*]., BELMONTE A.[**], CATANESE V.[***], DI CARLO F.[*], DONDI F.[*], SCOCCIANTI M.[*], LUCERTI G.[*]
[*]ENEA, UTEE AGR, Via Anguillarese 301 - 00123 Roma, Italy,
[**] CSA srl, Via G. D'Annunzio, 78 - 97100 Ragusa, Italy
[***] 5PV Consulting - 90145 Palermo, Italy
campiotti@enea.it

Abstract: The greenhouse acclimatization is considered an important issue in sector of protected cultivation, because it enables the grower to achieve high plant production and better quality of products, independently of outside weather conditions. In the last decade, however, important changing happened to the agri-food markets of almost all European countries, i.e.: the rising of retail market channels for year-round fresh fruit and vegetable, the liberalization of the European market, and the increase of consumers demand for high-quality fruits and vegetables. These trends, however, have created the escalating of energy consumption in greenhouse agriculture in order to maintain the most important plant growth factors, as temperature, light, humidity, ventilation, etc., at optimum levels. As a result, interest in renewable energy has become more intense for greenhouse operators for reducing their energy costs. In fact, despite the large presence of renewable energy sources in several European regions with a significant greenhouse production, the renewable technologies have still a limited application for greenhouse acclimatization. The aim of this paper is to present information of the cost-effective potential of renewable energy utilization, i.e.: solar PV, solid biomass and geothermal fluids, as sustainable energy for the greenhouse agriculture. The European directives which support the application of the renewable technologies are also reported, together with data regarding both the investment costs and the CO2 emissions, with the perspective of a wider utilization of renewable energy sources in European agriculture.

Key words: greenhouses, geothermic energy, PV solar, solid biomass, geothermic pumps

1. INTRODUCTION

The contribution of agriculture to overall economic output in the EU does not reach the 3% of the GDP (Gross Domestic Product) with only 5% of employment. Nevertheless, due to the high proportion of rural land devoted to farming in most of Europe, the agriculture sector is both a primary supplier of food and raw materials and an important influencing factor on the management of land and environmental quality. Nowadays, the Common Agricultural Policy (CAP) accounts for almost 50% of the Community budget, with the rural areas in the EU-27 representing 80% of the territory and approximately 25% of the population, and nearly 17.5% of the EU's working population living in rural communities, of which about 10% live and work in predominantly rural areas.

Agriculture is estimated to account for a percentage between 2-5% of the direct Europe's total energy budget and to be responsible for 9% of total greenhouse gas emission of which 1.6% in terms of CO_2 emissions which comes from the use of fossil fuels for machinery, tractors and other vehicles, heating of farm buildings, grain drying, and horticultural greenhouse heating (these data are considered underestimated as it is often difficult to separate fuel used in agriculture from that used in other sectors). Several investigations, report that European agriculture consumes an amount of energy approximately equivalent to about 10 million TOE per annum. Within the different energy users in agriculture, the horticulture sector under greenhouse, was reported to represent not less than 60% of the total agriculture energy budget.

As general figure, in Europe there is a greenhouse covered surface of not less than 200,000 hectares of permanent structures, with the higher concentration in the Mediterranean countries, like Spain, Italy, France, Israel, Greece, Turkey, and the countries of the Central Europe like The Netherlands, Poland and Germany (Campiotti et al., 2009). However, the application of acclimatization technologies in greenhouses has steadily expanded throughout Europe during the recent decade due to the possibility of achieving high quality commodities throughout all the season in comparison with a non-acclimatized greenhouse.

As a result, total energy consumption of greenhouse agriculture is steadily increasing because most of the agriculture companies and growers made a shift from un-acclimatized to acclimatized greenhouses in order to satisfy the increasing demand of quality and vegetable production availability all-year-round, which now characterize the European agro-food industry. Thus, as a result the greenhouse sector consumes more energy and produces more emissions. As such, priority should be given to the exploitation of greenhouse district site-dependent from locally available energy and the implementation of laws and regulations to support renewable decentralized power sources, scattered in the rural and agricultural areas. Recently, building on the

EU's three principal goals for energy policy (security of supply, competitiveness and environmental sustainability) on 10 January 2007, the Commission proposed an integrated climate change and energy package (EC, 2007a; EC, 2008a) to reduce greenhouse gas emissions (GHG) by 20% by 2020, to increase the EU contribution from renewable energy to 20% of the total final energy consumption and to increase energy efficiency by 20%. Finally, the Directive 2009/28/EC recommend the Member State to adopt a National Action Plan on the renewable energy with the 2020's objectives on heating and cooling demand/supply and criteria of energy, economic and environmental efficiency. However, the promotion of renewable energy must take place at all levels – international, national, regional, and local, in order to maximize its benefits (Tab.1).

Table 1. Benefits of renewable energy if compared with traditional energy

Avoiding environmental damages, such as the destructive effects of ecosystems and climate change.
Avoiding the high costs of energy imports.
Increasing the security of energy supply by securing independent and more decentralized energy sources.
Avoiding subsidies for atomic and fossil energies, which amount around 300 billion USD annually world-wide.
Avoiding health damage and fatalities.
Avoiding political, economic and military conflicts over limited fossil fuels.
Providing economic opportunities for new industries and services.
Source: Project INCO 2002-C.1.3 n. 012066.

The sector of greenhouse agriculture can contribute to reach the European objectives on energy efficiency and energy saving on the base of three main strategies: i) reduce demand for fossil energy either by increasing renewable energy utilization for cooling and heating or by optimizing plant production and acclimatization technologies; ii) changes in plant production characteristics towards to plant species more local, more seasonal, and based on energy friendlier crop management, in order to save energy for transportation, handling, and plant disease protection; iii) utilization of renewable energy (photovoltaic, solid/residues biomass, geothermic fluids) for acclimatization of greenhouses; iii) contribute to reduce CO_2 emissions and to make agriculture more viable and resilient as energies (oil, gas and electricity). In this context, however, it appears reasonable to change the plant technology production and the energy systems (Tab. 2).

Table 2. Potential for energy saving in greenhouse agriculture

More energy efficiency	Measures of energy conservation techniques and efficiency
More local agriculture	Less transportation of fruits/vegetables by more farm-market
Less fertilizers	Soilless and/or organic agriculture
More renewable energy	Sustainable districts with local energies (solar PV, geothermic/industrial fluids at low temperature, solid biomass)
Less vegetable food waste	Approx. 1/3 of food is wasted in industrial countries

At this purpose, several recent publications demonstrated that the technical problems associated with the renewable technologies in greenhouse agriculture are solved in principle (Tab. 3). In this paper, however, it will be discussed only the cost-effective integration of renewable energy.

Table 3. Data on energy renewable sources

Energy	Cost (€)	CO2 per $1kWh^{-1}$el	Charact-eristics	Barrier factors
Oil	1,000 per kWth	Till to 700 g	Mature	Politics/Availability
Biomass	1,000 per kWth	Neutral	Mature	Logistic/ Location
Geothermic fluids	1,500-2,000 per kWth	Not less than 0,1 g	Mature	Site-dipendent
Geothermic heat pump	2,000-2,500 per kWth	Not less than 0,1 g	Mature	Market/ Commu-nication
Solar photovoltaic	2,000-3,000 per kWel	Till to 45 g	Mature	Market/ Commu-nication

2. SOLAR PV ENERGY AND TECHNOLOGY

Solar energy can cut a farm's electricity and heating bills. The PV capacity installed in the European Union during 2007 and 2008 reached up to 9,533.3 MWp (PV barometer 2009). Photovoltaics can power greenhouse electricity costs for actuators (opening and closing of windows, fertigation) and cooling operation in summer and supply water pumps, lights, electric fences (Fig. 1).

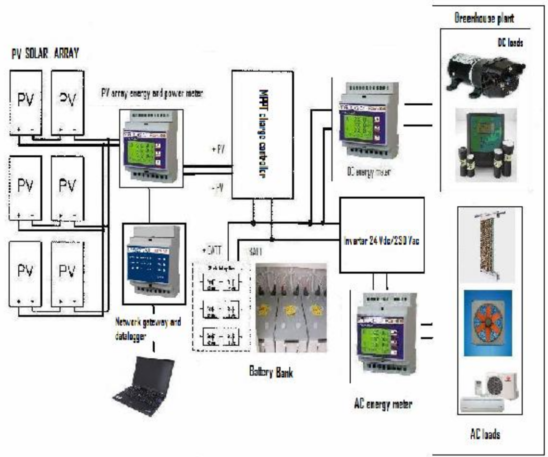

Fig. 1. Lay-out of a 1 kWp PV solar system "stand-alone" for greenhouses

Table 4. Characteristic of commercial biomass for combustion

Biomass	Termic power kWh/Kg (P.C.I.)	Energy capacity (kW)	Operation
Pellets	4.7-5	15-60	Suitable for automatic feeding of the biomass burners.
Briquettes	4.6-5.2	15-100	Less suitable for automatic feeding of the biomass burners.
Chips	3.1	200-3000	For big burners adapted for industrial uses and dwelling.

Since the associated goal is mainly to implementing solar PV systems into the greenhouse agriculture, the following criteria should be met: being simple, easy to manage and repair, and with the possibility of being manufactured locally. Previous experimental evaluations made in southern areas of Italy (36°50' latitude, 14°31' longitude, 87 m of altitude), showed that a 1 kWp m-PV arrays generated 333.6 kWhel during the period 10 September-23 December 2008.

However, it should be outlined that the recorded energy production was mainly referred to the energy delivered to both the battery storage and the greenhouse electric applied loads as inside light, various LEDs, data-loggers and pumps (Campiotti et al., 2008). Research is still in progress. Recently, on the market are being commercialized crystalline silicon modules coming from China, with relative low price (between 1,500 to 2,000 €/kWp). The promotion of PV modules integration in greenhouse agriculture have also a significant importance for reducing the environmental impact associated with the fossil energy (for each kWh_{el} it is reported till to 700 g of CO2 emissions) since the photovoltaic solar installations produce a corresponding GHG emissions between 21-45g of $CO2\text{-eq.}kWh^{-1}$ (Fthenakis and Alsema, 2006).

3. BIOMASS HEAT TECHNOLOGY

Solid biomass should exceed 75 Mtoe in 2010, including 1.6 Mtoe net imports from outside the EU, and thus contributing to reach the 2005 European Plan of action's for biomass which aimed for 149 Mtoe of consumption (55 Mtoe for electricity, 75 Mtoe for heat and 19 Mtoe for transport at the end of 2010) for all bioenergies (solid and liquid biomass, biogas and municipal wastes) (Solid biomass barometer, 2009).

However, the agricultural and forestry biomass resources should be considered as the most promising renewable energy sources from the agriculture sector. More than 300 million tons crop residues and over 230 million tons green residues and animal wastes are produced in Europe as unutilized by-products. Among the crop residues (biomass residues as organic by-products of food, fibre, and forest production), straw is the most important resource with not less than 21 million TOE, of which nearly 0.3 million TOE are utilized for agricultural heat supply, mostly in Austria, Denmark, Germany, and the United Kingdom.

The biomass energy sources are decentralized energies suitable for heat supply of greenhouses, individual farms or rural districts. The calorific value of absolutely dry bio-materials (17-18 MJ/kg) equal to that of the medium quality coal and even the air dry biomass sources, having 14-16 MJ/kg calorific value at 10-20% of moisture content, are excellent and clean energy carriers for direct combustion. Some 20% of biomass potential for combustion may cover the total heat demand of primary food production (agriculture and greenhouse districts) and a further 30% of it the heat requirement of rural communities.

Wood biomass can be considered as greenhouse gas (GHG) neutral when converted to heat energy if we exclude some greenhouse gas generation during harvesting, transportation, pre-processing. Fields of biomass application for heat generation are:

- low temperature heat and hot water preparation for single houses;
- district heat (with and without cogeneration);
- industry process.

The wide-scale practical distribution in greenhouse agriculture of this technology now depends on the national and European energy price policy and the introduction of subsidiary systems which are still necessary to make these technologies more attractive for the farmers (Project Accent, 2006). At present, the wood industry is addressed to introduce adapted cost-effective technologies and suitable supply chains for using pellets (15-60kW as biomass burners), briquettes (15-100kW as biomass burners) and chips (200-300 kW) (Tab. 2).

Biomass consumption as fuel for greenhouse heating is related to both the greenhouse surface and the specific energy needs of crops. Considering a thermal power of the greenhouse surface to be heated equivalent to 100 W/m^2, a conversion yield of 85%, biomass producing 3.9 kWh/kg, the annual average biomass consumption is about 45 kg/m^2 with 1.500 running hours, 90 kg/m^2, 3,000 running hours. Using biomass as an energy carrier, there is a closed CO_2 circle, that in the case of energy generation from biomass, there is no growing CO_2 -content in the atmosphere, no heavy metal emission during combustion, and very low emission of sulphur. Using biodiesel there is an emission save of 2.5 kg of CO_2/liter of gasoline.

4. GEOTHERMAL HEAT IN EUROPE

The geothermal capacity (ground source heat pumps and harnessing of low and medium energy geothermal resources) is nowadays about 14,430 MWth which is almost three times the target set by the European White Paper (5,000 MWth in 2010) (Geothermic barometer, 2009). Europe has geothermal electric power generation only in Iceland (170 MW_e), Italy (785 MW_{el}) and Portugal-Azores (16 MW_{el}). European countries utilize about 18,000 GWh/y of geothermal energy for direct uses of which greenhouse heating and aquaculture represent only a percentage of 14% and 11%, respectively.

Generally, medium-to-low temperature geothermal fluids (T<150°C) can be successfully exploited in direct heat uses in agriculture, e.g.: greenhouses and aquaculture applications, plant drying. High enthalpy geothermal fluids (T>150°C) are utilised to produce electric energy. For such applications, it was demonstrated that the energy substitution provided by geothermal heating solution can reach up to 90% of the heat needs, with a power capacity of 40% of peak load. Specifically, for what concerns the heating demand of greenhouses, in Mediterranean regions, requirements are in the range of 300-400 Toe/y/ha.

There are several heating options, i.e.: forced-air distribution systems, water-to-air heat exchangers, plastic pipes and finned tubes, liquid-based radiant heat in the floor, bench-mounted-liquid based radiant heat (Tab. 5).

The energy delivered by such geothermal systems is between 20 to 70 W/m^2. Furthermore, several investigations shown that simple horizontal ground-source heat pump (GSHP) configurations can supply 20-35 W per m^2 of loop (Campiotti et al. 1999; Popovski and Campiotti, 1999); Campiotti et al., 2009). It is possible, however, with some optimization to have 40-45 W per m^2 from a simple low-cost ground loop installed at deep of not more than 2 meters. The application of a 15 kWth ground source heat pump requires a soil surface where to bury the plastic pipes not less than 400 m^2. The cost of this technology, recently, came down to 2,500-3,000 €/kWth. The CO2 emission by such low-temperature geothermal options is negligible or in the order of 0-1g CO2/kWh depending on the carbonate of the water (Fridleifsson, 2005).

Table 5. The most important factors which influence the competitiveness of geothermal plant greenhouses

The distance between the resource and the greenhouses must be as small as possible to reduce the costs of pipelines and the lost of temperature.
The greenhouse plant should be designed sufficiently large and technologically adapted to reduce the investments and to guarantee a long lifetime to pay back the initial high investment.
The short-term applications makes geothermal energy application uneconomical because to achieve real benefits it must be used over a long period of the year and should be addressed to cover *base heat requirement* of the greenhouse energy load while *peek heat demand* should be meet with conventional heat technologies.
The pay-back period for covering investment costs is strongly influenced by the type of the heating system solution which, however, depends on the greenhouse technology level, the local climate, the dimension of the greenhouse.
The timing, the agro-techniques and the biological characteristics of the crops are of primary importance to achieve economical benefits with geothermal greenhouse.
To achieve appreciable savings as well as an optimal utilization factor, it should be adopted an *integrated* scheme and/or a *cascade* heat system to optimise the heat use from geothermal sources.

5. DISCUSSION AND CONCLUSIONS

Renewable energy offer a cost-effective alternative to fossil energy in European greenhouse agriculture. However, this asks to adapt the greenhouse sector to changing circumstances and market pressure as well as to the necessity to incorporate technology innovation. The integration of renewable energy into greenhouse agriculture by spontaneous initiatives from investors is not easy and measures are necessary to stimulate the operators starting from the reality critic points. However, most often, the lack of information has negative effects on the development of renewable projects i.e.: the economic value of this energy is underestimated and misunderstood; often the potential of existing and known resources are not fully evaluated by the local authorities which have to decide the development; planners and decision makers at local levels do not integrate this energy in the development plans even when the resource is available and known. Finally, the use of renewable energy in greenhouse agriculture is in line with the European priorities: Climate Change, Sustainable Development, Energy Security and the EU-27 targets on the objectives 20-20-20.

REFERENCES

[1] Photovoltaic barometer : 190. Eurobserv'er, March 2009.
[2] Solid Biomass barometer N.194. Eurobserv'er, March 2009.
[3] Geothermic barometer N. 193. Eurobserv'er , March 2009.
[4] EC, 2007a. Communication from the Commission to the European Council and the European Parliament. COM (2007) 1 final).
[5] EC, 2008a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 20- 20 by 2020.
[6] Acceleration of the cost competitive biomass use for energy purposes in the WBC. FP6-2002-Inco-WBC/SSA-3. Contract n. 2005-015139.
[7] Renewable Energy Co-ordinated Development in the Western Balkan Region. FP6 2002-Inco-C.1.3 n. 012066.
[8] Campiotti C. and Popovski K., 1990. Greenhouse Heating. Small Geothermal Resources: A guide to Development and Utilization. UNIDAR/UNDP Centre on Small Energy Resources, Rome - Italy. Editors by Mary H. Dickson and M. Fanelli.
[9] Campiotti C. et al. 1999. Low cost geothermal heating technology as heat acclimatization for protected cultivation in agriculture. International Geothermal Days – Oregon 1999.
[10] Campiotti C. et al. 2008. Photovoltaic as sustainable energy for closed greenhouse system in southern Italy. Acta Horticulturae 797, 2008.
[11] Campiotti et. al. 2009. Renewable energy and innovation for sustainable greenhouse districts. CIE, 15th edition, Clean and Available Energy",June 4-5, 2009, Oradea.
[12] Campiotti et al. 2009. Preliminary results of a PV closed greenhouse system for high irradiation zones in South Italy. ISHS Conference, Quebec 2009 (to be published).
[13] Fridleifsson, I.B., R. Bertani, E. Huenges, J. W. Lund, A. Ragnarsson, and L. Rybach. 2008. The possible role and contribution of geothermal energy to the mitigation of climate change. IPCC Scoping Meeting on Renewable Energy Sources, Proceedings, 20-25 January.
[14] Fthenakis V. and E. Alsema. 2006. Progress in photovoltaics: research and applications. Prog. Photovolt: Res. Appl. 2006; 14:275-280.