ENERGY EFFICIENCY AND PHOTOVOLTAIC SOLAR FOR GREENHOUSE AGRICULTURE

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Abstract : Greenhouse industry has evolved in the last decade as a very important economical activity in agriculture. As a result, the interest towards investment in this sector has been increasing in many countries of Europe. In Italy, most of the greenhouse areas are located in the southern regions where there is an enormous amount of incoming solar energy. On average, this large availability allows a generation of PV energy not less than 200 kWh/m^2/year, that can be used for a variety of applications in greenhouse (motorization, pumping, ventilation, heating and cooling). Evaluations made from ENEA, estimated a total greenhouse energy consumption of 0.73 MTOE/year, to which correspond to about 2.06 MTons of CO_2 emissions. Furthermore, data achieved by the ENEA project Modem to improve the energy efficiency and to support the development of photovoltaic solar greenhouses are reported. Both these subjects are being investigated with the general aim to find out solutions to cut down fossil energy demand and CO_2 emissions, in order to innovate Italian greenhouse agriculture sector.

Keywords: **photovoltaic energy, energy efficiency, greenhouse industry, CO_2 emissions.**

1. INTRODUCTION

In Europe-27 are operating not less than 200000 hectares of greenhouses plants which according to numerous investigations, account for 3 to 5% of the EU's total energy consumption [7, 16, 26] . The largest greenhouse areas, mainly covered with plastics, are concentrated in the Mediterranean countries, like France, Italy, Spain and Turkey, while glass greenhouses are mainly located in the countries of Northern Europe, like The Netherlands, Germany, Belgium and the new central European countries as Poland and Hungary [12, 17]. In Italy, the National Statistic Institute (ISTAT) estimated an area of greenhouses of 30000 ha, of which 52% of flower crops and 8% of horticultural crops cultivated under greenhouse (Tab. 1).

Tab. 1 - Agriculture in Italy

CROPS	A Green house (ha)	B Open field (ha)	C UA A[1] (ha)	A/C Green house	B/C Open field
Flowercrops (a)	4964	4645	960 9	52%	48%
Horticulture (b)	34888	421256	456 144	8%	92%

[1] UAA = Utilized Agriculture Area.
Source: ENEA on data ISTAT.

Agriculture at EU level produces about 9% of total EU-27 CO_2 emissions [13], of which the plant production under greenhouse represents one of the highest responsible, due to the peculiarity of its plant production process, which requires to be successful high energy consumption. It is reported for the south of Europe that the cost of the greenhouse heating forms over 30% of the overall operational cost [10, 21]. This is in large part due to the fossil energy used for maintaining an optimal microclimate of the greenhouse. The Kyoto Protocol on the reduction of CO_2 emissions, called also to agriculture farms to introduce more sustainable operative techniques and to develop greenhouse production process characterized from low fossil energy demand, and consequently, low CO_2 emissions. For the past years, a raising interest was given to renewable technologies, especially of solar and geothermal energies, for greenhouse acclimatization [9, 10, 20]. Recently new of greenhouses and acclimatization systems as those relating to the concept of photovoltaic solar as energy technology either to produce electricity [1, 2, 3, 5, 6, 14, 17, 24] or to produce both electricity and thermal energy [23, 25]. Furthermore, the concept of closed greenhouse typology was also developed as innovative typology for reducing fossil energy consumptions [18, 19]. Italy is one of the European countries most vulnerable to the impacts of high energy cost and this is particularly true for the greenhouse agriculture where the acclimatization energy is a crucial element for growers and companies to compete on the global market. In fact, the new trade practices, the consumer's request of fresh and convenient vegetables all year-around and the increasing fluctuations of the energy cost have had a tremendous impact on the structure of the protected horticulture in Italy. As result, the Italian horticulture is on the one hand pressed to obtain products of high-quality throughout an increasing energy-demand system, on the other hand is forced to limit the energy cost and the wastes. The general objective of improving the energy efficiency in greenhouse agriculture is therefore taken into consideration by this paper, and measures for implementing energy saving measures are briefly indicated. Furthermore, some of the elements which deals with the photovoltaic energy when applied to greenhouse acclimatization are also addressed. Finally, the research and the development activity of a project, so-called Modem [8], in progress at ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), and aiming perspectives to innovate the greenhouse agriculture sector by introducing the photovoltaic technology as sustainable energy option in place of fossil energy for the acclimatization of greenhouses are also illustrated.

2. METHODS

2.1. Energy efficiency

Over the past four years, researchers have investigated a large number of energy reducing techniques for acclimatization of greenhouses and cropping systems by study, simulation and experimentation. Most of the energy conservation techniques were developed either to reduce inside air temperature or to improve greenhouse insulation without compromise the plant crop production. It now seems well-established that the fossil energy consumption of greenhouse horticultural activity can be diminished by various efforts, of which the most important are: the improvement of energy efficiency of the heating and cooling systems, the application of renewable energy, the insulation techniques and the right maintenance of acclimatization systems and structures. To support the innovation of greenhouses in Italy, however, ENEA made at national level some specific evaluations in order to define the energy consumptions in terms of heating, cooling and electricity. As result, it was established a total consumption of greenhouse energy demand amounted to 0.73 MTOE which potentially is equivalent to about 2.06 MTons of CO_2 emissions (Tab.2 and Tab.3). Such evaluation which updated a previous one it was elaborated by considering the days-degrees for the most important greenhouse areas in Italy [9, 12]. However, the investigation was carried out by referring to a percentage of only 20% of the national greenhouse area provided with some acclimatization systems.

Tab. 2 - Estimation of fossil energy consumption of most important greenhouse areas in Italy

Climate area (days-degrees)	Green-houses (ha)	Heating (MWh)	Cooling (MWh)	Electric consumption (MWh)
B (Sicily, Sardinia)	2200	220000	42768	14331
C (Campania, Latium)	3000	4312500	28350	19542
D (Liguria, Tuscany)	400	870000	1800	2606
E (Veneto)	400	1050000	864	2606
TOTAL	**6000**	**8432500**	**73782**	**39085**
TOE		**706786**	**16232**	**8598**

Tab. 3 - Total energy consumption and CO_2 emissions of the Italian greenhouse sector*

Total area greenhouses (ha)	Total annual consumptions (MWh)	TOE	CO_2 emissions (Tons)
6000	8545366	731617	2055842

* Conversion factor utilized for the tables above reported: 0.0860 TOE/MWht; 0.201 TOE/MWhe. 1 TOE equal to 2.81 tons of CO_2 emissions.
Source: AEEG (The Regulatory Authority for Electricity and Gas) 2009.

Energy efficiency in agriculture is generally defined as the direct energy consumption per unit of physical production. Because the ratio of energy used per unit of produce can be enhanced either by increasing the production or by reducing the energy input, attention must be given to the reduction in energy consumption for the acclimatization systems. Therefore, in order to limit energy demand, it is of primary importance a proper management of both the acclimation system and the plant productive process under greenhouse [4, 11, 22]. Thus, to meet the general objective of decreasing the energy demand without compromise the economic value of plant crop production, a series of measures and physiological parameters were identified (Tab. 4).

Tab. 4 - Energy efficiency for greenhouse sector

Systems and measures	Benefits
More greenhouse insulation	Reduce heat loss.
Installing thermal screens on the ceiling	Decreasing the air-conditioned greenhouse volume.
Strategies of check and planning of temperature and RH	Heating according outside luminous intensity. Methods of "integrated temperature" of plants. Calibrating the temperature and UR measurements near the “set-points”
Systems and solar passive techniques	Maximization of incoming solar radiation and of inside air-conditioning.
Transparent covers/filters to regulate the transparency to visible/infrared radiation	Increasing of visible radiation (PAR) and decreasing of infrared radiation (NIR) in greenhouse.
Increase the diffusion of direct solar radiation with covers	Increasing of the visible radiation for plants.
Increase the windows’area	More natural ventilation for cooling.
Renewable resources and CHP systems	Cost-effective use of local renewable energy resources (biomass, geothermal water, solar radiation).
Use of slow-selling lights or LEDs (Light Emitting Diodes)	Improvement of plant yields and increase of the lights’ life-cycle.
Biomass boilers, geothermal heat pumps,photovoltaic solar systems	Greenhouse innovation and minimization of CO_2 emissions.

Such measures, however, should be already mandatory in new greenhouses and also integrated in the renovation of old and/or existing greenhouses. At this scope, it is advisable that authorities will set up specific legislation to support the development of an intensive

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activity aimed at stimulating the greenhouse renovation.

2.2. Photovoltaic solar in agriculture

Italy lies in the geographycal region between the latitudes 35° and 45° Nord. Specifically, the Italian paeninsula receives a daily amount of solar energy which for the northern regions ranges on an average between 10.5-11 MJ/m^2/year, and for the southern to 12.5-14 MJ/m^2/year. Therefore, the photovoltaic energy (a device that converts sunlight directly into electric energy) comes along as one of the most promising future energy resource for application in greenhouse acclimatization. For the last three years, due to favourable incentives associated with the PV plant installation (Tab. 5), the Italian PV sector has greatly progressed not only in the civil building but also in the agriculture sector. In addition, the cost of PV moduleshas dropped from 6 €/W to 2.5-3 €/W, and this has stimulated many growers and agriculture farms on the opportunity to invest in PV systems. At moment, it is reported in Italy a greenhouse surface of about 50 ha.

Tab. 5 - Platform roofs, pergola, roofs, acoustic barriers, greenhouses

Power	Plants in operation by 30 April 2011	Plants in operation from 30 April 2011 to 31 August 2011	Plants in operation from 31 August 2011 to 31 December 2011
[kW]	[€/kWh]	[€/kWh]	[€/kWh]
1≤P≤3	*0.382*	*0.369*	*0.357*
3<P≤20	*0.358*	*0.341*	*0.323*
20<P≤200	*0.340*	*0.325*	*0.304*
200<P≤1000	*0.335*	*0.319*	*0.290*
1000<P≤5000	*0.332*	*0.308*	*0.283*
P>5000	*0.315*	*0.293*	*0.269*

Source: GSE, 2011 [15]

First results from the ENEA Project MODEM has confirmed that the electric energy requirements of a typical low-cost greenhouse (heating, cooling or ventilation) ranges from a maximum of 90000 $kWh_{el}.ha^{-1}$ to 20000 $kWh_{el}.ha^{-1}$ in relation to the quality of greenhouse structure (data from Project Modem).
Assuming a PV module efficiency (ηPV) equal to 0.13, a 7.5 m^2 panel area is needed to generate 1 kW_p DC peak power and an annual yield of 1500 kWh_{el}, we have on yearly basis, a value of DC peak power to generate 1000 kWh_{el} equal to 1000/1500 = 0.66 $kW_p \cdot (1000\ kWh_{el})^{-1}$.
Measurements made on a typical low-cost greenhouse (Fig. 1), provided with a multi-cristalline PV system of 3.3 kWp installed on the outside lateral rooftop showed during two days of observations an energy production of 14 kWh and 1.5 kWh, respectively. This difference was in relation to the value of the intensity of the outside solar radiation that was about 800 W/m^2 in the first day and only 100 W/m^2 in the second day (Fig. 2).

Fig. 1. PV greenhouse (Source: ENEA Project MODEM)

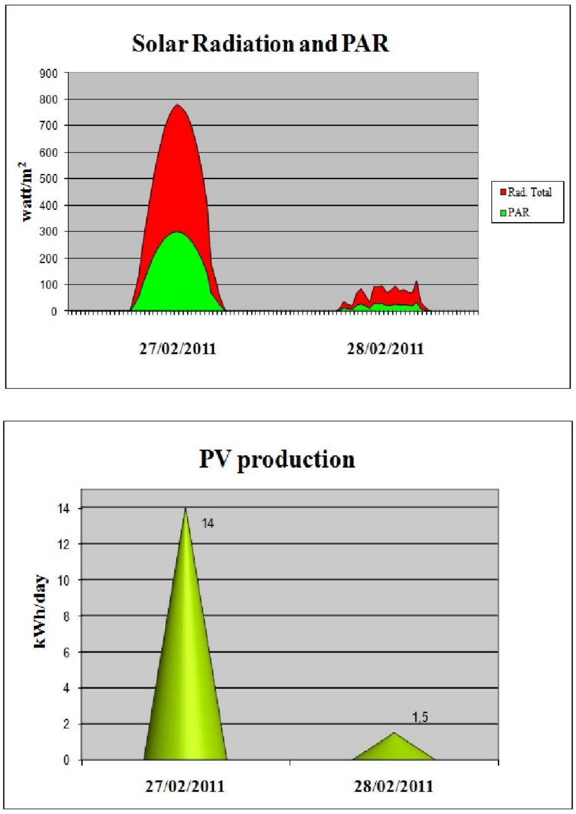

Fig. 2. Outside total solar radiation and PAR (*Photosynthetically Active Radiation*), and PV energy production (Source: ENEA Project MODEM)

From such data, it is evident that the application of the PV technology in greenhouse agriculture still poses some problems to growers and agricultural farms since the photovoltaic greenhouse performance needs to be fully characterized in terms of annual electricity production, photovoltaic system performance, greenhouse energy demand, in order to maintain optimal microclimate inside the greenhouse, adapted crop position of both the plants and the PV modules, and costs. In Tab. 6 are reported some evaluations mainly referred to the various positions of the greenhouse PV systems associated with the greenhouse, and the relative energy efficiency productions.

Tab. 6 - Positioning of PV modules on greenhouse

Parameter	Units	Ground	Roof	Side position
Energy delivery	$kWh_{el}.y^{-1}$	55000[1]	55000[1]	55000[1]
Peak power	kW_p	35	35	40[2]
PV panel area	m^2	268	268	300
Gross area	m^2	618[3]	618[3]	440[4]
Cost [5]	Euro	100000	100000	120000

[1]Mean energy demand; [2]15% loss of overall efficiency; [3]2.3 times the PV panel area due to multiple rows' shadow path; [4]horizontal projection of PV panels+1.0 m belt; [5](VAT and installation included).

Furthermore, in the Fig. 3 it is reported the values of the inside solar radiation intensity in relation to the inside ground area interested from the PV modules shadow.

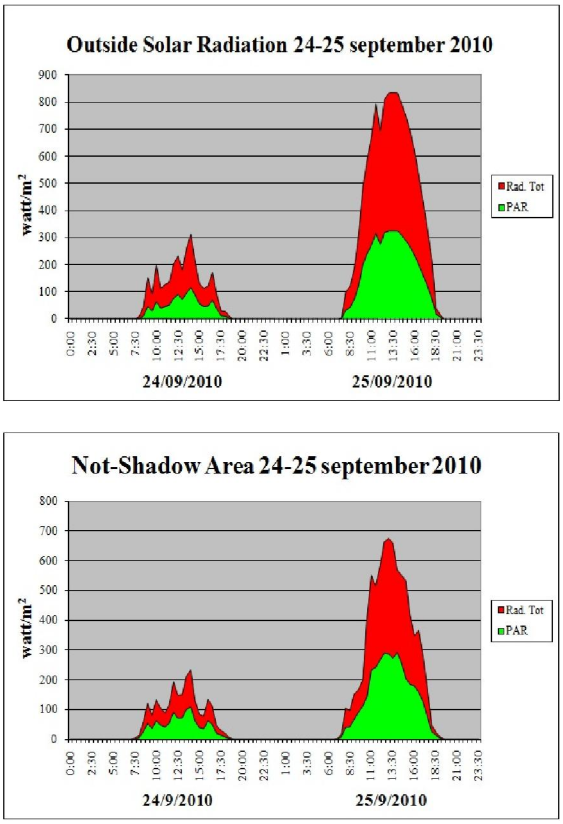

Fig. 3 - Reduction of light inside the photovoltaic greenhouse: on the left the shadowed area, on the right the non-shadowed area (ENEA Project MODEM)

From these data and on the base of a public incentive of 0.30 €.$(kWh_{el})^{-1}$, calculations made in Italy on the pay-back period for some different PV photovoltaic technologies showed values of pay-back in the range of 6 years for the amorphous panel, 9 years for the mono-crystalline panel and 11 years for the poly-crystalline panel (Tab. 7 and Fig. 4). Such results, however, needs more data in terms of light interception by the PV modules to allow to evaluate the plant production losses in quantity and quality, especially in regards of the plant crop (Fig.3-4).

Tab. 7 - Parameters and evaluation of pay-back period of different PV modules

PV Power : 5.5 kW_p - **Feed-in-tariff :** 0.30 Eur/kWh
Pay Back Period (years) : 6 (AmorphousPV) - 9 (monoPV) - 11 (polyPV)
Plant : VAT – maintenance-insurance
Discount rate : 5% - **Inflation :** 2%
Price : 3000 €/kW_p (PV mono/poly-crystalline) 2000 €/kW_p (PV amorphous)
PV efficiency (kWh/m^2/year) (BOS 75%) : 231.6 (M.);173.7 (P.); 82.8 (A).

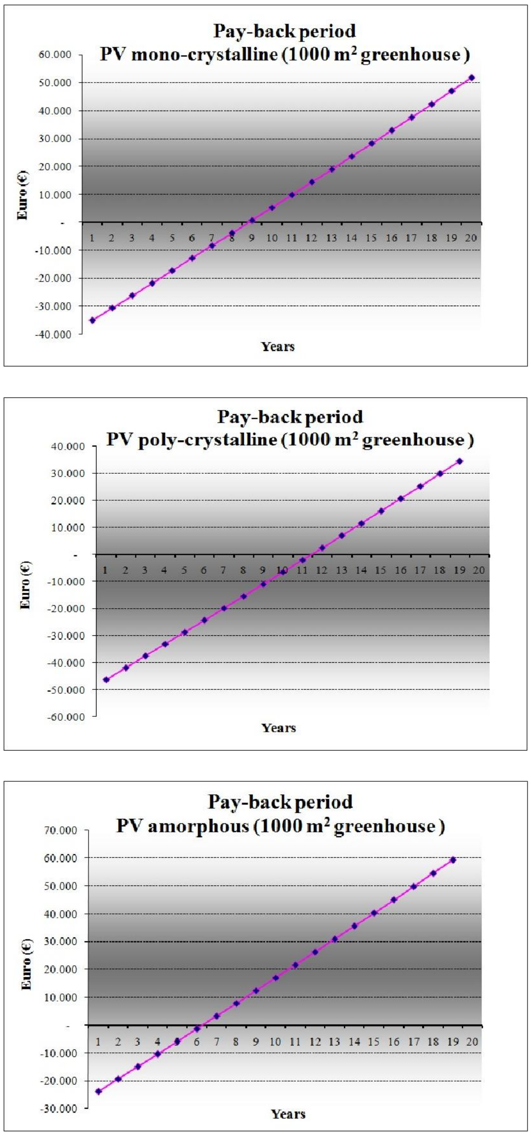

Fig. 4. Evaluation of pay-back period of different PV modules (ENEA Project MODEM)

3. RESULTS AND DISCUSSION

The photovoltaic technology has an important role to play in the modern agriculture either as renewable

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energy option for acclimatization systems or as strategy to contribute to reduce fossil fuels and CO_2 emissions in greenhouse agriculture. Accordingly, due to the large availability of solar energy in southern areas of Europe, the setting up of photovoltaic greenhouse districts can be of significant importance for contributing to improve socio-economic conditions of rural and agriculture regions. A systematic process of assessment and renewable energy planning should be done in all European regions with existing large activity of greenhouse production in order to identify the best mix of renewable technologies to fulfill specific requirements of greenhouses. A major problem, which is in many cases overlooked or considered insignificant, but which can become critical mainly in agriculture activities is the PV greenhouse technology acceptance in terms of environmental impacts. The challenge is to develop a photovoltaic greenhouse model which guarantees both the crop production and the PV energy for the greenhouse. In addition, the model should also allow an energy production performance suitable to sell surplus of PV energy to electric companies. The cost-effective performance of the photovoltaic option should be evaluated in the long period considering both the PV technology cost and the availability of solar irradiation in order to allow proper evaluation of the operating time to pay back the initial investment. In addition, it is of significant importance the definition of PV energy production schemes e.g.,: stand-alone or grid-connected technology, the materials and structures, the greenhouse typologies, and the harmony between the availability of solar radiation and the yearly demand of energy users. The viability and the cost-effective application of the PV options to greenhouse agriculture depend also on the dissemination of information and the capacity of the growers to manage this innovative energy technology.

4. CONCLUSIONS

The potential of both the energy efficiency policy and the use of the photovoltaic energy technology (PV) as innovative options for reducing fossil energy consumption in greenhouse agriculture was taken into consideration. Some of the main technical characteristics of the PV application in terms of the energy production performances and the existing incentives plant process were briefly illustrated. From the data and information reported in the paper, however, it can be outlined that although the utilization of PV technology might be profitable now or in the near future, its applicability needs to be continually updating in terms of technology. This, however, asks the scientist and the greenhouse companies to adapt innovative agriculture to agro-market changing circumstances by incorporating the PV technology and the potential of energy efficiency measures into a new productive model. Particularly, the environmental impact and the adaptability of plant cropping systems need to be carefully investigated to foster penetration of PV technology in regions with large greenhouse industry. Although the utilization of photovoltaic greenhouse might be profitable now or the near future, still the most serious problems facing growers and agricultural farms in Italy are the risk and the uncertainty on the national incentive schemes. The research community, the energy companies, the authorities, the stakeholders and policy-makers should give their support to deal successfully with this innovative concept of greenhouse agriculture. With this kind of policy, the PV energy resource together with the improvement of energy efficiency can certainly reduce the fossil energy use in greenhouses, and thus complying with the European Climate Package 20-20-20. By its activity on energy efficiency and photovoltaic greenhouse ENEA has much to contribute in terms of research, technology and development to turn these valuable and innovative options into cost effective application in greenhouse agriculture.

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