INSTITUTE FOR SUSTAINABLE ENERGY, UNIVERSITY OF MALTA

SUSTAINABLE ENERGY 2013:
THE ISE ANNUAL CONFERENCE
Thursday 21st March 2013, Dolmen Hotel, Qawra, Malta

THE PHOTOVOLTAIC GREENHOUSES: A UNION BETWEEN SUSTAINABLE DEVELOPMENT AND AGRICULTURE

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ABSTRACT: The purpose of this study is to show the efficiency of introducing PV systems in greenhouses from the point of view of agriculture, from the technological point of view and from the economic point of view. The nursery greenhouses are the main sector in which PV may develop. Greenhouses in fact have qualities that a photovoltaic system needs: the right exposure to direct sunlight and large areas available. If we add to this to the fact that many ornamental plants need shading systems, it is possible to understand how the use of the roofs of greenhouses like structures on which to apply the photovoltaic panels in place of traditional plastic film cover, avoids the use of shading nets or painting and is an excellent investment for the nursery. For horticulture action instead the shading action of the solar panels is a limiting factor for crop growth. Experiments of cultivation of rocket under photovoltaic greenhouse are in progress; the first results show a qualitatively higher than that grown in traditional greenhouses, even if the shelf life is less. The conclusions of this work thus tend to highlight how the technical, functional and aesthetic components of photovoltaic technology coincide with structural components and means of agricultural production, allowing to boost farm income, diversifying income: from the cultivation of vegetables, from the production of ornamental plants, and from the production of electricity.

Keywords: Photovoltaic greenhouses, Nursery, Summer horticulture

1 CLIMATE ASPECTS OF THE PROVINCE OF RAGUSA, ITS AGRICULTURAL VOCATION AND DEVELOPMENT OF SOLAR GREENHOUSES

The agricultural vocation of the territory of Ragusa, Sicily (Italy), characterized by a soil with suitable physical and chemical characteristics and favorable climatic factors, is the pivot on which is based the economy of province of Ragusa. In particular, this has allowed the development and diffusion since the early sixties of horticultural protected cultivation, thanks to the possibility of using plastic film for covering the greenhouses, whose flexibility and lightness allows realizing structures craft and the use of which, in areas with a Mediterranean climate like the Sicilian, is fully compatible with the production of vegetables. For some years in that province some farms have introduced innovations in the cultivation of vegetables and expertise aimed at a return to "sustainable use of resources, their protection and saving" producing natural foods, not manipulated or contaminated by chemical products, allowing the return to its oldest and qualified horticultural Sicilian tradition (method of "organic farming"). This return to sustainability has been further enhanced by the application of photovoltaic technologies to traditional greenhouses, since the latter have the right exposure to direct sunlight and large available areas, under the impulse of national and community policies aimed at encouraging the production of energy from renewable sources.

In the province of Ragusa have thus developed solar greenhouses, fully integrated photovoltaic systems consisting of greenhouse structures in which the photovoltaic modules are integrated into the outer covering of the structures themselves. Greenhouses covered with solar panels instead of plastic film produce electricity for 12 months a year, part of which is used by the farm itself which sees highly reduced energy costs and part is sold to the grid operator. The availability of electrical energy also allows optimization from the

technological point of view, using "clean" energy, all auxiliary systems of farming such as the conditioning of the environment, fertigation systems, the management and control of the structure.

The choice of the photovoltaic artefact represents a considerable advantage for the summer horticultural products that needs to be repaired by the excessive sunlight. The roof with solar panels fully solves the need of shading that you have at certain times of the year.

In summary, this type of structure is a real "program for agricultural environmental improvement" weighted with a view to promote the "life" of the production of energy with the functional skills of rural areas, providing an exportable model in Malta, whose territorial and climatic conditions are common to the island of Sicily (Italy).

In Italy, Ragusa is the sunniest province [18]. In it, the availability of solar energy can be determined by examining the data of the UNI 10349 [13] for monthly average daily values of solar radiation on the horizontal plane, shown in Table 1 and Figure 1. In fact, compared with the capitals of the other Italian regions, they are the highest, as can also be seen from the Map of the sun of Figure 2.

Table 1: Monthly average daily radiation on the horizontal plane [kWh/m²]

Gen	Feb	Mar	Apr	May	Jun
2.50	3.31	4.75	5.97	7.06	7.36
Yul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
7.42	6.89	5.56	4.22	3.03	2.11

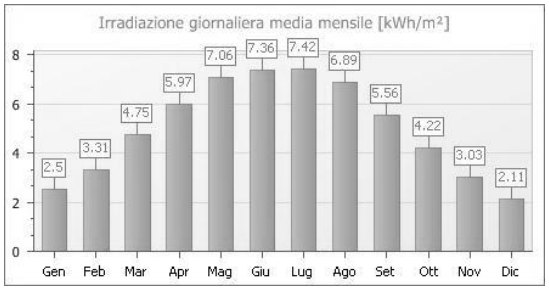

Figure 1: Histogram for monthly average daily radiation on the horizontal plane [kWh/m²]

Favorable climatic data and soil characteristics have determined the conditions for the development of agriculture in the province of Ragusa. The agricultural vocation of territory has allowed first the development of the crops in open field and, since the sixties, the development of horticulture in protected cultivation, i.e. under greenhouse, typically with a pentagon or arc structure.

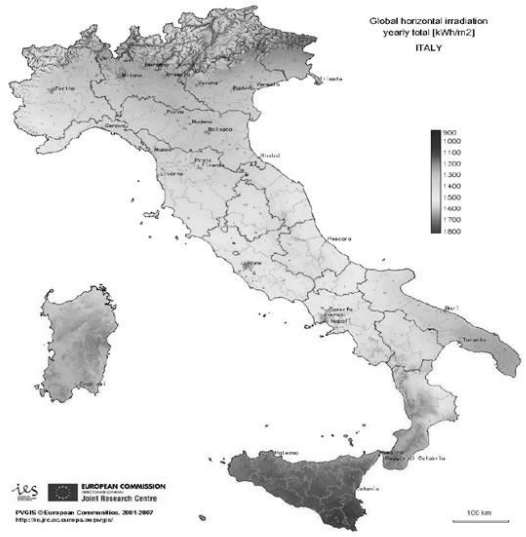

Figure 2: Map of the sun

The greenhouses today normally used in the territory of Ragusa in agriculture have an arched multitunnel section with coverage in plastic film of polyethylene. Generally, these are arranged in the longitudinal direction in accordance with the north-south to reduce the excessive radiation in the central hours of the day.

Figure 3: Multitunnel greenhouse in galvanized iron

Figure 4: Cultivation under greenhouse of peppers

Under the impulse of national [2] and community policies [1, 2, 12, 20], through the "Conto Energia" (the program of economic incentives for the production of energy from photovoltaics) [4, 5, 6, 7, 8, 19] and appropriate fiscal policies [10, 11] and following the Dutch model which has a long tradition of cultivation in solar greenhouses, the solar greenhouses are becoming more widespread in Italy, especially in the province of Ragusa.

Included in this category installations where the PV modules are the building blocks of the cover or the walls of artifacts used, permanently for the duration of the incentives of the "Conto Energia", as greenhouses for to agricultural cultivations or floriculture.

They are an interesting example of integration of photovoltaic technology with the world of agriculture, while ensuring simultaneous production of agricultural products and electricity.

The idea that underlies the solar greenhouses is that of converging and finding the best compromise between two different needs:

- the best use of the contributions of light and heat of the sun for cultivation;
- the use of solar energy for the production of "clean" electricity by photovoltaic conversion apparatuses.

2 CHARACTERISTICS OF PHOTOVOLTAIC GREENHOUSES

The photovoltaic greenhouses can be single-aisle, in turn divided into single-pitch (i.e. with a single pitch of roof) and double-pitch (i.e. with two slopes, also called "hut"), or multi-pitch (the latter also called double-pitch multi-aisle). In the first case (single-pitch on Figure 5), the cover must be totally made with photovoltaic panels or, alternatively, with checker-board arrangement (modules and transparent glasses); in the second case (double-pitch on Figure 6), the part facing to the south is dedicated to the installation of the modules and the remaining part to the transparent glass. Furthermore, the greenhouses double-pitch can be with symmetrical or asymmetrical pitch. The multi-aisle greenhouses have the same characteristics as that double-pitch as regards the coverage of the pitches

In the case of single-aisle greenhouse, the aisles, which may be of variable length, are arranged along the north-south, while in the case of multi-pitch greenhouses (Figure 7), they are arranged along the east-west; the pitch "absorber", on which are placed the photovoltaic modules, is always pointed toward the south.

Figure 5: Single-pitch greenhouse

Figure 6: Double-pitch greenhouses (with double symmetrical pitch)

Figure 7: Multi-pitch or double-pitch multi-isle greenhouses

In the case of systems with more greenhouses arranged parallel along the north-south must maintain a minimum distance in the installation (varies depending on the latitude and the slope of the place of installation) to reduce losses due to shading each other.

Finally, there are "hybrid" solar greenhouses (single-aisle or multi-aisle), that is formed by the union of a solar greenhouse with straight pitches (single-pitch or double pitch) and a greenhouse vaulted semicircular. Even in this case the aisles, of variable length, are arranged along the north-south if single-aisle or east-west if multi-aisle, with the "absorber" pitch facing south.

The typical configuration of solar greenhouse provides in all cases on the pitch of the roof facing south the installation of photovoltaic modules.

The system allows the use of large areas of greenhouses with devices for photovoltaic conversion with total architectural integration.

Thanks to a coverage photovoltaic they are also

capable of producing electricity and this solves the problem of high energy consumption, both electric and heating, necessary for the agricultural production.

The electricity produced by photovoltaic modules can in fact be used for the same greenhouse: installations for air conditioning, for its control and its management, irrigation systems, handling of pallets and openings for ventilation, and so on.

3 ADVANTAGES OF PHOTOVOLTAIC GREENHOUSE

The advantages of a photovoltaic greenhouse in respect of a classic photovoltaic system are:

- the structure of the greenhouse and the activities that take place below are compatible with the PV installation and farming, in particular nursery; the nursery greenhouse needs in fact to shield the light radiation and the use of modules PV as a coverage is therefore generally useful and not an obstacle to cultivation;
- you have the possibility to develop plants also of large size, avoiding at the sime time the subtraction of agricultural land, as in the case of parks with photovoltaic installations on the ground;
- maximum profitability of the spaces occupied by greenhouses;
- use of electricity at no cost to the holders of the greenhouses, as produced by the plant on the roof; the electrical energy produced by the plants placed on the greenhouse itself can in fact be used for the activities of air-conditioning, control, irrigation which crops require and then feed into the grid the surplus of electricity produced.

From the standpoint of legal, administrative and tax benefits in Italy are:

- chance to benefit from a procedure for the authorization faster than for normal ground photovoltaic installations;
- greenhouses normally do not require special permits from the municipal bodies;
- in general, there is a favorable attitude of public bodies thanks to the employment potential that is the ability to create jobs through the creation of new jobs through the use of specialized personnel in the agricultural sector and ordinary labor;
- tax advantage: the greenhouse can be registered as agricultural building, and as such is exempt from all local property taxes (known as ICI – Imposta Comunale Sugli Immobili/ IMU - Imposta Municipale Unica or Imposta Municipale Propria), to instead are subject solar farms;
- possibility of considering the photovoltaic power generation as agricultural activity connected and therefore subject to taxation based on the cadastre, assimilating the income due to profits from the production of energy and agricultural products with well-defined thresholds [10, 11];
- high financial returns due to a rapid return on investment thanks to higher rates of the "Conto Energia" [4, 5, 6, 7, 8, 19];
- effective response to the demands of regional regulations on agriculture involving the progressive use of renewable energy;
- ability to access funds through the Rural Development Programme (RDP) [12] which provides for the granting of contributions, combined with those of the "Conto Energia", to facilitate the establishment of young farmers and farm modernization [20].

The system allows you to make the structure energy independent, and to feed the surplus electricity into the grid.

The photovoltaic greenhouse is therefore an installation anchored to the ground the consists of two sources of business: under the cover it is a normal greenhouse dedicated to the cultivation, while the roof is covered with solar panels for the production of electricity.

The photovoltaic roof, then through the optimal integration with the greenhouse, does not impact in any way on the surface of cultivation.

In addition, the exposure of existing greenhouses is generally favorable, as it is in favor of solar radiation directly, and then you can suggest simple actions of conversion, if you want to transform a traditional greenhouse in photovoltaic greenhouse.

In Italy, in order to obtain the incentives of the Fifth "Conto Energia", a solar greenhouse must currently meet the following requirements [3, 4, 5, 6, 7, 8, 19]:

- ground minimum height of photovoltaic modules of 2 meters;
- photovoltaic modules must be the building blocks of the cover or of the walls;
- use, for the whole duration of giving the incentives;
- fixed structure, anchored to the ground and possibly seasonally removable closure;
- *Ground Cover Ratio* (GCR), i.e. the ratio between the projection on the ground of the surface covered by the photovoltaic modules and that of the entire surface of the roof of the greenhouse, less than 30% (limit of 50% valid for greenhouses authorized before the promulgation of the Fifth "Conto Energia").

The last aspect, introduced recently by the Gestore Servizi Energetici (GSE), the company that provides economic incentives in Italy for the production of energy from renewable sources,

doesn't want to create a cover that prevents the excessive solar radiation to penetrate inside the greenhouse, effectively transforming the structure in a plant on the floor of two meters from the ground.

The latter criterion puts an end to the structures in Italy strongly opaque, with the pitch facing south covered for 100% of photovoltaic modules.

To obtain a *Ground Cover Ratio* (GCR) less than 50%, in greenhouses single-pitch, you can only use half of the available surface area of the pitch.

In greenhouses double-pitch however, you can use all the pitch in the south for the integration of photovoltaic modules.

4 STRUCTURAL DIFFERENCES WITH CONVENTIONAL GREENHOUSES

Classical greenhouses for agricultural use that are currently on the national territory are light metallic structures calculated in accordance with regulations to withstand the loads corresponding to a useful life of 10 to 15 years. The solar greenhouses instead have duration of at least 25 years to survive to the PV on the roof.

Figure 8: Photovoltaic greenhouses

The design of these structures should be processed in accordance with European standard EN UNI 13031-1 [14] (under which must be in class A30) and the regulations dictated by the "Technical Standards for construction" (Norme Tecniche per le Costruzioni - NTC) [9] in relation to snow loads, wind and degree of seismicity different for region of Italy.

Figure 9: Photovoltaic greenhouses

In particular, they are calculated and constructed to undergo, in addition to its own weight considering roofs with PV modules, also exceptional snow loads (usually snow loads of 120 kg / sq.m.) and typically dimensioned for wind zone 6/7.

The modules, which can be either crystalline thin film, laminates without frame, can also be semitransparent i.e. with a transparent bottom for allowing a greater passage of light than opaque (10% transparency), or with less cells redistributed for single panel.

The structure of the greenhouse, metal, wood or masonry, is closed (the closure may possibly be seasonally removable), fixed and anchored to the ground.

The support structures are usually made of tubular steel hot-dip galvanized. Generally used is a metal structure obtained by the repetition of a basic module of appropriate dimensions.

The cover profiles in addition to being carriers must ensure a good water-tight structure to ensure that there are no infiltrations of water. The photovoltaic panel is in fact included in the profiles by means of suitable fasteners and sealing is ensured by appropriate seals.

The side panels may be of different types, such as for example polyethylene film, fiberglass, polycarbonate or glass.

For the ventilation of greenhouses are provided for windows and openings which can be manual or automatic, on the ridge, on the side or on the heads.

With regard to the anchoring system, greenhouses can be anchored to the ground using prefabricated plinths or formats in reinforced concrete. The size and the share of laying of the plinths are conditioned by the characteristics of the land on which the plant is to be installed. With this system, the structure can be considered to be removable.

The greenhouses, finally, include:

- an installation for electrical connection (with relative power line);
- a heating system;
- the "avanserra";
- a water system for irrigation;

- an electrical system;
- heat exchangers;
- some surveillance system,

over the fence of the structure, the gate, a prefab, the system supply water and/or steam and urbanization and, of course, means and equipment for agricultural use.

In some Italian regions, permission to build a greenhouse is granted only in the presence of a well or a point of access to water for irrigation.

5 AGRONOMIC STUDY IN PHOTOVOLTAICS GREENHOUSES

In harmony with the solar project requires careful study agronomy.

The following considerations are valid for solar greenhouses with the pitch facing to south covered in panels up to 100%, this condition is possible, in order to obtain the incentives, with the First, Second and Third "Conto Energia".

The nursery greenhouse is the main area where the PV can develop. Greenhouses in fact have qualities that a photovoltaic system needs:

- right exposure to direct sunlight;
- large areas available.

If we add to this the fact that many ornamental plants need shading systems, it is understandable how the use of the roofs of greenhouses like structures on which to apply the photovoltaic panels in place of traditional plastic film cover, avoids the use of shading nets or painting and is an excellent investment for the nursery.

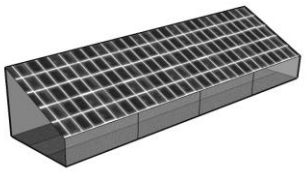

Figure 10: Single-pitch photovoltaic greenhouse

With this action, you get a fully integrated system. The technological solution chosen is compatible with the quality of production, within the perspective of environmental sustainability, fulfills the concept of multifunctionality of agriculture can be associated to income derived from the cultivation of the funds also to the production of electricity and the incentive.

Plants have been identified compatible and suitable for cultivation in solar greenhouses, belonged to the palm family as ornamental species. The palm trees selected, appreciated for the characteristic "pinnate" leaves, are: Cycas, Chamaedorea, Kentia and Phoenix roebelinii.

Figure 11: Kentia tree

Figure 12: Phoenix roebellini

Figure 13: Chamaedorea tree

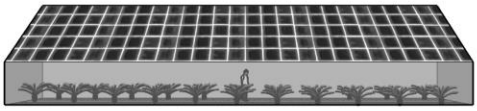

Figure 14: Photovoltaic greenhouse with cultivation of Cycas in place

These plants grow preferably away from direct sunlight, in a partially shaded; the condition must be respected especially in the period from June to September. Inside the solar greenhouse, the cultivation environment is shaded in the interval between June and September, producing ideal conditions for the cultivation of these palm trees.

Figure 15: Cycas tree

For horticultural plants the reduction of solar radiation, due to the action shading due to photovoltaic panels, becomes a limiting factor for the growth of crops. From a morphological point of view the plants have elongated internodes abnormally, while the leaves have reduced the flap and leaf petioles are elongated. In essence, the plants being in a dark place, go in search of light extending internodes of the stems that are filiform. The total number of differentiated flowers for plant decreases in solar greenhouse. You are instead conducting a test of growing arugula, leaf vegetable, under solar greenhouse. The plant growing in the shade is low in fiber and hence is more aromatic (most appreciated by consumers), however, has a poor shelf life.

Figure 16: Rocket under photovoltaic greenhouse

The protected crops, those whose production occurs in a protected environment, for the most part horticultural and nursery, require certain climatic conditions, in particular light and temperature, as well as relative humidity [15].

The first limit to be overcome to make the greenhouse production in agriculture, without compromising the quality and quantity of agricultural production below, is the shading on the persistent culture which decreases the density of light (photosynthetically active light PAL – daily light integral DLI).

The solar greenhouses must be investigated to ensure the right balance between an adequate internal radiation in winter and sufficient protection from excessive radiation during the summer.

The brightness of the greenhouse is in fact crucial for the crops that it must be uniform as much as possible and guaranteed for the greatest possible number of hours per day.

The prolonged lack of light in the crops, as is known, in fact causes the spinning of the internodes, the yellowing of the foliage, the poor quality of fruiting and problems of flowering.

The solar greenhouses must be designed not to limit the illumination of the interior of the structure, which is essential for the agricultural activity that takes place here and then it is important to minimize the size of the cone of shadow projected on the ground inside of the greenhouse structures.

There must be an extreme attention to the shape and size of the shadow cones that the panelled surface projects to the ground, i.e. to the amount of photosynthetically active radiation (PAR) that arrives on the crop.

Therefore, crops that require direct light of high intensity (horticultural crops) may be placed in greenhouses in which the modules do not cover the entire surface but are placed in a chessboard so as to guarantee a certain solar radiation during the day. Alternatively, you can consider using semitransparent photovoltaic panels.

For example, the multi-aisle photovoltaic greenhouses are ideal for the production of vegetables in the summer period; in fact prefer the diffused light than the direct one.

Yet, may be used, within the greenhouse, the aid of lamps, system widely used in northern Europe but that adds significant costs of energy consumption, or provide for a photovoltaic structure to partially cover, or even, alternatively, with moveable structures that allow the operator to leave if necessary crops in the open.

These data were also confirmed by CeRSAA - Regional Centre for experimentation and agricultural assistance - Special Agency of the Chambers of Commerce of Savona - Albenga (Savona, Italy), which, as a result of numerous tests carried out since 2007 and observations made in the course of investigations performed within solar greenhouses made of some Italian regions, has announced the results indicate that, in relation to the solar cover on the roof of the greenhouse, which crops can be grown profitably or, or, in other words, which are able to provide products that have the quality standards required by the market [16, 17].

In contrast, the risks of PV on greenhouses are:

- ectofiti plant pests (e.g. Mal white) attack early in the environments also slightly shaded;
- shading for higher (> 50%) and large shadows and a strong decline in the quality and quantity of production, in addition to the decrease in temperature and an increase in the RU, with increased risks of attacks of pathogens.

6 INNOVATIVE PHOTOVOLTAICS GREENHOUSES

In Spain, for the precision in Bizkaia, in the Basque Country, is being tested an innovative photovoltaic greenhouse combining the photovoltaic modules with a lens system which convey the light toward the inside, to simultaneously maximize the agricultural crop and that due to solar energy.

Figure 17: The prototype of photovoltaic greenhouse of Bizkaia

Depending on the season of the year, in fact, the system diverts the solar radiation exploiting the annual oscillation and the height of the trajectory of the sun, through a system of optical lenses, placed on the roof of the greenhouse together with the photovoltaic modules, which has not need trackers or other mechanical devices, ensuring crops a cooler environment in the summer and lighter in winter.

In particular, when the sun is lower on the horizon, as in winter, the light is directed inside the greenhouse, while when it is more perpendicular, as in summer, part of the light is diverted to maintain fresh cultures and maximize at the same time the electrical output, generating an increase of the 15%, according to the first data.

Inside there are growing tomatoes and peppers, crops selected for their dissemination and to the large amount of light they need to grow.

This greenhouse project is a collaboration between ULMA Agrícola consortium, research and development area of ULMA Group, and Neiker-Tecnalia, public institute for agricultural research in the Basque Country.

7 THE LARGEST PHOTOVOLTAIC GREENHOUSE FARM IN THE WORLD

The largest photovoltaic greenhouse farm in the world, with 134 greenhouses on 26 hectares of land, called “Su Scioffu” (literally “the pit” in Sardinian dialect), named after the town where it is located, is in Villasor in the province of Cagliari, on the island of Sardinia (Italy).

Figure 18: The photovoltaic greenhouse farm "Su Scioffu"

The 84,400 polycrystalline silicon panels that cover the greenhouses, 20 MW of installed capacity, produce energy equivalent to the annual electricity consumption of 10,000 homes, with 25,000 tonnes of CO_2 emitted into the atmosphere.

Figure 19: Detail of the photovoltaic greenhouse farm "Su Scioffu"

There are twelve crops in greenhouses activated on Su Scioffu, with about three crops a year: it is vegetables and floral products, namely cauliflowers, lettuces lolli, peppers, celeries, radishes, tomatoes, eggplants, lettuces, fennel, favini, roses berry and roses cut

Figure 20: Detail of the interior of the photovoltaic greenhouse farm "Su Scioffu"

The implementation of this system, which is a pilot project, was made possible thanks to an investment of € 70 million by the Indian multinational Moser Baer Clean Energy Limited (Mcbel), project manager, and the American giant General Electric

6 CONCLUSIONS

The area of the province of Ragusa is one of most important greenhouse districts of Italy. However, since the early 90, the sector has significantly decreased and this situation remains until the present times, in fact affected by competition from other production areas of the Mediterranean (Morocco, Tunisia, Egypt). The competition with the North African countries is further accentuated by the liberalization of trade.

To counter the crisis facing horticulture and to continue the exponential growth in terms of cultivated areas, which allowed the employment of hundreds of workers, it is desirable to combine the cultivation of vegetables in conventional greenhouse with nursery in solar greenhouse, aimed at the production of ornamental plants and renewable energy, in particular the sun. To achieve this objective, lends itself well to the solar greenhouse as well as studied that allows to match the technical, functional and aesthetic components of photovoltaic technology with the structural means of agricultural production, allowing to boost farm income, diversifying it in coming from the production of ornamental plants, the production of electricity.

Furthermore, from the point of design life is possible to predict the oversizing of the distance between the greenhouses obtaining, in addition to the reduction of a visual impact on the territory (different occupation of the surface in terms of density), a reduction of the residual effect of shading in the winter period, the latter device oriented to optimize the energy performance of buildings.

The following figure shows two photographs of the rendering of solar greenhouses and the topographic view from satellite of greenhouses already existing in the area of Santa Croce Camerina, in the province of Ragusa. This clearly shows the different occupation of the surface in terms of density.

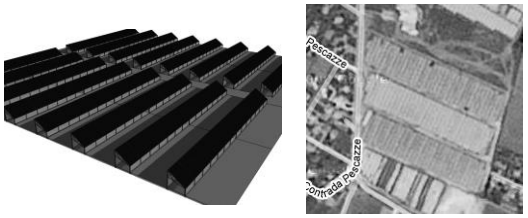

Figure 21: Rendering of photovoltaic greenhouses and satellite view of existing conventional greenhouses

The installation of photovoltaic greenhouses in Sicily, is a real "program for agricultural environmental improvement" weighted with a view to promote the "life" of the production of energy with the functional skills of rural areas.

Unlike the normal installation of plants for the production of energy, photovoltaic greenhouses therefore not only don't deplete the agriculture of arable areas, but rather the incentive, encouraging the union between nature and energy that is the real strength in energy development.

The "model Ragusa", finally, is a exportable model in Malta, whose territorial and climatic conditions are common to the island of Sicily (Italy).

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