Increase of landscape ecosystem services generated by agrivoltaics systems

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Abstract. UN estimated that the world population will probably grow by 75% in 2050. This will press food and energy production to satisfy human needs. In recent years, the agricultural and energy sectors have been in competition for land use, as many arable lands have been changed in photovoltaic (PV) farms with a loss of food production and ecosystem services. Indeed, in many PV farms the flora is ruderal, with the prevalence of nitrophilous-type plants, and requires frequent mowing with a cost for the companies to prevent panel shading and reduce fire risk. The agrivoltaics system represents a new frontier for renewable energy policy, by associating energy production with food security. The agrivoltaics system combines the PV panels installation with the possibility to develop crop production under them. This provides a new perspective of vegetation management in the agrivoltaics field, mainly allowing to replace invasive plants (passive vegetation management) into crop production (active vegetation management). This allows the implementation of food production and raw material, besides the improvement of ecosystem services provisioning. In this study, we estimated the ecosystem services increase by three agricultural scenarios of agrivoltaics systems, such as vegetables vegetation and woods vegetation. The results show that these potential solutions can give the possibility to generate new economic activities in agrivoltaics farms with potential benefits from a local scale (e.g., cultural services) to a global one (e.g., regulation services). In the agrivoltaics system, the provisioning of ecosystem services is deviated by the feedback of agricultural knowledge, PV technologies and vegetation development. They represent Innovative-based Solutions creating more landscape and environmental externality for human needs through multifunctional land use.

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1 Introduction

Natural capital plays an important role for human life since it guarantees benefits and goods to satisfy human needs, referred to as ecosystem services. To date, there is an increasing awareness that the global economic growth depends on the natural capital capacity to support the provision of ecosystem services in the future. The agroecosystem is one of the most important natural capital components for human well-being because it can provide food for direct human nutrition, support cattle breeding, and raw material for secondary goods [1, 2, 3].

Currently, the human well-being is compromised by the climate change that negatively impact the natural capital with a strong effect on the agroecosystem [4, 5]. The increase in global temperature and drought events has direct consequences on food security, reducing crop production and quality or altering the genetic biodiversity of agroecosystems with a loss of cultural capital linked to traditional crop products. Moreover, the temperature and water stress can alter the metabolic functions in plants with a possible loss of food quality. This means that the plant-derived foods that we currently consume in our diet could have less health benefits in the future [6,7,8].

Therefore, the climate change produces a loss of ecosystem services generated by agroecosystems for human-wellbeing compromising food sustainability. These consequences will be amplified with the increase in world population that UN estimated by 75% in the future [9]. The effects of climate conditions on food security and population's growth can reduce the capacity of the economic system to satisfy the UN aims, such as No Poverty, No Hunger, Good Health and Well-being, Reduced Inequalities, Responsible Consumption and Production, and Climate Action [10].

Agricultural production has been compromised by energy policies, since many photovoltaic (PV) farms have been built in cropland fields with a loss of agricultural production. This produces a sort of paradox, since actions aimed to mitigate global warming are likely to cause local aberrations in the land use, with negative effects on human well-being [1, 2, 3].

Therefore, the agrivoltaics system can be considered as a new frontier of energy and crop production that combines PV panel technologies with natural capital, such as agroecosystems [11, 12, 13]. This produces a new element in the landscape system, by increasing the multifunctional land use and by passing from a negative vegetation management of the field used for the installation of PV farms, to an active vegetation management, which promotes food production. Indeed, in conventional PV farms the vegetation growth is characterized by neutrophilous vegetation with low ecological value in terms of ecosystem production. Therefore, the common action is mowing such vegetation to reduce shadow and fire risk. In agrivoltaics systems, on the other hand, vegetation management is characterised by agricultural practices aimed at avoiding the loss of assets and crop production. However, the need to switch from conventional PV farms to agrivoltaics system should promote technological adaptations to allow crop production under the panels [1,2,3,14]. In this regard, some scientific studies have shown that the microclimate generated by the PV panels may have positive effects on crop production, by reducing the combined effects of high temperature and drought events [11, 12, 13, 15]. Therefore, the agrivoltaics system can be highlighted as Innovative-based Solutions (IbSs), in which the applied technologies are functional in supporting natural capital to increase human well-being associated with food security. The aim of this work is to assess the ecosystem services in scenarios generated by following the Italian guidelines for PV panels technologies, agrivoltaics systems installation, and potential crop production.

2 Materials and methods

We analysed the differences in ecosystem services provisioning from those generated by the current vegetation growing under the PV panels to potential ecosystem services generated by crop production under and around the panels in the agrivoltaics system. The current ecosystem services production of PV farms (Scenario T0, Fig. 1) was mainly quantified by orthophoto analysis (with GIS software) of the vegetation in existing PV farms, and by referring to previous scientific studies [1, 2, 3, 13]. The ecosystem services production in agrivoltaics system (Scenario T1) was derived by considering the potential crops that can be produced under PV farms and promoted by the Regional and National Portal of Environmental Impact Assessment (EIA) in Italy. Moreover, this scenario was derived also considering the Italian guidelines for agrivoltaics system.

Starting from the Ecosystem Services matrix of land use by Burkhard [16], and with the help of experts, the land use change generated from Scenario T0 to Scenario T1 was characterized in terms of ecosystem services, by considering the international ecosystem services scheme developed by TEEB [17, 18, 19, 20].

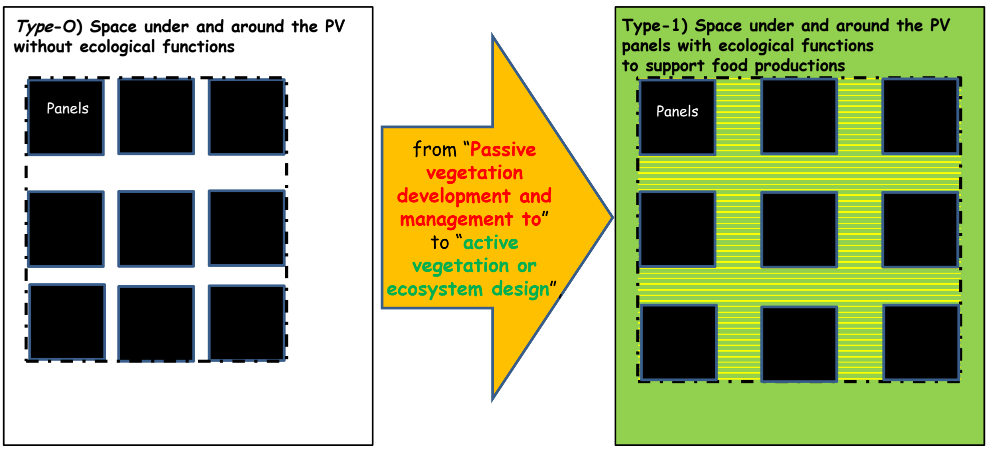

Fig. 1. Schematic representation of the change in new photovoltaic (PV) farms design by passing from a passive vegetation development to an active management with crop production.

3 Study Area

The Scenario T0 considered the Italian Apulia region as the main study area where the analysis of potential ecosystem services in the PV farms was carried out, whereas the Scenario T1 was derived by using different agrivoltaics projects submitted to the Italian EIA procedures, with different geographic localizations.

4 Results

We selected by orthophoto analysis some PV farms with high percentage of free surface land compared to the area occupied by installed PV panels. Visual inspections confirmed that PV panels are surrounded by ruderal herbaceous vegetation with low capacity to support ecosystem services [1, 2, 3, 19]. The ruderal vegetation characterises land potentially exploitable for human activities. This situation can typically occur in the PV farms, where land occupation is not planned or without direct management of the vegetation growing around and above the panels [76]. This situation may be found also in other phytogeographical areas like those found in the Apulia region.

Considering the current agrivoltaics projects submitted to the EIA procedure and National Guidelines for agrivoltaics system, two scenarios were considered to assess the ecosystem services provisioning between Scenario T0 and Scenario T1. We mainly have assumed two typologies of crops: vegetable cultivation and trees.

By taking as reference the Scenario T0, Scenario T1 with trees vegetation shows more increase of ecosystem services provisioning than Scenario T1 with vegetable cultivation. These effects are due to the majority of tree canopies structures characterised by wood. This has therefore a strong effect on "*Regulation functions*", even though some differences in ecosystem services production can depend/account from the cultivated tree species. In this study we mainly considered the general behaviour of the agricultural vegetation.

In the case of "*Regulation Functions*" there is not much difference between scenario T1 with vegetable vegetation and scenario T0, because both biophysical structure and processes can produce the same. In this case, the differences depend on the single species considered and specific ecological processes of the vegetation and their interaction with environmental. However, in the "*Regulation Functions*" there are some negative effects due the irrigation actions needed for crop cultivation. The crop vegetation can need strong water support, and without a system of rainwater recycling this aspect could produce an overuse of clean water.

For "*Habitat functions*" we didn't find differences because each cultivation supports a different fauna biodiversity, therefore a specific analysis would be required for each single vegetation crop.

The increase of ecosystem services in the "*Production functions*" is comparable in both cases of Scenario T1 because it strongly depends on the cultivation system and of the type of harvest. However, such increase compared to Scenario T0 is very high considering the absence of production from the vegetation.

The *"information functions"* increase in both systems, but not to a high degree because this is highly dependent on the use of the area and the new landscape patterns generated by the combination of vegetation and photovoltaic panels. Therefore, this aspect needs more consideration about the features of the single project and at the moment they cannot be generalized. However, there are some projects that promote the cultivation by specific associations giving a social value to the actions. Improving the fruition of the area not only for the energy activities but also for educational and scientific activities can be useful to increase these ecosystem services. Indeed, the change from ruderal vegetation to crop vegetation can give the possibility to amplify the secondary actions linked with crop activities. For example, the use of aromatic vegetation can give the possibility to promote educational activities and laboratory of products derived by this vegetation, such as soaps, herbal teas and more [1,2,3].

The "*Carrier functions*" is not valuable because this aspect needs an assessment of the context of the project and its integration with the social aspect of the landscape.

Table 1. Functions, goods and services identified from Scenario T0 to T1 with vegetable crop, or from Scenario T0 to T1 with trees, with the potential variation of such services associated with the land use change. ☺, indicates positive alteration; ☹, indicates negative alteration; =, indicates no significant alteration. The number of emoticons express the intensity of the variations of provisioning ecosystem services in the land use change: 1, low variation; 2, medium variation; 3, strong variation. [17, 18, 19, 21, 22, 23].

Functions		Ecosystem Services	From Scenario T0 to Scenario T1 (Vegetable crops)	From Scenario T0 to Scenario T1 (trees)
"Regulation functions"	*Gas regulation*	UVB-protection by O_3 (preventing disease). Maintenance of (good) air quality. Influence on climate.	☺☺☺	=
	Climate regulation	Maintenance of a favourable climate (temperature, precipitation, etc.) for human habitation, health, cultivation.	☺☺☺	=
	Disturbance prevention	Storm protection (e.g., by coral reefs). Flood prevention (e.g., by wetlands and forests).	☺☺☺	=
	Water regulation	Drainage and natural irrigation.	☹☹	☹☹
	Water supply	Provision of water quality (e.g., drinking, irrigation, and industrial use).	☹☹	☹☹
	Soil retention	Maintenance of arable land Prevention of damage from erosion/siltation.	☺☺	☺
	Soil formation	Maintenance of productivity on arable land. Maintenance of natural productive soils.	☺	☺
	Nutrient regulation	Maintenance of healthy soils and productive ecosystems.	☺	☺
	Waste treatment	Pollution control/detoxification. Filtering of dust particles (air quality). Abatement of noise pollution.	Not valuable	Not valuable
	Pollination	Pollination of wild plant species. Pollination of crops.	☺	☺
	Biological control	Control of pests and diseases. Reduction of herbivory (crop damage).	Not valuable	Not valuable
"Habitat functions"	*Refugio function*	Maintenance of biological and genetic diversity.	No valuable	No valuable
	Nursery function	Maintenance of commercially harvested species.	☺☺☺	☺☺☺
"Production functions"	*Food*	Hunting, game, fruits, etc. Small-scale subsistence.	☺☺☺	☺☺☺

	Raw materials	Building and Manufacturing (e.g., lumber). Fuel and energy (e.g., fuelwood).	☺☺	☺
	Genetic resources	Improve crop resistance to pathogens and pests. Other applications (e.g., health care).	No valuable	No valuable
	Medicinal resources	Drugs and pharmaceuticals. Chemical models and tools. Test and assay organisms.	No valuable	No valuable
"Information functions"	*Aesthetic information*	Enjoyment of scenery (scenic roads, housing, etc.).	☺	☺
	Re-creation	Travel to agroecosystems for eco-tourism and (recreational) nature study.	☺	☺
	Cultural and artistic information	Use of nature as motive in books, landscape symbol and arts.	☺	☺
	Spiritual and historical information	Use of nature for religious or historical purposes (i.e., the heritage value of natural ecosystems and features).	☺	☺
	Science and education	Use of natural systems for education. Use of nature for research.	☺☺☺	☺☺☺
"Carrier functions"	*Habitation*	Living space (ranging from small settlements to urban areas).	=	=
	Tourism-facilities	Tourism-activities (outdoor sports, walking, etc.).	=	=

5 Conclusion

Many PV farms currently are realized in marginal soils, with low value for agricultural use and production. These are classified as IV class of Land-Capability classification (soils with very strong restrictions on agricultural use), allowing only a limited choice [24] (Fig. 3). The problem of low agricultural use of some lands is connected to scarce water availability or erosive processes [25]. Therefore, the agrivoltaics capacity to improve ecosystem services for crop production compared to traditional PV farms should be set considering the water availability and should develop adaptive strategies for water use in agricultural activities. The crop choice should also consider the water availability.

In Apulia region many PV farms are often located in peri-urban areas. Therefore, a cultural leap in the design of agrivoltaics systems should include them in priority ecosystem services, such as aesthetic information, opportunities for recreation and tourism, inspiration for culture, art and design, and spiritual experience. In this way, they could represent a direct social use increasing the psycho-physical well-being of the population.

An important step to apply the crop production in PV farms and create shared value between economic, social, and ecological aspects of sustainability, is the development of a direct connection between benefits and incomes produced by ecosystem services in the management processes of energy and farm companies.

However, an important aspect in developing agrivoltaics project lies on an integrated knowledge during the design and planning process. This is important to overcome the fears generated by a lack of knowledge in the individual processes.

For this reason, a transdisciplinary approach that involves all stakeholders and experts becomes an important element in bridging the knowledge gaps generated by sectoral approaches, creating a holistic vision of the involved professional skills and experiences. The trans-disciplinarity can therefore promote agrivoltaics system as IbSs characterized by a combination of natural capital and technologies to increase ecosystem services for human well-being.

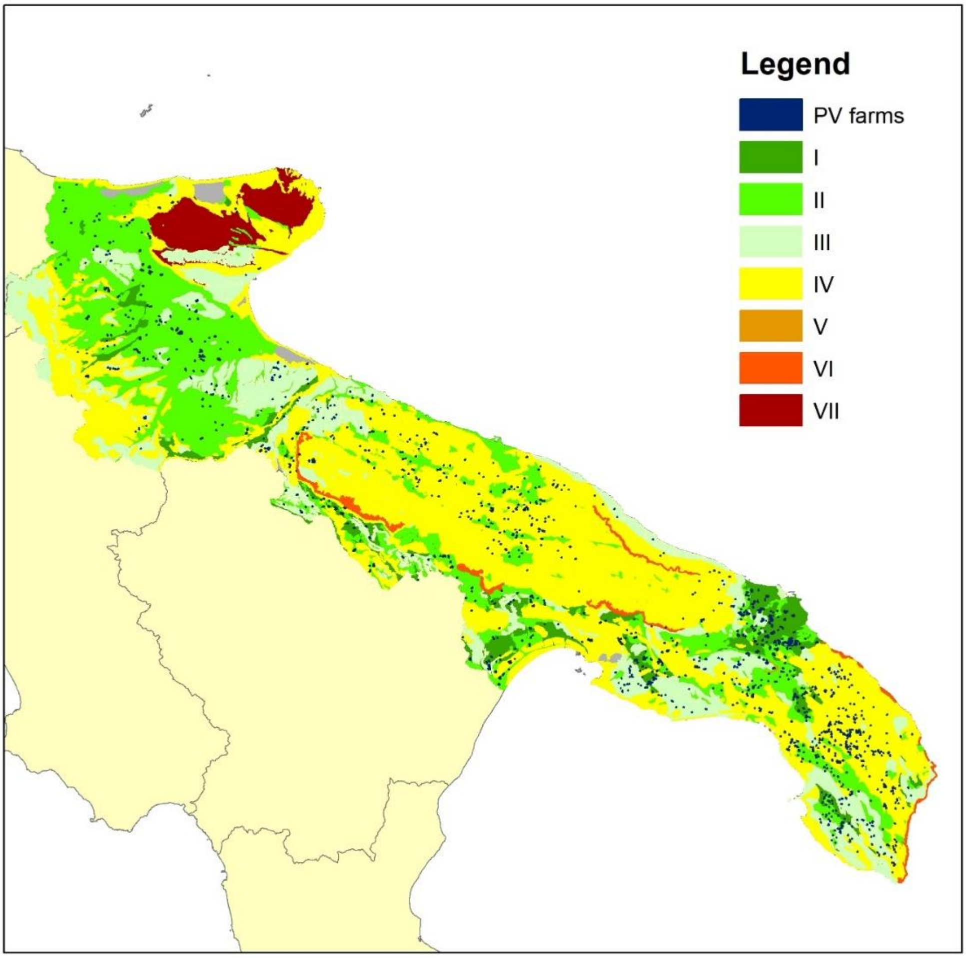

Fig. 2. Land Capability Classification in the Apulian region considering the available data on SIT Puglia, overlapped with realized PV farms [24, 25].

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