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ECOSYSTEM SERVICES' BASED IMPACT ASSESSMENT FOR LOW CARBON TRANSITION PROCESSES

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ABSTRACT

Low carbon transition represents one of the main challenges engaging territorial governments in a multi-scale structure of planning and actions. The thematic focus on renewable energies sources (RES) development prevailed on an integrated approach to plan such relevant process in a more integrated and systemic view based on multiple territorial values estimation and the assessment of potential conflicts depending on technological and landscape impacts

RES transition implies extensive territorial transformations and, in the case of Italy, the public management spent more effort in targeting RES installation objectives more than proposing a territorial plan of suitable area where such a process might be development preserving local territorial structure and values.

This paper presents the results of an ex-post analysis carried out to assess the effects of the rapid advent of renewable energy plants in a specific territorial context: Melfi area in Basilicata (Italy). Such a context is characterized by agricultural vocation and high natural values, but also representing the settlement place of the biggest industrial automotive center in the south of Italy.

The research approach is based on ecosystem services assessment through selected INVEST tools according with the presence of relevant specific features in the investigation area: carbon stock and storage, crop production, crop pollination and habitat quality.

Results allow to quantify an extensive territorial impacts generated by photovoltaics plants and wind-farms compared with production potential. Consequently policy recommendation are proposed in order to improve the governance model for future development of the sustainable energy sector in Basilicata.

KEYWORDS:
RES; Ecosystem services; Low carbon; Energy transition

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针对低碳转型过程、基于生态系统服务的影响评估

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摘要

在各种需要地域政府开展多尺度结构规划及行动的各种主要挑战中，低碳转型是典型的一种。这一课题关注与可再生能源（RES）的开发，因此需要寻求一种综合方法，来从一个更加完整和系统性的角度、基于多种地域价值观的估量和对取决于技术和景观影响的潜在冲突的评估，进行相关过程的规划。

RES转型意味着大量的地域变化；而在意大利，公共管理方在实现RES装置目标方面投入的工作超过了为适当地区制定地域计划的努力——在这样的地区，这一过程可能是保护开发的当地地域结构和价值观。

本文介绍了旨在评估特定地域环境下迅速出现可再生能源植物的影响的事后分析的成果：意大利巴斯利卡塔大区的梅尔菲地区。该地区的特征为农业职业和较高的自然价值，其同时还是意大利南部最大的汽车工业中心所在地。

研究的方法是基于通过选定的投资工具进行的生态系统服务评估，根据调查地区有关具体特征——碳储量、作物生产、作物授粉和栖息地质量等的情况确定。

研究结果可以将光伏发电厂和风力农场产生的广泛地域影响对比生产潜力，并进行量化比较。并据此提出了政策方面的建议，以期改善巴斯利卡塔将来在可持续能源领域谋求发展所采用的治理模式。

关键词:
可再生能源RES; 生态系统服务; 低碳能源; 能源转型

1 INTRODUCTION

The hoped-for energy transition to renewable sources of supply has had a major boost in recent years. Incentive policies and simplified authorization have led to the widespread presence of RES plants that in some contexts have radically changed the landscape. It is the task of urban and territorial planning to define a methodological framework and significant criteria for assessing the sustainability of these measures for the transformation of the territory.

1.1 ECOSYSTEM BASED PRO-VOCATION

The 2005 Millennium Ecosystem Assessment (MA) could be considered one of the main efforts to promote worldwide effective environmental assessment approaches, sponsored by the United Nations. The most provoking contribution promoted by MA is based on the concept that the ecosystem values in decision-making should be grounded on the idea of services provided to humans. This requires new interpretative parameters and computational tools in order to produce the required additional knowledge to reinforce the rational 'decision makers' in making 'better' decisions and policy choices (Owens, 2005; Sanderson et al., 2002).

Compared to that, "sustainability" has become a main policy concern both domestically and internationally, with increasing prominent place in decision-making processes concerning environmental issues (Bulkeley & Jordan, 2012). However, such a rising awareness in political debate produced strong thematic commitments: i.e. RES transition as a way to reduce CO_2 emissions. We are in the case of a conflict between human activities and the environment (fossil energy production, mainly) had been addressed through a generalized technological settlement of new systems which strongly reduced impacts of energy production in terms of CO_2 emissions, but generates other externalities affecting territorial values and landscape identities in a context of de-regulation in urban and regional planning.

Ecosystem services allowed to oppose a quantitative assessment of eco-systemic values in the procedure of environmental impacts assessment for RES plants settlement process. It becomes a tool for decision makers to govern more effectively territorial transformation even urban plans are not suitable to face the issue of RES installation according with the current normative system.

In order to demonstrate such conflictual situation we refer to a specific case study area: Melfi municipality in Basilicata (Italy). We consider the achieved results as a contribution in developing understanding of ecological knowledge use in policy driven processes that are more sensitive to the issues of power and control (Cowell & Mick, 2014; McKenzie et al., 2014; Scorza, Pilogallo & Las Casas, 2018), the ambition is to provoke strong advances in territorial governance by the mean of the new paradigm of ecosystem services based planning.

2 CASE STUDY AREA DESCRIPTION

The research has been structured on the municipal scale. In facts the study area includes the territory under the administrative jurisdiction of Melfi municipality. Melfi is located in the Basilicata region in southern of Italy (Fig. 1). Melfi is the third largest municipality in the region for resident population and territorial extension. The territory is characterized by the presence of San Nicola industrial area. An extended industrial area where most important plant for car production in the South of Italy where established by Fiat Chrysler Automobiles group (FCA). On the natural and landscape point of view the study area presents a strong agricultural vocation with relevant sites characterized by considerable naturalistic and environmental features. The area is significant because it has a peculiar land uses structure and, since 2010, it has been affected by numerous installations of RES plants. In 2018, in the study area, we mapped 66 installations of large wind farms (power of each wind tower greater than or equal to 1 MW) and 113 concerning small wind farms (power less than 1 MW). The estimation of total installed wind-power production capacity is around 219 MW. Moreover, for the photovoltaic sector there are 7 photovoltaic fields for a total occupied area of about 140.000 square metres.

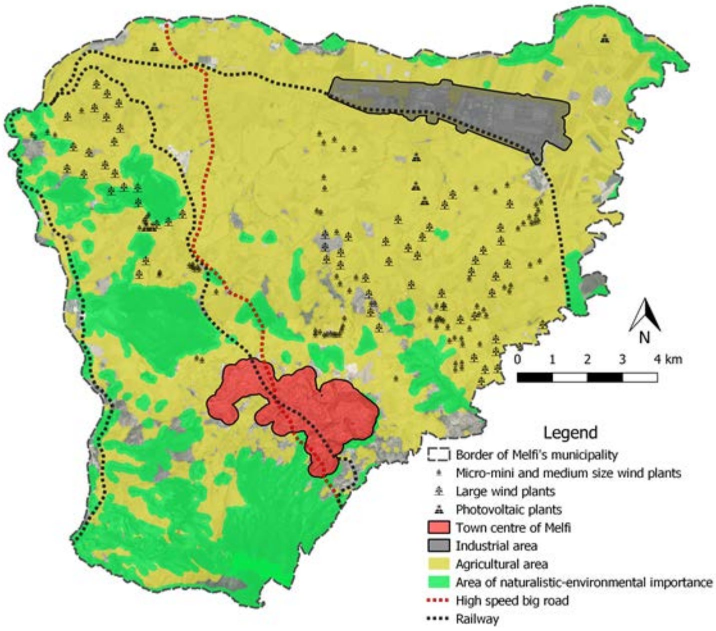


Fig. 1 Geographical overview of the study area, major land use classes, wind-power plants and main mobility infrastructures

3 METHODOLOGY AND RESULTS

This research aims to describe the impacts of a widespread growth in the renewable energy production plants in terms of loss of ecosystem services. For this purpose, considering the specific territorial features synthetically described in the previous paragraph, the analytical process had been based on four ecosystem services: Carbon Storage and Sequestration, Crop pollination, Crop production and Habitat Quality.

The analytical models used are included in the InVEST (Integrated Valuation of Ecosystem service and tradeoffs) suite (Nelson et al., 2018); territorial analyses were then produced in order to obtain a representation of the spatial distribution of the thematic and cumulative impacts depending on RES installation with consequences on the territorial capacity to provide ES.

3.1 CARBON STORAGE AND SEQUESTRATION

The assessment of the carbon stored within the study area was carried out using the tool "Carbon Storage and Sequestration" which returns a raster map which, pixel by pixel, is associated with the value of carbon stored in Mg/ha.

Input data are land use/land cover (LULC) map and a corresponding table with the four values of carbon pools. The resulting raster maintains the same resolution as the input cover map. The pixel size is 5x5 m and this allows a higher spatial accuracy including also the contribution in terms of carbon stored by urban green areas. The Tab. 1 shows the values used for each LULC class. The carbon pools estimation includes values provided by INFC (Gasparini & Tabacchi, 2011) for wooded classes plus IPCC (international panel of Climate Change) (IPCC, 2006) for the remaining ones.

The working hypothesis is to assimilate the areas affected by RES plants to the urban environment or, more generally, to a process of "land take" that cancels the contribution of these surfaces in terms of ecosystem services.

LUCODE	DESCRIPTION	C_ABOVE	C_BELOW	C_SOIL	C_DEAD
11	Residential buildings in compact urban centres	0.00	0.00	0.00	0.00
12	Residential buildings in dispersed urban centres	0.00	0.00	0.00	0.00
13	Buildings for industrial and commercial use	0.00	0.00	0.00	0.00
2	Road network (roads and railways)	0.00	0.00	0.00	0.00
3	Quarries and landfills	0.00	0.00	0.00	0.00
4	Gardens and urban greenery	15.00	0.00	0.00	0.00
511	Orchards	63.00	7.85	1.00	0.00
512	Vegetable gardens	0.00	4.7	62.57	0.00
513	Arable land	0.00	4.7	62.57	0.00
514	Olive groves	63.00	7.85	1.00	0.00
515	Vineyards	63.00	7.85	1.00	0.00
53	Fallow pasture	0.00	4.7	64.50	0.00
54	Woods	160.00	58.00	64.50	20.50
541	Coniferous woods	160.00	52.00	64.50	20.50
542	Broadleaf woods	160.00	59.80	64.50	20.50
62	Watercourses	0.00	0.00	0.00	0.00
7	RES plants: wind farms and photovoltaic fields	0.00	0.00	0.00	0.00

Tab. 1 Summary table of carbon pools values used for the study area

3.2 CROP PRODUCTION

The "Crop production - percentile" was developed to carry out trade-off analyses where the transformation hypotheses concern changes in land use in favor of or starting from agriculture.

On the basis of a global scale climate model, it is possible to make productivity estimates of 175 kinds of crops. Data used by the model comes from the FAO database supplemented by national and regional datasets.

In order to assess tradeoffs between an increase in agricultural profitability and expected loss of ecosystem services, calculations make it possible to predict and to estimate the productivity of an area in relation to certain types of crops and their relative economic benefits, while neglecting the impact of different management practices.

An alternative field of application is that of the present work, which has instead aimed to estimate the effect of policies and phenomena of territorial transformation on agricultural productivity in the area under consideration. The result is a spatial distribution of the yield expressed in tons per pixel.

Required input data consists of a land use map and a corresponding table of crops. A further table is required containing the values in kg/ha of the nitrogen, phosphorus and potassium compounds on average used throughout the study area. For the purposes of this work, values indicated in the Integrated Production specifications of the Basilicata Region for wheat and vineyards have been adopted.

CROP NAME	NITROGEN RATE	PHOSPHORUS RATE	POTASSIUM RATE
Grape	80.0	100.0	125.0
Wheat	110.0	35.0	30.0

Tab. 2 Summary table of fertilizers compounds values used for the study area

The territory of Melfi is in fact one of the areas of cultivation included in the DOCG regulations of the *Aglianico del Vulture Superiore*. Wheat, on the other hand, has been selected as an example of the numerous and extensive non-irrigated arable crops present.

As far as non-irrigated arable crops are concerned, they cover about 20,174 hectares, with a much more advantageous distribution compared to the vineyards. Not having detailed information regarding type of crops actually present, analyses were carried out considering all the arable crops cultivated with wheat.

3.3 CROP POLLINATION

Among regulation ES, the aptitude of study area to host pollinating species was investigated by using "Crop pollination" tool of INVEST that allows to map cell by cell potential presence based on a model that evaluates appropriate environmental conditions in terms of presence of suitable places for nesting and food availability. The necessary data consist in: LULC map; a table reporting indicators of suitability for nesting and/or for hosting floristic species that serve as food sources for pollinators for each LUcode; a table summarizing main characteristics of each pollinator species (maximum range, seasonality, food preferences).

Elaboration results consist in two kind of maps for each pollinator species and for each season of the year. The first kind represents an index of "pollinator supply" that expresses a measure of the availability of pollinator species considering both the accessibility to food resources and the usability of sites suitable for nesting. The second one is a "pollinator abundance" map, that is the potential presence of pollinators per pixel.

In other words, while the first map represents sites where pollinators originate, the second type of map gives indications on the places where pollinators carry out their activity by considering jointly both the available food resources that attract pollinators in individual cells, and the availability of insects that have access to the same cells.

The INVEST model was applied by considering a generic pollinator and assigning the maximum values for the availability of suitable nesting sites and food resources to wooded areas and uncultivated pastures. Intermediate values were considered for the classes of land use reserved for agricultural use, favoring the role of orchards, olive groves and vegetable gardens over that of non-irrigated arable land and considering minimum values but not zero along the riparian strips and within urban gardens and green areas. The reference year against which the changes have been evaluated is 2010, when no RES plant is recorded.

3.4 HABITAT QUALITY

The ecosystem service related to habitat quality is considered as an index of overall biodiversity, and falls within the category of supporting services. It has been estimated using the "Habitat Quality" tool of INVEST. This tool returns two raster maps of the territory under examination, one relating to the quality of the habitats and another, complementary to it, relating to the degradation of the habitats. These maps are created by combining and crossing information from Land Use/Land Cover (LULC) and threats to biodiversity. Therefore, the tool allows to model geographically the variations of the quality of the habitats and to evaluate, the positive and negative interactions between the natural environment and the anthropic activities or on the practices of use of the land.

It estimates the effect of each threat considered on the habitats analyzed, also considering the indirect effects induced by a considered combination of all the threats. Threats are to be considered as explicit spatial variables that could cause the local extinction of one or more animal or plant species. To better explain the spatial variability of the effects induced by the threats, the distance between the habitats and the source of degradation is considered. Finally, the model assesses the sensitivity of each land cover class considered as habitat to each individual threat, with a different weight.

The input data required by the tool are: (1) LULC Map; (2) Threat table: containing all the threats that the model must take into account with their weight (between 0 and 1) and impact in space (in km); (3) Threat maps: binary type 0-1 raster maps where the value 1 indicates the presence of the threat and the value 0 indicates absence; (4) Sensitivity matrix: containing for each LULC class a number between 0 and 1 representing the suitability of that land use to be a habitat and the sensitivity of each habitat to each threat considered.

The elaboration (on a rater with a resolution of 5x5 meters) was carried out for three time intervals: 2010-2014; 2015-2017; 2017-2018. Those intervals are consistent with data availability on RES plant distribution. Moreover we included as as additional land use class the one concerning the areas occupied by RES plants. The categories set out in Tab. 3 have been taken as the source of the threat on the basis of comparisons between different attributes in a variety of scientific articles (Chu et al., 2018; Sharma et al., 2018; Salata, Ronchi & Arcidiacono, 2017).

LUCODE	DESCRIPTION OF THREAT	THREAT	MAX DISTANCE [KM]	WEIGHT [0-1]
From 511 to 515	Agricolture	AGRI	0.3	0.4
11-12	Residential buildings in compact urban centers and scattered urban centers	BUILD	1	0.85
13	Buildings for industrial and commercial use	IND	1.5	1
3	Caves and dumps	CADI	1.5	0.65
7	Wind and photovoltaic systems	RES	1.5	1
2	Main high-speed link roads and railways	BROAD	2	1
2	Local roads	SROAD	0.4	0.3

Tab. 3 Table of threats acting on the territory with their weights and distances of impact. Each threat represents a single class of land use (lucode) or an aggregation of several classes

For the sensitivity matrix (Tab. 4), maximum habitat values were assigned to the land use classes for forests and watercourses, and zero values were assigned to the anthropic land use classes for buildings and RES installations. For each LULC, a score of 0 to 1 was assigned corresponding to the sensitivity of that habitat to the relevant threat (Polasky et al., 2011; Sallustio et al., 2017; Terrado et al., 2016).

LUCODE	HABITAT TYPE	HABITAT SUITABILITY [0-1]	AGRI	BUILD	IND	CADI	RES	BROAD	SROAD
11; 12; 13; 2; 3; 4.	Anthropized urban area	0	0	0	0	0	0	0	0
4	Gardens and urban green areas	0.3	0.3	0.4	0.4	0.1	0.3	0.3	0.5
511	Orchards	0.5	0	0.3	0.5	0.2	0.5	0.4	0.5
512	Gardens	0.5	0	0.3	0.5	0.2	0.5	0.4	0.5
513	Arable land	0.4	0	0.5	0.6	0.2	0.8	0.4	0.5
514	Olive groves	0.5	0	0.3	0.5	0.2	0.5	0.4	0.5
515	Vineyards	0.5	0	0.3	0.5	0.2	0.5	0.4	0.5
53	Pasture or uncultivated areas	0.6	0.4	0.7	0.6	0.3	0.9	0.6	0.4
54	Mixed forests	1	0.8	0.8	0.7	0.5	0.5	0.7	0.5
541	Conifer woods	1	0.8	0.8	0.7	0.5	0.5	0.7	0.5
542	Broadleaf forests	1	0.8	0.8	0.7	0.5	0.5	0.7	0.5
62	Watercourses	1	0.5	0.4	0.8	0	0.3	0.8	0.4
7	Renewable energy production plants: Wind and Photovoltaic	0	0	0	0	0	0	0	0

Tab. 4 Sensitivity matrix where the habitat grade [0-1] is reported for each land use class (or group of classes) and the sensitivity of each habitat to the individual threat [0-1]

3.5 RESULTS

The Carbon Stock assessment allowed us to estimate in 2013 a total amount of 10,3 kTons in the study area. This value, considering only the transformations induced by RES energy production plants, undergoes a decrease of 0.31% corresponding to about 32 tons of carbon previously stored.

The agricultural productivity - Crop Production - was analyzed considering high value-added crops (viticulture) and cereal production. The RES plants almost exclusively concerned cereal production areas. Results show the presence of three climate zones within the study area, which involve the division into three classes of productivity. Regarding vineyards, values range into following three classes: low (up to 37.2 q/ha), medium (from 37.2 to 68.4 q/ha), high (greater than 68.4 q/ha).

Cereal production had been more affected by RES plants development: as can be seen from the Fig. 2, the area of greatest concentration of RES plants overlaps "Non-irrigated crops".

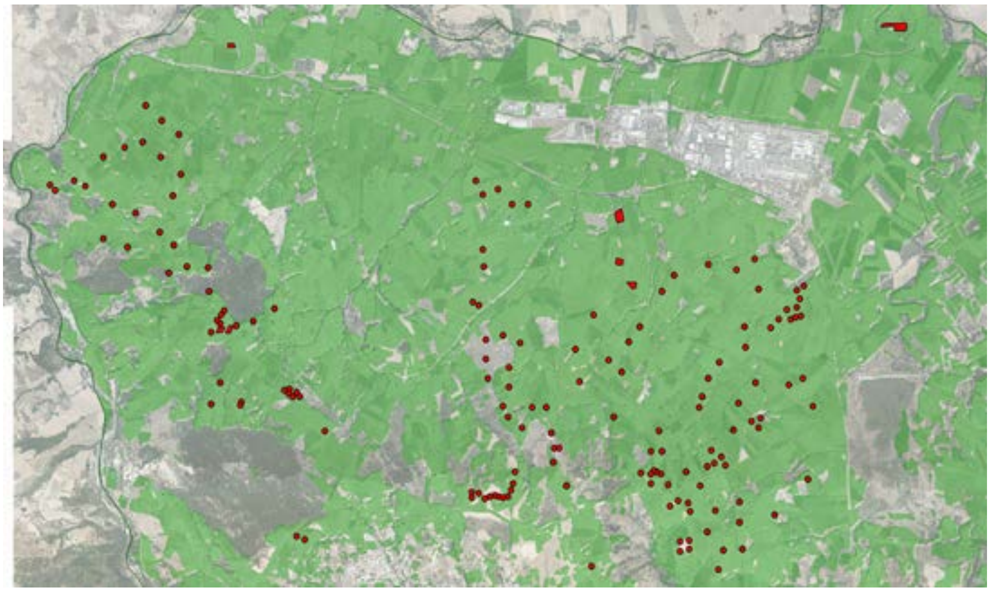


Fig. 2 Location of RES systems located in non-irrigated arable areas (in green)

Results as regards the ability to provide adequate habitats for pollinating species highlights the crucial role of wooded areas (dark red in Fig. 3) but also the variability that characterizes non-irrigated arable land on the basis of distance from urban areas.

This is particularly evident in the area immediately south of the industrial area where, although the dominant land use class is "non-irrigated arable land", the index decreases as urbanized areas come closer.

In order to evaluate the alterations INVEST has been run considering for every temporal step, plants to be added to the pre-existing ones. The following image is intended to represent precisely the loss with respect to 2010 of the index recorded by the model at the end of 2018. By overlapping RES plants to 2018, it can be seen that the ecosystem service in question is strongly affected by the density of the installations.

Concerning Habitat Quality the results were grouped into 4 macro-classes: "no-habitat", "low quality/degradation", "medium quality/degradation" and "high quality/degradation". On the habitats quality, in the time phases analysed, the percentages of land classified as "no-habitat" and "low quality" increased by 0.46% to the detriment of those classified as "medium quality", which on the contrary decreased by 0.45%.

For habitat degradation (Fig 5), in the time phases analysed, the area classified as "low degradation" decreases considerably, by 18%. In addition, the areas classified as "medium degradation" and "high degradation" together increase by about 18%.

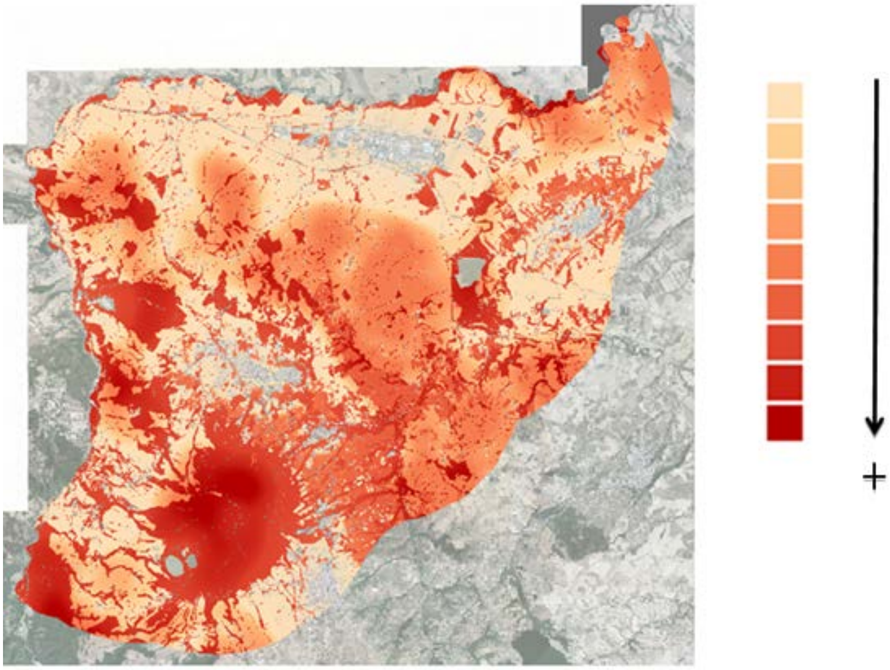


Fig. 3 Pollination supply index map for the year 2010

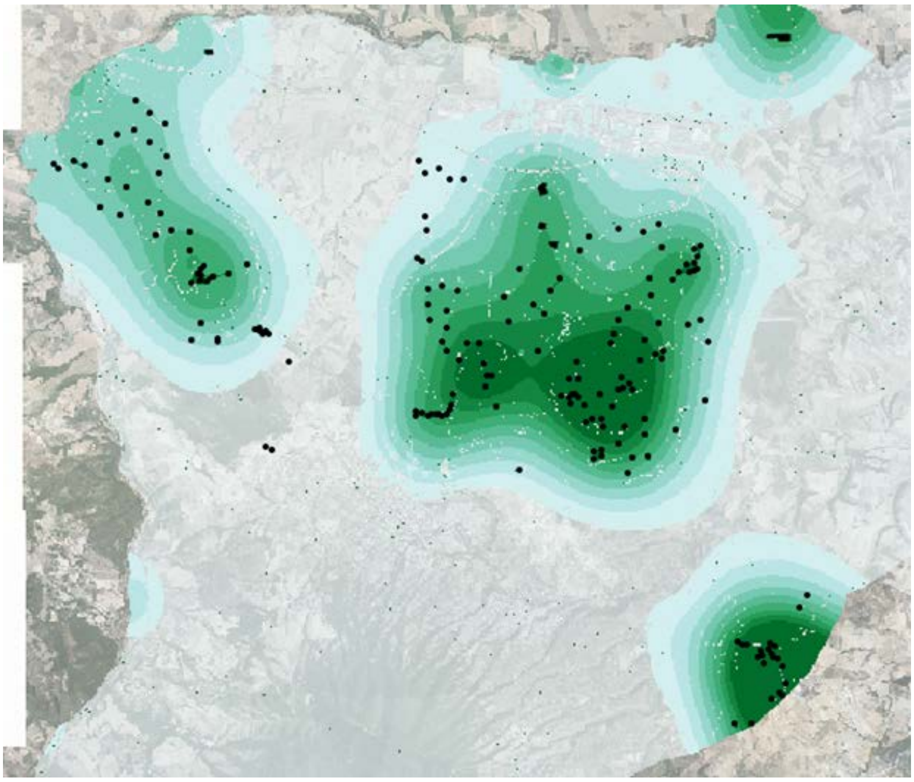
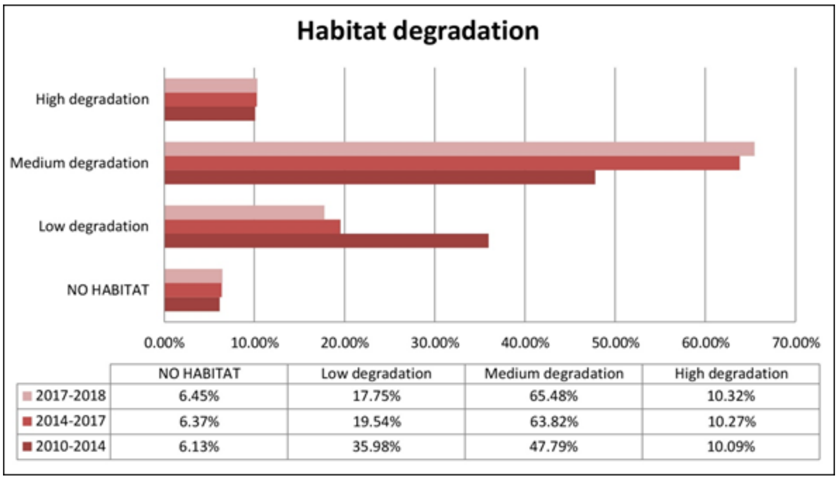


Fig. 4 Overlay between RES implants in 2018 and the evolution of the "Pollination abundance" index between 2010 and 2018

In order to provide a comprehensive estimation of the impacts produced by RES installations ore 2010 - 2018 time frame a synthetic map (Fig. 6) was delivered combining the results discussed before in a linear combination model. Such map represent the general loss of ecosystem services. Lighter colors correspond to less loss and vice versa. As it is possible to see, there are two areas that have been most altered: the first located north-west of the town, the second between the town and San Nicola industrial area.



	NO HABITAT	Low degradation	Medium degradation	High degradation
2017-2018	6.45%	17.75%	65.48%	10.32%
2014-2017	6.37%	19.54%	63.82%	10.27%
2010-2014	6.13%	35.98%	47.79%	10.09%

Fig 5 Graph of habitat degradation representing on the abscissas axis the amount of surface in percentage and on the ordinates axis the level of habitat degradation identified. The table under shows the percentage value for each time interval analysed

The first one is characterized by a low heterogeneity of the existing plants. In fact, there are mainly wind turbines with a generating power greater than 1 MW with two photovoltaic fields. The opposite situation is found in the second area in which there are wind and photovoltaic systems heterogeneous for power capacity, height of the tower and rotor diameter.

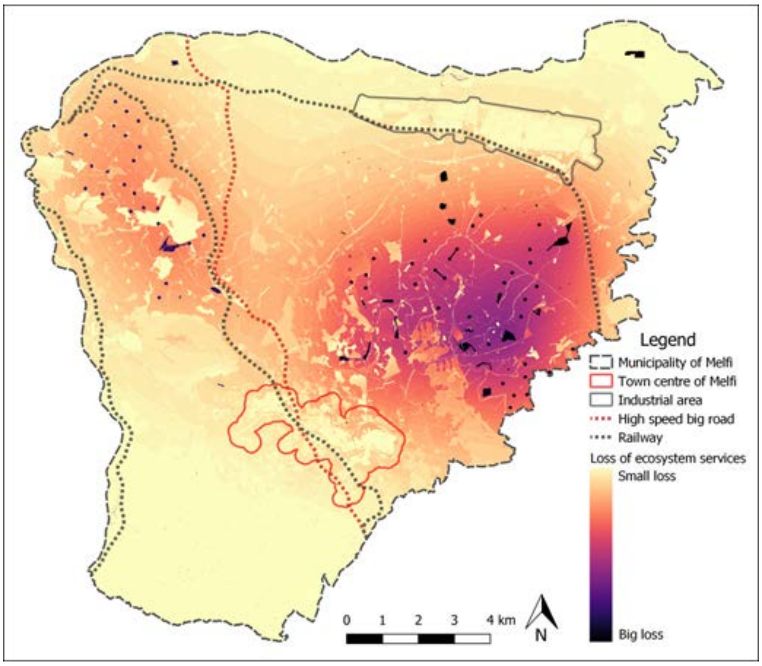


Fig. 6 Map representing the general loss of ecosystem services in the study area between extreme time intervals (2010-2018)

Such elaboration allowed to understand how the greatest cumulative impacts depends on the distribution of plants in those territories with higher density of wind-towers and photovoltaic plans. It is remarkable how the environmental assessment of a RES plants has to consider existing baseline and cumulative effects for the estimation of impacts scenario.

4 CONCLUSIONS

The aim of this work is the application of a method to evaluate territorial transformations induced by the installation of renewable energy production plants through the approach of ecosystem services (Scorza et al., 2019). The ecosystem services analyzed are those that best describe the identity characteristics of Melfi territory, capturing the aspects of natural and environmental value and the strong agricultural vocation that is characterized both by the large extension of cereal areas and for some valuable products such as vineyards of Aglianico. A cumulative effects comes out as a comprehensive assessment of the sectoral estimation as a form of territorial sustainability performance assessment (Dvarioniene et al., 2017). Such results has to be improved in terms of more detailed estimation of the parameters selected as INPUT in INVEST models and, mainly, in the estimation of effects combination calibrated on specific on-field evidences.

However it is possible to affirm how the current procedure of environmental impact assessment for big RES plants (ore that 1 MW power capacity) is un-effective in considering the cumulative effects of the new plants in the comprehensive settlement scenario. Furthermore the small plants are authorized even without such environmental assessment procedure and their effects may be even more disruptive and uncontrollable.

It is necessary to start a process of territorial transformation monitoring (i.e. starting from effective procedures of land take and urban sprawl detection) (Saganeiti et al., 2018) to support the elaboration of sustainable energy policy at regional and municipal level based on an integrated assessment of territorial values with the global issue of reducing CO_2 emission. The ESs combined with remote sensing and advanced spatial analysis techniques could balance conflicting objective of sustainability: low-carbon energy transition, preservation of natural resources, reinforcing agriculture and food production.

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