

Ecosystem Services Approach to Evaluate Renewable Energy Plants Effects

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Abstract. Economic, social and environmental aspects have led local, regional and national governments to promote policies to increase the spread of renewable energy (especially wind energy). The transformation into an energy system based on renewable sources is therefore already underway. In this context, the effects of renewable energy sources on ecosystems are to be analyzed. In this regard, the 2005 Millennium Ecosystem Assessment (MA), promoted by the United Nations, is an international reference for the development of a global environmental assessment approach. One of its most innovative contributions is to promote a structured approach in which the value of the ecosystem in the decision-making process should be based on the idea of the services it provides to humans.

This work presents the results of an ex-post analysis carried out to assess the effects of rapid growth of renewable energy plants in a low-density area with a strong agricultural vocation, characterized by an important industrial center and areas of high natural values. The approach used is that of ecosystem services through the use of the most significant INVEST tools in the context: carbon stock and storage, crop production, crop pollination and habitat quality. A spatial combination has been performed in order to assess ecosystem services cumulative loss.

Keywords: RES · Ecosystem services · Carbon stock · Habitat quality · Crop production · Crop pollination

1 Introduction

The transition to renewable energy sources (RES) is considered one of the main component to pursue sustainable development goals [1]. From our observatory we have to point out that, especially in the South of Italy, at a regional level, this instance has been implemented by simplified authorisation procedures for the installation of RES plants based on the European incentive policies. This transformation process took place in the absence of a sufficiently robust scoreboard [2]. RES plants impact, indeed, can be critical since they involve land use change e land take, alter landscape perception, are responsible for the fragmentation of ecosystems in which they are located and they lead

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S. Misra et al. (Eds.): ICCSA 2019, LNCS 11624, pp. 281–290, 2019.
https://doi.org/10.1007/978-3-030-24311-1_20

to alterations in habitats quality. Essentially, they affect the capacity to deliver ecosystem services (ES).

This approach, promoted by the United Nations through the Millennium Ecosystem Assessment [3], is a useful toolkit to support the decision-making process, to conduct adequate and effective scenario analysis, to build a robust and spatial-explicit assessment scoreboard for all-scale territorial transformations [4–6].

Within this methodological framework, the present work aims to describe the effects of a widespread and scattered growth in RES plants in terms of cumulative ES loss in a context characterized by a low population density and a fragmentation degree ranging between medium and high [7–9].

The study area, representative of the reality of several municipalities located between Basilicata, Campania and Puglia, is characterized by a strong and deep-rooted agricultural vocation, components of naturalistic-environmental value and the prominent presence of a very large industrial center.

Four ecosystem services have been selected to assess specific features of this case study: Carbon Storage and Sequestration, Crop pollination, Crop production and Habitat Quality.

The analytical model used to assess and to represent ES is the InVEST (Integrated Valuation of Ecosystem service and trade-offs) suite [10]; further analyses carried out in GIS environment were then produced in order to obtain a representation of the spatial distribution of the overall cumulative impacts on ecosystem and its capacity to provide ES.

Finally the assessment of cumulative effects was carried out by a spatial combination of effects obtained for each of considered ES.

Our results show that on the basis of the results obtained from the proposed methodology, it is possible to formulate policies that effectively consider local territorial features and values in order to better understand the impacts deriving territorial transformation process.

2 Materials and Methods

2.1 Study Area

Melfi municipality is located in the northern part of the Basilicata region (Italy) on a territorial area of about 205 km^2 and totals 17.878 inhabitants at 2017 [11]. It is characterized by a settlement structure based on two main components: the historic town surrounded by the post second world war residential expansion, and a huge industrial area where the most important Italian Fiat Chrysler Automobiles group (FCA) production plant was established. The rest of the municipal territory is characterized by a strong agricultural vocation and widespread areas of high natural and environmental value that are already fragmented by three railway lines and a high-speed suburban road that serves as the main link with the regional capital, Potenza.

Since 2010, the year of adoption of the Regional Environmental Energy Guideline Plan (PIEAR), this territory has been affected by an intense installation of RES plants, attracting numerous and significant investments from large operators in the sector. By 2018, the number of RES plants in the study area had been set at about 200, including wind turbines and photovoltaic fields, with an installed electricity production capacity close to 200 MW.

2.2 Dataset

Informative layers considered are: (1) TRC land use (Regional technical cartography produced by the Basilicata Region and distributed through OGC standards in RSDI [12]) at 2013; (2) the dataset of RES plants including the most significant dates of the authorization and construction cycle, and attributes concerning the installed generation capacity [Kw] or [Mw] of individual wind turbines.

Concerning land use, we referred to the following LCC: (a) Residential buildings in compact urban centres; (b) Residential buildings in dispersed urban centres; (c) Buildings for industrial and commercial use; (d) Roads and railways; (e) Caves and dumps; (f) Gardens and urban green areas; (g) Orchards; (h) Gardens; (i) Arable land; (j) Olive groves; (k) Vineyards; (l) Pasture or uncultivated areas; (m) Mixed forests; (n) Conifer woods; (o) Broadleaf forests; (p) Watercourses.

The RES plants datasets comes instead from the integration of TRC and GSE (National Energy Services Manager) [13] layers and further plants derived from aerial photogrammetric survey different dates.

In order to carry out an overall assessment of the land take connected to plants construction, a buffer with a radius proportional to the installed power has been created for each wind turbine (see Table 1).

Table 1. Wind plant classification

	Power output	Radius of influence
Micro-mini turbines	0–200 Kw	15 m
Medium sized turbines	200–999 Kw	25 m
Big sized turbines	>1 Mw	50 m

In addition, in order to consider the reduction in the capacity to provide ecosystem services in all the areas included between different turbines, individual installations have been aggregated using as a reference a limit distance of 250 m. With the same purpose, for photovoltaic fields a 25 m belt of pertinence from the perimeter was considered (Fig. 1).

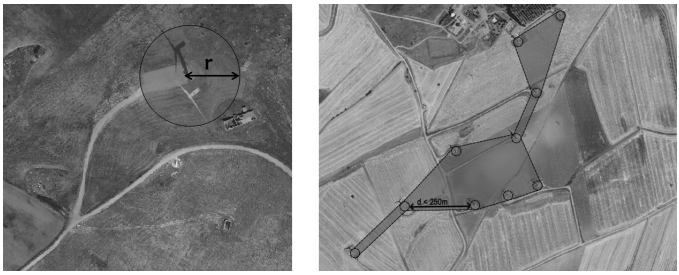

Fig. 1. Aggregates construction.

2.3 Methods

Global policies since Kyoto [14] have strongly promoted the transition to a low-carbon economy stimulating actions involving local authorities, SMEs and citizens [15–17]. A significant component of this development process is related to the installation of RES plants (in particular wind turbines and photovoltaic fields). Nevertheless these processes of technological settlement generate significant territorial impacts.

The aim of this work is to assess these effects within a low-density settlement context by considering the cumulative impact as a loss of ecosystem service provision.

For this reason, the methodology is essentially composed of two successive steps: the first consists of the evaluation of individual ecosystem services on the two dates considered (2013–2018). To this end, the INVEST modules considered most suitable to describe the peculiarities of the study area were used: Carbon Storage and Sequestration, Habitat quality, Crop Production and Crop Pollination.

The second step was instead aimed at considering the cumulative effects by a weighted combination of the results of the previous step.

Carbon Storage and Sequestration

INVEST Carbon Storage and Sequestration tool requires as input data a land use/land cover (LULC) map and a corresponding table with values of each of the following carbon pool:

- Aboveground biomass including carbon stored in foliage and wood but not in herbaceous cover;
- Belowground biomass including carbon stored in root system;
- Soil, defined as organic carbon (SOC) because stored just in the mineral layer;
- Dead organic matter including carbon present within litter and dry biomass.

It gives as result a raster maintaining the same resolution as the input cover map.

For this work, a pixel size of 5 m was considered in order to include the contribution from urban green areas.

In the lack of data at regional level (as already stated in previous works [18]), values relating to the four carbon tanks have been obtained considering as reference the Guidelines for national greenhouse gas inventories published by the Intergovernmental Panel on Climate Change (IPCC) in 2006 [19].

Our working hypothesis was to assimilate 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.

Crop Production

By using "Crop production" tool, it is possible to make productivity estimates of 175 kinds of crops on the basis of a global scale climate model derived on the base of FAO database supplemented by national and regional datasets.

Developed with the aim of assessing trade-offs between an increase in agricultural profitability and expected ES losses, this tool makes it possible to predict the productivity of an area in relation to different kind.

In our work this tool finds a different application that is an evaluation of policies and territorial changes effects on agricultural productivity with regard to the case study area.

Required input data consist of a land use map, a table of crops and a further summary table containing the values in kg/ha of the nitrogen, phosphorus and potassium compounds on average used throughout the study area. Concerning this work, values indicated in the Integrated Production Specifications of Basilicata Region for wheat have been adopted (Table 2).

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

Crop name	Nitrogen rate	Phosphorus rate	Potassium rate
Wheat	110.0	35.0	30.0

Not having detailed information regarding type of crops actually present, analyses were carried out considering all the arable crops cultivated with wheat.

Crop Pollination

"Crop pollination" tool of INVEST allows to map cell by cell potential presence based on a model that evaluates the presence of appropriate environmental conditions or suitable places for pollinators nesting and food availability. Required are:

- a 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 LULC code;
- a summary table about main characteristics of each pollinator species (maximum flight range, seasonality, food preferences).

Results are two maps for each pollinator species and for each season of the year: the first represents "pollinator supply" index that is a measure of pollinator species availability considering both accessibility to food resources and usability of nesting sites; the second map represent "pollinator abundance" map that explicitly shows spatial distribution of pollinators' potential presence.

In this work, the 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 agricultural use while minimum values were assigned to riparian strips and within urban gardens and green areas. Seasonality has not been taken into account.

Habitat Quality

Combining and crossing information from Land Use/Land Cover (LULC) and threats to biodiversity, "Habitat Quality" tool returns two complementary raster maps, one related to the habitats quality and the second that represents habitats degradation. This tool allows indeed to show both positive and negative interactions between the natural environment and anthropic activities further considering distances between the each habitat and degradation sources. It estimates effects of each threat and indirect effects induced by a considered combination of all other threats.

Finally, the model assesses the sensitivity of each land cover class considered as habitat to each individual threat, with a different weight.

Data required are: (1) LULC Map; (2) Summary table of all threats ranging between 0 and 1 and the related impact distance (in km); (3) Threat maps that are binary type raster maps (1 = max threat; 0 = no threat); (4) Sensitivity matrix including values about the suitability of each land use to be a habitat and its own sensitivity to each threat.

Habitat quality literature [20–22] was our data source for compiling threats table while the sensitivity matrix was filled in considering forests and watercourses as most high naturality classes. Zero values were assigned to artificial covers (i.e. urban and settlement and RES plants, as well). Sensitivity values were derived from scientific literature [23–25].

3 Results

The above mentioned elaborations were carried out with reference to two dates: 2013, the year in which the regional cartography was carried out, and 2018. For each of the ecosystem services analysed, the loss over the last 5 years has been calculated considering the territorial transformations induced by RES installations (Fig. 2).

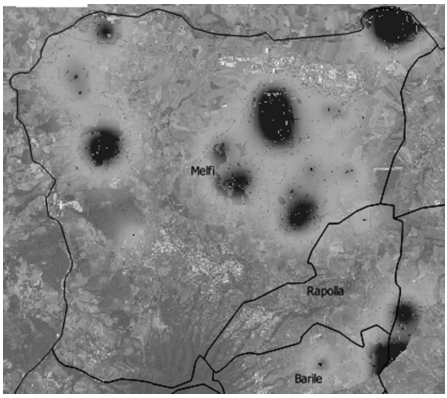

Fig. 2. Loss of ES related to carbon storage in the period 2013–2018.

Losses thus calculated were subsequently normalized in order to work with comparable scale of quantitative outputs. The aim of the work was in fact to obtain a spatial distribution within the study area of the cumulative effects due to ecosystems degradation induced by the presence of photovoltaic systems and wind turbines.

The spatial combination of the individual losses has allowed to obtain a map that represents, by means of gradual color ranges, areas most affected by the coexistence of impacts deriving from each ES included in the analysis.

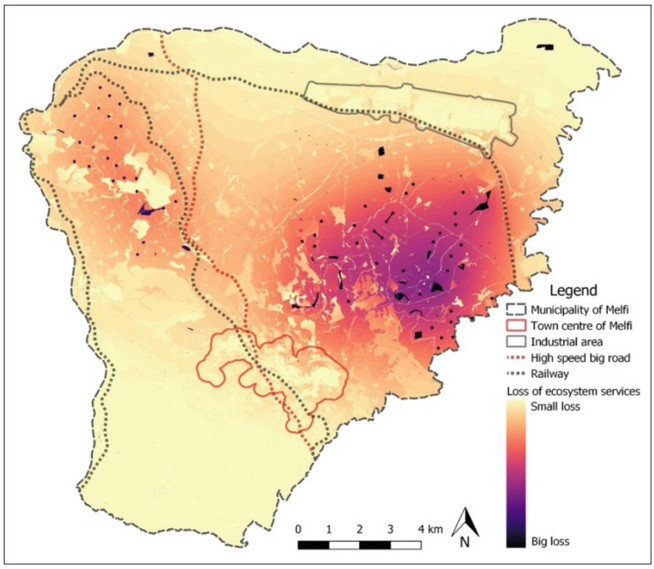

Fig. 3. Cumulative ES losses in the period 2013–2018

As can be seen from Fig. 3, areas suffering maximum degree of cumulative loss coincide perfectly with the aggregates of the installations.

In addition, it is significant that the most compromised area is the one between the city center and the industrial area, where the highest turbines density is recorded.

On the opposite, plants located in the north-west of Melfi municipality do not seem to have caused a marked change in the capacity to provide ES.

4 Conclusions

This work represents a first effort to establish an effective evaluation framework of territorial transformations depending from the evolution of 'energy landscapes'.

If we consider the normative framework developed by Basilicata Region in order to manage such process of energy production transition toward a low carbon model we identifies a simplified authoritative procedures. It is the case in which a lack of integration between sectorial policies (the Energy Plan) and territorial management tools

(urban and regional plans) didn't allowed to monitor the effective consequence of the spread development of RES installation on other territorial components. In Basilicata, the approach to identify only a target for RES production without comparing it with suitability criteria of territorial transformation represented a critical weaknesses of decision making process. Our research contributes to demonstrate the result of such approach in term of ex-post assessment and could also be considered as a base-line for future policy development as a mean of the territorial planning toolkit [26–29].

Conspicuous and widespread growth of RES installations, however, has led to significant changes at the local level, especially in the study context, characterized by low population density and weak prevision of urban growth [30, 31].

In this research, in order to assist in the formulation of a tool able to assess these transformations considering the specificity of the places and the instances that come from the different scales of planning, an evidence based methodology has been tested.

By jointly analyzing impacts of different ecosystem services loss, the most critical effects had been identified where the proximity of numbers of RES plants occurred. It suggest recommendations to include maximum density threshold in RES regulations.

As highlighted in previous work [18], future research developments could be aimed at improving information sources possibly by drawing on elaborations carried out in the same study region and testing multi-criteria spatial analyses for the cumulative combination of impacts.

Acknowledgements. This research has been developed within the MEVCSU and INDICARE projects supported by the Environmental Observatory Foundation of Basilicata Region (FARBAS).

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