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Trade-off between photovoltaic systems installation and agricultural practices on arable lands: An environmental and socio-economic impact analysis for Italy

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ABSTRACT

The paper introduces and discusses an open-source spatial-based model (called *r.green.solar*) able to quantify the energy production from solar photovoltaic (PV) ground-mounted panels. Socio-economic and environmental impacts can be evaluated by the model. The model starts from the theoretical quantity of solar PV potential energy and estimates a reduction of total amount of energy based on legal, technical, recommended and economic constraints. Model outputs were used for a trade-off analysis between energy production and traditional crops for food/feed cultivation on not irrigated arable land. The model was tested at regional level for a Mediterranean context (Italy). The results confirm that the economic profitability of PV systems follows a north-south gradient, but the main impacts are related to local peculiarities – such as the disposal of not irrigated arable land and the presence of constraints, in particular the landscape maintenance, the morphological variables and the specialization index – and crop yields.
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1. Introduction

In order to cope with negative effects of climate change, several political measures and actions have been applied worldwide in recent years. Normative rules have been particularly focused on the reduction of carbon dioxide emissions and substitution of fossil fuels with renewable energy (RE) sources. In this sense, the European Commission released the Directive 2009/28/EC on the promotion of the use of energy from renewable sources. This Directive – also known as 20-20-20 strategy – reports on mandatory national targets and measures for the use of energy from renewable sources, highlighting at the same time the need of national RE action plans. Despite to date several environmental and socio-economic benefits have been recognized to RE, in the recent scientific literature a growing interest is given to the evaluation of potential negative impacts as well as integrated analysis (see e.g., Valodka and Valodkienė, 2015; Bilgili et al., 2016). Taking into account the Directive 2009/28/EC, sustainability criteria for RE production are strictly defined only for biofuels and bioliquids. However, also the other RE sources (i.e. geothermal, hydropower, wind and solar power) can affect a specific production and/or consumption areas in ecological, social and economic terms. Particularly, these RE sources can have significant impacts on certain Ecosystem Services (ESs). To cope with risk of negative impacts, a number of studies and models have been carried out, paying particular attention to biomass/biofuels production (see e.g. Verkerk et al., 2011; Dominik and Rainer, 2014; Upham and Smith, 2014), wind power (Kouloumpis et al., 2013; Yuan et al., 2015), hydropower (Daini, 2000; Chen et al., 2015) and solar energy (Kaygusuz, 2009; Wanderer and Herle, 2015).

One of the first studies focused on assessment of the potential impacts of solar energy was developed by Neff (1981). In that work, the author pointed out some important relationships between the implementation of photovoltaic (PV) technology and the consequences on public occupational safety and health. A particular emphasis was given to the indirect effects on labor market as well as to environmental consequences. In this sense, land use,

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Nomenclature

η_{Theo}	Conversion efficiency related to the Carnot efficiency limit (%)
S_{EN}	Total solar energy (kWh/m^2 year^{-1} per each kWp of installed power)
S_{EN}	Total solar energy (kWh/m^2 year^{-1} per each kWp of installed power)
TH_{EN}	Theoretical energy (MWh/pixel year^{-1})
nsres	North-south resolution of raster map (m)
ewres	East-west resolution of raster map (m)
LE_{EN}	Legal energy (MWh/pixel year^{-1})
AL	Pixel classified as not irrigated arable lands (code 2111 of IVth level corine land cover)
LC	Pixel classified as areas with landscape constraint
NA	Pixel included in protected areas
TE_{EN}	Technical energy (MWh/pixel year^{-1})
k	Actual net available surface for PV plants installation (%)
η	PV plant efficiency (%)
sl	Slope (%)
alt	Altitude (m asl)
m	Municipality
r	Region
$NIAL_m$	Municipal surface of not irrigated arable land (ha)
$NIAL_r$	Recommended energy (MWh/pixel year^{-1})
FR	Pixel classified as high flood risk
LR	Pixel classified as high landslide risk
ER	Pixel classified as high earthquake risk
REV	Revenues from PV energy selling (€/pixel year^{-1})
p	Market price of PV energy (€/MWh)
inc	Additional optional incentives for PV energy (€/MWh)
RPV	Revenues present value for PV plants (€/pixel)
CPV	Costs present value for PV plants (€/pixel)
NPV_{PV}	Net present value for PV plants (€/pixel)
r	Discount rate (%)
d	Yearly decay of performance of photovoltaic modules (%)
lc	Life cycle for PV plants (years)
P	Installed PV power (MW/pixel)
u	Unit cost for fixed ground-mounted PV panels installation (€/MW)
i_C	Purchase and installation cost for PV plants (€/pixel)
g_C	Cost for PV plants connection to electric grid (€/pixel)
R_{AL}	Cost for rent of not irrigated arable land (€/ha year^{-1})
r_C	Surface rent cost (€/pixel year^{-1})
m_C	Maintenance cost for PV plants (€/pixel year^{-1})
c_C	Cleaning cost for PV plants (€/pixel year^{-1})
a_C	Administrative and consultancies costs for PV plants (€/pixel year^{-1})
s_C	Insurance cost for PV plants (€/pixel year^{-1})
d_C	Decommissioning cost for PV plants (€/pixel)
x	Specific crop
NR	Net revenues for crop (€/ha year^{-1})
GAP	Gross agricultural production (€/ha year^{-1})
C	Cost for crop production (€/ha year^{-1})
GAP	Gross agricultural production (€/ha year^{-1})
C	Cost for crop production (€/ha year^{-1})
NPV_X	Net present value for crops (€/ha year^{-1})
rot	Rotation period for crop (years)

thermal and climatic effects and emissions were identified as relevant issues to be evaluated. A balance in positive and negative impacts of solar PV energy was defined in Swapnil Dubey et al. (2013), by a categorization of consequences in different classes: (i) land use and landscape, (ii) infrastructure, (iii) political, (iv) energy market, (v) industry, R&D, education and (vi) public & marketing. More insights about large-scale PV plants were given in Phillips (2013). The author depicted how the PV systems can be conducive to achieving a high level of sustainability, compared to traditional energy sources for both construction and operation phases. Detrimental effect could be revealed for few wildlife species (i.e. for flight hazards). Neutral impacts were defined for other features such as visual aesthetics, land occupation or habitat fragmentation. In addition, unknown effects were highlighted by the author, in particular related to soil and water impact as well as to local climatic variation (change in surface albedo and other surface energy flows). Life Cycle Assessment (LCA) approach – including disposal, and/or recycling phase of panels – is another applied methodology for PV impact appraisal (see e.g. Fthenakis and Chul Kim, 2009; Turconi et al., 2013; Dubey et al., 2013). A recent approach deals with the analysis of PV impact on ESs following the classification proposed by the Millennium Ecosystem Assessment (Hastik et al., 2015).

A literature review about territorial and landscape impacts for solar power plants was implemented by Chiabrando et al. (2009), with a real application for ground-mounted PV. Among different potential negative effects the authors introduced an in-depth assessment of glare risk due to panels. Zanon and Verones (2013) stressed the risk of PV conflicts on the use of fertile areas or the impact of technical equipment on the landscape. Public perception of PV systems was investigated by Tsantopoulos et al. (2014) in Greece with resulting environmentally-friendly, sustainable and socially acceptable opinions for this RE from citizens. Heras-Saizarbitoria et al. (2011) investigated the public acceptance of PV solar energy in Spain through the role played by the media. However, as shown in Brudermann et al. (2013), although some decision makers – such as farmers – usually have rather strong eco-attitudes and ethical considerations about PV systems implementation, these factors do not seem to be good predictors with respect to the adoption of PV technology.

An awkward problem concerning ground-mounted PV plants is often depicted in land use competition with crop production. Some studies showed the importance of site characteristics for trade-off analysis: for example, soil fertility or type of agricultural land (arable land, marginal land etc.) were considered with different degrees of suitability for PV energy production/crop cultivation (Nonhebel, 2005; Sliz-Szkliniarz, 2013; Calvert and Mabee, 2015). A PV energy vs. food trade-off was analyzed in Nonhebel (2005) stressing the yield importance of different locations. The evaluation of ground-based PV applications related to land quality were carried out in a GIS-based model of Sliz-Szkliniarz (2013). In a study by Calvert and Mabee (2015) market parameters – energy density as well as potential electricity production – were chosen as key elements to establish a trade-off analysis between solar energy and energy crops cultivation on marginal land in Ontario (Canada). Optimization techniques such as the agrivoltaic system, implemented by means of Land Equivalent Ratios, were applied to combine in a same area PV plants and agriculture production in order to maximize total energy efficiency (for both solar panel and crops) (Dupraz et al., 2011).

As outlined in the literature, a consistent number of scientific works concerning potential conflict between PV plants and agricultural production was depicted. Nevertheless, the examination of the above mentioned studies denotes the presence of a few flexible and updatable Decision Support Systems (DSS) suitable for analysis at different scale, in different contexts and with diverse input dataset available to decision makers.

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