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An assessment of the regional potential for solar power generation in EU-28

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HIGHLIGHTS

- A European suitability map for the solar energy (PV) systems deployment is created.
- PV systems can contribute in a sustainable energy production in many regions in EU.
- There is no correlation among the EU investment and the suitability in solar energy.
- Using marginal lands to place PV systems might avoid the uptake of agricultural land.
- Validation of the EU suitability map demonstrated a satisfactory degree of accuracy.

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ABSTRACT

In this study we aim at assessing the potential of European regions to solar power generation and its comparison with recent European Union (EU) incentives for the development of this renewable energy source. In this study we use a multi-criteria assessment (MCA) supported by Geographical Information System (GIS) to combine already existing information on solar radiation with other geographical factors such as slope, land use, urban extent and population distribution, as well as proximity to the power grid to generate a suitability map for photovoltaic (PV) power plants across the EU at high spatial resolution. A validation exercise showed that the resulting suitability map is a good predictor of appropriate locations for the deployment of PV power plants. The suitability map was in addition compared to the regional distribution of European funds for development of solar energy from the EU Cohesion policy (2007–2013 programme). Regions were classified according their overall suitability for solar energy power systems and the allocated solar investments by the EU Cohesion policy. This analysis allowed to identify potential mismatches between fund allocations and actual regional suitability for solar energy. It is recommended that future fund allocations take into account suitability criteria for solar energy for optimised results of public policies.

1. Introduction

The climate and energy legislative package launched in December 2008 established different measures to mitigate climate change, promote renewable energy and energy efficiency. This EU framework includes the Renewable Energy Directive (2009/28/EC) which aims at promoting the use of renewable energy sources (RES) within the energy system and transport sectors (CEU, 2008; EC, 2009). A legally binding EU target, among others, was set, according to which 20% of the total energy consumed in the EU must be produced from RES (Tampakis et al., 2013). Solar energy is one of the renewable energies capable of contributing to the reduction of foreign energy dependence as well as energy-related environmental impacts (IPCC, 2011; Panwar et al. 2011).

According to Eurostat data (Eurostat, 2012), Germany was the largest producer of solar energy in Europe in 2012, with 2.26 Million toe (tonnes of oil equivalent) produced, followed by Italy (1.62 Million toe), and Spain (0.7 Million toe). Other countries with high suitability for solar energy generation, such as France, Greece and the United Kingdom produced much more modest amounts in 2012, with respectively 0.345, 0.145 and 0.102 Million toe.

Supporting the deployment of solar energy systems, NREP (National Renewable Energy Plans) detail the Member state strategies and measures to meet the binding 2020 target for the total

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energy consumption (CD, 2009). Additionally, the EU Cohesion policy (EC, 2014) is a complementary instrument, among many initiatives to promote social and territorial cohesion, which is also used to promote solar energy and thus supporting the Renewable Energy Directive targets (EC, 2013a).

Solar radiation can be converted into sustainable-produced electricity by using photovoltaic (PV) technology. Large-scale photovoltaic (PV) systems provide significant environmental benefits and advantages when compared to conventional, non-renewable energy sources, the reduction of greenhouse gas emissions, and the reuse of marginal lands being two key examples (IPCC, 2011). However, the large area required may cause undesirable impacts on land use, landscape, and biodiversity (Graebig et al., 2010). Ideally, these installations should be located on unused, low productivity agricultural and/or pasture land and, in general, areas covered by grasslands or scrublands to minimise such impacts (Turney and Fthenakis, 2011; Tsoutsos et al., 2005). Non-ideal locations are those characterized by forest land cover, extreme remoteness, instability and high degree of existing development.

Solar energy potential can be defined as the physically available solar radiation on the earth's surface (Angelis-Damakis et al., 2011). Various global and European studies have been carried out in order to estimate solar energy potential. This estimation relies on different factors among which solar radiation is considered essential (Tsoutsos et al., 2005). The use of (meteorological) satellite data and/or interpolation methods are the most typical approaches for the determination of solar radiation and were used, for instance, in the Heliosat method[1] and Meteonorm database[2] (Angelis-Damakis et al., 2011), respectively. At a European scale, Šúri et al. (2007) presented an analysis of solar electricity generation from their previous development of the Photovoltaic Geographical Information System, PVGIS (EC, 2013b; Šúri et al., 2005), concluding that the contribution of solar energy to the energy systems was still considerably low at the time despite its enormous potential as energy source. A more ambitious project is presented by Grossmann et al. (2013) in which an optimisation method for site selection, generation and storage of solar electricity generation across large geographical areas is developed in order to solve the problem of the intermittent nature of solar electricity. Additional questions were also addressed regarding site location given geopolitical and environmental concerns and transmission line costs, among others.

However, the solar estimated potential (theoretical potential) is significantly reduced when technical, economic, social and environmental factors and constraints for the deployment of solar energy systems are considered. The determination of such limiting factors enable us to identify more accurately the suitable areas for installation of photovoltaic (PV) systems (Hoogwijk and Graus, 2008), and in turn determining the feasibility and sustainability of energy system developments.

Solar energy is considered environmentally and socio-economically beneficial if a proper design, planning, siting and management. It also enjoys favourable public acceptance, as studies from Tampakis et al. (2013) and Tsantopoulos et al. (2014) have shown. However, wider and faster adoption of solar energy systems requires appropriate incentive schemes, or innovative business models to limit high initial costs and long-term uncertainties regarding expected rents (Bauner and Crago, 2015; Overholm, 2015; Malagueta et al., 2013; Phillips, 2013; Santoyo-Castelazo and Azapagic, 2014).

[1] Webpage: www.helioclim.net.

[2] Meteotest. Meteonorm version 6.1 – handbook; 2008. Webpage: www.meteonorm. com.

Table 1
Main constrains and factors determining the overall suitability for PV systems deployment.

Criteria	Description	Data source
Constraints	Protected and sensitive natural areas	(EEA, 2013a; EEA, 2013b)
	Built-up areas, wetlands, water bodies and forest	CORINE LC-refined (Batista e Silva et al., 2013a)
Suitability factors	Solar radiation	PVGIS project (EC, 2013a, 2013b)
	Topographic parameters (slope, aspect, elevation)	SRTM, 2013; PVGIS project (EC, 2013a, 2013b)
	Population potentially affected	JRC population grid map (Batista e Silva et al., 2013b)
	Proximity to roads	Teleatlas
	Proximity to the electricity grid	EC-DG REGIO

The contribution of this paper mainly falls on the representation of a European suitability map for the installation of PV systems based on a Geographical Information System Multi-criteria Assessment (GIS-MCA) method using a set of relevant geographical variables. Afterwards, the EU regional investment assigned to the development of solar energy systems is analysed against the EU suitability map. This assessment could help allocating more efficiently the EU regional funds for solar energy generation. The main purpose of this paper is twofold: 1) to estimate the degree of suitability for the installation of PV systems across Europe, both at detailed level (1-km grid resolution) and aggregate level (NUTS3 regions); and 2) to analyse the allocation of EU Cohesion funds in relation to the European suitability map for solar energy production systems. Finally, the study presents a validation process of the European suitability map, and summarises the main conclusions.

2. Material and methods

A GIS-MCA approach was proposed to produce a European suitability map for the development of large-scale solar power plants[3]. In this context, the 'suitability' was defined as the quantification of the appropriateness of each location to hold PV systems, and it was determined by a set of biophysical and socio-economic factors, which were mapped at pan-European level using the available data sources (see Table 1 and Annex I). Fig. 1 illustrates the workflow designed to achieve the two objectives of this study. In the next sections, the methodology is described more in detail, focusing separately on the components that integrate the European suitability map for the installation of solar power plants.

2.1. Identifying the land availability: natural and artificial constraints

The deployment of PV systems in certain areas can be constrained by technical or environmental reasons. To capture most of these aspects, we considered constraints like areas in which the development of PV systems is either technically unfeasible or not recommended due to environmental sensitivity. Two types of information were used: the location of sensitive natural areas and specific land use/cover types (Table1 and Annex I).

[3] Large-scale systems includes ground mounted power plants in the power range from 10 kWp to many MWp which are installed in areas with low land-use competition and requiring large land areas. Example of these type of PV systems can be found in Italy, Spain and Germany. See, for instance, the *Large-Scale photovoltaic power plants* (the Annual review 2000–2010) document (from: http://www.pvresources.com/Portals/0/Download/AnnualReview2010.pdf).