Suitability Analysis of Solar Photovoltaic farms: A Portuguese Case Study

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Abstract- The threat that burning fossil fuels poses to global warming is forcing society to look for renewable energy solutions. Among these, the use of solar energy has a high potential for growth in the current international energy mix. It is important to provide information to decision-makers that deal with the installation of new production facilities. This study combines Geographical Information Systems (GIS) and Multi-criteria Evaluation (MCE) techniques to assess the land suitability for the installation of solar farms in the municipality of Ourique in the South of Portugal. Several exclusionary constraints and weighting factors were used in the modelling process with the help of expert knowledge and an extensive literature review. Results show that approximately 21% of the area is classified as "highly suitable" for installing solar farms. These results are in line with the existing and planned photovoltaic (PV) projects in the region, which are mostly located in "medium" or "medium to high" suitable areas. This approach can easily be adapted to include different criteria and/or different weights to deliver information to managers, helping them in the decision regarding locating solar farms.

Keywords Geographic Information Systems; Multi-criteria Evaluation; Solar energy; Photovoltaic potential; Site Suitability; Ourique.

1. Introduction

Despite the still relative abundance of fossil fuels, the damage they are likely to cause regarding global warming has led many countries to switch to renewable energy sources [1]. One of the challenges is to implement photovoltaic (PV) projects in locations thought to be most suitable, i.e. locations that concentrate the largest number and highest values of productivity factors (e.g., high levels of sunlight and solar radiation, gentle slope, vague, good road accessibility, proximity to power lines, etc.) and the lowest number of identified territorial constraints (e.g. legal restrictions).

The aim is to achieve the highest performance with minimal interference and negative impacts on environmental ecosystems and infrastructure, both cultural and social, with positive effects in terms of simplification of administrative procedures and authorization [2,3]. The suitability of a territory for a specific use, as with PV energy suitability, depends of the intrinsic factors of that territory combined with the potential factors resulting from its transformation [4]. Additionally, a strategy for reconciliation purposes is needed to promote the completion of the investment [3].

Multi-criteria Evaluation (MCE) methods have been widely applied together with GIS in site selection activities, providing a framework for integrating environmental, economic, and social factors that affect land suitability [5]. Suitability analysis with MCE has been applied to many Renewable Energy Sources (RES) domains, including solar energy [1,5-8]. The results of this approach are usually displayed on a map highlighting areas from high to low suitability [9].

Considering the positive outlook for growth and development of PV, it is important to provide tools to support decision-makers in the installation of new production facilities according to the capacity and suitability of the territories [10]. Studies that present this kind of analysis are more frequent for national [11], regional [8], and urban areas [12]. However, studies that make a local analysis in rural areas with operational data at a very detailed level are scarce and, to our knowledge, nonexistent for Portugal. The objective of this paper is to develop an MCE modelling approach with GIS that combines yield factors with territorial conditions to help in the decision about locating the solar farms in Ourique municipality, Portugal.

1.1 Study area

Portugal has excellent conditions for exploiting RES and is expected to fulfill the European and national commitments in terms of energy quota based on this kind of energy by mid-2020 [13]. The country has a very high potential for solar power generation due to its geographical position, which influences the intensity and the rate of incoming sunlight, and to its climate conditions, which positively affect the amount of incoming solar radiation [13-15]. Located in the subtropical zone of the northern hemisphere, between latitudes 37º and 42º, in the range of contact between the Atlantic Ocean and the European continent, Portugal presents insolation values of 1800-3200 hours of sunshine (Fig. 1) and 4.86 kWh/m²/day of solar radiation [15-19]. Within RES PV emerges as the technology with the greatest potential for development and exploitation in Portugal [20,21]. This potential is due to the high availability of resources (sunlight) and to the residual expression of this technology as part of RES and its contribution to the national energy production, approximately 1.6% in 2013 [22].

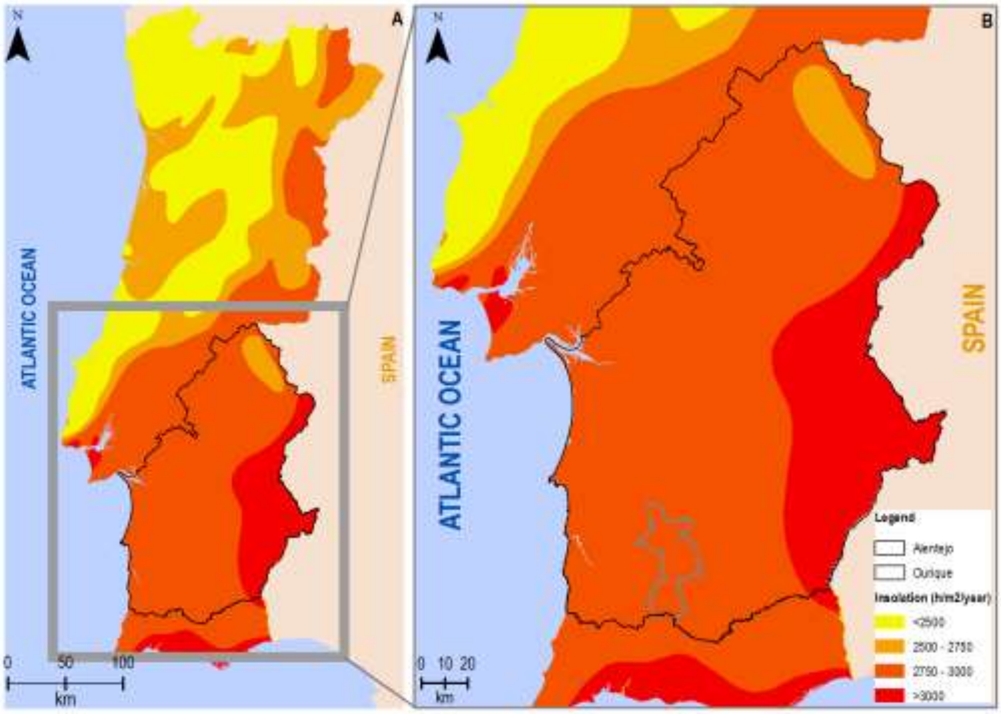

Fig. 1. Average annual insolation in 1931-1960: A – Continental Portugal; B: Alentejo region.

Alentejo is the most favorable region in Portugal for solar energy production considering the insolation values, solar radiation, relatively low slopes, electricity network capacity, and infrastructure integration [23-25]. Consequently, this region is the largest contributor to the national production of energy by PV sources (76.3%), mainly supported by Baixo Alentejo [26,27]. This sub-region occupies a notable position in production installed capacity (number of hours) and the number of plants (31) [27,28].

This study was applied to the municipality of Ourique, which covers an area of 663.4 km², approximately 8% of the Baixo Alentejo. Ourique had 5839 inhabitants in 2011 and is a territory of low population density, strongly aged, very rural, and with a wide dispersion of the population, in small or very small places, often isolated [29]. The economy of Ourique is based on tertiary and primary sectors, in which the local authority is the main employer and promoter [30]. Ourique is characterized by good road access to the district capital (Beja) and to the metropolitan areas of Lisbon and Faro. It has a climate of Mediterranean influence, with a high temperature range, a dry and hot season in the summer, and cool winters with low rainfall [31]. Ourique presents a clear differentiation in terms of landscape, slope, and occupation, where the north is characterized by cereal landscape of dry plains with lower and uniform slopes (0-8%) and the south is characterized by mountainous landscape, with higher slopes (8-35%) and with a vegetation of Mediterranean characteristics [30,32].

Additionally, Ourique is located in a region that combines good conditions for PV technology, such as: the highest number of hours of sunshine in the country (2750-3000 hours), the highest global solar radiation values in the country and Europe (4.64 kWh/m²/day), the topographic and climate conditions, existing infrastructure (power transmission lines and roads), and the availability of land [7,16,33-35]. This area was selected because of its high solar potential due to its geographical location and biophysical characteristics.

2. Data and Methods

Suitability analysis in a GIS involves the use of several geographical data sources either as weighted factors, or as exclusionary layers, to establish the appropriateness of land for a specific use, in this case for installing solar farms [36,37]. The weighted factors have an impact on the suitability analysis given a specific objective. The choice and weights of these factors can be determined by using a number of varied techniques, such as Analytic Hierarchy Process (AHP) [38], which normally includes a panel of experts or stakeholders, or by using a literature review [37,39,40]. The exclusionary constraints are used to exclude from the analysis the areas that for some particular reason make the land inadequate for a specific purpose (e.g. legislation, planning restrictions, etc.) [37,39].

The methodology developed in this work comprises 5 steps and is described in the flowchart of Fig. 2. A detailed description of this municipality and the pertinence for installing PV in the area was carried out (Step 1). The definition of criteria for PV suitability were identified in Step 2 through expert consultation and bibliographic analysis. These included solar PV productivity factors and location features, i.e. territorial constraints and exclusionary areas. In Step 3 the variables to be included in the GIS model were identified and data collection activities were carried out. In Step 4 GIS modelling using MCE techniques were applied to the input datasets. This phase included the weighting of factors made with the help of experts and bibliographic review. Finally, in Step 5 a final map of PV suitability was produced and analyzed.

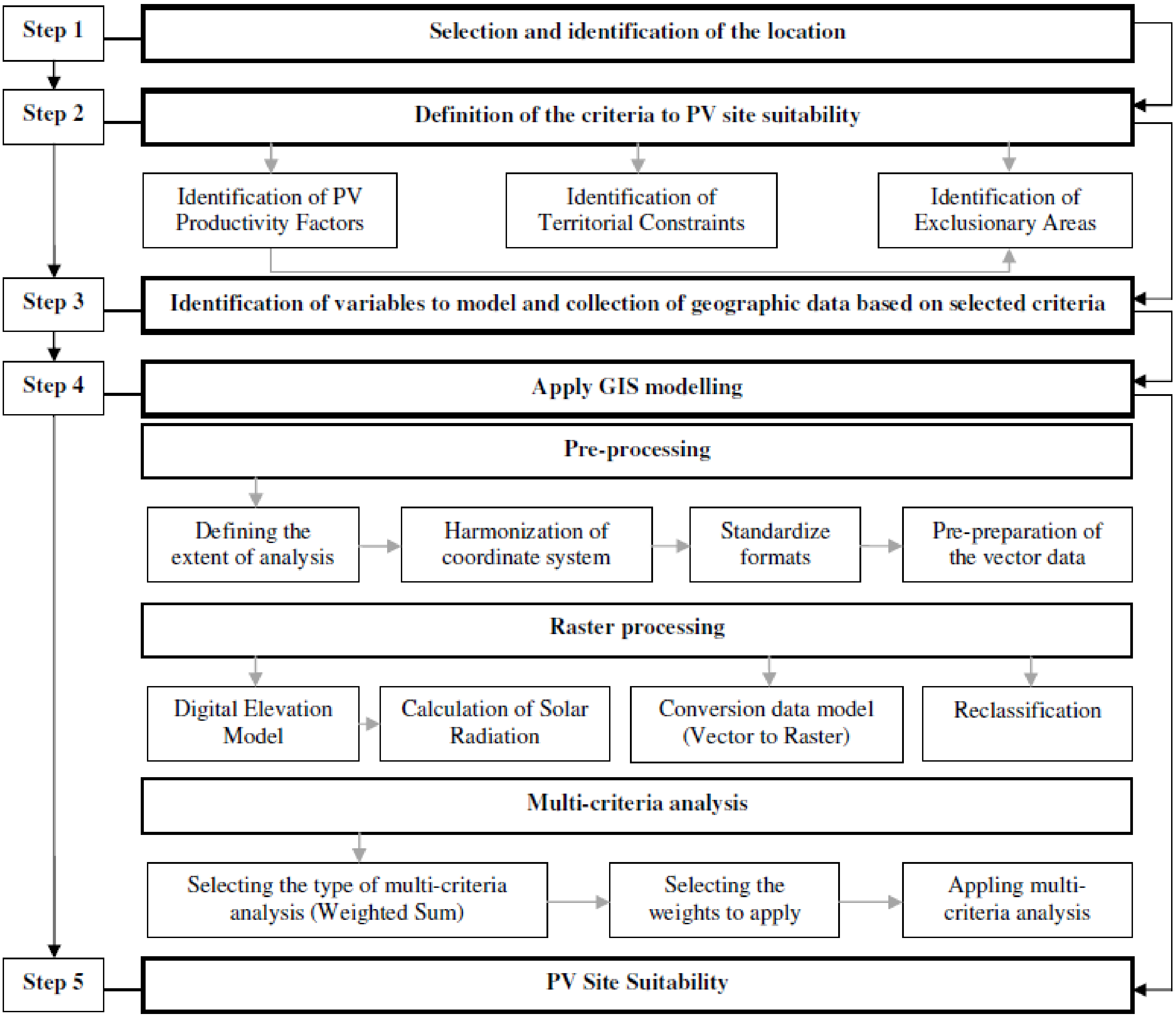

Fig. 2. A 5-step methodology for photovoltaic site suitability.

The datasets used in the GIS model are described in Table 1. These are divided into three categories: (i) productivity factors; (ii) territorial constraints; and (iii) exclusionary areas. The productivity factors were used as weighted variables for the suitability analysis. The territorial constraints considered the areas with a low degree of preference for installing the solar farms.

Finally, the exclusionary areas were excluded from the site analysis (e.g. areas identified in specific legislation to be incompatible with the production of PV solar energy at a large scale). Urban areas were excluded from the analysis because they favor the increase of the price of land and, therefore, are a constraint to the investment in this activity.

Table 1. Datasets used in the study

Type[1]	Theme	Source	Year	Scale/ Resolution	Format
PF	Digital Elevation Model	ASTER-GDEM2 – METI/NASA [43]	2011	30m	Raster
PF	Maximum average temperature	[44]	1961-1991	111,1m	Raster
PF / TC	Medium and low tension power lines	[45]	2014		Vector
PF / EA	Road network	[46]	2014	1/25000	Vector
TC	National Agriculture Reserve	[47]	2001	1/25000	Vector
TC	Cork, oak, and holm areas	[47]	2001	1/25000	Vector
TC	Burnt areas	[48]	2000-2012		Vector
TC	Protected Areas	[49]	2012		Vector
TC / EA	National Ecological Reserve	[50]	2014	1/25000	Vector
EA	Rivers	[51]	2006	1/1000000	Vector
EA	Public water reservoirs	[52]	2007		Vector
EA	Reservoir intervention limits	[53]	2010	1/25000	Vector
EA	Quarries	[54]	2014	1/10000	Vector
EA	Hydroagriculture	[55]	2014	1/25000	Vector
EA	Protected heritage	[56] and extraction from ArcGIS Basemaps			
EA	High and very high tension power lines	[45]	2014		Vector
EA	Railroad	[57]	2006		Vector
EA	Connecting section between the radio electric centers of Fóia and Castro Verde	[58] and extraction from ArcGIS Basemaps			
EA	Geodetic markers	[59]	2014		Vector
EA	Urban areas	[47]	2001	1/5000	Vector
EA	Detailed Plan	[60]	2011	1/25000	Vector

[1] EA – Exclusionary Areas; PF – Productivity Factors; TC – Territorial Constraints

Additionally, the study of solar suitability areas in urban areas needs to consider the building coverage which differs from the approach adopted for rural areas [12,17,41]. Some datasets fall into more than one category, e.g. the road network is both a productivity factor and an exclusionary area. All the datasets had or were converted into a common geographic projection ETRS89/PT-TM06. The base administrative layer was the Portuguese Administrative Official Map [42].

The data pre-processing stage included the preparation of the collected data to be used in the GIS model. This is a time-consuming task and is decisive for the quality and reliability of the results obtained. In this case, the datasets exhibited a varied thematic diversity, were obtained from different sources, and had different technical characteristics such as scale, resolution, reference system, and different formats. Several tasks for data harmonization were carried out, such as projection transformations and spatial geoprocessing operations (e.g. selection, digitizing, and buffer analysis).

The raster processing phase corresponded to the generation of raster data for the subsequent application of multi-criteria analysis. It included the preparation of the slope and aspect maps, the calculation of the solar radiation, the conversion of vector data to raster, the calculation of Euclidean distances to transmission lines and roads, followed by reclassification operations.

The slope and aspect maps were derived from the digital elevation model (DEM) of the Advanced Satellite image Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM2) [43]. This dataset has a horizontal resolution of 1 arc-second (approximately 30m) and is available in Georeferenced Tagged Image File Format (GeoTIFF) with the WGS84 (EPSG code 4326) coordinate system [61,62].

There are various productivity factors and territorial conditions that influence the viability of photovoltaic projects. The most important factors are: (1) topography (obtained through the digital elevation model used to derive slope and aspect); (2) solar radiation (input information associated with solar photovoltaic systems); (3) temperature (Ambient temperatures above 25 ° C influence the productivity of the photovoltaic system, although this influence has a residual impact on the efficiency of PV cells); (4) proximity to power lines; (5) proximity to system roads; and (6) the elements that characterize the environmental sensitivity [11,63-65]. These elements consider the technical and economic aspects and the territorial management, and favor the simplification and de-bureaucratization of the installation of a PV project. The criteria used in the site analysis are described in Table 2 [63,66]. These criteria were established using expert knowledge and a literature review.

Table 2. Criteria used in the model.

Type	Description
Productivity factors	Global solar radiation levels, preferably above 3 kWh/m²/day [24,67]
	Slope, preferably around 5%, although slopes between 6 and 8% with Southern exposure are accepted [7,68-70]
	Proximity to power lines [7,68,71]
	Road network accessibility [7,68]
	Areas in which average temperature is lower [5,72-73]
Territorial constraints	Preferably outside National Agricultural Reserve [74]
	Preferably outside cork oak forests [75]
	Preferably in burned areas [76]
	Preferably outside National Ecological Reserve [77]
	Preferably outside protected areas [78-80]
Exclusionary areas	Hydrologic domain [81]
	Public water reservoirs (Monte Gato, Monte Miguéis, Pomarinho) [82,83]
	Areas subject to public water reservoir plans (Monte da Rocha and Santa Clara) [84,85]
	Quarries [81]
	Hydroagriculture areas [86]
	Incompatible areas of National Ecological Reserve [77]
	Classified archaeological heritage (Castro da Cola, Cerro do Castelo or Forte de Garvão, and Necrópole da Atalaia) [87-89]
	Power lines and non-aedificandi areas (20 m for 30 kV and 50 m for 150 kV) [81]
	Road network [90,91]
	Railroad [92]
	Central power connection of Fóia and Castro Verde [58]
	Geodetic markers [93]
	Urban areas
	Areas subject to detailed plans (Campanador and Quinta da Arrábida – Monte da Rocha)

In this study, the areas for the installation of PV projects are not subject to public easements, restrictions of public utility, and/or to a minimum of territorial constraints of specific legislation. The aim is to reduce bureaucracy involved in the authorization or licensing of a PV project (a discouraging factor usually identified as a threat to Portugal's economic development) to ensure the optimization of space, achieve full respect for the natural environment, and reconcile the uses and capabilities of territories [3].

In order to meet the specified criteria for determining the PV suitability in Ourique, the most adequate slopes (lower slopes) were combined with the most suitable aspect (mainly South) [70]. These maps were reclassified into four categories, prioritizing the lower slopes and the Southern orientations (between 135 to 225º) through a map algebra operation.

The global solar radiation was calculated using the Area Solar Radiation tool available in ArcGIS Spatial Analyst extension [94], based on the DEM. The result was reclassified using natural breaks giving higher suitability values to the higher recorded radiation levels.

The temperature is a crucial factor, as it negatively affects the productivity of the PV system whenever it exceeds 25 °C, and was included in the calculation of the PV suitability [5,72,73,95].

This variable was obtained from the raster of the maximum average temperature of the hottest three months in the 1961-1991 period for mainland Portugal prepared by [44], since the temperature effect is more important during the hottest hours of the day (when solar radiation is greatest) [95]. After reclassification using natural breaks, the lowest maximum average temperatures were prioritized.

The power lines, roads, and conditions layers were converted from vector to raster. The selected raster resolution was equal to the DEM resolution, i.e., 30m. The proximity to transmission lines and road accessibility were calculated using the Euclidean Distance tool available in ArcGIS Spatial Analyst extension [94], allowing the calculation of distances for each raster cell based on a defined maximum or range. These maps were reclassified using natural breaks, prioritizing the areas closer to these infrastructures [64].

The input datasets used in the GIS model were subject to several raster processing operations and spatial analysis for the implementation of multi-criteria integrated analysis in ArcGIS 10.2 software [94]. These operations resulted in six input layers used in the MCE evaluation: slope/aspect, global solar radiation, temperature, distance to transmission lines, distance to roads, and territorial constraints (Fig. 3).

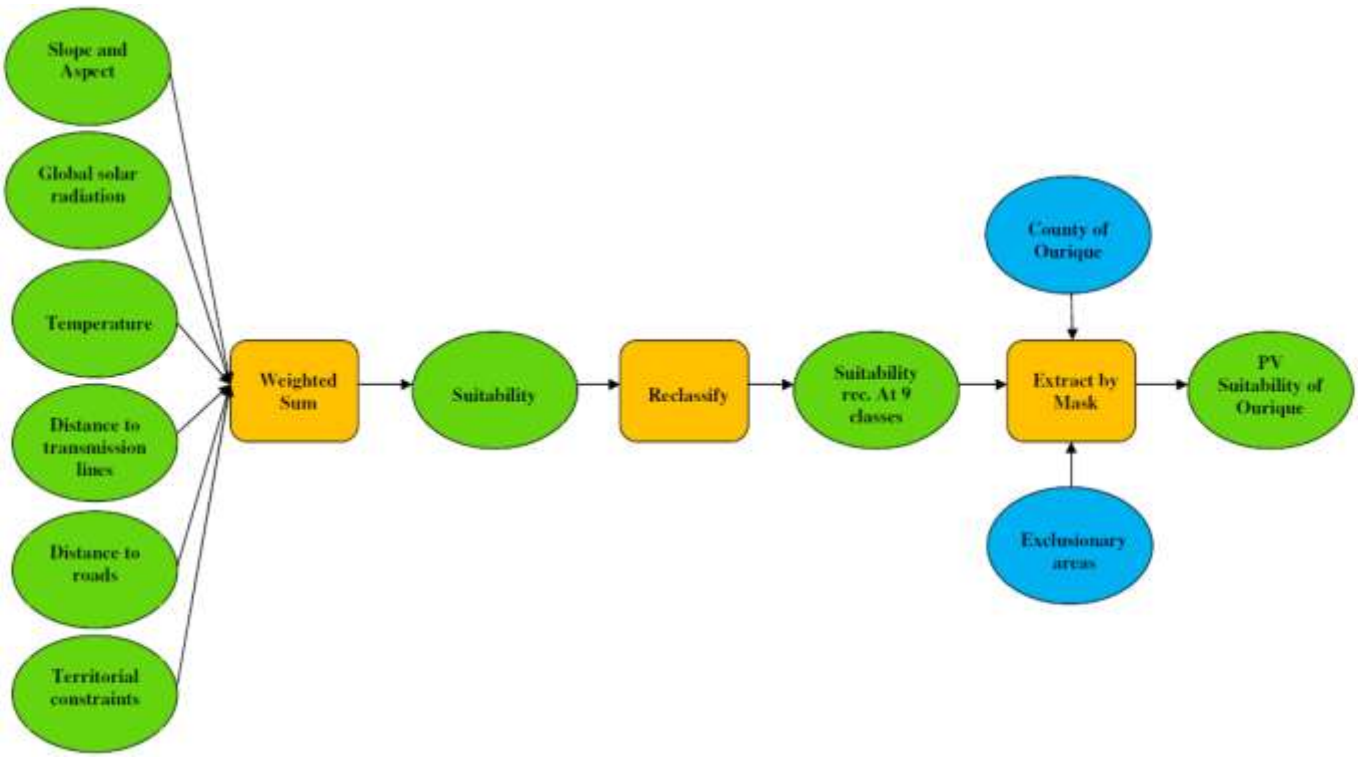

Fig. 3. Flowchart of the GIS procedures for multi-criteria analysis.

The Weighted Sum tool available in ArcGIS Spatial Analyst extension [94] enabled us to combine these six input layers and assign them a weight (Table 3). The weights reflect the technical prioritization logic (combined slopes and aspects), followed by the use criteria (global solar radiation), the technical criteria that affect the resource (temperature), the technical criteria affecting the investment (proximity to power lines and roads), and the criteria that affect the suitability of the territory (territorial constraints). The weights of these criteria were established using expert knowledge and a bibliographic review. This model can easily be changed using different criteria and/or different weights.

Table 3. Weights assigned to each GIS variable in the MCE (darker areas represent higher suitability)

Layer	Variable	Weight
	Slope/Aspect	5
	Global solar radiation	4
	Temperature	3
	Distance to transmission lines	2
	Distance to Roads	2
	Territorial constraints	1

The result of the multi-criteria analysis was reclassified into a range of suitability of nine categories (1: very low suitability to 9: very high suitability). These categories were then grouped in three generalized classes to allow a simpler interpretation (Low, 1-3; Average, 4-6; High, 7-9). A mask with the Ourique border was applied to the final output followed by the extraction of the exclusionary areas.

3. Results

Results show that, although largely characterized by an average photovoltaic site suitability, Ourique has 13,863 ha classified as high suitable areas, corresponding to approximately 21% of the municipality's area. These are concentrated in the northwest and center of Ourique municipality (Fig. 4 and Table 4).

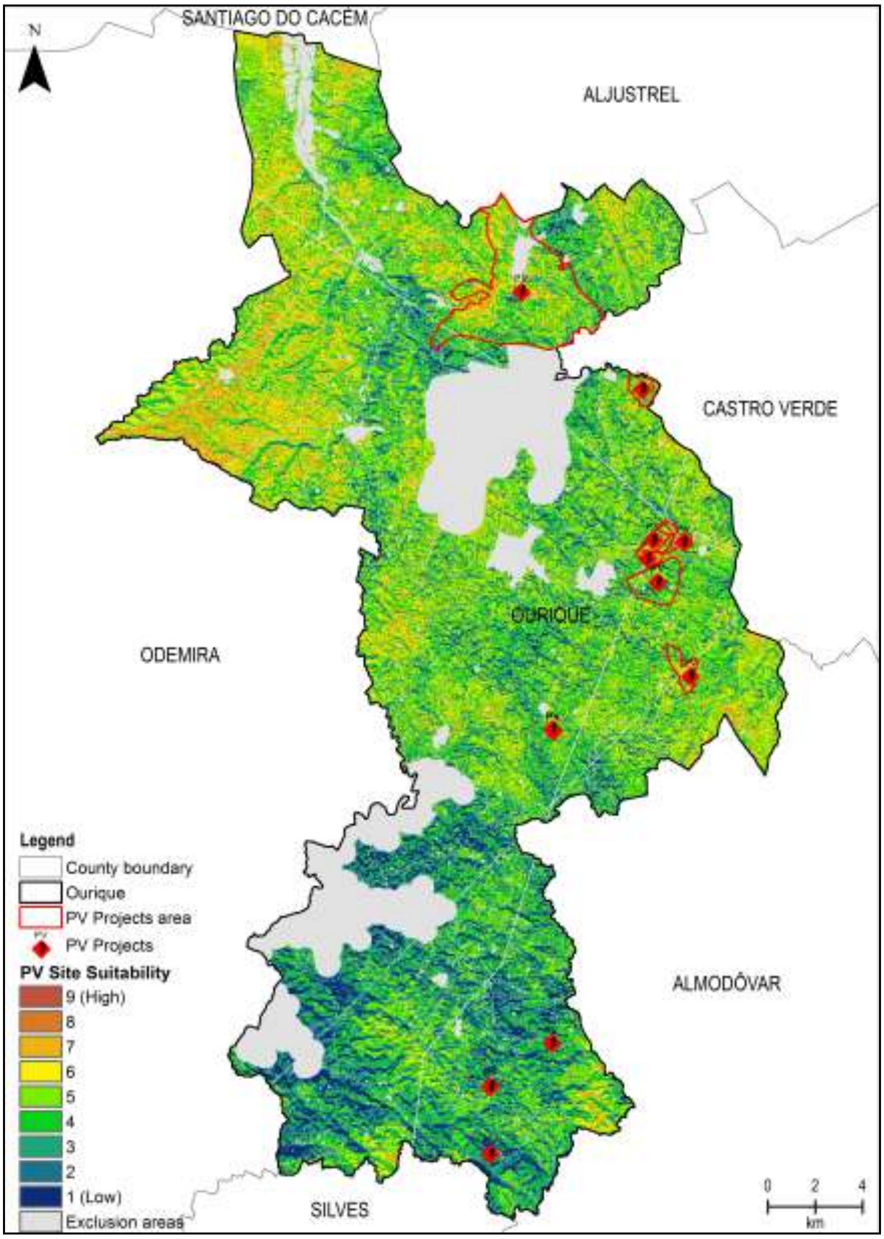

Fig. 4. Photovoltaic site suitability of Ourique.

Table 4. Photovoltaic suitability in Ourique, for classes, and percentage area

Photovoltaic suitability			Area (ha)	Classes (%)		PV Projects (nr.)
Code	**Classes**	**Description**				
0	n.a.	Exclusionary areas	10633.70	16.03	16.03	0
1	Low	Non-suitable	653.66	16.13	0.99	1
2		Very low suitability	3470.03		5.23	0
3		Low suitability	6573.94		9.91	0
4	Average	Low to medium suitability	8804.61	46.94	13.27	0
5		Medium suitability	11100.74		16.74	6
6		Medium to high suitability	11225.90		16.93	5
7	High	High suitability	8395.25	20.90	12.66	0
8		Very high suitability	4513.46		6.80	0
9		High suitability	954.63		1.44	0
Total			66325.95	100.00	100.00	12

The exclusionary areas represented about 16% of the area and were not considered in the analysis. The location of suitable areas show a direct relationship with the topography and the areas with less population, as is the case of Santana da Serra. These results are in line with the existing, or planned, photovoltaic projects in Ourique, which are located in medium (6 PV) or medium to high (5 PV) suitable areas, whose location is primarily determined by the proximity to transmission lines. There is one PV located in a non-suitable area.

4. Discussion

The value obtained of 13,863 ha classified as “high suitable areas” for the municipality of Ourique is comparable with the existing PV farm of Amareleja in Alentejo with 14,000 ha. This PV uses the same PV technology type with azimuthal orientation and polycrystalline silicon panels. Considering the similar conditions and characteristics, we estimate that it would be possible to install 56 PV projects of the size of the Amareleja project, with 2576 MWp power and a production of 5208 billion kW. This value is enough to supply 1.68 million households (about 30% of mainland Portugal accommodation in 2011) and avoid the annual emission of about 5005.5 tons CO_2 [96,97].

The use of multi-criteria analysis in a GIS environment proved to be an interesting option for modelling the suitability analysis of PV farms. The combination of a set of weighted criteria with spatial representation into a single suitability map provides valuable information for helping decision makers on where to install the solar farms in Ourique. The aim was not to decide which the “best possible location” was. This is a decision which is up to the stakeholders. The aim was rather to make available an explicit spatial approach to enable an informed discussion with the stakeholders. This approach can easily be adapted to include more constraints or other weights in the modelling process. Besides affording an understanding of the tradeoffs among the different criteria, another important outcome is the provision of a flexible tool that fuels an informed discussion between all the stakeholders that participate in the decision of locating the solar farms.

Considering the volume of investment, expected return values, and the impact that PV projects have in the territories and lives of people in a context of global resource optimization, it is important to develop approaches that help in the selection of the most suitable and appropriate locations for installing these infrastructures by maximizing the system performance and minimizing production losses. The decision to locate a PV project also depends on economic factors relating to the system's productivity and economic viability; and technical factors related to the suitability of the sites for the implementation, which must consider the natural features that ensure the productivity of the system with minimal interference of territorial and environmental constraints.

Despite the attempt to use the best possible available datasets, not all of them shared the same technical characteristics (e.g. different dates, scale). Thus, the results of the model are to be used with caution. However, because off the way the model is built, using a reusable toolbox, one can easily change the model to include more adequate datasets if these become available.

5. Conclusion

We developed a 5-step GIS-based methodology to measure the suitability of terrain for installing solar PV farms. The spatial modeling approach adopted covered a set of variables that influence the solar energy system production and the environmental, social, and economic planning balance.

The methodology presented is an on-going work seeking to develop an application tool that is adaptable, flexible, and useful for providing technical support to decision making for the implementation of PV investments in the most suitable locations in full respect of other uses of the territory. The adaptation of this approach to other territories can easily be achieved after considering their specific characteristics. We believe that this work comes at an opportune time because the number of solar farms authorization requests for the municipality of Ourique has been increasing (in the last year, there were six applications for PV installation in Ourique with a medium size of 50 mW).

Future actions should include more detailed and updated datasets, particularly of territorial constraints and climatic variables, especially in the temperature parameter, using the average monthly temperature of every month for a given year or period [95]. Datasets and information to enable an evaluation based on technological, economic, and financial issues such as suggested by [98] are also envisaged.

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References

[1] J. R. Janke, "Multicriteria GIS modelling of wind and solar farms in Colorado", *Renewable Energy,* DOI: 10.1016/j.renene.2010.03.014, Vol. 35, No. 10, pp. 2228-2234, 2010.

[2] NREL, National Renewable Energy Laboratory Report to Congress on Renewable Energy Resource Assessment Information for the United States, Prepared for U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2006.

[3] T. Rowe, Global Market Outlook for Photovoltaic's 2014-2018, European Photovoltaic Industry Association, 2014.

[4] S. Camp, and G. Hora, "Aplicação da Metodologia de Avaliação Multicritério ao Estudo da Aptidão da Bacia Hidrográfica do Rio Alenquer à Edificação, Usos Agrícola e Florestal", 4th Geographic Information Users Meeting (ESIG), Lisbon, 2-4 June 2004.

[5] J. A. Carrión, A. E. Estrella, F. A. Dols, M. Z. Toro, M. Rodríguez and A. R. Ridao, "Environmental decision-support systems for evaluating the carrying capacity of land areas: Optimal site selection for grid-connected photovoltaic power plants", Renewable and Sustainable Energy Reviews, DOI: 10.1016/j.rser.2007.06.011, Vol. 12, No.9, pp. 2358–2380, December 2008.

[6] J. C. Castella, T. N. Trung and S. Boissau, "Participatory simulation of land-use changes in the northern mountains of Vietnam: the combined use of an agent-based model, a role-playing game, and a geographic information system", Ecology and Society, Vol. 10, No. 1, Art. 27, 2005.

[7] Y. Charabi and A. Gastli, "PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation", Renewable Energy, DOI: 10.1016/j.renene.2010.10.037, Vol. 36, No. 9, pp. 2554–2561, September 2011.

[8] J. M. Sánchez-Lozano, J. Teruel-Solano, P. L. Soto-Elvira, and M. S. García-Cascales, "Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain", Renewable and Sustainable Energy Reviews, DOI: 10.1016/j.rser.2013.03.019, Vol. 24, pp. 544–556, 2013.

[9] J. A. LaGro, Site Analysis: Informing Context-Sensitive and Sustainable Site Planning and Design, 3rd ed. Wiley, 2013.

[10] EC, Science for Energy, JRC Thematic Report, European Commission, Joint Research Centre, 2013.

[11] A. Gastli and Y. Charabi, "Solar electricity prospects in Oman using GIS-based solar radiation maps", Renewable and Sustainable Energy Reviews, DOI: 10.1016/j.rser.2009.08.018, Vol. 14, No. 2, pp. 790–797, February 2010.

[12] T. Santos, N. Gomes, M. Brito, S. Freire, A. Fonseca and J. A. Tenedório, "Solar Potential Analysis in Lisbon Using LIDAR Data", 31st EARSeL Symposium, Prague, 30 May-2 June 2011.

[13] C. Ramos and J. E. Ventura, "A Energia Solar em Portugal: potencialidades e diferenciação Regional", 2nd Congress of the Portuguese Geography, Lisbon, 1999.

[14] R. S. Brito, Portugal: Perfil Geográfico. Lisbon: Editorial Estampa, 1994.

[15] S. Daveau, Portugal Geográfico, 3rd ed. Edições João Sá da Costa, 2000.

[16] APA, Map I.1 – Insolation: Environmental Digital Atlas, Scale 1/1000000 (Portugal), Agência Portuguesa do Ambiente, 1974.

[17] M. Šúri, T. A. Huld, E. D. Dunlop and H. A. Ossenbrink, "Potential of solar electricity generation in the European Union member states and candidate countries", Solar Energy, DOI: 10.1016/j.solener.2006.12.007, Vol. 81, No. 10, pp. 1295–1305, 2007.

[18] T. Huld, R. Müller and A. Gambardella, "A new solar radiation database for estimating PV performance in Europe and Africa", Solar Energy, DOI: 10.1016/j.solener.2012.03.006, Vol. 86, No. 6, pp. 1803–1815, 2012.

[19] Photovoltaic Geographical Information System. Institute for Energy and Transport of Joint Research Centre, European Commission, 2015. Available from: http://re.jrc.ec.europa.eu/pvgis/index.htm, accessed Mar 30, 2015.

[20] MEID, Renewable, Novas Energias a Inspirar Portugal. Ministério da Economia da Inovação e do Desenvolvimento, 2010.

[21] Resolução de Conselho de Ministros n.º 29/2010, D. R. I Série, 73 (15-04-2010), 270-271.

[22] DGEG, Installed capacity in producing Central Electricity 1995-2013 (Portugal), 2015. Available from: http://www.dgeg.pt?cr=8583, accessed Jan 25, 2015.

[23] P. Carvalho and J. Ribeiro, Territórios em Transformação: O Caso do Alentejo. Departamento de Prospectiva e Planeamento e Relações Internacionais – Divisão de Informação e Comunicação, 2009.

[24] GTES, Manual de Engenharia para Sistemas Fotovoltaicos. CEPEL – CRESESB, 2014.

[25] IPMA, Global Solar Radiation of Portugal for February 2015, Instituto Português do Mar e da Atmosfera, 2015.

[26] INE, Anuário Estatístico da Região do Alentejo, Instituto Nacional de Estatística, 2013.

[27] DGEG, Renewable Energy, Quick Stats, nº 120 (Portugal), 2014. Available from: http://www.dgeg.pt/?cn=6891700271487149AAAAAAAA, accessed Jan 25, 2015.

[28] CCDRA, Uma Estratégia de Especialização Inteligente para o Alentejo. Comissão de Coordenação e Desenvolvimento Regional do Alentejo, 2014.

[29] INE, XV Recenseamento Geral da População, Instituto Nacional de Estatística, 2011.

[30] EGA and AJS&A, Agenda 21 Local de Ourique: Diagnóstico para a Sustentabilidade. Environmental Governance Advisors and Câmara Municipal de Ourique, 2011.

[31] CMO, Plano Municipal de Defesa da Floresta Contra Incêndios do Concelho de Ourique (2008-2014), 2008.

[32] EGA and AJS&A, Agenda 21 Local de Ourique: Caracterização da Área Estratégica – Energias Alternativas. Environmental Governance Advisors and Câmara Municipal de Ourique, 2011.

[33] M. C. Branco and A. Coito, Servidões e Restrições de Utilidade Pública. Direção Geral do Território, 2011.

[34] T. Funabashi, A GIS Approach for Estimating Optimal Sites for Grid-Connected Photovoltaic (PV) Cells in Nebraska. Environmental Studies Undergraduate Student Thesis, University of Nebraska, Lincoln, 2011.

[35] IPMA, Global Solar Radiation of Portugal for June 2015, Instituto Português do Mar e da Atmosfera, 2015.

[36] J. Malczewski, GIS and Multicriteria Decision Analysis. Wiley, 1999.

[37] J. R. Eastman, IDRISI Selva. Clark Labs, 2012.

[38] R. W. Saaty, "The analytic hierarchy process what it is and how it is used", Mathematical Modelling, DOI: 10.1016/0270-0255(87)90473-8, Vol. 9, No 3, Art. 5, pp. 161–176, 1987.

[39] J. Malczewski, "GIS-based land-use suitability analysis: a critical overview", Progress in Planning, DOI: 10.1016/j.progress.2003.09.002, Vol. 62, No. 1, pp. 3–65, 2004.

[40] V. N. Martins, D.S Silva and P. Cabral, "Social vulnerability assessment to seismic risk using multicriteria analysis: the case study of Vila Franca do Campo (São Miguel Island, Azores, Portugal)", Natural Hazards, DOI: 10.1007/s11069-012-0084-x, Vol. 62, pp. 385–404, 2012.

[41] P. Gagnon, R. Margolis, J. Melius, C. Phillips and R. Elmore, Rooftop Solar Photovoltaic Technical Potential in the United States, National Renewable Energy Laboratory, 2016.

[42] DGT, Carta Administrativa Oficial de Portugal, 2014. Available from: http://www.dgterritorio.pt/ficheiros/cadastro/caop/caop_download/caop_2014_0/contaadcaop201, accessed Dec 10, 2014.

[43] NASA, Aster Global Digital Elevation Map, 2012. Available from: http://asterweb.jpl.nasa.gov/gdem.asp, accessed Feb 02, 2015.

[44] T. Monteiro-Henriques, Landscape and Phytosociology of the Paiva River's Hidrographical Basin. Doctoral Dissertation, Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Lisbon, Portugal, 2010.

[45] CMO, Low, médium, high and very high tension power lines of Ourique, shapefile format, 2014.

[46] CMO, Road network of Ourique, shapefile format, 2014.

[47] CMO, Master Plan of Municipality of Ourique, shapefile format, 2001.

[48] ICNF, National mapping of burnt areas 2000 to 2013, 2013. Available from: http://www.icnf.pt/portal/florestas/dfci/inc/infogeo, accessed Aug 10, 2015.

[49] ICNF, Mapping of Rede Natura, 2000 in Portugal, 2012. Available from: http://www.icnf.pt/portal/naturaclas/cart/ap-rnramsar-pt, accessed Aug 10, 2015.

[50] CCDRA, National Ecological Reserve, shapefile format, 2015. Available from: http://www.ccdra.gov.pt/ren/download.asp?Path=http://www.ccdr-a.gov.pt/Ren/download_data, accessed Feb 10, 2015.

[51] APA, Rivers – Water Atlas, National Information System of Water Resources, 2006. Available from: http://geo.snirh.pt/AtlasAgua/#, accessed Jan 2, 2015.

[52] IGP, Land Cover Land Use Map for Portugal (2007), level 1, shapefile format, 2010. Available from: http://www.igeo.pt/e-IGEO/egeo_downloads.htm, accessed Apr 3, 2012.

[53] CMO, Public Reservoir Plans, shapefile format, 2010.

[54] CMO, Quarries of Ourique, shapefile format, 2014.

[55] CMO, Ourique Hydroagriculture, shapefile format, 2014.

[56] DGPC, Website of Direção Geral do Património Cultural, 2015. Available from: http://www.patrimoniocultural.pt/pt/, accessed May 5, 2015.

[57] CMO, Railroad of Ourique, shapefile format, 2006.

[58] Decreto-Regulamentar n.º 59/1984, D. R. I Série, 187 (13-08-1984), 2497-2500.

[59] CMO, Geodesic marks, shapefile format, 2014.

[60] CMO, Detailed Plans in Municipality of Ourique, shapefile format, 2011.

[61] METI and NASA, ASTER Global Digital Elevation Model Version 2 – Summary of Validation Results. Ministry of Economy, Trade and Industry of Japan and National Aeronautic and Space Administration, 2011.

[62] METI and NASA, ASTER GDEM 2 README. Ministry of Economy, Trade and Industry of Japan and National Aeronautic and Space Administration, 2011.

[63] J. Clifton and B. Boruff, Site Options for Concentrated Solar Power Generation in the Wheatbelt, Perth, Australia, Prepared for the Wheatbelt Development Commission, 2010.

[64] D. A. Ignizio, Suitability modeling and the location of utility-scale solar power plants in the southwestern United States. Master Thesis, University of New Mexico, Albuquerque, USA, 2010.

[65] K. Eldrandaly, "Developing a GIS-Based MCE Site Selection Tool in ArcGIS Using COM Technology", The International Arab Journal of Information Technology, Vol. 10, No. 3, pp. 276-282, 2013.

[66] K. Tisza, GIS-based suitability modeling and multi-criteria decision analysis for utility scale solar plants in four states In the southeast U.S. Master Thesis, The Graduate School of Clemson University, Clemson, South Carolina, USA, 2014.

[67] IEA, Technology Roadmap: Solar photovoltaic energy, OECD/International Energy Agency, 2010.

[68] Hill, Solar Energy Site Assessment (Phase 1), Final Report Prepared for: The Tucson Water Department and Arizona Electric Power Cooperative, Inc., Tucson, 2008.

[69] EGA and AJS&A, Agenda 21 Local de Ourique: Caracterização da Área Estratégica – Localização Geográfica. Environmental Governance Advisors and Câmara Municipal de Ourique, 2011.

[70] R. Hott, J. Brownson and R. Santini, "GIS-based Spatial Analysis for Large-scale Solar Power and Transmission Line issues: Case Study of Wyoming, U.S.", Solar Conference, Boulder, Colorado, pp. 2274–2279, 2012.

[71] D. Dahle, D. Elliott, D. Heimiller, M. Mehos, R. Robichaud, M. Scwartz, B. Stafford and A. Walker, Assessing the Potential for Renewable Energy Development on DOE Legacy Management Lands, Report of the National Renewable Energy Laboratory, 2008.

[72] E-LEE, Site of Association for promotion of e-Learning tools for Electrical Engineering, 2003. Available from: http://e-lee.ist.utl.pt/association/association.htm, accessed Oct 25, 2014.

[73] K. Komoto, C. Breyer, E. Cunow, K. Megherbi, D. Faiman and P. V. D. Vleuten, Energy from the Desert 4: Very Large Scale PV Power - State of the Art and Into The Future, Vol. 13, International Energy Agency – Photovoltaic Power Systems Programme, 2014.

[74] Decreto-Lei n.º 73/2009, D. R. I Série, 63 (31-03-2009), 1988-2000.

[75] Decreto-Lei n.º 169/2001, D. R. I Série-A, 121 (25-05-2001), 3053-3059.

[76] Decreto-Lei n.º 139/1988, D. R. I Série, 94 (22-04-1988), 1572-1573.

[77] Decreto-Lei n.º 239/2012, D. R. I Série, 121 (02-11-2012), 6308-6346.

[78] Decreto-Lei n.º 49/2005, D. R. I Série-A, 39 (24-02-2005), 1670-1708.

[79] Decreto-Lei n.º 142/2008, D. R. I Série, 142 (24-07-2008), 4596-4611.

[80] Decreto-Lei n.º 151B/2013, D. R. I Série, 211 (31-10-2013), 6328(6)-6328(31).

[81] Aviso n.º 1534/2014, D. R. II Série, 23 (03-02-2014), 3394-3404.

[82] Decreto-Lei n.º 107/2009, D. R. I Série, 94 (15-05-2009), 3014-3032.

[83] Portaria n.º 522/2009, D. R. I Série, 94 (15-05-2009), 3032-3035.

[84] Resolução de Conselho de Ministros n.º 154/2003, D. R. I Série-B, 225 (29-09-2003), 6333-6343.

[85] Resolução de Conselho de Ministros n.º 185/2007, D. R. I Série, 246 (21-12-2007), 8992-9005.

[86] Decreto-Lei n.º 86/2002, D. R. I Série-A, 81 (06-04-2002), 3257-3281.

[87] Decreto de 16-06-1910, D. R. I Série, 136 (23-06-1910), 2163-2166.

[88] Decreto n.º 29/1990, D. R. I Série, 163 (17-07-1990), 2972-2974.

[89] Decreto n.º 24/2013, D. R. I Série, 142 (25-07-2013), 4388.

[90] Lei n.º 2110/1961, D. R. I Série, 192 (19-08-1961), 1029-1044.

[91] Lei n.º 34/2015, D. R. I Série, 81(27-04-2015), 2080-2098.

[92] Decreto-Lei n.º 276/2003, D. R. I Série-A, 255 (04-11-2003), 7340-7348.

[93] Decreto-Lei n.º 143/1982, D. R. I Série, 96 (26-04-1982), 1012-1015.

[94] ESRI, ArcGIS Help, 2014. Available from: http://resources.arcgis.com/en/help/main/10.2/, accessed Aug 01, 2015.

[95] M. Boxwell, Solar Electricity Handbook: A Simple, Practical Guide to Solar Energy: how to Design and Install Photovoltaic Solar Electric Systems. Greenstream Publishing, 2011.

[96] INE, V Recenseamento Geral da Habitação. Instituto Nacional de Estatística, 2011.

[97] CMM, Website of Câmara Municipal de Moura, 2015. Available from: http://www.cm-moura.pt/, accessed Aug 15, 2015.

[98] EPA, Solar Decision Tree, United States Environmental Protection Agency's and National Renewable Energy Laboratory, 2013.