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Discussions

Optimal Site Selection for Sitting a Solar Park using Multi-Criteria Decision Analysis and Geographical Information Systems (GIS)

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Abstract. Among the renewable powers sources, solar is rapidly becoming popular being inexhaustible, clean, and dependable. It is also becoming more efficient since the photovoltaic solar cells' power conversion efficiency is rising. Following these trends, solar power will become more affordable in years to come and considerable investments are to be expected. Despite the size of solar plants, the sitting procedure is a crucial factor for their efficiency and financial viability. Many aspects rule such decision; legal, environmental, technical, and financial to name some. This paper describes a general integrated framework to evaluate land suitability for the optimal placement of photovoltaic solar power plants, which is based on a combination of a Geographic Information System (GIS), remote sensing techniques and multi-criteria decision making methods.

An application of the proposed framework for Limassol District in Cyprus is further illustrated. The combination of GIS and multi-criteria methods, consist an excellent analysis tool that creates an extensive database of spatial and non spatial data that will be used to simplify problems, to solve and promote the use of multiple criteria. A set of environmental, economic, social and technical constrains based on recent Cypriot legislation, European's Union policies and experts' advices, identifies the potential sites for solar park installation. The pair-wise comparison method in the context of the analytic hierarchy process (AHP) is applied to estimate the criteria weights in order to establish their relative importance in site evaluation. In addition, four different methods to combine information layers and check their sensitivity were used. The first considered all the criteria as being equally important and assign them equal weight, while the others grouped the criteria and graded them according to their objective perceived importance. The overall suitability of the study region for sitting solar park is appraised through the summation rule.

Strict application of the framework depicts 3.0% of the study region scoring best suitability index for solar resource exploitation, hence minimizing risk of a potential investment. However, using different weighting schemes for criteria, suitable areas may reach up to 83% of the study region. The suggested methodological framework applied can be easily utilized by potential investors and renewable energy developers, through a front end web based application with proper GUI for personalized weighting schemes.

Keywords: GIS Modeling; Remote Sensing; Decision Analysis; Site Evaluation; Solar Radiation; Renewable Energy Sitting; Analytic Hierarchy Process

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1 Introduction

Energy is an essential part of modern life as almost all human activities are strongly connected with it. The availability and security supply of energy are considered important prerequisites of economic and social development of a country. The current economic situation although, the rational use of the available resources and the need to overcome the negative environmental impacts and other problems associated with fossil fuels, have forced many countries to enquired into and change to more environmental friendly alternatives that are renewable to sustain the increasing energy demand (Sanchez-Lozano et al., 2013; Bahadori and Nwaoha, 2013).

Among the renewable power sources, solar is growing exponentially, worldwide during the last decade. This is not surprising as the sun can provide more than 2500 terawatts (TW) of technically accessible energy over large areas of Earth’s surface and solar energy technologies are no longer cost prohibitive (Hernandez et al., 2014). Nevertheless, presently it only covers a minor portion of global energy demands (0.05% of the total primary energy supply) and photovoltaic (PV) power generates less than 1% of total electricity supply (Solangi et al., 2011), solar energy has great future potential.

Solar energy is obviously environmentally advantageous relative to any other non-renewable energy source and the linchpin of any sustainable development program. It can be exploited through the solar thermal and PV routes for various applications. The main direct or indirectly derives advantages of solar energy are: no emission of greenhouse or toxic gasses, reclamation of degraded land, reduction of transmission lines from electricity grids and increase of regional/ national energy independence. In addition, it can provide diversification and security of energy supply, acceleration of rural electrification in developing countries, job opportunities, improvement of life quality in developing countries and investment security for park development as solar panels are resistant to extreme climate conditions with a life expectancy greater than 35 years (Solangi et al., 2011; Tsoutsos et al., 2005; Torres-Sibille et al., 2009; Hernandez et al., 2014). However, conflicts can also arise between renewable energy and nature conservation policy. The environmental impacts from photovoltaic power generation include generally effects on visual impact, land use intensity, wildlife impacts, reflection effects, depletion of natural resources and waste management (Torres-Sibille et al., 2009; Tsoutsos et al., 2005; Turney and Ftenakis, 2011). The number of direct animal deaths at solar parks although, is thought to be negligible (Katzner et al., 2013). The worst impacts of ground-mounted solar installations occur when all natural habitat in the vicinity is cleared, stripping vegetation and compacting soil. This can reduce the carbon content of the soil compared to undisturbed areas and, in arid regions, allows the transport of dust, which can reduce the efficiency of solar panels (Hernandez et al., 2014). Other risks to wildlife from solar park operation include chemical, such as dust suppressants and rust inhibitors (Hernandez et al., 2014). Water is also used to clean the panels, which may pressurize scarce resources in dry regions (Cameron et al., 2012). It is also important to take into account the life-cycle assessment: processes involved in obtaining rare materials used for making solar panels may lead to biodiversity impacts elsewhere, e.g. at the source of extraction (European Commission, 2014).

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The sitting of photovoltaic power facilities consists of proper land use planning and sustainable development. Any site selection and assessment procedure must address the technical, economic, social and environmental aspects of the project to determine whether it is suitable for solar energy development. As a result, energy and electricity industry professionals and policy groups have developed a variety approaches to mitigate sitting of solar parks. Geographical Information Systems (GIS) is popular and effective decision making tool for the selection of optimal sites for different types of activities and installations (Carrion et al., 2008; Tegou et al., 2010; Kontos et al., 2005). Applications of GIS and renewable energy sources planning include wind farm sitting, photovoltaic electrification, biomass evaluation, visual impact assessment of wind farm, etc (Tegou et al., 2010; Georgiou et al., 2012; Maser et al., 2006; Ramachandra et al., 2007). One of the most common GIS based strategies that have been designed to facilitate decision making in site evaluation and land suitability is Multi-criteria Analysis (MCA) (Torres-Sibille et al., 2009). The Analytic Hierarchy Process (AHP) method that introduced by Saaty (1980) is a flexible and easily implemented MCA technique and its use has been largely explored in the literature with many examples in locating facilities and in land suitability analysis (Tegou et al., 2010; Kontos et al., 2005; Georgiou et al., 2012; Masera et al., 2006).

The scope of this paper is to develop and present an integrated framework to quantify and evaluate land suitability for the optimal photovoltaic solar power plants placement with application to Limassol District in Cyprus. This should be considered as a tool where different users can change respectively weights, in order to produce a custom made map for their own ‘most suitable’ areas for solar park investment. The proposed framework comprises of a combination of already established methods and tools for solar resource assessment, remote sensing techniques, spatial analysis and multi-criteria decision making methods. The Analytic Hierarchy Process (AHP) has been chosen as a means of weighting the suitability criteria; the Simple Additive Weighting (SAW) method has been used as an aggregation algorithm, and Geographical Information Systems (GIS) as an integrated platform of analysis and presentation. Innovative aspects comprise of straightforward integration and modeling of available tools, the integrated evaluation of potential sites taking into consideration a variety of constrains and criteria and the overall development of a consistent methodology which is flexible enough for applying “what if” scenarios.

2 Material and Methods

2.1 Study site and data specifications

Located in the South part of the island of Cyprus (Fig.1), the study area of Limassol District covers an area of about 1370km^2. The island of Cyprus is located in the northeastern part of the Mediterranean Sea and therefore, has a typical eastern Mediterranean climate with long hot dry summer, mild winter and more than 3000 hours of sunshine annually. One of the most important aspects of Cypriot budget is energy as it is characterized by high dependence on imported energy sources, the intense use of oil in the energy balance, isolation from European energy networks and low degree of exploitation of renewable energy sources. Regarding primary energy, 90% is oil-based, 6% is coal-based and the remaining 4% is based in solar energy and basically in solar thermal energy (Pilavachi et al., 2009; Maxoulis and

Kalogirou, 2008). For those reasons, as well as the fact that Cyprus is an island, it must be as much energy independence as possible.

Place Figure 1 here

This study aims to develop a framework model using a GIS system, supporting satellite imagery and both raster and vector as input data. Spatial data sets of archaeological sites, road network, electricity grid, solar radiation, digital elevation model (DEM), NATURA 2000 areas, rivers, land use, built up areas, surface waters, airport area, slope and aspect consist the geo-database. This geo-database can be easily expanded with more layers of information, once they are available.

The land use, built up areas and surface waters were produced from the analysis of a Landsat-8 OLI/TIRS image as further illustrated. The image was acquired on September 26, 2015 and contains 11 bands. Vector data such as archaeological sites, road network, rivers and airport were digitized by 1:50.000 maps of Cyprus while NATURA 2000 areas and electricity grid were produced by Ministry of Agriculture Natural Resources & Environment and Electricity Authority of Cyprus (EAC) respectively. Finally, the DEM was produced by the Cyprus Geological Survey Institute.

2.2 Landsat-8 OLI/TIRS data pre-processing

Prior to deriving the spectral indices necessary for the analysis, the Landsat-8 OLI/TIRS data had to undergo radiometric calibration and atmospheric correction. The Digital Number (DN) values of the multispectral and thermal bands had to be converted into Top of Atmosphere (TOA) reflectance and be corrected with sun angle respectively.

The TOA spectral radiances of the multispectral and thermal bands of the Landsat-8 OLI/TIRS imagery can be calculated using Eq. (1).

$$L_{\lambda'}(Landsat - 8) = M_L Q_{cal} + A_L \tag{1}$$

Where M_L and A_L are, respectively, the band-specific multiplicative and additive rescaling factors from the metadata; and Q_{cal} is the quantized and calibrated standard product pixel values (DN). Source: (USGS, 2016).

In the correction of the reflectance with the sun angle, we used the TOA planetary reflectance without the sun correction ($L_{\lambda'}$) and the local sun elevation angle (θSE) using Eq. (2). The scene center sun elevation angle in degrees is provided in the metadata. Source: (USGS, 2016).

$$L_\lambda = \frac{L_{\lambda'}}{\cos \theta SE} \tag{2}$$

2.3 Classification of main area categories

2.3.1 Production of Index-derived Images

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In order to exclude certain areas from selection, the Area of Study (AoS) was grouped into three generalized categories, i.e., vegetation, open water and built-up land. Based on these three elements, three indices, NDVI, MNDWI and NDBI, were selected in this study to be used for extraction of those three major land-use classes, respectively.

NDVI – derived Vegetation Image

There are various vegetation indices to enhance vegetation information in remote sensing imagery usually by ratioing a near-infrared (NIR) band to a red band. This takes advantage of the high vegetation reflectance in NIR spectral range and high pigment absorption of the red light (Hangiu, 2007). Normalized Difference Vegetation Index (NDVI) is the best indicating factor for plant growth status and the spatial distribution of vegetation, which has linear relationship with the density of vegetation distribution (Haoxu et al., 2011); the formula is shown as Eq.3:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{3}$$

Where NIR presents near-infrared wavelength and RED represents red wavelength. They belong to bands of the Landsat-8 OLI/TIRS and respectively represented the fifth and fourth band.

Once the NDVI was finalized, a threshold of 0.45 was selected as most appropriate for the extraction of high vegetation locations.

MNDWI – derived Water Image

As the study area is crossed by several rivers and distributed with some reservoirs and small lakes, in order to extract surface water, the Modified Normalized Difference Water Index (MNDWI) was adopted (Haoxu et al., 2011). The formula is as follow:

$$MNDWI = \frac{Green - MIR}{Green + MIR} \tag{4}$$

Where Green represents the Green wavelength, MIR represents the middle-infrared wavelength and they belong to bands of the Landsat-8 OLI/TIRS and respectively represented the third and sixth band.
Based on the ground survey data and hence the information about the known eater body location, a threshold of 0.2 was selected as most appropriate for the extraction of surface water.

NDBI – derived Built up image

The build-up land image was produced using the Normalized Difference Building Index (NDBI) which takes advantage of the unique spectral response of the build-up lands that have higher reflectance in MIR wavelength range than in NIR wavelength range (Zha et al., 2003); the formula is shown as Eq.5:

$$NDBI = \frac{MIR - NIR}{MIR + NIR} \tag{5}$$

Where MIR represents the middle-infrared wavelength, NIR the near-infrared wavelength and they belong to bands of the Landsat-8 OLI/TIRS and respectively represented the fifth and sixth band. However, in the resulted index map found that many vegetated areas have positive NDBI values and in some circumstances, water bodies can also reflect MIR stronger than NIR. Consequently, the contrast of the NDBI images is not good as NDVI and MNDWI images, because many pixels of vegetation and water areas having positive NDBI values show medium gray tones and present as noise mixed with built-up features. Some studies address similar problems (Hangiu, 2007; Zha et al., 2003) with low accuracy in the final extraction of NDBI. These suggest that the urban build-up land features could not be extracted merely based on a NDBI image. In this study, a combination of NDBI with NDVI and MNDWI is used to extract urban built-up land features. This combination can remove the vegetation and water noise, and hence improve the extraction accuracy.

The method that used to extract built-up land features based in an "if-the-else" logic calculation through a band spectral signature analysis (Hangiu, 2007). A new image dataset was created, which used NDVI (Band1 - RED), NDBI (Band2 - GREEN) and MNDWI (Band3 - BLUE) images as three bands (Fig.2). A simple rule-based logic tree is used to segment urban build-up lands from non-urban build-up features. Examining the signatures of the three new bands found that there are no major differences between means of NDVI and NDBI that might cause confusion between built-up land and vegetation classes. Therefore, the logic calculation that used to assist the extraction is as follows:

If BAND 1 < 0.15 and BAND 2 > BAND 3 then 1 Else 0

The maximum of build-up land class in Band 1 (NDVI) is 0.15, whereas the minimum of vegetation class in that band is 0.45. Therefore, using 0.15 as a threshold value can help avoid the confusion between vegetation and build-up land classes and greatly increase the extraction accuracy.

Place Figure 2 here

2.3.2 Accuracy assessment

To compare the extraction accuracy, the extracted data of build-up areas, high vegetation and surface waters checked by a reference map. A GeoEye Ikonos with finer spatial resolution provided as base map in ArcGIS^{TM} was used as reference dataset from which the extraction results were compared. A random sampling method was used and the results from each dataset where evaluated to see whether there are any difference between them.

2.4 The AHP Method

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach that can be used for solving complex and unstructured problems. It helps to capture both qualitative and quantitative aspects of a decision problem and provides a powerful yet simple way of weighting the decision criteria, thus reducing bias in decision-making (Saaty, 1987; Georgiou et al., 2012). The AHP is based on pair-wise comparisons and used to derive normalized absolute scales of number whose elements are then used as priorities. By comparing pairs of criteria one at a time and using integer numbers from the 1 to 9 scale of the AHP, decision-makers can quantify their judgment about the relative importance of criteria. Then a pair-wise comparison matrix is formed where the relative importance weight of each criterion is computed as the normalized geometric mean of each row of the matrix. A consistency index (CI) that measures the inconsistencies of pair-wise comparison calculated as follows (Eq.6), where λmax is the largest eigenvalue and n the number of rows or columns:

$$CI = \frac{\lambda \max - n}{n - 1} \tag{6}$$

A measure of coherence of the pair-wise comparisons is calculates in the form of consistency ratio (CR) where *RI* is the average *CI* of the randomly generated comparisons (Pilavachi et al., 2009):

$$CR = \frac{CI}{RI} \tag{7}$$

CR value of 10% or less is considered as acceptable otherwise, one has to revise his judgments.

2.5 Simple Additive Weighting (SAW) method

The Simple Additive Weighting (SAW) method is the simplest way for aggregating the used criteria in order to compute a Suitability Index (SI) for each cell in the study area. More specific, each evaluation criteria is multiplied by the respective weight and then all criteria are summed in order to provide a total performance score for each cell. The *SI* lies between 0 and 100, corresponding to the “worst” and “best” sites respectively. The applied formulation is (Georgiou et al., 2012):

$$SIi = \sum_{j=1}^{n} \mathrm{W}j * \mathrm{V}ij \tag{8}$$

Where:

SI*i*:	Overall suitability index for cell *i*
W*j*:	Relative importance weight of criterion *j*
V*ij*:	Score of cell *i* under criterion *j*
n:	Total number of criteria

3 Case Study

3.1 Methodological framework

The methodological framework considers that each potential site that may host a solar park should satisfy a number of functional parameters and assesses their comparative importance. To do so, a combination of MCA with GIS where used, with the AHP method as additional tool to assign weight of relative importance to each evaluation criterion. An overall suitability index (SI) is then calculated for each potential cell in the map using the weighted overlay technique.

The presented methodological framework involves several stages as presented in Fig.3. More specific, the first step is to define and gather all appropriate data layers that needed for the analysis in order to set up the digital geo-database. The next step is to establish the constraint factors that will determine unsuitable areas and will be in form of a binary map; where "0" refers to unsuitable areas and "1" to areas suitable for further examination of solar exploitation. At the exclusion areas, local and EU legislations where used to define criteria in addition with GIS and Remote Sensing techniques for the production of them. The next step is to establish the cost functions for all available criteria and estimation of weights of the evaluation criteria according the AHP algorithm. These weights based on subjective criteria that can be changed accordingly the needs of researchers. The final step consists of the formulation and calculation of the final suitability index map using the SAW method and the presentation of the results in thematic maps.

Place Figure 3 here

In Fig.4, the model of proposed methodology approach is presented as organized and developed in a GIS environment.

Place Figure 4 here

The definition of both bounding constraints and evaluation criteria depended on standing legislation and on the characteristics of the study area. All factors were selected in accordance with the Cypriot legislation for RES sitting (Law 29(I), 2005) and in some cases, under the advice of the experts of the Ministry of Agriculture Natural Resources & Environment. In addition, European's Union policy (European Commission, 2014) and previous similar researches in renewable energy systems field (European Commission, 2014; Carrion et al., 2008; Katsaprakakis, 2012; Mari et al., 2011) are used to configure the list of parameters that used.

3.2 Establishment of Constraints factors

The constraint factors that were used presented in Table 1 and comprise of environmental, safety, social (in terms of pressure in society) and technical parameters. A binary GIS mask is created for each constraint, with cells falling within a constrained area assigned "0" and the rest of them assigned "1".

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The constraints C_3, C_4, C_5, C_8 and C_9 are according the national legislation, while the C_{10} set by experts to exploit the best performance of a solar panel that derives from areas with aspects South, Southeast and Southwest. The C_1 and C_7 are set in way to avoid any reflections from solar park in these directions and finally, C_2 and C_6 are set by researchers under environmental and technical concern respectively.

The constraint factors exclude 17% (227 km^2) of the district area.

Place Table 1 here

3.3 Establishment of Evaluation criteria and normalization

The evaluation criteria that score the potential sites are based mainly on financial parameters as presented in Table 2. After the evaluation criteria were determined and assessed, they were normalized through distance cost functions in a scale from 0 to 100 in order to allow direct comparability, with 100 representing the most desired value and 0 representing the most undesired value (Fig.5). This research focuses on developing a workbench GIS model for sitting solar parks and as such does not focuses in detail to the cost functions themselves. It should be noted that once the GIS model is being established the cost functions and the weighting schemes can easily adapt to support a more precise and detailed cost function scheme. It should be noted here, that if the suggested method is to be used for financial investment analysis, then each of these cost functions should be fine-tuned. Further analysis of the cost functions will not be further analyzed here, as this is not the scope of the paper.

Place Figure 5 here

In technical terms, very steep slopes of land are not suitable for solar park installation. For that reason, land slopes greater than 45^0 excluded while the remaining got grading values of 0 to 100. In addition, high altitude areas have higher transportation cost and are not preferable. Finally, solar radiation values greater than the mean value of the study area took into consideration, getting grading values from 0 to 100.

In the other hand, in financial terms, the distance from road network and electricity grid increase the investment cost since additional infrastructure is necessary. In that way, areas farther than 2500m from the road network and 2000m from the electricity grid are considered as not economically viable, assigned the value of "0". Finally, the land value is strongly correlated with the distance from the shoreline, as seaside areas cost more and therefore not affordable for such installations. Finally, in social terms, the visibility of potential sites from primary roads has taken into consideration grading from 0 to 100 where "0" presents high observation frequency and "100" zero visibility respectively.

Place Table 2 here

3.4 Assessment of criteria weights through AHP

The AHP method is used to assign weight to the criteria as not all of them are equally important. The pair-wise weight matrix for the calculation of the overall weights of the evaluation criteria is created (Table 3), and the priority weights estimated (Table 3). The AHP parameters are also shown, indicating that the original judgments are consistent.

The rationale behind the particular criteria weighting (corresponding to case 2 in the results paragraph), is highlighted in the following:

- The solar radiation is considered to be the most important criterion since it determines the output of the solar park;
- The distance from electricity grid (EAC) and from roads follow, as they determine the final cost of installation;
- The slope and elevation pose mild technical criteria, which might increase the investment;
- The land value thought to be less significant as it has only to do with the cost of the land that will host the solar park;
- Finally, the viewshed from primary roads placed last, as social concern considered less significant despite the other criteria.

Place Table 3 here

4 Results

The Suitability Map is derived from the multiplication of the Constrain Map (binary map) with the Evaluation Map (Fig. 6), hence totally removing the restricted areas from the Evaluation Map. The most appropriate areas for solar park istallation are those shown in light yellow, with suitability index 70 – 80. Nevertheless, there are no best-ranked sites (with score 100) in the study area, showing that there are no sites that meet all criteria’s best grades. It is also noticable that most of the study area (83%) is restricted from solar park istallation, while only a considerably small percentage (1%) of the area achieved suitability index of 80, even though solar energy is favourable in more areas.

Place Figure 6 here

4.1 Sensitivity Analysis

In a multi-criteria analysis a “what if” sensitivity analysis is recommended as a means of checking the stability of the results against the subjectivity of the expert judgments. The most common method is to modify the weightings obtain from the experts, while the assumption of equal weightings is also used (Cameron et al., 2012). In this project, the sensitivity analysis performed, considers the effect of changes of criteria weights upon the overall suitability index. To that aim, the following four cases were examined:

- Case 1: All criteria have the same weights.

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- Case 2: The weight of the criterion "solar energy" has the biggest score.
- Case 3: The weight of the criteria "solar energy" and "land value" have the biggest score while the rest distributed equally
- Case 4: All economical criteria (road network, electricity grid and land value) have weights equal to zero (0).

The results and statistics information of the four cases are illustrated in Fig 7. As observed, the present framework is sensitive to the criteria weights. This was expected since the evaluation criteria are selected with respect to the specific characteristics of the study area. The change of the final suitability map that is derived from the changing of criteria weights implies that each selected criterion is influential in the evaluation of the study area.

Place Figure 7 here

It is noticeable that, although the resulting maps for the four cases of the sensitivity analysis show considerable modification in the suitability index, Fig.8, shows that the number of the most suitable areas (SI > 80) for solar park sitting remains low and in some cases null. In Case 4, where no economic criteria taken into consideration a noteworthy variation is observed: the majority of potential sites are classed from 45 to 60 with few high scored potential sites. In addition, a noticeable lack of potential sites with SI > 80 observed in Case 2 and Case 3 with most of the pixels to be concentrated in SI ~ 54 and SI ~ 50 respectively. Finally, only in Case 1 pixels with high values are presented, with SI values to be even distributed.

Place Figure 8 here

4 Conclusions

In this article, a decision analysis methodological framework for solar energy exploitation and site evaluation is developed and applied in Limassol district in Cyprus. The framework it is a combination of already existing tools of multi-criteria analysis and integrated site evaluation in a straightforward way. It also combines GIS and remote sensing techniques for spatial analysis, modeling and visualization. The objective of the paper is to propose a method for solar park installation suitability analysis, taking into account a number of financial, social, environmental and technical criteria. The pair-wise comparison method in the context of the AHP was utilized to assign the relative weights to the evaluation criteria while SAW method used as a way for aggregating the used criteria, in order to compute the SI for each cell in the study area. GIS established the spatial dimension of constrains and evaluation criteria and elaborated them for the production of the overall suitability map. A sensitivity analysis on the weights of the evaluation criteria was also performed, showing that each criterion is influential in the evaluation of the suitability of site.

The results identified promising sites for electricity generation from solar energy, excluding over 80% of the whole study region. The best score areas (SI > 70) cover only the 3.0% (40.3 km^2) of the study area. However, the proposed methodology allows the analyst to consider even less suitable sites, by reducing the acceptable threshold of suitability index. This would result in the identification of more areas as appropriate for solar park development in combination as well with field inspection. Thus, future work could include the individual assessment of the optimal locations in conjunction with field inspection in order to make the final selection of sites.

The innovation of this work derives from the proposed modeling of the entire methodology, providing a versatile platform of analysis and semi-automation of the operations, which might also extended into fully automated. That makes it flexible for performing 'what if' scenarios. In addition, an innovator dimension gives the way that the evaluation criteria were used in conjunction with the legislative boundary constrains under a unified multi-criteria decision aiding. Finally, it provides accuracy and precision in less evaluation time, allowing checking the robustness and stability of the results obtained. For these reasons, it may well be helpful for potential investors in solar park investments and also in other kinds of project sitting, due to the generic nature of the framework. In addition, the proposed GIS model may be further developed with contributions from EAC's experts, in order to become a valuable tool for sitting small, medium or large solar parks, through adaptation of the basic model presented here.

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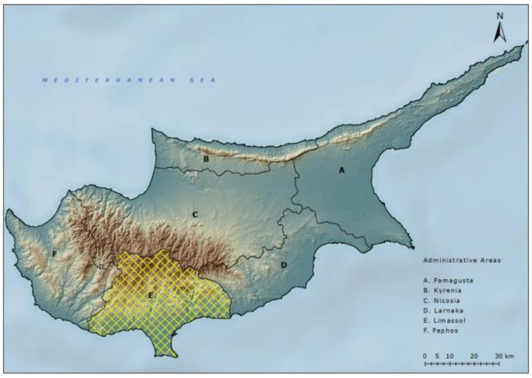

Figure 1: Study area of Limassol District

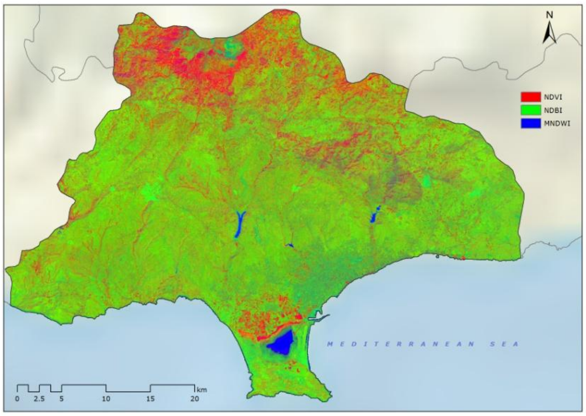

Figure 2: Composed image dataset from NDVI, NDBI and MNDWI

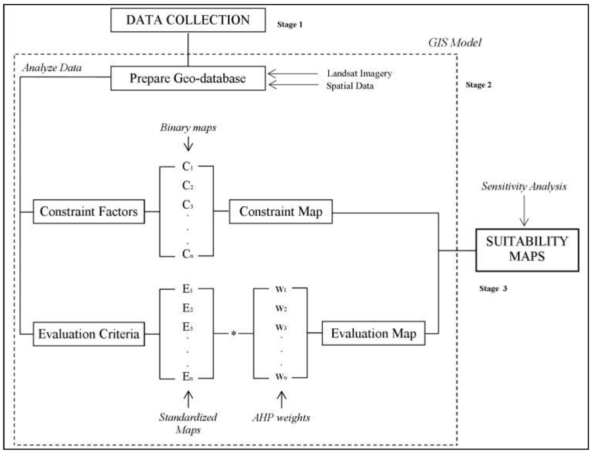

Figure 3: Flow chart of proposed methodology framework

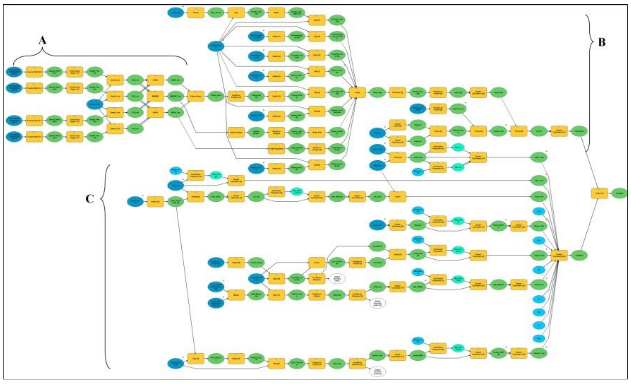

Figure 4: Methodology modeled in ArcMap^{TM} environment as script (a) Landsat-8 OLI/TIRS image analysis; (b) Constraint factors analysis; (c) Evaluation criteria analysis

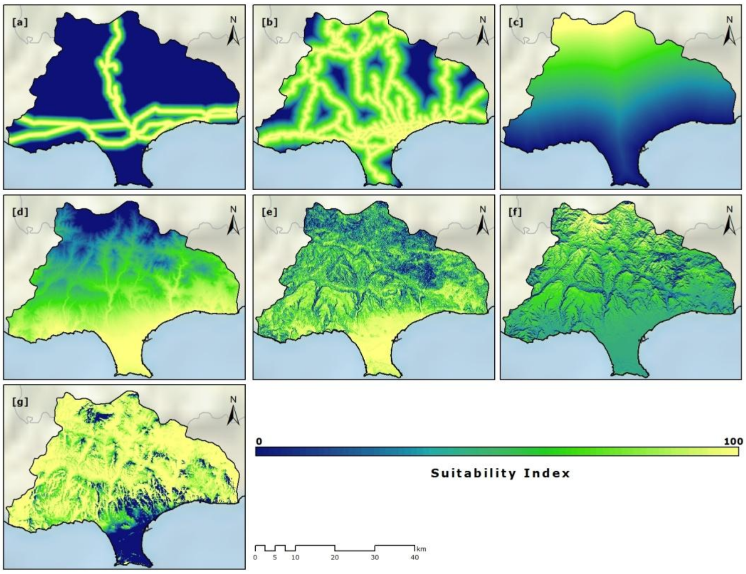

Figure 5: Standardized evaluation layers (a) Electricity Grid, (b) Road Network, (c) Land Value, (d) Elevation, (e) Slope, (f) Solar Energy, (g) Viewshed from primary roads

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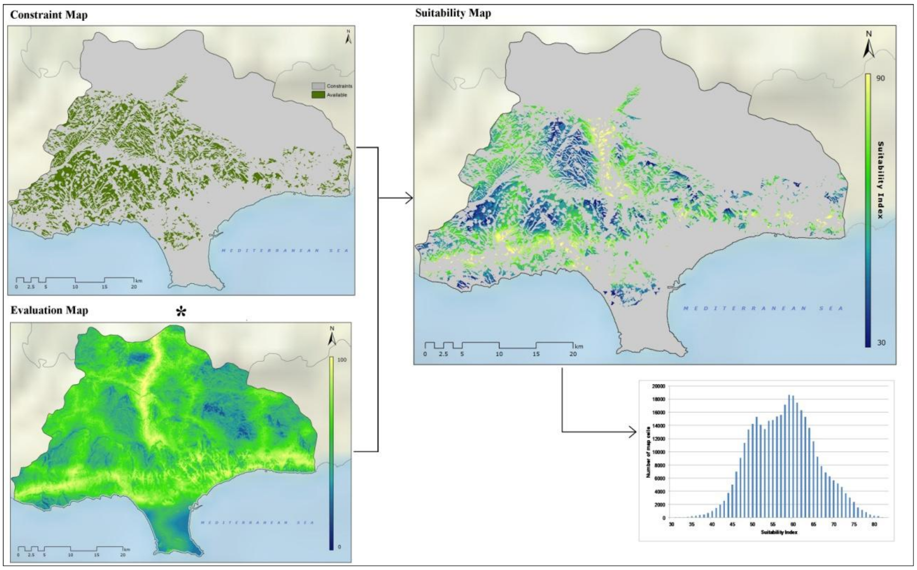

Figure 6: Suitability Index map of study area. The graph presents the distribution of suitability index

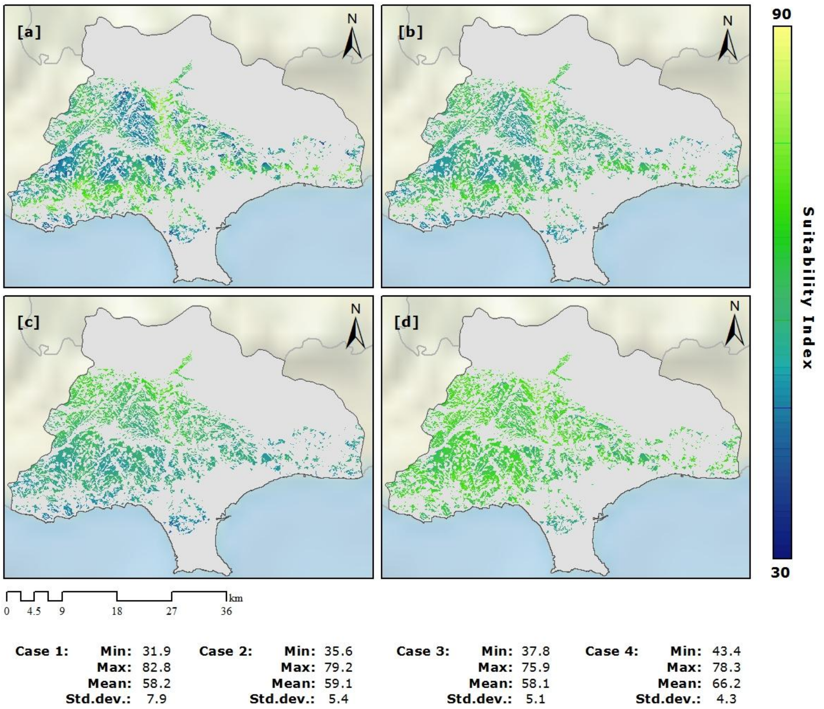

Figure 7: Sensitivity analysis results (a) Case 1; (b) Case 2; (c) Case 3; (d) Case 4

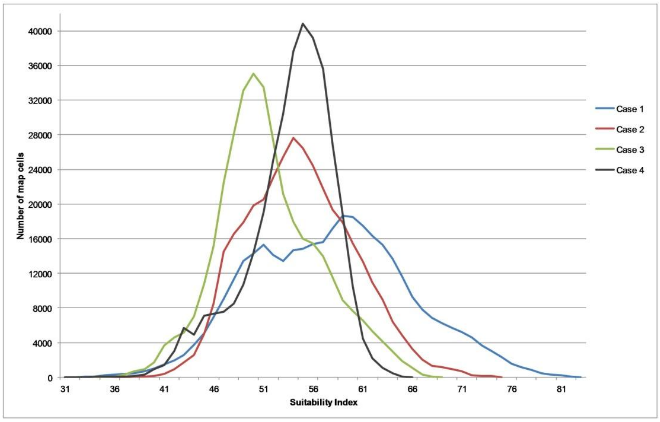

Figure 8: Number of map cells for each case of sensitivity analysis

Table 1: Constraint factors of the case study

	Constraint factors	Type
	The solar park must not be within:	
c_1	50m from primary and secondary roads	Social Impact
c_2	High vegetation	Environmental/Technical
c_3	200m from NATURA 2000 areas	Environmental
c_4	200m from National forest	Environmental
c_5	200m from urban zones	Social
c_6	100m from surface waters	Environmental
c_7	2000m from airport	Safety
c_8	200m from archaeological sites	Social Impact
c_9	200m from shoreline	Social Impact
c_{10}	Areas with aspect: East | West | North | Northeast | Northwest	Technical

Table 2: Evaluation criteria of the case study

	Evaluation Criteria	Type	Normalization
E_1	Elevation	Technical	0 – 100
E_2	Slope < 45^o	Technical	0 – 100
E_3	Viewshed from primary roads	Social	0 – 100
E_4	Land value	Financial	0 – 100
E_5	Distance from road network < 2500m	Financial/Technical	0 – 100
E_6	Distance from electricity grid < 2000m	Financial/Technical	0 – 100
E_7	Solar Radiation > mean radiation of the area	Technical	0 – 100

Table 3: Case 2: Pair-comparison matrix and relative importance weights on the last column

	Viewshed	Land Value	EAC	Slope	Solar	Elevation	Roads	Weight
Viewshed	**1.000**	1.000	0.333	0.500	0.111	0.500	1.000	0.037
Land Value	1.000	**1.000**	0.500	2.000	0.143	2.000	0.500	0.078
EAC	3.000	2.000	**1.000**	3.000	0.143	3.000	2.000	0.133
Slope	2.000	0.500	0.333	**1.000**	0.111	1.000	0.333	0.051
Solar	9.000	7.000	7.000	9.000	**1.000**	9.000	9.000	0.545
Elevation	2.000	0.500	0.333	1.000	0.111	**1.000**	0.500	0.052
Roads	1.000	2.000	0.500	3.000	0.111	2.000	**1.000**	0.105

CR = 0.071 < 0.1