# Spatial Analysis Using GIS for Obtaining Optimal Locations for Solar Farms— A Case Study: The Northwest of the Region of Murcia

**J.M. Sánchez-Lozano, M.S. García-Cascales, M.T. Lamata and J.L. Verdegay**

**Abstract** One of the first decisions that must be taken when hosting a photovoltaic solar farm to pour the energy generated into the grid is to choose a proper location (towns, existing infrastructure, etc.). The legislative framework that is applicable must also be considered since it involves a large number of restrictions (protected areas, streams and watercourses, etc.) that will provide us with the guidelines to eliminate those unsuitable areas, as well as certain criteria (proximity to power lines, slope, solar irradiation, etc.) according to which an evaluation of the suitable areas that condition any facility will be made. It is precisely for these reasons why the management of spatial visualization tools such as Geographic Information Systems (GIS) is particularly useful. The objective of this paper is to demonstrate how the aggregation of GIS to decision procedures in the field of renewable energy can solve complex location problems. In the present case a GIS (called gvSIG) will be employed in order to obtain suitable locations to host photovoltaic solar farms in the Northwest of the Region of Murcia, in Spain.

**Keywords** Geographic information systems · Solar farms · Decision making

J.M. Sánchez-Lozano
Centro Universitario de La Defensa. Academia General Del Aire,
Universidad Politécnica de Cartagena, Murcia, Spain

M.S. García-Cascales (✉)
Dpto. de Electrónica, Tecnología de Computadoras Y Proyectos,
Universidad de Politécnica de Cartagena, Murcia, Spain
e-mail: socorro.garcia@upct.es

M.T. Lamata · J.L. Verdegay
Dpto. Ciencias de La Computación E Inteligencia Artificial,
Universidad de Granada, Granada, Spain



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## 1 Introduction

More and more frequently, the Earth is warning us of the dangers involved in carrying out uncontrolled and disproportionate industrial development. The planet's response is manifested in the form of an increased number of forest fires, rising levels of seas and oceans, more droughts, extreme storms, as well as constant and frequent heat waves. These are just some of the most significant effects that are being caused by increased temperatures on our planet as a result of the increase in emissions of greenhouse gases [1]. From an energy point of view, in addition to the problem of global warming we must add a continuous rise in the prices of fossil fuels such as petroleum and natural gas [2]. Therefore, the human being must find alternatives that take advantage of the multitude of resources available and which will mitigate these significant negative effects.

In the last century, policies were developed globally [3–7] and at European level [8, 9] which promoted sustainable development strategies [10] and encouraged the implementation of renewable energy (RE) installations, with the objective that such technologies should play an important role in the generation of electrical energy in the future (Fig. 1).

In Spain, the fulfillment of the objectives set by the European Union was the main reason why different energy plans were developed [11, 12]. The objective was to reach at least 20 % of final energy consumption for 2020 using renewable technologies. As a result of this favourable legislative framework, in Spain the implantation of this type of facility was extended, with solar photovoltaics being one of those with the highest growth. This positioned Spain as the second world photovoltaic power in 2009 [13]. Recent analyses [14] have demonstrated that solar technologies, and in particular photovoltaic technology, have a stable learning curve, allowing to reach very high yields in regions where there is high solar radiation.

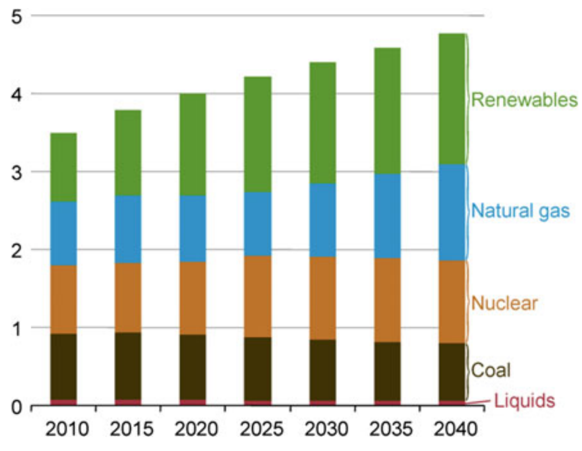


**Fig. 1** Forecast for the generation of electrical energy by fuel in the European countries belonging to OECD, (trillions kWh) [2]

The objective of this work is to find the best location to install a solar photovoltaic farm. To do this, it will be necessary to find an area where solar radiation is high. On the other hand, it is necessary to define a number of attributes (slope, area, field orientation, distance to main roads, distance to power lines, distance to towns or villages, distance to electricity transformer substations, solar irradiation and average temperature) that will be important to evaluate the most favourable suitable location for the implementation of the solar farm.

The Region of Murcia is situated in the southeast of Spain, and has one of the highest levels of solar radiation in the country [15]. Therefore, it has become one of the areas with greater appeal to deploy photovoltaic solar farms. However, on its territory there are inland areas (Northwest region) which for various reasons (land less appropriate for the development of agriculture, low land prices, lower urban and residential occupation, etc.) present greater suitability than others to implement such facilities. So, an in-depth analysis, enabling to locate the best areas to deploy photovoltaic solar farms is of notable interest.

To carry out studies of this nature, it is evident that management tools such as geographic information systems (GIS) are very useful [16] since they are able to provide extensive databases, in the form of thematic layers and tables, which can be very useful to solve complex location problems [17].

## 2 GIS Methodology in Obtaining Suitable Surfaces to Deploy Installations of RE in the Northwest of the Region of Murcia

GIS are tools that manage geo referenced information and allow us to digitally represent the real world based on discrete objects. The information of these objects is expressed numerically and provides a collection of referenced data that acts as a reality model. The space data in a GIS is a set of maps that represent a portion of the actual surface, so that each one of these maps is defined by means of a thematic variable and when it is introduced in a GIS it receives the name of thematic layer.

### *2.1 The gvSIG Software*

Although commercial GIS are widespread nowadays (ArcGIS, IDRISI, etc.), this paper will use an open source version called gvSIG (www.gvSIG.org); this was developed in 2004 by the Ministry of infrastructure and transport of the Valencian Community and is available to any user for its use and development.

In the proposed study, thematic layers that represent and define the surface covering the study area will be introduced in gvSIG, as will the restrictions i.e., areas in which it is already impossible to implement photovoltaic solar farms, because the current state of the terrain prevents it or it is prohibited by the legislation in force. Through the operations of edition of gvSIG, it will be possible to reduce the initial zone of study, taking into account the restrictions that affect it until the locations that are feasible to implement this type of facility are obtained.

## 2.2 *Stage 1: Search for Viable Locations*

The first stage will consist in selecting and refining the study area. In the proposed problem the zone will correspond to the Northwest of the Region of Murcia, which consists of five municipalities (Moratalla, Caravaca de la Cruz, Bullas, Calasparra, and Cehegin) and has an area of 2,379.62 $km^2$ (Fig. 2). Once the area of study is known, then the restrictions to apply will be described. These are the areas in which due to the current status of the territory (roads, railway, urban lands, etc.) and legislation, (European, national and regional regulations) it is not possible to deploy photovoltaic solar farms.

Each one of the seven constraints (Table 1) will be defined on the basis of the legislative framework that may apply so that, according to the current regulations


**Fig. 2** Northwest of Murcia region

**Table 1** Legal restrictions

| Nº | Name of restrictions |
|---|---|
| 1 | Suitable for urban development and urban lands |
| 2 | Landscape value, water infrastructure, military areas and cattle trails |
| 3 | Runways and watercourses and streams |
| 4 | Archaeological paleontological and cultural heritage |
| 5 | Road and railway network |
| 6 | Sites of community importance (LICs) |
| 7 | Special protection areas for birds (ZEPAs) |

[18–21], photovoltaic solar farms may not be implanted in any urban lands or lands suitable for urban development (restriction 1).

According to the law 42/2007 and law 3/1995 of 23 March, areas of high landscape value and earmarked for water supply infrastructures, military zones and cattle trails (restriction 2) are also protected areas. In Runways and watercourses and streams (restriction 3) and in their bands of buffer it is not possible to implant an installation [19]. In addition, law 16/1985 of 25 June, and the Legislative Decree 1/2005, establishes measures for the conservation of scheduled areas such as archaeological, paleontological and cultural heritage (restriction 4). The road and rail networks (restriction 5) are also protected by the regulations in force [24], as well as places of LICs (restriction 6) and areas of special protection for birds (restriction 7) which are protected by the Directive 92/43/EEC of 21 May 2009 [25].

In addition to the above restrictions, we must consider a further two factors, since those areas having any construction or installation of importance in its interior (marsh, agricultural construction, etc.), or that its area is less than that which experts consider to be the minimum to implement this type of installations (less than 1000 $m^2$ surface area) will be necessary to be discarded. Each of the restrictions will be introduced in the software gvSIG in the form of thematic layers. The thematic layer of the Northwest of the Region of Murcia will be initially introduced in gvSIG (Fig. 2). This layer will not only serve to delimit the study area but also to classify it by means of municipalities (which in turn divide their territory into polygons, plots and cadaster subplots). The thematic layers of restrictions will subsequently be added in a way which, with the commands of gvSIG (area of influence, difference, filter, etc.) they will be discounting, from the initial surface of the study area, the surface occupied by the restrictions to produce a new thematic layer that will contain the feasible locations (Fig. 3).

The feasible locations occupy an area of 1,036.11 $km^2$. Their surface is composed of 17,740 cadastral parcels according to the Cadaster General Directorate and these constitute the alternatives under analysis in the later stages. The following steps consist of selecting, from among the above alternatives, which are the best to implement this type of facilities, based on a number of criteria.

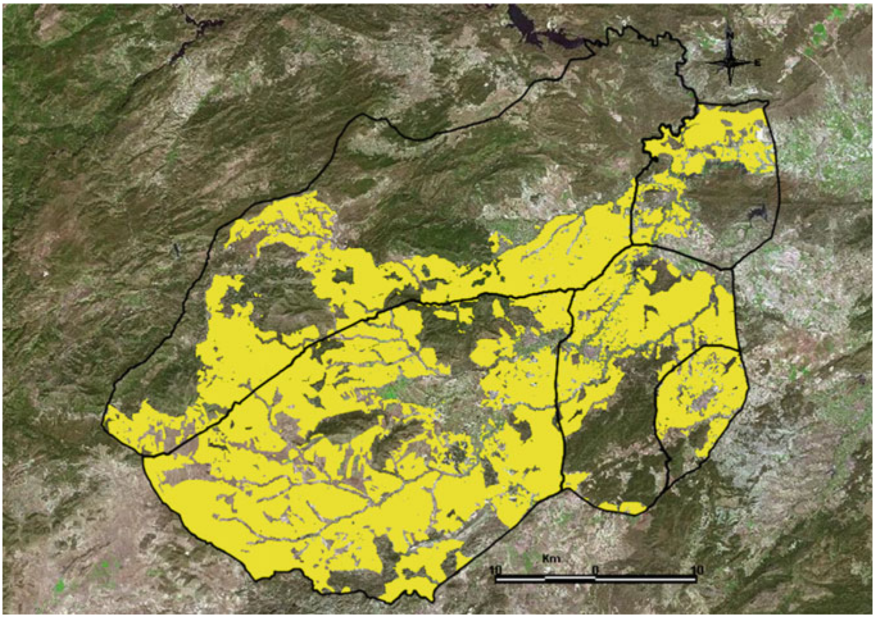


**Fig. 3** Feasible locations to install photovoltaic solar farms

## *2.3 Stage 2: Optimal Locations Analysis*

**Criteria**

In implementing renewable energy facilities, not only must it be taken into account that the analyzed zone is not affected by any legal restrictions, but we also have to rely on a series of criteria that influence the selection of the best location. Although research and studies have been conducted that define characteristics which these criteria must contain [16, 17], the choice of these criteria will depend mainly on the area of study. Therefore, following the guidelines indicated in Aran Carrion et al. [26], for the particular case, three groups of general criteria (location, orographic, and climatological) that are defined, will be broken down into a number of specific criteria which constitute the set of criteria which will influence the location, i.e., those that will opt for one location rather than another. Below we describe briefly each of the above-mentioned specific criteria:

$C_1$: Slope (%): Land slope, the higher percentage of having a surface inclination, the worse aptitude to hold a solar plant

$C_2$: Area ($m^2$): surface contained within a perimeter of land that can accommodate an RE installation

$C_3$: Field Orientation (degrees): Position or direction of the ground to a cardinal point. The most focused point is land oriented to the geographic South (270 °)

$C_4$: Distance to main roads (m): space or interval between the (Highway) road network and the different possible locations
$C_5$: Distance to power lines (m): space or interval between the nearest power line and the different possible locations
$C_6$: Distance to towns or villages (m): space or interval between centers of population and the different possible locations
$C_7$: Distance to electricity transformer substations (m): Space or interval between transformer substations of electric power and the different possible locations
$C_8$: Solar irradiation (kJ/$m^2$ day): value of the amount of solar irradiation that a field receives per unit area ($m^2$)
$C_9$: Average temperature (°C): corresponds with the average annual temperature in the different possible locations

**Database**
In order to create a database containing all alternatives and criteria, we followed a similar process to that followed in the definition of constraints. Thus, there were a total of 17,740 alternatives object of analysis, displayed by thematic information represented in rows and columns, so that rows constitute geographical objects which in this case will be alternatives to select linked (plots), and the columns will define named attributes or thematic variables (cadastral information and criteria) constituting an array with data relating to each plot for each of the nine criteria above. The attribute table is the database that will be used in the third stage.

## *2.4 Stage 3: Selection of Optimal Locations*

The database created with gvSIG allows to obtain the numeric values of all the criteria for each of the alternatives. These values will be used to carry out a process of filtering according to a classification of alternatives by categories. To do so, an expert in photovoltaics will state not only the number of categories in which the alternatives based on the nine criteria should be classified, but he also establishes the limits of such categories for each of the criteria. According to the expert, it is possible to classify the alternatives into four categories (Cat 1, Cat 2, Cat 3, Cat 4) depending on the fitness or capacity for a solar farm (regular, good, very good, and excellent capacity, respectively), and the limits set (Table 2) of these categories based on the domains of the criteria that influence the decision.

Initially, the expert considers that the worst classification should only be regular (category 1) because, when determining in stage 1 areas in which a solar farm cannot be implanted, there is no alternative that can be termed as poor. Similarly, there should be a category defined as excellent (category 4) with the objective of being restrictive when making the selection process.

The selection process will consist in gradually, and using screening techniques, eliminating those choices that are lower, and thus obtain the sites located in the top

**Table 2** Boundaries of categories of alternatives $A_i$ for each of the criteria

| Criteria | Cat 1 | Cat 2 | Cat 3 | Cat 4 |
|---|---|---|---|---|
| Slope (%) | Ai > 30 | 30 ≥ Ai > 20 | 20 ≥ Ai > 10 | Ai ≤ 10 |
| Area ($m^2$) | Ai < 1500 | 1500 ≤ Ai < 3500 | 3500 ≤ Ai < 10000 | Ai ≥ 10000 |
| Field orientation (°) | 45 ≤ Ai < 135 | 135 ≤ Ai < 225 | 0 ≤ Ai < 45 | 225 ≤ Ai < 360 |
| Distance to main roads (m) | Ai > 10000 | 10000 ≥ Ai > 5000 | 5000 ≥ Ai > 100 | Ai ≤ 100 |
| Distance to power lines (m) | Ai > 10000 | 10000 ≥ Ai > 3000 | 3000 ≥ Ai > 100 | Ai ≤ 100 |
| Distance to town or villages (m) | Ai < 100 | 100 ≤ Ai < 500 | 500 ≤ Ai < 1000 | Ai ≥ 1000 |
| Distance to electricity transformer substations (m) | Ai > 15000 | 15000 ≥ Ai > 10000 | 10000 ≥ Ai > 7500 | Ai ≤ 7500 |
| Solar irradiation ($kJ/m^2$ day) | Ai < 1200 | 1200 ≤ Ai < 1700 | 1700 ≤ Ai < 2000 | Ai ≥ 2000 |
| Average temperature (°C) | Ai < 12 | 12 ≤ Ai < 15 | 15 ≤ Ai < 17 | Ai ≥ 17 |

categories. Therefore, the first step will consist of deleting those alternatives that have values in some of their criteria in category 1 in order to reduce the number of alternatives to those whose capacities of reception are good, very good or excellent (categories 2, 3 and 4, respectively). Once this first filtering has been completed, a new thematic layer (Fig. 4a) will have reduced the number of alternatives, so from

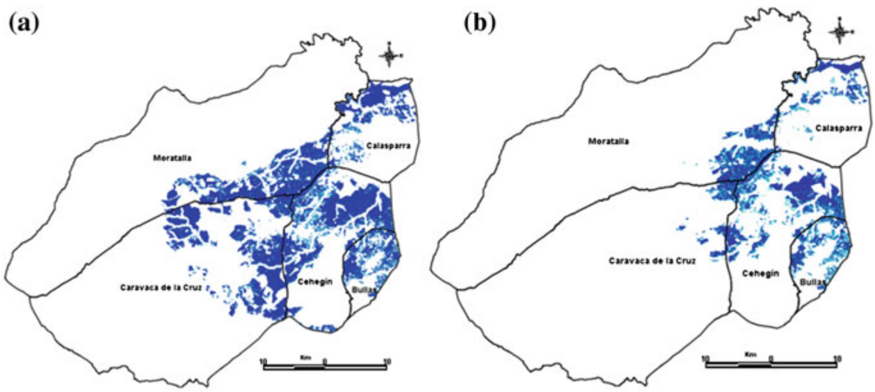


**Fig. 4** **a**, **b** Alternatives resulting after removing those alternatives with criteria in category 1 (filtering nº1) and category 2 (filtering nº2)

17,740 possible initial locations it this case they will have been reduced to 8,961, all placed in categories 2, 3 and 4.

Continuing with the process of selection, the previous thematic layer (Fig. 4a) will be taken as a starting point and out a new filter will be carried out that removes those alternatives with values in some of their criteria in category 2. By so doing, the 8,961 will be reduced to 3,496 alternatives (Fig. 4b), all in categories 3 and 4.

Once this second filtering has been done, we will proceed analogously performing a third filter in order to obtain the best alternatives; that is those with all their criteria situated in the best category (Category 4), reapplying the gvSIG filter command to the 3,496 alternative obtained in the second filtering it is reduced to only seven. The location and identification of these alternatives are shown in Fig. 5.

Figure 5 shows that there is no optimal alternative located in the municipalities of Moratalla, Cehegín and Bullas. Most of the optimal alternatives are located in the municipality of Calasparra (specifically six of the seven best alternatives are located in it) and the remaining optimal alternative is located in the municipality of Caravaca de la Cruz.

Analyzing the criteria values for optimal alternatives it is observed that the criteria $C_4$ (Distance to main roads), $C_5$ (Distance to power lines) and $C_9$ (Average temperature) have the same values. Therefore they have no influence on the choice of the best alternative. It is also noticeable (Table 3) that certain criteria such as slope $C_1$, field orientation $C_3$ and solar irradiation $C_8$ have very similar values to

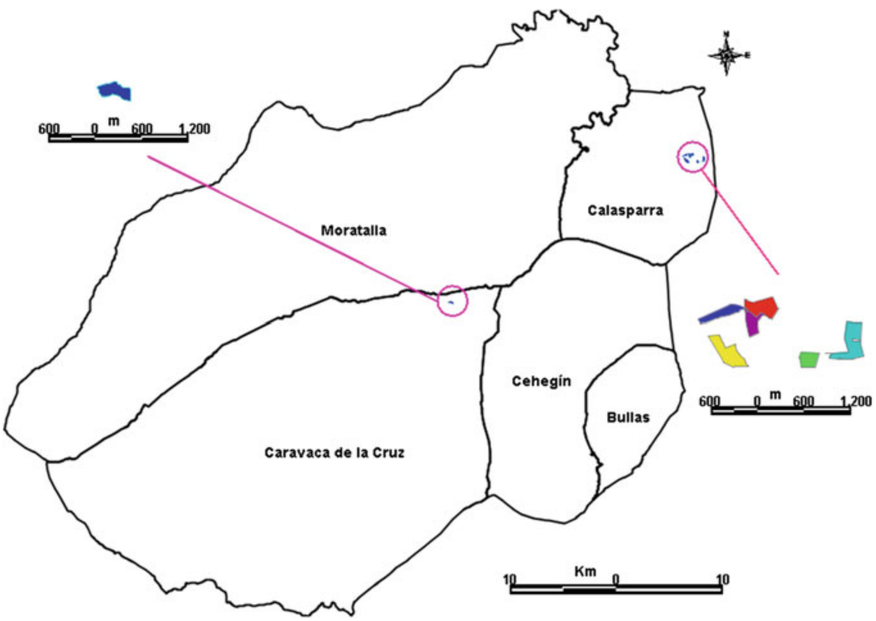


**Fig. 5** Alternatives resulting after removing those alternatives with criteria in category 3 (filtering nº3)

**Table 3** Values of criteria for optimal alternatives

| Alternatives | $C_1$ | $C_2$ | $C_3$ | $C_6$ | $C_7$ | $C_8$ |
|---|---|---|---|---|---|---|
| | Min. | Max. | Max. | Max. | Min. | Max. |
| $A_1$ | 0.26 | 89298.37 | 360.00 | 6028.68 | 5793.66 | 2086 |
| $A_2$ | 0.34 | 43903.39 | 360.00 | 6400.45 | 6192.66 | 2081 |
| $A_3$ | 0.25 | 76262.28 | 360.00 | 6376.42 | 6174.85 | 2081 |
| $A_4$ | 0.29 | 44092.23 | 360.00 | 7225.17 | 6989.63 | 2062 |
| $A_5$ | 0.48 | 106290.92 | 360.00 | 7547.42 | 7319.09 | 2070 |
| $A_6$ | 0.77 | 61831.30 | 359,57 | 1120.08 | 2002.35 | 2031 |
| $A_7$ | 0.30 | 54748.54 | 360.00 | 5847.85 | 5624.50 | 2084 |

each other which means that these values are not very influential in the decision. Only criteria such as the area of the plot $C_2$, Distance to town or villages $C_6$ and distance to electricity transformer substations $C_7$ have variable values, therefore choosing the best location is determined by the weight or importance coefficient of these last criteria.

## 3 Conclusions

With this study it was found that the GIS software are not only excellent tools able to solve and visualize complex location problems, but also that they can generate important databases which provide an ideal starting point to address any problems of territorial nature.

In the proposed particular case different conclusions have been reached: In relation to obtaining suitable surfaces for locating photovoltaic solar farms (Fig. 3), it is concluded that the Northwest Region of Murcia is an optimal place to implement such facilities because, once all the restrictions have been considered, we have obtained a high percentage of suitable area available (43.54 %).

With the tools of GIS software and using the information provided by experts, it has been possible to perform a search and selection of the best places to locate such facilities, successfully reducing the initial alternatives to only a very small and manageable number of alternatives (Fig. 5).

Among the limitations of this study which could be included in possible future work one might mention extending the case study to the whole national territory or other areas where there is a desire to implement solar farms, as well as to increase the number of renewable technologies to be implemented (wind, solar thermal, biomass, biogas, etc.). It would also be interesting to combine GIS with other decision support tools such as multicriteria decision methods with the aim of establishing a comparison of methodologies for evaluating the different locations available.

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