

# Chapter 15

## GIS, Territory, and Landscape in Renewable Energy Management in Spain

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**Abstract** Geographical information systems (GIS) must play an important role in the development of a new model for the rational and integrated planning of renewable energies. They can also facilitate the decision-making process from a territorial and landscape perspective. The importance of GIS has increased in recent years with the development and implementation of the INSPIRE Directive in Europe, which has led to substantial improvements regarding access to and dissemination of geographical information, and has permitted the creation of new indicators and methodologies for the management of this type of energy. Despite GIS being one of the most powerful tools in any planning process, its successful use requires the prior definition of a referential conceptual framework for each territory and of the scale at which the analysis will be performed. The purpose of this work is to perform a comparative analysis of various different experiences of wind power planning at different scales using GIS in Spain, a country in which this type of energy has been widely deployed, focusing particularly on the methodologies applied and on the main problems preventing effective use of this tool. We also describe two experiences of planning using GIS in Andalusia (Southern Spain), in which access to and dissemination of geographical information was improved, enhancing public participation in the planning process and optimizing its management.

**Keywords** Geographical information systems • Wind power • Planning • Landscape • Spain

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## 15.1 Introduction

Renewable energies are in most cases positively regarded by politicians, trade unions and society at large, because, amongst other reasons, they offer real opportunities to promote better balanced, endogenous territorial development (Díaz et al. 2010; Espejo and García 2012). However, the speed of their deployment, their excessive concentration and their competition with other land uses have given rise to numerous conflicts in relation to plant location, sometimes resulting in strong criticism of particular installations (Frolova and Pérez Pérez 2008; Prados 2010; Prados et al. 2012).

The implications of renewable energies on landscape were explored in a report entitled 'Landscape and Wind Turbines' presented to the 6th Council of Europe Conference on the European Landscape Convention (Council of Europe 2011). The objective of this report was to produce general guidelines for the member states to help bring about the integration of wind power into the landscape. The report avoided setting out any one specific methodology, so that its recommendations could be applied in all member states. According to this report, effective wind power planning must identify exclusion areas according to technical (network connection, wind energy potential, noise, etc.) and biological criteria (protection of bird and bat species) and then select suitable areas in terms of wind, infrastructure and landscape conditions.

Thus, the correct planning of renewable energies requires an analysis that approaches the issue from various different perspectives: social, environmental, economic, spatial planning, etc. This integrated analysis can be conducted using GIS, a powerful geographical analysis tool which is capable of processing and generating information that provides extensive knowledge of the territory, thanks to built-in features for the capture, search, management, analysis and output of geographical data.

Given these characteristics and the possibility of combining them with other techniques, it is hardly surprising that GIS are now frequently used in planning and decision-making. They have also been applied in the field of energy and, particularly, renewable energies, where they have proved useful in both the deployment of the energy system, from initial planning to site selection (Domínguez et al. 2010).

Over the last 20 years, a wide range of approaches have been applied in the assessment of suitable locations for the installation of renewable energies. Various researchers and institutions have used GIS in conjunction with multi-criteria assessment techniques (MCA) in order to identify the best locations for the deployment of these types of energy at different scales and in different territories (Voivontas et al. 1998; Baban and Parry 2001; Rodman and Meentemeyer 2006; Lejeune and Feltz 2008; Simao et al. 2009; Janke 2010; Cowell 2010).

Although a GIS is clearly a powerful tool, objections have at times been raised linking their use to a negative approach to land use planning dubbed 'negative planning' (identifying areas in which renewable energy plants would not negatively affect any previously defined interests) or to analyses limited by existing administrative boundaries (Shang and Bishop 2000; van der Horst and Lozada-Ellison 2010; Pérez 2010).

Their use in terms of landscape and renewable energy interaction has traditionally involved viewshed, proximity and density analyses of potential sites for wind turbines (Möller 2010), as well as the prohibition of these infrastructures in places of great scenic value or high landscape quality, criteria which can be perfectly addressed through GIS but which must be revised for two main reasons: firstly, because one of the most remarkable advances set out in the European Landscape Convention (Council of Europe 2000) is that all territory should be considered as landscape, no matter how commonly occurring it is, and as such it must be protected, thus going beyond the previously held notion that only exceptional landscapes should be protected, and secondly, because even if visual impact is one of the most important factors giving rise to negative perceptions of wind power (Wolsink 2007), the most commonly used GIS methods (known as ‘viewshed analysis’) offer only a limited representation of the true individual human experience (van der Horst and Lozada-Ellison 2010).

The objective of this research is to analyse the use of GIS in the planning and management of wind farms in Spain, setting out the advantages and disadvantages of using these tools to facilitate the territorial and landscape integration of wind power infrastructures.

For this purpose we conducted a comparative analysis of different experiences of wind farm planning in Spain conducted using GIS at different scales, concentrating above all on the methodologies that were applied. We then focused on two case studies using GIS and renewable energies in Spain, in which cooperative decision-making and public participation in the wind farm installation process was promoted, both necessary elements for improving the integration of these infrastructures into the landscape (Frolova 2010). These experiences can now be built on and developed, thanks to improvements in the dissemination of and access to geographical information.

## **15.2 Using GIS in the Identification of Suitable Sites: The Case of Wind Power in Spain**

In the case of Spain, location assessments aimed at identifying the optimum sites for wind power installation have been conducted at national, regional and subregional levels, although planning has only taken place mainly at regional level. This is due above all to the fact that the deployment of wind energy in Spain is subject to national government policy, although decisions regarding changes in zoning schemes are taken at regional level (Frolova 2010). This can lead to planning problems in that in order for landscape to be properly assessed in wind energy planning, studies must be conducted at all spatial levels. We will now go on to tackle these issues by analysing some of the experiences in Spain at each different scale, paying particular attention to the methodology they applied, their use of geographical information systems and the consideration of territory and landscape in their analysis.

### 15.2.1 *Experiences at a National Level*

At a national level, there is only one official planning document in which GIS and MCA techniques were used to identify both exclusion zones and suitable areas for the installation of wind farms in Spain: *Strategic Environmental Study of the Spanish Coastline for the Installation of Marine Wind Parks (Estudio Estratégico Ambiental del Litoral Español para la instalación de parques eólicos marinos)*, which was approved in April 2009 (Ministerio de Industria, Energía y Turismo y Ministerio de Medio Ambiente, Medio Rural y Marino, 2009).

The objective of the *strategic study*, carried out by the Spanish Ministry of Industry, Tourism and Commerce, was to determine those areas within the public maritime and terrestrial domains which, environmentally speaking, offered favourable conditions for the installation of offshore wind farms.

This official study identified two kinds of impact: environmental impact and impact on strategic territorial elements, all of which were treated using GIS. Seventy-two marine wind areas were identified and divided into three categories: 'exclusion areas', 'suitable areas with environmental constraints' and 'suitable areas'.

Exclusion areas were defined according to the following criteria:

- Areas located between the coast and an imaginary line marking a bathymetric level of 10 m, in order to reduce the effects on coastal dynamics
- Protected natural spaces and sensitive areas (areas with endangered species, fields of Mediterranean tapeweed or other spermatophytes) and a 1-mile peripheral protection area around them
- Coastal wetlands and a 6-mile protection and buffer zone from the coastline around them, in order to guarantee conservation of the main bird migration routes along the coast
- Heritage areas or underwater archaeological sites that have been declared *Sites of Cultural Interest*
- Approach and take-off areas for air traffic and main shipping routes
- Fishing grounds
- Oil drilling and aggregate extraction areas
- Scientific research areas
- Subterranean petrol and gas pipelines and submarine cables and the space required for their maintenance

Once these areas were excluded, the *strategic study* established the areas considered as 'suitable albeit with constraints' as those in which further examination of the environmental impact assessment of wind projects was required.

The remaining areas were classified in the document as suitable for the installation of wind energy projects, although the final decision would be taken in the local environmental impact assessment for each project, in accordance with *Royal Legislative Decree 1/2008*, through which the amended text of the Law for the Assessment of the Environmental Impact of projects was approved.

Although this document offered an initial estimate of Spain's nationwide potential for the deployment of offshore wind power, it aroused some criticism in that it implemented a zoning system based on geographical grids which did not match the specific territorial reality of the population living adjacent to the coast (Pérez 2010). Another drawback was that it was conducted at a level at which it was impossible to address more local criteria, such as landscape and social perception, two major reasons for the rejection of wind power by both the general public and conservationist organizations.

An analysis of similar documents issued at a regional level reveals that in general they do not take landscape criteria into consideration when assessing suitable sites for wind power, apart from prohibiting the installation of turbines in places of outstanding scenic or natural beauty. They also reveal the need to establish local scale tools that take into account criteria that cannot be considered at regional or national level.

### ***15.2.2 Experiences at a Regional Level***

At a regional scale, several Spanish autonomous communities have already devised wind energy plans using GIS and MCA techniques. A list of these plans can be seen in Table 15.1, which also includes the current spatial planning documents for each autonomous community.

In some regions (Valencia, Cantabria and Galicia), specific guidelines and plans for wind power deployment were devised before it was considered in regional spatial planning. As a result, sustainable, coherent, spatial planning has not been achieved, because wind power planning was carried out from a limited sectorial standpoint on the basis of strategic plans with no real territorial dimension or by executing a series of emblematic projects (Hildebrand 2006).

In general terms, the combined use of GIS and MCA techniques has proved a very useful tool in drawing up these plans, despite a lack of coordination in both the methodology and the regional guidelines and planning of all issues related with and influencing wind energy production (Spatial Planning, Industry, Environment, etc.).

All the plans establish exclusion areas in which wind farms may not be installed. These are identified mainly through a series of criteria, which for the most part are common to all the different regions, such as the existence of protected natural spaces, increased biodiversity, cultural interest, woodlands, distance to population centres and minimum wind levels, although the degree of restriction applied varies from one plan to the next. In Catalonia, for example, wind energy development is not permitted in any protected natural areas, irrespective of the category to which they belong, whereas in the Basque Country and Galicia, a protected area categorized as a Place of Importance for the Community (LICS) or a Special Protection for Birds Areas (ZEPAS) would only be excluded after a specific study of the area had been conducted.

In the case of Galicia, Cantabria, the Basque Country, Castile Leon and Valencia, wind zoning plans were based on a previous study of winds in the region, so that later they would only have to study the suitability of territories with a high wind

**Table 15.1** Wind energy plans and spatial planning in autonomous communities of Spain

Autonomous communities of Spain	Wind energy plan		Spatial planning
Galicia	Galicia Wind Power Sector Plan – Plan Sectorial Eólico de Galicia (1997)		Territorial Planning Guidelines – Directrices de Ordenación del Territorio (2011)
Valencia	Valencia Region Wind Power Plan – Plan Eólico de la Comunidad Valenciana (2001)		Valencia Region Territorial Strategy – Estrategia Territorial de la Comunidad Valenciana (2011)
Basque Country	Basque Region Wind Energy Sector Territorial Plan – Plan Territorial Sectorial de la Energía Eólica de la CAPV (2002)		Basque Country Territorial Planning Guidelines – Directrices de Ordenación territorial de la Comunidad Autónoma del País Vasco (1997)
Catalonia	Sector-based Territorial Plan for the Deployment of Wind Energy in Catalonia – Plan Territorial Sectorial de la Implantación de la Energía Eólica de Cataluña (2002)		Catalonia General Territorial Plan – Plan Territorial General de Cataluña (1995)
Asturias	Plan for the identification of priority development areas for the installation of wind farms in Catalonia – Plan de determinación de zonas de desarrollo prioritario para la implantación de parques eólicos en Cataluña (2012)		
Cantabria	Sector-based Guidelines for Territorial Planning for the Exploitation of Wind Energy – Directrices Sectoriales de Ordenación del Territorio para el aprovechamiento de la Energía Eólica (2008)		Regional Territorial Planning Guidelines – Directrices Regionales de Ordenación del territorio (1991)
Castile-La Mancha	Environmental strategy for the exploitation of Wind Energy in Cantabria within the framework of the Cantabria Energy – Plan Estrategia ambiental para el aprovechamiento de la energía eólica en Cantabria en el marco del Plan Energético de Cantabria (2008)		Regional Territorial Plan (currently being drawn up) – Plan Regional de Ordenación Territorial (in press)
Castile-La Mancha	Castile-La Mancha Wind Energy Plan – Plan eólico de Castilla La Mancha (2011)		Strategic Territorial Plan ‘Territorial Strategy for Castilla La Mancha’ (currently being drawn up) – Plan Ordenación del Territorio ‘Estrategia Territorial de Castilla La Mancha’ (in press)
Castile Leon	Castile-La Mancha Wind Energy Plan. Documents for the 9 provinces – Plan eólico de Castilla-La Mancha. 9 Documentos provinciales (1999–2000)		Castilla-León Essential Territorial Planning Guidelines – Directrices Esenciales de Ordenación del Territorio de Castilla y León (2008)

potential. Even though this approach allows for a more detailed analysis of high-potential areas, the main drawback is that advances in wind power technologies and systems may mean that some areas with apparently little potential become viable in the future, and there would be no data for assessing the environmental impact of projects in these areas.

Other regional plans have selected specific locations for the installation of wind energy plants. This is counterproductive in large autonomous communities, such as Valencia and Castile Leon, where no proper landscape studies have been carried out to establish specific areas for wind power implementation. At such a large scale, it is virtually impossible to perform a detailed analysis of the different landscape criteria or indeed of any other type of criteria at each individual site. As a result almost all of these plans have attracted negative criticism from conservationist and citizens groups worried about their impact on landscape and heritage and other environment-related aspects.

### ***15.2.3 Experiences at a Subregional Level***

There are relatively few cases in which locations for wind power deployment have been planned and assessed at a subregional or local level in Spain. Two examples which stand out due to their special methodology are the Special Supramunicipal Plan for the Organization of Wind Energy Infrastructures in La Janda Area (*Plan Especial Supramunicipal de Ordenación de Infraestructuras de los recursos eólicos en la Comarca de la Janda*) (ARE 2004a) and the Special Plan for the Organization of Wind Energy Resources in Jerez de la Frontera (*Plan Especial de Ordenación de los recursos eólicos de Jerez de la Frontera*) (ARE 2004b). Furthermore, these were the first plans in Spain to assess the impact of these infrastructures on the landscape and the environment (Frolova and Pérez Pérez 2011).

As in the other cases described above, the combined use of GIS and MCA techniques proved an essential tool for assessing the potential for wind farm deployment. It is worth mentioning that identical methodologies were used for the wind farm plans in La Janda and Jerez de la Frontera, both based on the analysis of the main variables that must be considered for the regulation of wind power deployment (wind farm potential for the region, decisive technical factors, studies of physical space, landscape assessment, ornithological studies, etc.). Their objective was to regulate the installation of the necessary transport and transformation infrastructures required to feed the energy produced by new wind plants into the grid (not included in any of the previous plans).

They therefore began by conducting a wind study to estimate the gross wind power potential and then analysed the limitations imposed by vegetation, fauna, population, economic activities, lithology, physical factors, urban planning, natural spaces and landscape.

The plan established three types of area, namely, exclusion areas, areas considered compatible subject to certain conditions and areas not subject to specific deter-

mining factors, generally considered suitable for wind power deployment. They classified as exclusion areas those considered to be of high environmental quality or fragility or in which wind power development could compete with or harm other socioeconomic activities or negatively affect their environmental, urban and landscape characteristics. Other areas were classified as suitable subject to certain conditions, in which it was necessary to demonstrate the compatibility of wind power projects with the surrounding environment, while in the remaining areas, energy companies would be free to install plants and would only be subject to the general procedures established in local environmental impact guidelines and other applicable municipal legislations.

These plans also forced developers of wind farm projects to present joint planning and integration proposals for the area and to share power transmission infrastructures in order to keep their environmental and landscape impact to a minimum.

Landscape resources were studied in both plans by creating an inventory which identified the particularities of the landscape and other important features. Viewsheds and made 3D visual simulations were also analysed, as was the way landscape is perceived from population centres, commonly frequented itineraries (roads etc.) and scenic points.

These analyses showed just how important GIS are for location assessment. Having said this, it is important to make clear that before using them for wind power planning, it is necessary to develop a referential conceptual framework for the use of this energy, since otherwise GIS would not fulfil their role in the development of a rational, integrated planning model for renewable energies.

#### ***15.2.4 Proposal of a Referential Conceptual Framework for Wind Farm Planning***

Our analysis of different experiences of wind energy planning using GIS has shown the need to establish a reference framework prior to using the tool. For effective wind farm zoning, various territorial and landscape factors must be considered in the installation of each project, including the particularities of each territory in terms of useful resources for wind energy and the character of each landscape (those elements or attributes that make it unique) (Díaz et al. 2010). In addition, general criteria for the selection of locations can and must be established, since the size of the investment and the environmental/territorial effect of each intervention require the development of a highly detailed project that foresees and analyses all its repercussions, including a complete and accurate territorial contextualization. This will require analysis at different spatial scales for a number of reasons.

This is firstly because the use of different scales is sometimes of key importance for understanding a particular situation in all its complexity, above all in the context of an increasingly interdependent world. As an example, the installation of a particular infrastructure may have a balancing or unbalancing effect depending on the



scale at which it is studied (Gutiérrez 2001). These seemingly contradictory views are in fact complementary and can give us a clearer understanding of the situation.

In the case of wind power, at regional level, it would be more efficient in technical and economic terms to concentrate wind farms in a given area, and this would minimize their impact at a regional level by sharing common infrastructures. However, it would also concentrate the impact at a local level, resulting in highly imbalanced deployment compared to other towns and villages that do not have such installations.

Secondly, because even though problems at a local scale can be addressed more effectively through local action, it is essential to look beyond the strict immediate scope of the study, so avoiding the risk of viewing the territory in question in isolation, which would be a serious mistake (Zoido 1998).

Thirdly, because shifts in scale uncover certain differences and aspects which are hidden from view in the preceding scale, and which can be enormously enriching, while in the opposite case, according to Harvey (2003), if we analyse all aspects of a problem at a single scale, the results will be unreliable, if not misleading.

For these reasons, it is clear that wind farm site selection requires a detailed assessment of the territory, which can be carried out almost entirely using GIS applied at different territorial scales.

The effective use of GIS for establishing coherent wind farm zoning also requires previous identification of the elements, criteria, contents and methods that must be focused on at each scale. All of these must be linked, on the one hand, to component aspects and operational factors in each spatial dimension and, on the other, to political competencies, administrative organization and planning at each territorial level (Zoido 2001).

Thus, at a regional scale, the generation of location models for wind farm zoning using GIS must seek to establish a referential territorial framework, which identifies the territories with environmental, physical, efficiency and public health-related limitations for the deployment of wind power. In no case must these result in the selection of specific areas for installing wind farms, since this would entail taking decisions about non-defined realities, given that we cannot know where the final projects will be installed and what they will be like (Pérez et al. 2007) and because some of the criteria that must be considered (wind resources, impact on bird species or landscape, etc.) cannot, due to their nature, be properly and fully addressed at a regional scale, particularly in large territories.

Work at a regional scale must also identify those areas that must be studied in more detail at a subregional level. Subregional studies should include the analysis of criteria not addressed in the regional model, such as landscape criteria and public perception, as well as a more detailed analysis of other criteria already considered at the higher scale.

GIS models built at a local or project scale must seek to identify the most suitable locations for wind farms. This must be done coherently with regional and subregional models, and establishing the optimum distribution of the different elements in the wind farm must be tried in order to bring about or at least improve its integration into the landscape, at times even pinpointing the exact location of the installation and the wind turbines.

### **15.3 GIS for Territorial and Landscape Analysis: Viewers Generation- Geodatabase of renewable Energy in Andalusia. Identification of wind power landscapes in Andalusia**

The great analytical capability of GIS is well known, and the improvements in recent years in the access to and dissemination of spatial data, the implementation of geographical databases and spatial modelling and the rapid development of GIS applications have further increased their analytical possibilities. We now present some examples of how improvements in these systems are providing an even more exhaustive knowledge of territories and landscapes.

#### ***15.3.1 An Improvement in the Access to and Dissemination of Geographical Data: Viewers Generation***

In essence, an information system is data structured and stored in such a way that, via various consultation methods, users can obtain a response to a request for information. However, user access has become an important bottleneck preventing these systems from providing this service to the largest possible number of users (Ojeda and Cabrera 2006).

In the last few years, great advances have been achieved at a European level in the access and dissemination of geographical information. The transposition of the INSPIRE (2007/2/CE) Directive in Spain and the passing of Royal Decree 1545/2007 regarding the National Cartographic System have enabled the development of the Spanish Infrastructure of Spatial Data (<http://www.idee.es/>), which allows access to and management of groups of data and geographical services through the Internet (described through their metadata). This system complies with a series of norms, standards and specifications which regulate and guarantee the interoperability of geographical information, thereby promoting its use by the general public and providing easy access to the data it contains.

Despite the advances in access to information, thanks to the transposition of the INSPIRE Directive, in most cases, users must have a 'minimum' technical qualification to access this data. This is why a large part of GIS research in recent years (Serra 2002; Metternicht 2006) has been focused on methods and tools to improve data access and dissemination.

With this in mind, the Coastline Planning and Territorial Information Technology research group from the University of Seville has been working on a project to develop geographical viewers for coastal areas. The objective was to make a viewer that was easily consulted (interactive tactile viewer) and accessed (through web browsers) by the general public, whether they be general or technical users.



**Fig. 15.1** 3D view of the Buena Vista wind farm (Barbate, Cádiz) in the viewer designed by the research group from the University of Seville

These tools have enabled the design of a variety of useful applications for the planning and management of renewable energies, including the simulation of their impact on the landscape, using 2D, 2.5D and 3D (Fig. 15.1) viewing tools, as well as other features such as visibility analysis, interactive flights, etc.

These functionalities are highly valued both by specialists and by the general public, as they allow non-expert potential users to view elements of the terrain from a more familiar perspective, thus enabling the participation of local stakeholders, which will ultimately lead to an improvement in the governance of these spaces.

### ***15.3.2 Generation of a Renewable Energy Geodatabase in Andalusia: Wind Farm Landscapes in Andalusia***

The development of the National Aerial Orthophotography Plan (PNOA), a project coordinated by the National Geographic Institute (IGN) and the National Geographical Information Centre (CNIG), provided digital orthophotographs of the whole country. These included data obtained from photogrammetric flights, field support, aerial triangulation and digital elevation models. The project is in constant evolution and is updated every 2 years in line with user needs and technological developments.

In the case of Andalusia, these orthophotographs are available as Web Map Services at the spatial data infrastructure (SDI) node for Andalusia (<http://www.ideandalucia.es>) and are easily viewed through any GIS software or viewer. This

advance in the access to spatial information can also be applied to the case in hand – GIS and renewable energies – in that we can now access spatial information about renewable energy power plants installed in the autonomous community of Andalusia via the photointerpretation and digitalization of a series of aerial photographs from 1998, 2002, 2004, 2006 and 2009.

In this way, all the wind turbines and the areas covered by solar plants in Andalusia have been digitalized. Spatial information about biomass and mini-hydraulic power plants has also been compiled. All this spatial data has been gathered from information provided by a variety of energy-sector sources – the Wind Energy Producers Association and the Photovoltaic Industry Association and the Andalusian Energy Agency, amongst others – and has allowed us to characterize each plant according to data about the installed power, the name and height of the wind turbines, etc. All this data about renewable energy power plants has been entered into a geographical database together with the spatial information showing municipal and regional boundaries, landscape types and other details. The database can be easily consulted through simple SQL (structured query language) queries, permitting the dynamic generation of a large number of indicators for renewable energies.

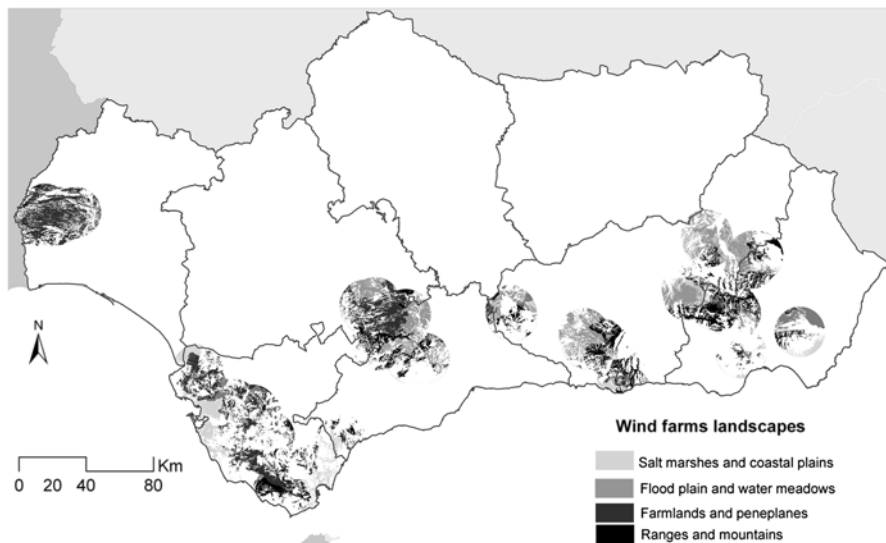
The result of this work is a powerful geographical database on renewable energy in Andalusia, which will be of great interest for the analysis and management of these installations. The use of the geographical database will not only mean an improvement in the results of previously performed analyses but will also enable the generation of new indicators of great landscape and territorial importance, such as the density of wind turbines by municipality or landscape unit. In Andalusia the town with the highest density of wind turbines is Tarifa (Cádiz), with 1.51 wind turbines/km<sup>2</sup>. Other indices we calculated include the location of solar plants and the area they occupy (275 plants, covering a total area of 2.309,7) and the number of wind turbines located inside protected natural spaces (360).

Another example of a key indicator obtained using the spatial database described above was the calculation and identification of the area of Andalusian land that has undergone landscape changes as a consequence of the installation of wind farms, on the basis of the criteria established by De Andrés and Iranzo (2012), who identified what are known as wind power landscapes.

Our aim was to perfect this analysis and apply it in Andalusia, since information as to the exact location of each wind turbine and its altitude was already available in the turbine specifications. In our analysis we also took the influence of topography into account, by applying the 1:10,000 Digital Elevation Model, the DEM with the highest resolution and hypsometric accuracy in the region, which is composed of a 10×10 dot regular mesh of planimetric resolution.

In this way, we were able to identify the areas visible from each wind turbine. To achieve this, we performed a series of visibility analyses from wind turbines using GIS, in this case the ESRI Arc-GIS viewshed module together with the model builder tool. This is also part of ESRI software applications, through which a large number of spatial analysis operations can be carried out easily and efficiently.

After operating the GIS and processing the information on areas of influence (those visible up to a distance of 15 km) around the wind turbines installed in



**Fig. 15.2** Wind farm landscapes in Andalusia, 2009

Andalusia, we then cross-referenced this information with the Atlas of Spanish Landscapes (Mata and Sanz 2004), which identifies and characterizes landscapes in the Iberian Peninsula and the Spanish islands. The results can be seen in Fig. 15.2.

This shows that the location of wind farms in one province can have landscape repercussions on adjacent land in neighbouring provinces. This also happened in cross-border areas between Spain and Portugal, where the wind farms located in the Andévalo region of the province of Huelva affected certain adjacent Portuguese landscapes.

Wind power plants were also shown to have landscape implications for some of the region's protected natural spaces, in which although spatial planning prohibited the installation of wind farms, their deployment in the immediate vicinity would have evident impacts on the landscape.

Finally, with regard to the affected area, and ignoring any obstacles arising from the presence of buildings or other elements that might hide or reduce visibility of some of the wind turbines, the installation of wind farms has brought about important landscape changes affecting a total of 6,528 km<sup>2</sup>, about 7.4 % of the surface area of Andalusia.

## 15.4 Conclusion

When used in conjunction with multi-criteria evaluation techniques, GIS are excellent tools for the identification of suitable areas for the installation of renewable energy plants. Research on this question in Spain has shown the great potential of

this tool. Nevertheless, in order to take full advantage of its functionalities, it is necessary to establish a referential conceptual framework for each of the renewable energies before GIS can be used at each scale and for each territory. This conceptual framework should establish the contents and criteria that must be taken into account in each location model built using GIS. These criteria must be defined by the authorities responsible for territorial and landscape quality, who must take the opinion of local stakeholders into account. In the case of landscapes, these criteria must not be limited to mere visibility analysis or the prohibition of renewable energy plants in scenic landscapes and must include public perception and participation, given that landscapes are dynamic and changing both in their configuration and their social requirements.

To this end, the recent technological developments and advances in production and access to spatial information have permitted the gathering of information of great interest for the assessment of the implications of these energies on different areas and landscapes. From this perspective, digital technology and 3D geovisualization can be used to create a virtual visual environment which accurately reproduces the real situation and is especially useful in applications relating to territorial and environmental management or in constructing tools that enhance public participation. There are also increasing demands from the Internet environment and from general users for the development of visualization tools that are easy to use (viewers).

In this sense, Spain continues making major efforts to implement a spatial data infrastructure and to produce standardized, interoperable services and data which have a positive impact on the availability of geographical information and, therefore, on the creation of new indicators that can help improve spatial and landscape planning of renewable energy.

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