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Renewable energy transition and its impacts in Andalusian landscapes (Southern Spain)

Key words: renewable energy landscapes, energy transition, landscape impacts, Andalusia, Spain

Due to its ambitious policies Spain has achieved a very successful implementation of renewable energy (RE) projects, which peaked in 2000-2010. Over the first decade of the 21st century decentralized energy infrastructures have spread quickly through rural areas in Spain. In some cases, they have transformed their physical landscape. This has raised issues regarding landscape practices and values. These infrastructures have often been a source of tension, triggering the emergence of new attitudes towards landscape. The aim of this paper is to analyse the impact of energy transition in Andalusian landscapes in order to identify success factors and social barriers affecting the rate of RE implementation and the role of this new landscape in the energy transition in Andalusia.

1. INTRODUCTION.– In response to climate change, limited fossil fuels and rising global energy demand the EU climate and energy policy has triggered a spectacular growth in renewable energy development. Its rapid expansion in European countries is largely due to favourable national policies, based on quantitative targets and economic incentives as well as more or less favourable social, institutional and political conditions.

Due to its ambitious policies Spain has achieved a very successful implementation of renewable energy (RE) projects, which peaked in 2000-2010. In 2019 the Spanish RE installed capacity was 55,322 MW (AAE, 2019). Among the main factors of rapid expansion of renewable energy (RE) infrastructure in Spain are: absence of conventional energy sources (1); energy dependence on exterior (2); strong economic incentives (feed-in tariff system) and stable regulatory framework during the first decade of the XXI century (3); availability of varied RE resources (4); planning system which has been maintaining local population at the distance in decision-making

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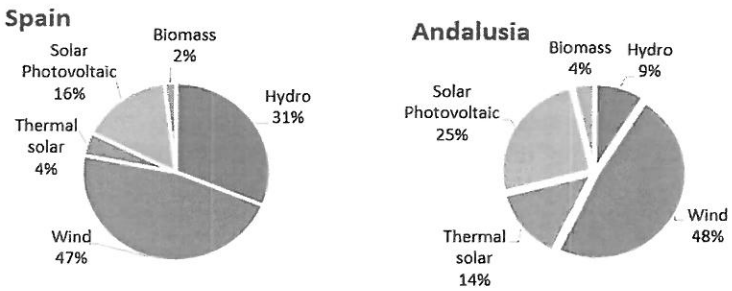
process (5). This energy transition is coupled with an important landscape transition. Spread of decentralized energy infrastructures through rural areas of Spain have transformed its landscapes, landscape practices and values.

Andalusia became a leader in the development of RE in Spain. The installed capacity of Andalusian REs in 2019 was 7,215 MW, which is 13% of Spain's RE installed capacity (AAE, 2019). There is almost no difference between the share of the dominant RE source -wind energy (WE)-between Spain and Andalusia (Fig. 1). By contrast, there is a significant difference between the share of the installed capacity of hydroelectric energy (HE) in this Spanish region (9%) and the total capacity in Spain (31%), due to the geographical situation of Andalusia in the very south of Spain. Due to this geographical situation and great availability of solar energy (SE) in this region, the share of the installed capacity of solar PV and concentrated solar thermoelectric (CST) energy in Andalusia (25 and 14 % respectively) is significantly bigger that the average of Spain (16 and 4 % respectively). The share of biomass installed capacity is also slightly bigger in Andalusia.

Fig. 1 - Share of sources in renewable capacity installed (2019)



Authors' elaboration, Source of data: AAE (2019).

2. OBJECTIVE, METHODOLOGY AND THEORETICAL BACKGROUND. – The aim of this paper is to analyse the impacts of energy transition in Andalusian landscapes. Our research consisted of three parts. Firstly, we have reviewed existing literature, policy documents and industry reports. Secondly, the map was prepared with the location of the plants of the major RE sources in Andalusia (wind, solar PV, concentrated solar thermoelectric, hydroelectric and biomass) in the main landscape categories, according to the Landscape Strategy of Andalusia, based on superposing of geomorphology, land uses and vegetation cover layers. Through the literature analysis, an additional comparison was made of landscape impacts of different RE technologies. Finally, the main challenges for mitigation of the effects of wind, solar

and biomass energy facilities on land use and landscape can be reduced were explored.

We consider energy landscape as a landscape defined as a multi-layer landscape characterized by one or more elements of the energy chain comprising combinations of technical and natural sources of energy within a landscape (Kruse and Marot, 2018). Our paper takes into consideration substantive and spatial characteristics of energy landscapes. The substantive characteristic is based, fundamentally, on the type of energy resource. In this paper, we study landscapes related with hydro, wind, solar and biomass energy. The spatial qualifications are based on the amount of space required for energy development (energy density) (Pasqualetti and Stremke, 2018).

According to Frolova *et al.* (2019), we consider landscape impact as the effect of RE systems on the physical landscape, which may give rise to changes in its character, its biophysical characteristics and how these are experienced by people. We focus on visual/aesthetic landscape impacts of RE facilities. However, we take into consideration that changes resulting from impacts on rocks and soils, water bodies, biodiversity, and natural habitats may also affect the perceived character of the landscapes concerned to various extents. Finally, there are various disturbing effects that may potentially influence human perception (e.g. smell and noise).

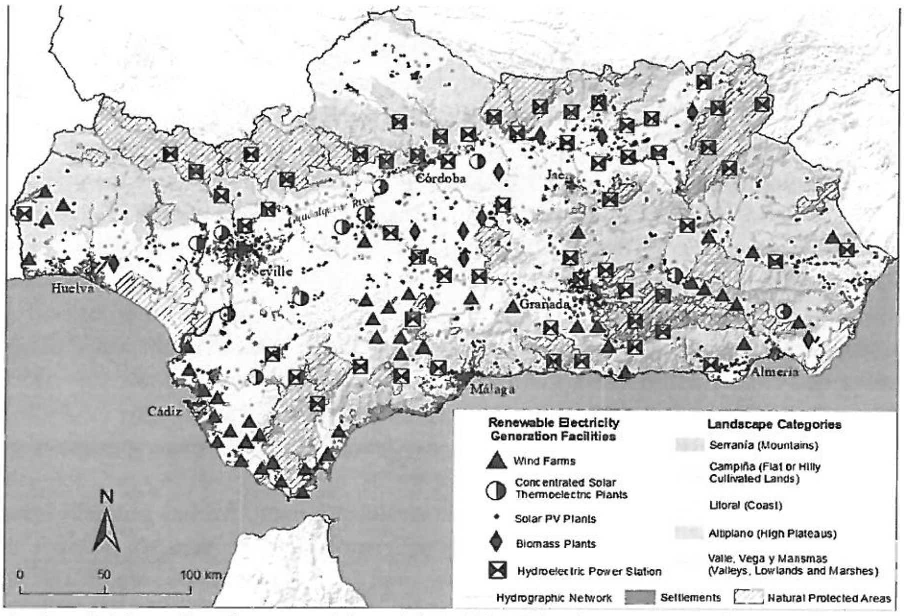
Each type of RE system transforms the landscape in its own specific ways. Landscape impacts of all the RE developments depend on their type, size, the landscape in which they are placed and scale of development. RE has generally lower energy densities than other sources, requiring more surface area to produce an equivalent amount of power as non-RE systems (Van Zalk and Behren, 2018) and their relative visual impact is often higher. Direct land occupation of RE facilities raises the issue of the spatial extent of renewable technologies with a large land use footprint, which is linked to low power density of most of these developments.

On the other hand, due to unique visual properties of the most part of RE facilities combined with large size, ordered angular geometry, and highly reflective surfaces of wind and solar power plants, they add strongly contrasting artificial elements in the rural landscape. In addition, because of the motion of wind turbine blades, glare from solar facilities, and the changes in visibility of RE installations, the visual experience of RE landscapes is dynamic in nature (Apostol *et al.*, 2017). These facilities do not merely represent new elements in the landscape, but often change the patterns of the landscapes concerned (Frolova *et al.*, 2019). However, perception of visual impacts of RE systems may depend on the original state of the landscape and its cultural value.

3. STUDY CASE: ANDALUSIA AUTONOMOUS REGION. – Andalusia is the southern region of the Iberian Peninsula. Its extension is 87,269 km2, covering 17.2% of the territory of Spain. The population of Andalusia is 8,406,738 inhabitants in 2019, representing 17.89% of the state total. The population density of 96.38 inhab / Km^2 is less than the average population density of the European Union (105.35 inhab /

Km²). According to the Landscape Strategy of Andalusia (EPA, 2012), there are five landscape categories: Mountains; Flat or Hilly Cultivated Lands (Campiña); Valleys, Lowlands and Marshes; Coasts and High Plateaus (Fig. 2).

Fig. 2 - Renewable Electricity Generation Facilities in Andalusia.



Authors' elaboration. Sources of data: AAE, 2019; MIEA, 2018; DERA, 2020; Landscape Strategy of Andalusia.

The most developed RE sources in Andalusia are wind, solar and biomass systems (AAE, 2019) (Fig. 3). More than a half of electricity production of Andalusia corresponds to WE; this fact is consequence of its situation between the Mediterranean Sea and the Atlantic Ocean, an area with a powerful wind window. The second important RE source is SE, since this region boasts with more than 3,000 hours of sunshine per year. Biomass is also an important source of RE in Andalusia, due to abundance of agricultural and forest residues, mostly by-products of olive-oil and paper industry linked to eucalyptus plantations.

Tab. 1 - Renewable electric power in Andalusia

Type of renewables	*Electric power (MW)*	%
Biogas	33.45	0.46
Biomass	273.98	3.80
Wind	3448.34	47.79
Solar Photovoltaic (SPV)	1808.24	25.06
Hydroelectric	649.9	9.01
Concentrated Solar thermoelectric (CST)	997.4	13.82
Other	4.5	0.06
Total	7.215.81	100.00

Authors' elaboration, Source of data: Datos Energéticos de Andalucía, 2019.

4. RENEWABLE ENERGY TECHNOLOGIES AND ANDALUSIA'S LANDSCAPES.–

4.1. *Wind energy*. – WE landscapes are the most common in Andalusia since wind farms are located in all the categories of landscapes. However, "Campiña" is the most affected landscape, probably due to the fact that it is the least protected landscape category. A wind farm (WF) in Andalusia needs from 50 to 150 m^2 per installed KW, being its installed capacity from 6 to 20 MW per square Km (Díaz Cuevas *et al.*, 2016). All these farms have a large industrial scale. However, only about 5-10% of land, used for wind development, is directly impacted by WE infrastructures, and the total area required includes the land in between wind turbines (*Idem.*). Therefore, within these installations other land-uses are frequent, such as other energy production, agriculture, grazing and industry. A WF of 50 MW can occupy about 7 Km^2, 6 of which can be used for other activities, which permits to reduce its land use impact (Villarubia López, 2012). However, given the fragmenting effect of wind turbines on landscape and habitats, its impact spreads on this total area required. Considerable WFs concentrations in Andalusia are located in Tarifa and in the north of the Malaga province with 1.33 and 0.78 wind turbines per km2 respectively (Díaz Cuevas *et al.* 2016). Wind turbines are characterized by the considerable height (up to 160 m), which has an important visual landscape impact and can be visible from the distance up to 15 km in optimal atmospheric conditions (Idem.). This visual impact of wind farms can be reduced by their proper design, layout and location, avoiding their visibility from particularly sensitive viewpoints (Scottish Natural Heritage, 2014). Other negative landscape of WFs is related to the hazards that they pose to birds and bats, noise pollution, and destruction and loss or degradation of natural habitats.

Landscape is often cited as an argument in the conflicts that arise around WE projects, but its relationship with these developments is not always conflictive. From an aesthetic point of view, wind turbines can be perceived as sculptural elements in the landscape, evoke positive association by thematic relation to modern structures, and become associated with technological efficiency, progress, environmental cleanliness and utility (Frolova *et al.*, 2019). Wind turbines may not be considered as a problem for local inhabitants, but instead they could constitute a positive aspect of the construction of a local landscape and sense of place and affirmation of an identity in a given landscape (Frolova *et al.*, 2015a).

4.2. *Solar energy.* – SE infrastructures are also common in all the categories of landscapes in Andalusia, but "Campiña" and Valleys, Lowlands and Marshes are more affected by them. Their land use and landscape impacts depend significantly on the type of technology, size of the installations as well as on their concentration in a certain area. We studied two main SE systems: solar PV and concentrated solar thermoelectric power (CSP). Solar PV landscapes include subtypes based on two principal types of solar PV topologies: on-ground PV (generally large systems) and building added/integrated PV (generally small systems). On ground PV plants are wide-spread in all the categories of landscapes in Andalusia. Large PV installations are more concentrated in landscape classified as Valleys, Lowlands and Marshes and High Plateaus. In agricultural plains and mountains, these plants are smaller and more dispersed, and are related with energy needs for irrigation and olive groves.

The landscape impacts of solar power facilities depend significantly on the size of the installations as well as on their concentration in a certain area. Landscape impacts of large scale on-ground PV are numerous: land use effects; visual and aesthetic impacts, including glare; landscape and habitat fragmentation; impacts on ecosystems and soil erosion. The negative effects of a massive expansion of large-scale solar systems on landscape can cause an important change in landscape functions and structures. However, land use and visual impacts are the main concerns.

PV arrays commonly required in Andalusia from 2 Ha/MW (fixed arrays) to 6 Ha/MW (mobile arrays) (Muñoz Vélez, 2012). The average spatial extent of solar photovoltaic plant is almost 14 hectares, but this average is not very representative. 93% of the facilities correspond to the small and dispersed so-called solar orchards, with the average extension of 1-2 hectares, represent about 65% of land occupied by PV installations (Mérida-Rodríguez *et al.*, 2012). Large PV plants correspond only to 7% of these facilities, but occupy almost 35% of PV landscapes in Andalusia (Idem.). Their additional visual landscape impacts are effects from PV arrays, reflecting mirror arrays, and concentrating solar towers for large-scale facilities) (Pasqualetti and Smardon, 2017). As for building added/integrated PV topology installations, they are located in farmhouses, where they are dispersed, and in population centres, where they are more concentrated. These PV modules are added or integrated onto/into the building envelope and therefore no additional land use is required for their installation, therefore their landscape negative effect is less prominent (Frolova *et al.*, 2019). CST power plants need large extensions of flat areas, therefore they are mostly located in the landscapes of flat agricultural land or high plateaus. As larger RE systems, have significant spatial extent and visual impact. This facility structures are taller than on-ground PV, may require cooling and require tall structures for tracking the sun (power tower up to 114 m) (Pasqualetti and Smardon, 2017). As for CSP, the glare effect from the mirrors and metal structures, the visual impact of the tall vertical cooling towers and the columns of steam released into the atmosphere are the main visual landscape impacts. Effects related to water issues are also essential, since CSP installations consume large amounts of water and are normally situated in semi-arid areas of Andalusia, in which water is a scarce resource that is essential for population and activities such as agriculture and tourism. Finally, the negative impacts on biodiversity of large on-ground PV and CSP is considered an important issue.

In addition, they are normally located further away from demand and have an important transmission requirement. The land occupation of CST plants in Andalusia ranges from 60 to almost 600 ha. As in the case of wind power, the infrastructures linked to these technologies and the required safety parameters make that CST power plants occupy areas between from about 3 to 12 km^2 (Sánchez, 2018).

Due to the spatial needs of this energy, large scale on-ground SPV/CST infrastructures have a major impact on land use and landscape. While the CSP negative landscape impacts are more prominent than PV facilities CSP installations require less land and they are appropriate for energy storage) (Pasqualetti and Smardon, 2017).

4.3. *Biomass energy.* – Biomass used in Andalusia is generally associated with agricultural and forest residues that are generated when crops are harvested, trees pruned and cut down. Andalusian biomass plants are mainly linked to olive groves in the landscapes of "Campiña" and Valleys, Lowlands and Marshes. There is also a biomass plant in the Huelva industrial estate, located in an old paper complex linked to the cultivation of eucalyptus.

Although bioenergy surface area requirements are the highest among the RE technologies (Frolova *et al.*, 2019), in the Andalusian case their land use and landscape impact is not significant due to their complementary character, since they use residues of production of olive oil and are generally integrated into oil factories.

4.4. *Hydroelectric energy.* – Hydro energy landscapes are the best established among RE landscapes of Andalusia, due to the long history of development of hydro power in this region. However, due to the geographical situation of Andalusia in the very south of Spain, relatively low precipitations and summer droughts, hydroelectric resources are limited in this region. Hydroelectric infrastructures are concentrated in the landscape categories with the presence of river courses and more or less steep slopes (Fig. 2). While in the Northern part of Andalusia (Sierra Morena) conventional hydroelectric dams prevail, in the higher Southern mountains (Sierra Nevada, etc.) run-of-river plants predominate and dams are rare.

Hydropower developments' impacts depend on their type, size and the landscape in which it is placed. Due to differences in the spatial extent of different types of facilities, and the visual dominance of HE infrastructures their impact varies greatly. Negative landscape effects of large facilities could derive from construction of power stations, damming rivers, and creating artificial reservoirs. In addition, in case of large hydropower plants, dams, power stations and transmission lines are huge structures and their presence constitutes substantial change in landscape features (Hastik *et al.*, 2015). The river flow fluctuation caused by hydropower plants results in dramatic changes in downstream ecosystems and sometimes in the landscapes of entire river basins. Fish ladders help mitigate this impact on the river ecosystems. The inundation of areas traditionally used for agriculture, the displacement of people and the loss of valuable cultural landscape features are other common landscape impacts of dams (Frolova, 2010). Landscape impacts of small hydropower developments, predominant in Andalusia, are considered relatively small. They often utilize natural differences in altitude, small flows or the decline in the pipes from water infrastructure. In Andalusia run-of-the-river design is often used. It may require a small, less obtrusive dam, diverts a portion of a river's water into a canal or pipe to spin turbines, and usually does not need a large reservoir. However, penstock/pipelines used by small facilities are usually located above surface or are visible from the surface while some of the infrastructures of large facilities are generally located underground (Frolova *et al.*, 2019).

Diversion of water can lead to drying up of watercourses and the damming of rivers can lead to the erosion of the shoreline, therefore damaging soil quality and biota. Increased water discharge can cause a bigger riverbank erosion downstream of power plants (Rosenberg *et al.*, 1995). Rapid flow variations due to hydro power plants can affect water quality and water-related ecosystems (Evans, 2009).

However, hydro power systems also have positive landscape impacts. Large dams and artificial lakes can generate positive visual impact and become tourist attractions. In addition, power stations and lines as well as the accompanying infrastructure could be placed underground to reduce their visibility whenever feasible (Hastik *et al.*, 2015). Furthermore, utilizing existing old infrastructure like abandoned mills for the construction of small facilities may help to reduce their negative impact on the landscape.

5. DISCUSSION AND CONCLUSION. – WE landscape is by far the most important category of RE landscape in Andalusia, not only due to the share of WE in its total RE mix and its presence in all the categories of Andalusian landscapes, but also owing to its great landscape and land use effect. Visual/aesthetic impact and the hazards that they pose to birds and bats are the most important concern for WE.

The next in importance is the SE landscape, also due to the share of SE in its total RE mix and the presence of solar power plants of different types and sizes in all the categories of landscapes. Land use is the most important concern for on-ground solar PV and CST impacts, due to their spatial extension, in particular in case of large-scale facilities, although their visual/aesthetic impacts are also significant.

Andalusian biomass plants are mainly linked to olive groves in the landscapes of "Campiña" and Valleys, Lowlands and Marshes. Their land use and landscape impact is not significant due to their complementary character, since they use residues of production of olive oil.

In this research, the use of landscape categories for studying energy landscapes from the Landscape Strategy of Andalusia showed its limitations:

- Its landscape categories of this document are two general and a more detailed landscape characterization is needed.

- The scale used for landscape categories is too small for mapping energy landscapes, therefore sometimes in the map RE infrastructures are located in the erroneous categories.

- Some RE facilities extend through more than one landscape category, therefore sometimes analysis is deficient because all the area of RE facilities extension and its influence on landscape is not taken into account. In addition, many infrastructures are visible from the other landscape categories, and affect them.

- Mapping of co-use of the same areas for different RE infrastructures and different activities, like agriculture, grazing, industry, etc. is sometimes problematic. Therefore it is necessary to establish new landscapes subtypes based on mixed categories of land use and RE infrastructures.

Further research on RE landscapes of Andalusia for a more detailed scale is needed. Proper land use management is necessary for beneficial development of renewable energies. It should be focused on the RE plants and farms proper design and location, harmonization of different land uses and preservation of landscape quality. The strategies for mitigation of the negative landscape impacts of RE systems can include the following actions (based in Frolova et al., 2019):

1. Negative effects of many RE facilities on land use and landscape can be reduced through co-use of their area for other activities. It is especially important for wind resources, one of the least land-use efficient RE systems.

2. RE facilities can be designed so as to meet certain given landscape, ecological and educational objectives;

3. RE technology can be combined with existing infrastructure;

4. Solar and wind facilities can be also used for conversion of brownfield (underused, abandoned, and often contaminated land) in productive landscape;

5. The pattern of the PV and wind farms can be designed so as to improve the spatial definition of a certain area (e.g. public parks, bike lanes, walking paths);

6. PV modules can provide shade in spaces where this is needed;

7. In case of hydro power plants, some of their elements should be placed underground;

8. Abandoned mills can be restored for hydro power generation;

9. Incorporation of biomass facilities into existing olive oil factories reduces their landscape impact.

If these strategies are successfully applied, RE transition will be accompanied by conversion of a landscape with elements of the energy chain into a sustainable energy landscape.

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