Journal of Cleaner Production 366 (2022) 132920

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

How much solar PV, wind and biomass energy could be implemented in short-term? A multi-criteria GIS-based approach applied to the province of Jaén, Spain

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ARTICLE INFO

Handling Editor: Zhifu Mi

Keywords:
Renewable energy
Solar photovoltaic
GIS
Spatial energy planning
Social-acceptability

ABSTRACT

The progress made in the penetration of renewable energy (RE) sources in most parts of the world is not fast enough for achieving the international climate mitigation targets. Furthermore, there is a lack of energy planning strategies, methods and tools for assessing the implementation of RE technologies which considers the social support. In this work, we present a replicable multi-criteria spatial approach based on geographical information system to estimate the potential of solar photovoltaic (PV), wind and biomass energy technologies that could be implemented in the short-term in a given territory. This potential includes environmental, technical (with economic attributes) and geographical (with social-acceptability attributes) constraints, together with existing local power plants considerations for calculating the electricity generation by technology, and then estimating its jobs creation and greenhouse gas emissions reduction. The approach was applied to the province of Jaén (Southern Spain), which has a pronounced unbalance between its inner electricity production and consumption and apparently is a territory with great technical potential for the aforementioned technologies. Results show that this province has a short-term implementable potential that would annually produce 8.9 TWh from solar PV, 911 GWh from wind energy and 683 GWh from biomass plants; which is 3.8 times greater than the current electricity consumption and would require 1.5% of the total surface of Jaén. This potential can create about 92,800 direct jobs and avoid the emissions of 3.78–8.61 $MtCO_2$ to the atmosphere. The proposed approach can be useful for energy planning processes and for allowing decision-making to accelerate the implementation of RE power plants in order to achieve the climate mitigation goals.

1. Introduction

To avoid a point of no return when it comes to climate change on Earth, greenhouse gas (GHG) emissions must be reduced to half of the amount that is emitted today by 2035 at the latest (Masson-Delmotte et al., 2021). In this sense, the fastest way to achieve this target is to speed up the replacement of fossil fuel-based electricity generation plants by renewable energy (RE) technologies while conducting a global electrification of the energy services (Bogdanov et al., 2021). In fact, a transition towards higher RE shares will not only reduce GHG emissions but also would be one of the essential socio-economic contributors to job creation (Ram et al., 2022) and will decrease water scarcity by eliminating freshwater usage in thermal power plants (Lohrmann et al., 2019). However, the progress made in the penetration of RE in most parts of the world is not fast enough for achieving the international climate mitigation targets (REN21, 2021).

Furthermore, even though it is well-known that most of the territories on Earth have more than sufficient RE potential for generating electricity, the quantity of this potential that could really be implemented in the short-term can vary significantly due to a collection of factors, beyond the techno-economic ones (Osorio-Aravena et al., 2020). Thus, rather than the technological challenges for the massive integration of variable RE sources into the power grids, some of these technologies are facing social acceptance (Ellis and Ferraro, 2016) and environmental barriers (Serrano et al., 2020) at the local level that slow

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https://doi.org/10.1016/j.jclepro.2022.132920
Received 18 February 2022; Received in revised form 24 May 2022; Accepted 26 June 2022
Available online 28 June 2022
0959-6526/

Nomenclatures

Variables

AC_{opr}	Annual consumption of olive pruning residual with energy purposed [tons/year]
$ARG_{oc,i}$	Annual residual generation of irrigated olive crop [tons/ha-year]
$ARG_{oc,ni}$	Annual residual generation of non-irrigated olive crop [tons/ha-year]
DS_{PV}	Detected surface for solar PV plants [ha]
DS_{WO}	Detected surface for wind energy plants [ha]
$EF_{PV,C\&I}$	Employment factor in the C&I stage for solar PV [jobs/MW]
$EF_{PV,O\&M}$	Employment factor for O&M purposing for solar PV [jobs/MW]
$EF_{WO,C\&I}$	Employment factor in the C&I stage for wind onshore [jobs/MW]
$EF_{WO,O\&M}$	Employment factor for O&M purposing for wind onshore [jobs/MW]
$EF_{BP,C\&I}$	Employment factor in the C&I stage for biomass power plants [jobs/MW]
$EF_{BP,O\&M}$	Employment factor for O&M purposing biomass power plants [jobs/MW]
EGI_{opr}	Electricity generation index of olive pruning residual [MWh/ton]
EP_{BP}	Biomass electricity production potential [GWh]
EP_{PV}	Solar PV electricity production potential [GWh]
EP_{WO}	Wind onshore electricity production potential [GWh]
FLH_{BP}	Full-load hours for biomass power [h]
FLH_{PV}	Full-load hours for solar PV [h]
FLH_{WO}	Full-load hours for wind onshore [h]
OS_{PV}	Occupied surface by existing solar PV plants [ha]
OS_{WO}	Occupied surface by existing wind energy farms [ha]
PD_{PV}	Power density of solar PV [MW_p/ha]
PD_{WO}	Power density of wind energy [MW/ha]
PP_{BP}	Biomass power plant potential [MW]
PP_{PV}	Solar PV power potential [MW_p]
PP_{WO}	Wind onshore power potential [MW]
$US_{oc,i}$	Useful surface of irrigated olive crop [ha]
$US_{oc,ni}$	Useful surface of non-irrigated olive crop [ha]

Abbreviations

AAE	Agencia Andaluza de la Energía
C&I	Construction and installation
EF	Employment factor
GIS	Geographical information system
GHG	Greenhouse gases
O&M	Operation and maintenance
PV	Photovoltaic
RE	Renewable energy

down or inhibit the development of their implementation.

In fact, current energy planning policy strategies for implementing RE technologies in a given territory may not be sufficiently effective due to the fact that do not explore factors related to aspects beyond the techno-economic ones (Osorio-Aravena et al., 2020). For such purpose geographical information systems (GIS) together with multi-criteria analysis have become key tools for evaluating the implementation of RE technologies in a particular territory.

1.1. Literature review

Prior to the proposal of any method, a literature review of similar manuscripts have been undertaken. Table 1 presents a significant number of scientific works that applies GIS and multi-criteria approaches for evaluating the implementation of RE technologies. These references evaluate the suitability of certain sites considering aspects beyond the techno-economic ones. Wind onshore has been the most studied technology under aspects beyond the techno-economic ones, due to its particularities with ecological, socio-economic, land use, landscape aesthetics and public health concerns, among other; all of these relate to social barriers of this technology (Ellis and Ferraro, 2016). In this sense, Jäger et al. (2016) addressed a bottom-up methodology considering socio-economic constraints for estimating a feasible onshore wind energy potential. Höltinger et al. (2016) developed a participatory modelling approach to assess socio-political and market acceptance of wind energy potential. Harper et al. (2019) assessed socially acceptable locations for onshore wind energy and Enevoldsen et al. (2019) introduced a sociotechnical method of estimating wind energy potential.

In summary, the following gaps in the existing literature have been identified: i) the implementable potentials of solar PV and biomass energy have been less evaluated from the perspective of social acceptance; ii) there are a few studies that discuss the implementation of more than two RE technologies at the same time, however, social acceptance criteria is not considered and most of these works are only based on a spatial approach that has not calculated the electricity generation potential, and; iii) the job creation by technology of the implementable RE potential has not been reported in these works. Furthermore, existing local power plant considerations using real data is an important aspect that not always is addressed in conducting technical potential analysis on a specific territory under study.

1.2. Aim and contribution of this work

The main aim of this work is to propose a replicable multi-criteria GIS-based approach for estimating the potential for generating electricity of various RE technologies that could be implemented in the short-term in a specific territory. The proposed spatial-based approach considers environmental, technical (with economic attributes) and geographical (with social-acceptability attributes) criteria for calculating the potential of various RE technologies, analysing the overlap between them, and estimating the job creation and GHG emissions reduction of the short-term implementable potential by technology. The economic attributes are based on real data from existing local power plants that are already profitable and the social-acceptability attributes are based on lesson learned from published works. The basic idea behind the estimation of a technical potential with economic and social-acceptability attributes is to determine possible locations to install RE power plants, but assuring its chance of rapid implementation in economic terms and by the minimisation of social opposition. This approach will be useful for energy planning processes and for allowing decision-making which accelerate the implementation of RE power plants in a given territory, in order to achieve climate goals with social support.

Therefore, the contribution of this research to the existing literature is that this work presents the first spatial approach that address the calculation of the short-term implementable potential for three RE technologies at the same time considering social-acceptability attributes, and it reports and estimation of jobs creation of the implementable potentials by technology.

The proposed multi-criteria GIS-based approach was applied to the case of the province of Jaén (Spain), where solar PV, onshore wind and biomass energy technologies have been selected since this territory has great sources for this three technologies (Ruiz-Arias et al., 2012), they are the type of power plants that have experimented a more positive

Table 1
Studies that applied GIS and multi-criteria approaches evaluating the suitability of site to implement RE technologies that consider aspects beyond the techno-economic ones.

Technology	Methods	Aspects beyond the techno-economic ones	Reference
Solar PV	Delphi, DEMATEL, and VIKOR	Environmental, socio-political and risk	Abdel-Basset et al. (2021)
	GIS, AHP and DBC	Environmental	Agyekum et al. (2021)
	GIS, AHP and WLC	Legal, social, environmental and cultural	Doorga et al. (2019)
	GIS and AHP	Environmental	Finn and McKenzie (2020)
	GIS and AHP	Environmental	Ghose et al. (2020)
	GIS and AHP	Socio-environmental	Giamalaki and Tsoutsos (2019)
	GIS and AHP	Environmental	Günen (2021)
	BWM, GRA, VIKOR and MCSB	Environmental, social and risk	Kannan et al. (2021)
	GIS, PROMETHEE and AHP	Environmental and social	Marques-Perez et al. (2020)
	GIS, GREECE and ROM	Environmental	Pillot et al. (2020)
	GIS and AHP	Environmental	Ruiz et al. (2020)
	GIS and MapRE	Environmental and socio-economic	Shiraishi et al. (2019)
	GIS, AHP and OWA	Environmental	Shorabeh et al. (2019)
	GIS, AHP, WLC, and IDW	Environmental	Tercan et al. (2021)
	GIS	Environmental	Yang et al. (2019)
	GIS and AHP	Environmental	Zambrano-Asanza et al. (2021)
Wind onshore	GIS, AHP, FAHP, TOPSIS and FTOPSIS	Environmental	Amjad et al. (2021)
	GIS, AHP, ELECTRE III, ELECTRE-TRI and SMAA-TRI	Environmental	Atici et al. (2015)
	GIS, AHP and WLC	Environmental and social	Ayodele et al. (2018)
	GIS and AHP	Environmental and aesthetic	Baseer et al. (2017)
	GIS, AHP and WLC	Environmental	Cunden et al. (2020)
	GIS, Delphi and SEA	Environmental	(Diez-Rodríguez et al., 2019)
	GIS, DEMATEL, ANP and MABAC	Environmental and social	Gigović et al. (2017)
	GIS and AHP	Environmental and social	Höfer et al. (2016)
	GIS	Environmental	Mohammadzadeh Bina et al. (2018)
	GIS and AHP	Environmental	Moradi et al. (2020)
	GIS, AHP and WLC	Environmental	Potić et al. (2021)
	GIS, FAHP and FTOPSIS	Environmental and social	(Sánchez-Lozano et al., 2016)
	GIS and PROMETHEE-II	Environmental	Sotiropoulou and Vavatsikos (2021)
	GIS, BWM and WLC	Environmental	Tercan (2021)
	GIS and SFSPSD-RES	Environmental and cultural	Tsoutsos et al. (2015)
	GIS, AHP, DEMATEL, FTOPSIS, OCRA, VIKOR and OWA	Environmental and social	Villacreses et al. (2017)
	GIS, FAHP and WSRM	Environmental and social	Xing and Wang (2021)
	GIS, IAHP and VIKOR	Environmental and social	Xu et al. (2020)
	GIS and AHP	Environmental and social	Zahid et al. (2021)
Solar PV and wind onshore	GIS and AHP	Environmental	Ali et al. (2019)
	GIS and AHP	Environmental and human	Dhunny et al. (2019)
	GIS, BWM, TOPSIS and VIKOR	Environmental	Elkadeem et al. (2021)
	GIS and TOPSIS	Environmental and social	Rezaei et al. (2018)
	GIS and AHP	Socio-environmental	Saraswat et al. (2021)
	GIS and AHP	Environmental	Watson and Hudson (2015)
Biomass power plant	GIS, AHP and WLC	Environmental	Jeong and Ramírez-Gómez (2017)
	GIS and AHP	Environmental and socio-economic	Waewsak et al. (2020)
	GIS, TOPSIS, ELECTRE and SAW	Environmental, social and risk	Zhao et al. (2022)
At least solar PV, wind and biomass)	GIS, AHP and Delphi	Environmental	Díaz-Cuevas et al. (2019)
	GIS, Delphi and WLC	Environmental and cultural	Martínez-Martínez et al. (2022)
	GIS, ANP and WLC	Environmental	Nadizadeh Shorabeh et al. (2021)
	GIS	Environmental	Ruiz-Arias et al. (2012)

global trend (REN21, 2021), their cost is also projected to decrease in the near future (IEA, 2021; IRENA, 2020), the impact in the electrical grid caused by the intermittent production of solar PV and wind facilities can be reduce by a smart operation planning of the biomass power plants (Lehtveer and Fridahl, 2020), and, due to new business models with socio-economic benefits that could emerge based on these technologies.

1.3. Structure of the paper

This paper is structured as follows. Section 2 provides an overview of the study site, highlighting its renewable electricity status and theoretical RE potential. Section 3 presents and describes the multi-criteria GIS-based approach proposed to be applied to the province of Jaén. The results of this approach, differentiated by solar PV, wind and biomass energy technology, are shown in Section 4, whereas Section 5 discusses these results together with pointing out new research opportunities. Lastly, conclusions and recommendations of this work are exposed in Section 6.

2. Study area

2.1. Overview of the province of Jaén

The province of Jaén belongs to the Andalusia Autonomous Community and is located in Spain, in the southern part of the Iberian Peninsula (see Fig. 1, left). It has a total terrain surface of 13,484 km^2, with a population of 631,381 inhabitants (INE, n.d.). As can be seen in Fig. 1 (right), Jaén's territory is divided into two different topographic regions: the mountain systems of the south-eastern and northern facades; and the intermediate region, a flat terrain that houses the Upper Guadalquivir river basin. The highest peak is the Pico Mágina, on the southern facade, at 2,167 m above sea level. The mean altitude in the river basin is about 300 m above sea level.

Jaén's economy is mainly based on the olive oil industry. In fact, this province produces 50% of the Spanish olive oil, and more than 20% of

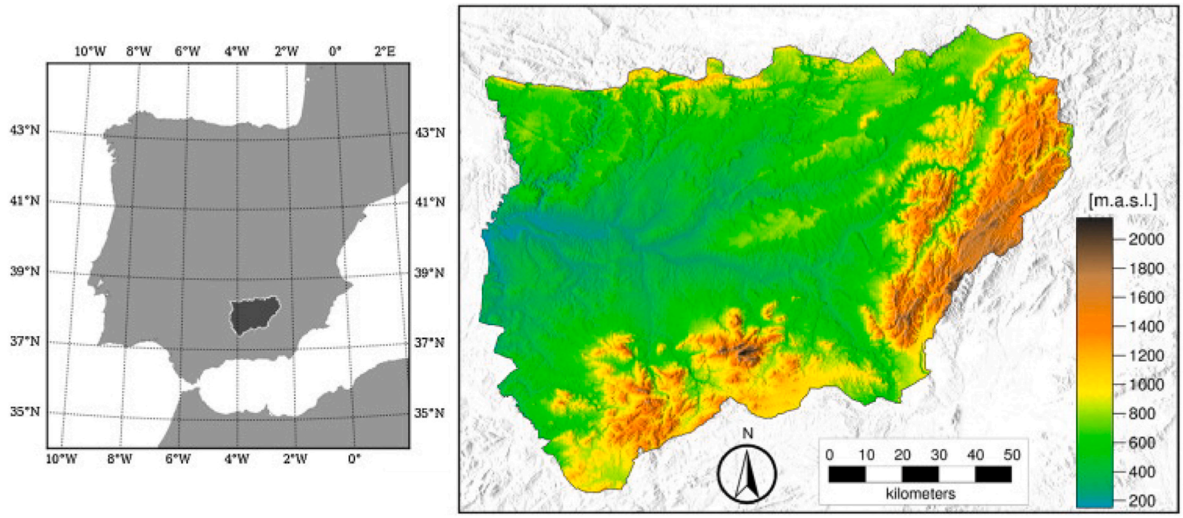

Fig. 1. Geographical location (left) and topography in meters above mean sea level (right) of the province of Jaén (Ruiz-Arias et al., 2012).

the world's olive oil (Esencia de Olivo, n.d.). It is also the crop with the highest potential for biomass production in the Andalusia Autonomous Community (AAE, 2020a).

2.2. Renewable electricity status in the province of Jaén

The current RE-power technologies (biomass, hydroelectric, solar PV and wind energy) represent 68% of the total installed capacity for generating electricity in Jaén. Although this province does not have conventional fossil fuel power plants, there are 175.5 MW of installed fossil fuel-based cogeneration plants that use the heat utilised in olive oil production processes for generating electricity (AAE, 2020b). The distribution of the 375.2 MW power based on renewable sources (see Table 2) is: 56.6% is hydroelectric, 29.2% solar PV, 10.2% biomass energy and 4.0% onshore wind (since Jaén has not sea coast). Nevertheless, in terms of electricity production, 40.1% was generated by biomass power plants and 29.9%, 25.6% and 4.4% by hydroelectric, solar PV and wind energy, respectively.

Fig. 2 shows the geographical distribution of solar PV, wind and biomass power plants in the province of Jaén, which are the technologies under analysis in this work. As can be seen in this figure, up to the date, most of the RE-power plants are solar PV systems with a capacity of no greater than 10 MW_p; the largest one has 11.8 MW_p of installed capacity. These more than 50 solar PV power plants occupy about 0.02% of the total terrain surface of Jaén. Additionally, there are three biomass power plants and just one wind farm operating in this province.

According to the Andalusia Energy Agency (AAE, by its Spanish acronym) (AAE, 2020b), Jaén consumed 2.79 TWh of electricity in 2019 so, based on the data from Table 2 the current renewable electricity generation is insufficient to meet the Jaén's total electricity consumption. The 595.8 GWh of renewable electricity generated in 2019 represents about 21% of total electricity consumption, meaning that 79% of the electricity consumed in Jaén is imported from surroundings provinces.

Table 2
Renewable installed capacity and electricity generation in the province of Jaén in 2019, based on AAE data (AAE, 2020b).

	Biomass	Hydroelectric	Solar PV	Wind energy	Total
MW installed	38.1	212.2	109.7	15.2	375.2
GWh generated	239.2	178.0	152.3	26.3	595.8

2.3. Renewable potential for generating electricity in the province of Jaén

Despite the fact that the renewable electricity currently only meets about one fifth of total electricity consumption in Jaén, it actually has a huge RE potential. Based on Ruiz-Arias et al. (2012) results, the theoretical solar PV and wind energy potential for generating electricity in the province amounts to approximately 1000 TWh and 110 TWh, respectively: this is 358 and 39 times higher than the total electricity consumption in 2019, respectively. These authors calculated that the technical solar PV potential for electricity generation is around 176 TWh, which is 63 times higher than the total electricity consumption in 2019. They also estimated that with the annual olive pruning residuals produced in Jaén could be generated 820 GWh per year.

Finally, Ruiz-Arias et al. (2012) proposed the installation of 420 MWp of solar PV power capacity (12 solar PV facilities of 35 MW each, which jointly could generate 656 GWh), 506 MW of wind power capacity (253 turbines of 2 MW each, which could produce 825 GWh) and 98 MW of biomass power capacity based on olive pruning residuals (5 biomass power plants, which could produce 763 GWh). The total amount of 2,244 GWh generated by the proposed solar PV, wind and biomass power plants would represent about 80% of the total electricity consumption in 2019, and, solar PV and wind energy would only occupy a 0.8% of the total Jaén's surface. However, they have not analysed or discussed potential socio-acceptability barriers related to these technologies that could impede their implementation.

3. Methodology

This section presents and describes a multi-criteria approach proposed to estimate the technical potential (with economic and social-acceptability attributes) of three RE technologies for generating electricity (solar PV, wind and biomass energy) that could be implemented in the short-term around a given territory's main electric power grid. Specifically, the proposed multi-criteria approach is an integration of environmental, technical (with economic attributes), and geographical (with social-acceptability attributes) GIS-based constraints with existing local power plant considerations. This approach is applied to identify sites and areas that could be used and exploited for implementing each kind of RE-power plant under analysis, in order to identify options for accelerating the decarbonization of the current energy mix. In this work, the proposed approach applies to the context of the Jaén province.

Fig. 3 illustrates the proposed multi-criteria GIS-based approach process to estimate the RE technical potential, which comprises three steps: i) detection of useful sites and areas for implementing RE-power

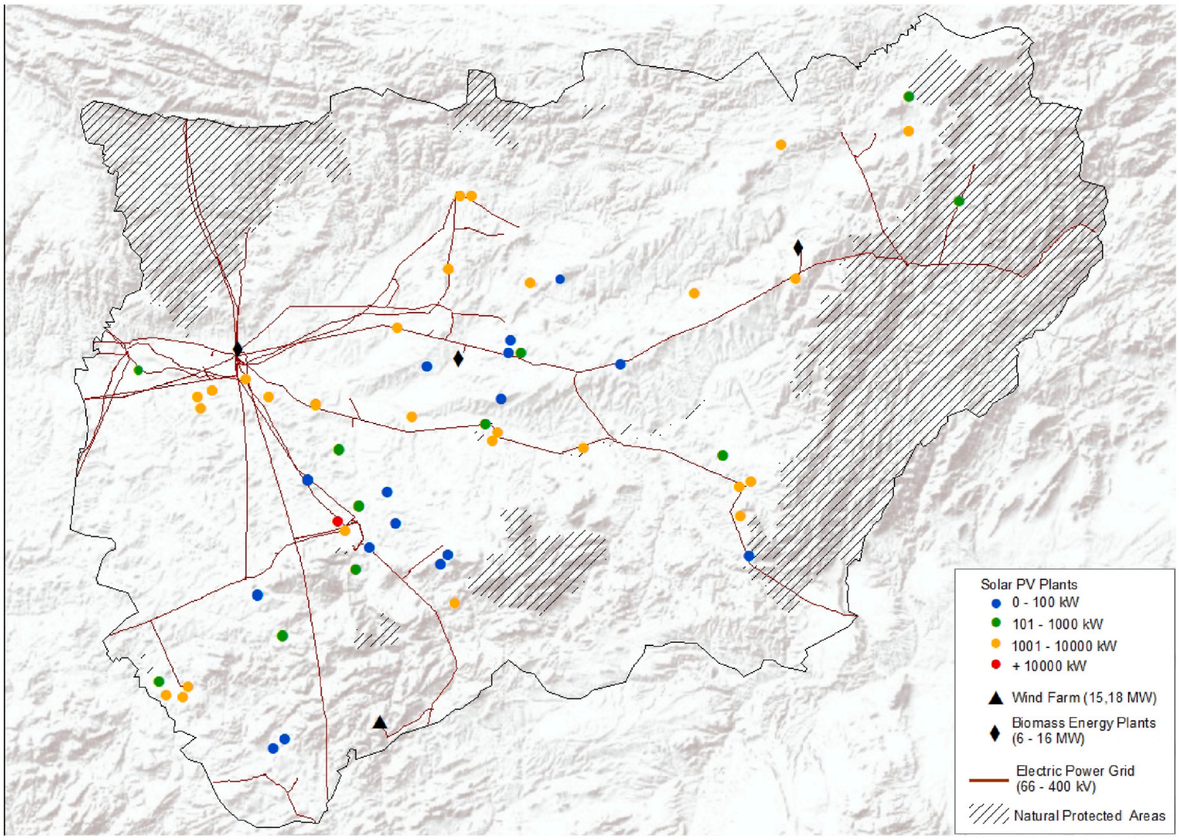

Fig. 2. Solar PV, wind and biomass power plants distribution in the province of Jaén.

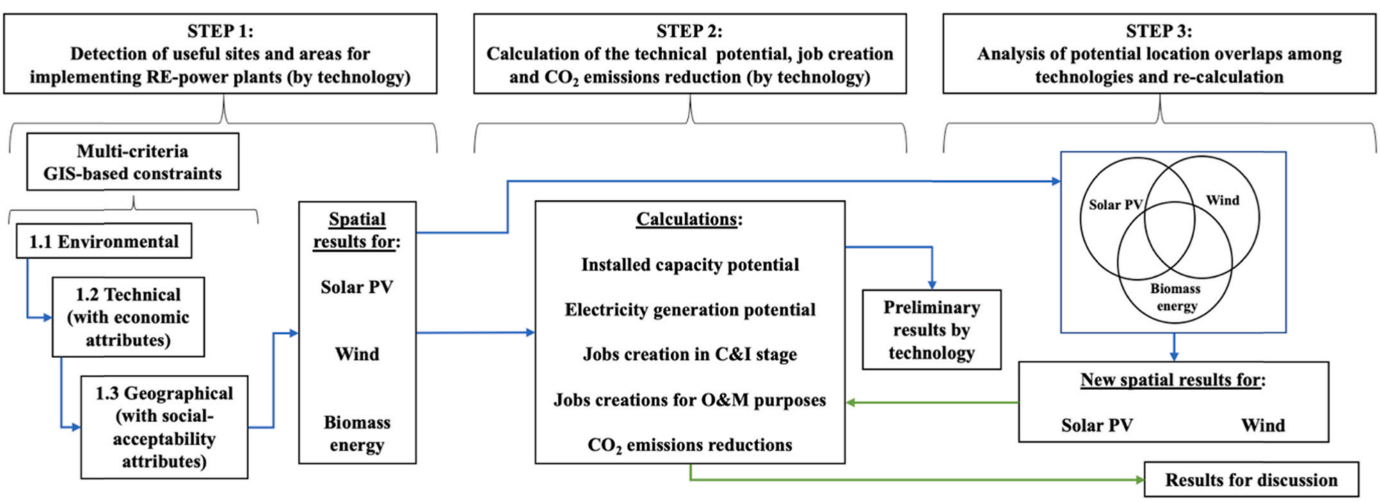

Fig. 3. Flowchart of the process for applying the multi-criteria GIS-based approach.

plants; ii) calculation of the technical potential of the specific RE technology based on a spatial approach, and a job creation estimation by technology and their corresponding CO_2 emission reduction; and iii) analysis of potential location overlaps among those technologies that could be implemented at one site, so a more realistic approximation of the installable RE potential in the selected territory is obtained.

ArcMap 10.3.1 ArcGIS tool, was used in the first step of the proposed approach. The multi-criteria mix of GIS-based constraints for detecting sites and areas, as well as the equations for the technical potential calculation, depends on each specific technology and are based on previous scientific works in the field that have been carried out in the European context and it also include existing local power plant consideration using real data. The latter aspect is important and not always is addressed in conducting technical potential analysis on a specific territory.

The applied GIS-based constraints and equations for solar PV, wind and biomass energy are presented in sub-sections 3.1, 3.2, and 3.3, respectively.

3.1. Solar PV potential

The type of solar PV power plant considered in this work is the fixedtilted ground-mounting. The previous step for the technical potential calculation of this type of RE technology was to apply the multi-criteria GIS-based constrains with existing local solar PV power plant considerations.

Table 3 exposes the GIS-based constraints by the criteria for this technology, following the order in which they were applied. The first constraint is related to the exclusion of natural parks and protected areas, which is a common environmental criterion in similar studies for estimating the solar PV (and wind energy) technical potential carried out in European countries, and in Spain in particular (Díaz-Cuevas et al., 2019).

The technical aspect (with economic attributes) is the next criterion applied. Sites located not more than 1 km from the main electric power transmission grid, as well with as a capacity factor equal to or greater than 15% have been evaluated, where the capacity factor is defined as the ratio of the net electricity generated, for the time considered, to the energy that could have been generated at continuous full-power operation during the same period. Specifically, site detections in the proximity of an electric power grid, this makes a certain RE project economically more viable, due to the fact of avoidance of great investment in large transmission lines. Additionally, it reduces other potential negative impacts associated with the power grid.

In the case of only considering zones where the capacity factor of a solar PV plant is equal to or greater than 15%, it assures a minimal electricity production that is within the range of existing plants in Jaén (based on AAE data (AAE, 2020b)), which validate its techno-economic feasibility. These locations were detected based on the results of a previous study carried out by Ruiz-Arias et al. (2012), in which a traditional fixed PV system with panels inclined 30° over the horizontal and permanently oriented southward was assumed. This reference configuration is close to optimal for the latitudes of the region.

The geographical constraints were determined based on studies applied to Europe (Finn and McKenzie, 2020; Günen, 2021; Marques-Perez et al., 2020; Ruiz-Arias et al., 2012; Tercan, 2021) and the location of existing solar PV power plants existing in the province of Jaén. Since the size of a solar PV project is a scientific and social concern in Spain (laSexta, n.d.; Serrano et al., 2020). This last input enables the geographical constraints to consider social-acceptability attributes, mainly the assumption that the local population of Jaén is familiarized with current locations of existing small-scale solar PV systems in the territory.

The multi-criteria GIS-based constraints application results in the solar PV potential calculation, in terms of installed capacity and electricity production, based on a spatial approach using equations (1) and (2). Solar PV power capacity potential was calculated as follows:

$$PP_{PV} = (DS_{PV} - OS_{PV}) \cdot PD_{PV} \tag{1}$$

Where PP_{PV} is the solar PV power potential in MW_p, DS_{PV} is the detected surface for solar PV plants in hectares (ha), which is a result of applying the multi-criteria GIS-based constraints. OS_{PV} is the occupied surface by existing solar PV plants in the range of 1 km from the main electric power grid in ha, and PD_{PV} is the power density of solar PV in MW_p/ha. In the case of Jaén, OS_{PV} is 119.2 ha, which was obtained using the repertoire of Andalusian Statistic and Cartographic Institute (*Instituto de Estadística y Cartografía de Andalucía*): Spatial Reference Data of Andalusia (*Datos Espaciales de Referencia de Andalucía*), provided by the Regional Andalusian Government (IECA, n.d.). Based on this same statistical source, PD_{PV} was estimated from the power density information provided by all the existing solar PV plants (fixed ground-mounted) located in this province, resulting in: 0.388 MW_p/ha as an average value.

Then, using the obtained PP_{PV}, solar PV potential for producing electricity was estimated as follows:

$$EP_{PV} = PP_{PV} \cdot FLH_{PV} \tag{2}$$

Where EP_{PV} is the solar PV electricity production potential in GWh and FLH_{PV} is the full-load hours for solar PV technology. In the case of Jaén, 1,350 h was assumed as FLH_{PV}, which is the mean value for the existing solar PV power plant in the region, based on the AAE data (AAE, 2020b).

Subsequently, equations (3) and (4) are used to estimate the direct jobs creation potential for solar PV plants in the construction and installation (C&I) stage and for operation and maintenance (O&M) purposing, respectively:

$$JC_{PV,C\&I} = PP_{PV} \cdot EF_{PV,C\&I} \tag{3}$$

Where $JC_{PV,C\&I}$ is the number of direct jobs created in the C&I stage for solar PV and $EF_{PV,C\&I}$ is the employment factor in the C&I stage for this technology: 13 jobs/MW_p according to Ram et al. (2022). And,

$$JC_{PV,O\&M} = PP_{PV} \cdot EF_{PV,O\&M} \tag{4}$$

Where $JC_{PV,O\&M}$ is the number of direct jobs created for O&M purposing for solar PV and $EF_{PV,O\&M}$ is the employment factor for O&M purposing for this technology: 0.7 jobs/MW_p according to Ram et al. (2022).

Regarding CO_2 emissions reduction estimation, 0.364–0.826 $ktCO_2$/GWh was considered, which is the range of CO_2 emission factor relying on the specific fossil fuel-based electricity generation technology (Eggleston et al., 2006).

Table 3
GIS-based constraints by criterion for solar PV power plants.

Criterion	GIS-based constraint
Environmental	Exclude natural parks and protected areas
Technical (with economic attributes)	Sites located not more than 1 km from the main electric power grid
	Zones with a capacity factor equal to and greater than 15%
	Terrain with a slope minor or equal to 10%
Geographical (with social-acceptability attributes)	100 m from urban areas, towns and villages as a minimum
	100 m from buildings (industrial, military and cottages) as a minimum
	50 m from infrastructures (primary and secondary roads, railways and airfields) as a minimum[i]
	100 m from rivers and water bodies as a minimum[ii]
	Sites with a minimum of 0.03 ha[iii]

[i] Distance to airports has not been considered as it does not exist in Jaén; however, it is recommended to apply this same constraint to other infrastructures.

[ii] Distance to marine coast has not been considered as it does not exist in Jaén; however, it is recommended to apply this same constraint.

[iii] For a solar PV power plant of 10 kW as minimum.

3.2. Wind energy potential

Based on the geographical location of the site under analysis, the type of wind energy power plant considered in this work is onshore. Likewise the solar PV analysis, the prior step for the technical potential calculation of this type of RE technology, in the application of the multi-criteria GIS-based constrains, and also taking into consideration the information provided by the existing (and only) wind farm in Jaén. Table 4 exposes the GIS-based constraints by criteria for this technology, following the order in which they were applied.

The first constraint is the exclusion of natural parks and protected areas, due to a common environmental criterion in several studies for estimating wind energy technical potential carried out in European countries.

The technical criterion excludes sites located closer than 1 km from the main electric power transmission grid as well as it only includes those installations with a capacity factor equal to or greater than 17%. This criterion has the same constraints items that the mentioned for solar PV. Areas with a minimum of 17% of capacity factor were selected based

Table 4
GIS-based constraints by criterion for onshore wind power plants.

Criterion	GIS-based constraint
Environmental	Exclude natural parks and protected areas
Technical (with economic attributes)	Sites located not more than 1 km from the main electric power grid
	Zones with a capacity factor of 17% as a minimum
	Terrain with a slope minor or equal to 20%
Geographical (with social-acceptability attributes)	1.5 km from urban areas, towns and villages as a minimum
	250 m from buildings (industrial, military and cottages) as a minimum
	100 m from infrastructures (primary and secondary roads and railways) as a minimum[i]
	100 m from rivers and water bodies as a minimum[ii]
	Sites with a minimum of 10 ha[iii]

[i] Distance to airports has not been considered as it does not exist in Jaén; however, it is recommended to apply a constraint of 1 km (Jäger et al., 2016).
[ii] Distance to marine coast has not been considered as it does not exist in Jaén; however, it is recommended to apply this same constraint.
[iii] Enough surface for the optimal operation of a wind turbine of 2 MW.

on a previous study applied to Jaén by Ruiz-Arias et al. (2012), in which a wind turbine of 2 MW with rotor diameter and tower height of 87 m was assumed.

The geographical constraints were determined based on studies applied to Europe. Wind turbines located in close proximity to urban areas can often cause conflicts with local residents, which lead to problems with overall acceptance (Ellis and Ferraro, 2016). Therefore, a minimum distance of 1.5 km was considered as a limit to install these sort of systems, which is more than the distance used for several studies applied to Europe (Eichhorn et al., 2019; Enevoldsen et al., 2019; Harper et al., 2019; Höltinger et al., 2016; Jäger et al., 2016). Additionally, this geographical constraint can reduce the social opposition associated to onshore wind turbines from local communities (Ellis and Ferraro, 2016), related to noise (Haggett, 2012) or health problems (Knopper et al., 2014). Other geographical constraints such as distance to buildings, infrastructures, rivers and water bodies are within the definition of socio-technical methods for the wind power potential estimation (Enevoldsen et al., 2019). The aforementioned constraints mean that the wind onshore technical potential assessed in this work has social acceptability attributes.

After the multi-criteria GIS-based constraints application, the wind energy technical potential, in terms of installed capacity and electricity production, is calculated, based on a spatial approach by the results from equations (5) and (6). Wind onshore power capacity potential was calculated as follows:

$$PP_{WO} = (DS_{WO} - OS_{WO}) \cdot PD_{WO} \quad (5)$$

Where PP_{WO} is the wind onshore power potential in MW, DS_{WO} is the detected surface for wind energy plants in ha, which is a result of applying the multi-criteria GIS-based constraints. OS_{WO} refers to the occupied surface by the existing wind energy farm in ha (76.7 ha), and PD_{WO} is the power density of wind energy in MW/ha. In the case of Jaén, PD_{WO} is 0.198 MW/ha, which match the mean value of installed power density of onshore turbines found in Europe (Enevoldsen and Jacobson, 2021).

Subsequently, the result from equation (5), i.e. PP_{WO}, wind onshore electricity potential was estimated as follows:

$$EP_{WO} = PP_{WO} \cdot FLH_{WO} \quad (6)$$

Where EP_{WO} is the wind energy electricity production potential in GWh and FLH_{WO} is the full-load hours for wind onshore technology. In the particular case of Jaén, 1,500 h has been considered as FLH_{WO}, which is the minimum value previously used by Ruiz-Arias et al. (2012).

Through equations (7) and (8), the potential of direct jobs creation for wind onshore power plants in the C&I stage and for O&M purposing, was estimated respectively:

$$JC_{WO,C\&I} = PP_{WO} \cdot EF_{WO,C\&I} \quad (7)$$

Where $JC_{WO,C\&I}$ is the number of direct jobs created in the C&I stage for wind onshore and $EF_{WO,C\&I}$ is the employment factor in the C&I stage for this technology: 3.2 jobs/MW according to Ram et al. (2022). In the case of jobs related to O&M tasks,

$$JC_{WO,O\&M} = PP_{PV} \cdot EF_{WO,O\&M} \quad (8)$$

Where $JC_{WO,O\&M}$ is the number of direct jobs created for O&M purposing for wind onshore and $EF_{WO,O\&M}$ is the employment factor for O&M purposing for this technology: 0.3 jobs/MW according to Ram et al. (2022).

The estimation of CO_2 emissions reduction, values mentioned previously: 0.364–0.826 ktCO_2/GWh were used.

3.3. Biomass potential for generating electricity

The biomass potential for the electricity generation obtained in this work is based on solid biomass from olive pruning residuals. A preliminary step of the technical potential calculation of this type of RE technology was the identification of the total area of irrigated and non-irrigated olive crops in the province of Jaén. This was carried out using the CORINE Land Cover database of the National Geographic Information Center (*Centro Nacional de Información Geográfica*) (CNIG, n.d.). Afterwards, land surface with olive crops that were located at a distance greater than 50 km from the main electric power transmission grids were excluded, based on a previous study that pointed out that the collection of olive pruning residuals further from this distance was not profitable (Ruiz-Arias et al., 2012). Additionally, because collection and residuals treatment with farm machinery becomes difficult in terrains with pronounced slopes, making their exploitation unfeasible, those land surfaces with a slope of more than 20% were also neglected (Ruiz-Arias et al., 2012).

Therefore, the biomass technical potential, in terms of electricity production and installed capacity, was calculated using equations (9) and (10), respectively. The biomass electricity production potential is calculated as follows:

$$EP_{BP} = \left[\left(US_{oc,ni} \cdot ARG_{oc,ni} + US_{oc,i} \cdot ARG_{oc,i}\right) - AC_{opr}\right] \cdot EGI_{opr} \quad (9)$$

Where EP_{BP} is the biomass electricity production potential in GWh, $US_{oc,ni}$ is the useful surface of non-irrigated olive crop in ha, $ARG_{oc,ni}$ is the annual residual generation of non-irrigated olive crop in tons/ha-year, $US_{oc,i}$ is the useful surface of irrigated olive crop in ha, $ARG_{oc,i}$ is the annual residual generation of irrigated olive crop in tons/ha-year, AC_{opr} is the annual consumption of olive pruning residual with energy purposed in tons/year, and EGI_{opr} is the electricity generation index of olive pruning residual in MWh/ton.

According to the study from Ruiz-Arias et al. (2012), based on exiting biomass power plants operating in the province of Jaén, in this research the following values have been considered: $ARG_{oc,ni} = 1.5$ tons/ha-year and $ARG_{oc,i} = 1.65$ tons/ha-year, and we used $EGI_{opr} = 1.06$ MWh/ton and $AC_{opr} = 276{,}620$ tons/year.

Then, using the result obtained for EP_{BP}, the biomass potential in term of installed capacity was estimating as follows:

$$PP_{BP} = EP_{BP} \cdot FLH_{BP} \quad (10)$$

Where PP_{BP} is the biomass power plant potential in MW and FLH_{BP} is the full-load hours for this technology. In the case of Jaén, 7,745 h has been used as FLH_{BP}, which is the mean value of the existing biomass power plants operating in Jaén (Ruiz-Arias et al., 2012).

The following equations (11) and (12) estimates the direct jobs creation prediction for biomass power plants in the C&I stage and for

O&M purposing, respectively:

$$JC_{BP,C\&I} = PP_{BP} \cdot EF_{BP,C\&I} \tag{11}$$

Where $JC_{BP,C\&I}$ is the number of direct jobs created in the C&I stage for biomass power plants and $EF_{BP,C\&I}$ is the employment factor in the C&I stage for this technology: 14 jobs/MW according to Ram et al. (2022). And,

$$JC_{BP,O\&M} = PP_{BP} \cdot EF_{BP,O\&M} \tag{12}$$

Where $JC_{BP,O\&M}$ is the number of direct jobs created for O&M purposing for biomass power plants and $EF_{BP,O\&M}$ is the employment factor for O&M purposing for this technology: 0.28 jobs/MW according to Ram et al. (2022).

To estimate the CO_2 emissions reduction, the same values as mentioned above were used: 0.364–0.826 $ktCO_2$/GWh.

4. Results

4.1. Solar PV technical potential

Fig. 4 shows the results associated with the sites detected for the solar PV power plants implementation in the province of Jaén, after the multi-criteria GIS-based constraints. In total, 1,703 sites were identified, accounting for 84,639 ha (6.3% of the surface of Jaén) with the following distribution: 277 sites with a surface suitable for installation of a solar PV system within a range of 10–99 kWp, 545 sites for 100–999 kW_p, 464 sites for 1–9.9 MW_p and 417 sites for PV systems greater than 10 MW_p. The largest identified site is 1,291 ha, which corresponds with a solar PV power plant of 503 MW_p.

The total detected surface can accommodate an installed solar PV capacity of 32.8 GW_p, which would produce 44.3 TWh of electricity. However, 80% of the sites are located in areas with olive crops, therefore comprising 11% of the total surface of olive crops in Jaén. This means that the effective solar PV technical potential with economic and social-acceptability attributes that could be installed in the short-term without use of land with olive crops corresponds to 6.6 GW_p (1.3% of the surface of Jaén), which is 17.5 times more than the current total RE installed capacity for generating electricity in Jaén and 59.9 times more than the current solar PV installed capacity in this province. Those 6.6 GW_p could create about 85,000 direct jobs in the C&I stage and around 4,500 direct jobs for O&M purposing.

This solar PV power capacity would generate 8.9 TWh of electricity per year, which is 3.2 times more than the total electricity consumed in this province in 2019 and 58.2 times more than the electricity generated by all the solar PV power plants operating in Jaén in 2020. This solar PV potential for generated electricity would prevent the emission of 3.2–7.3 $MtCO_2$ to the atmosphere.

4.2. Wind energy technical potential

Fig. 5 shows the geographical distribution of sites feasible for the implementation of wind power plants in the province of Jaén, after the application of the multi-criteria approach based on GIS. In total, 100 sites were detected, accounting for 12,162 ha (0.9% of the surface of Jaén) with the following distribution: 66 sites with a surface suitable for nine wind turbines of 2 MW, 23 sites for 10–29 turbines, six for 30–49 turbines and five for 50 or more turbines. The largest identified site was 894 ha, which corresponds to a wind farm of 176 MW composed of 88 wind turbines of 2 MW each.

The global suitable surface for the installation of a wind capacity of 2.2 GW (equivalent to 1,100 turbines of 2 MW each) which would produce 3.4 TWh of electricity annually. However, 58% of these sites overlap with solar PV and 73% are allocated in areas with olive trees –equivalent to 1.4% of the total surface of the olive crops in Jaén. This means that the effective wind technical potential with economic and

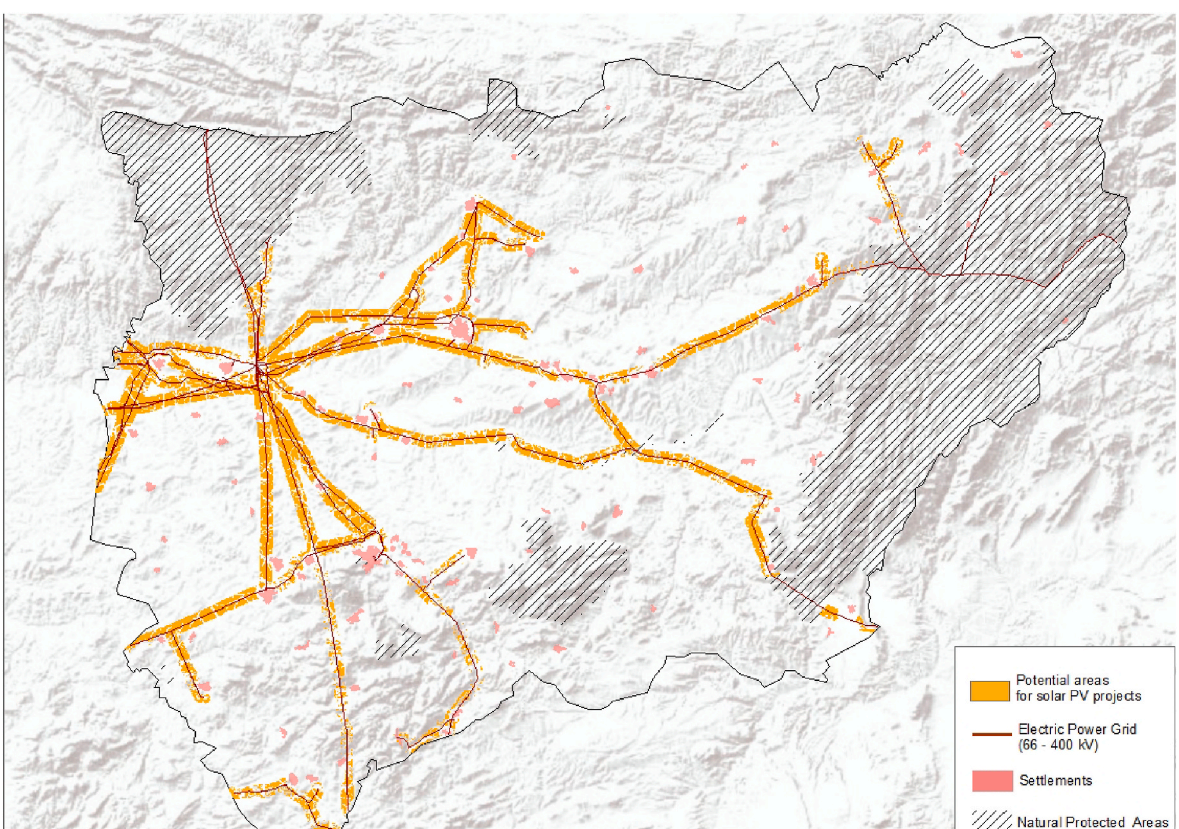

Fig. 4. Identified sites for the installation of solar PV power plants in the province of Jaén.

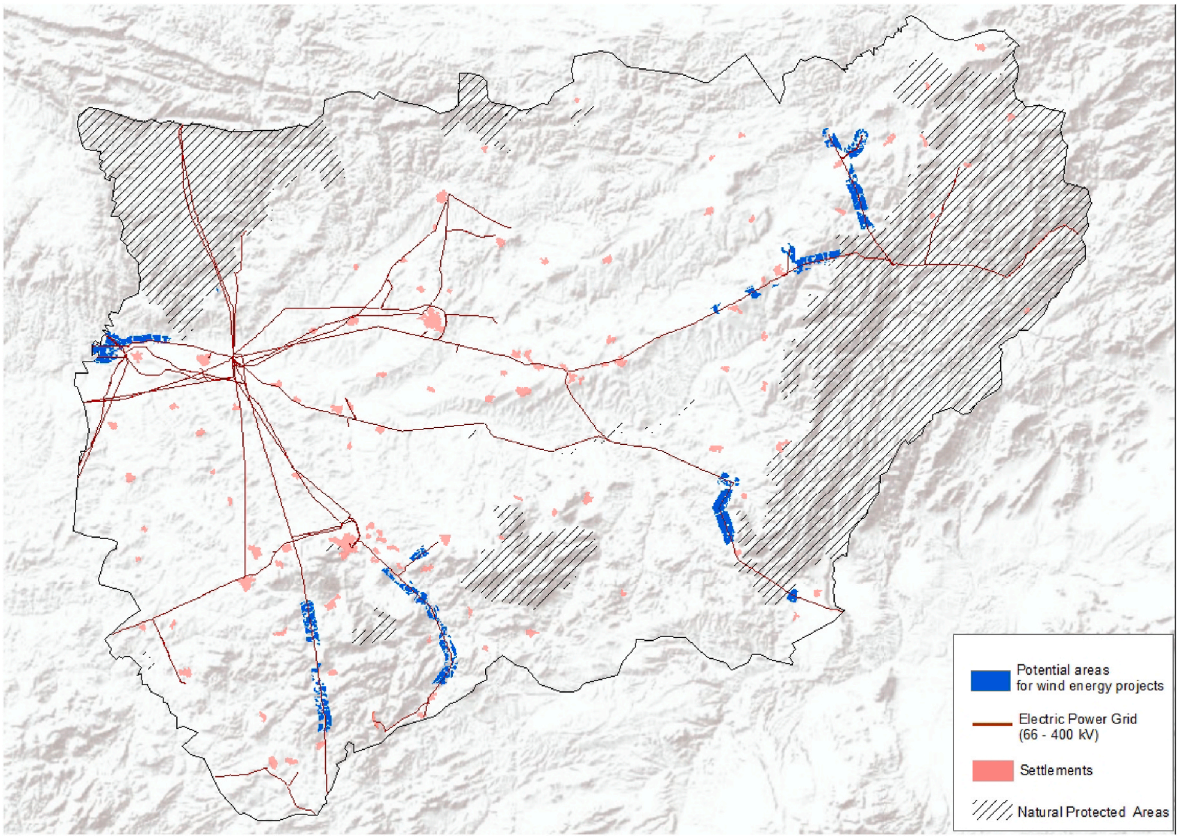

Fig. 5. Identified sites for the installation of wind energy power plants in the study region.

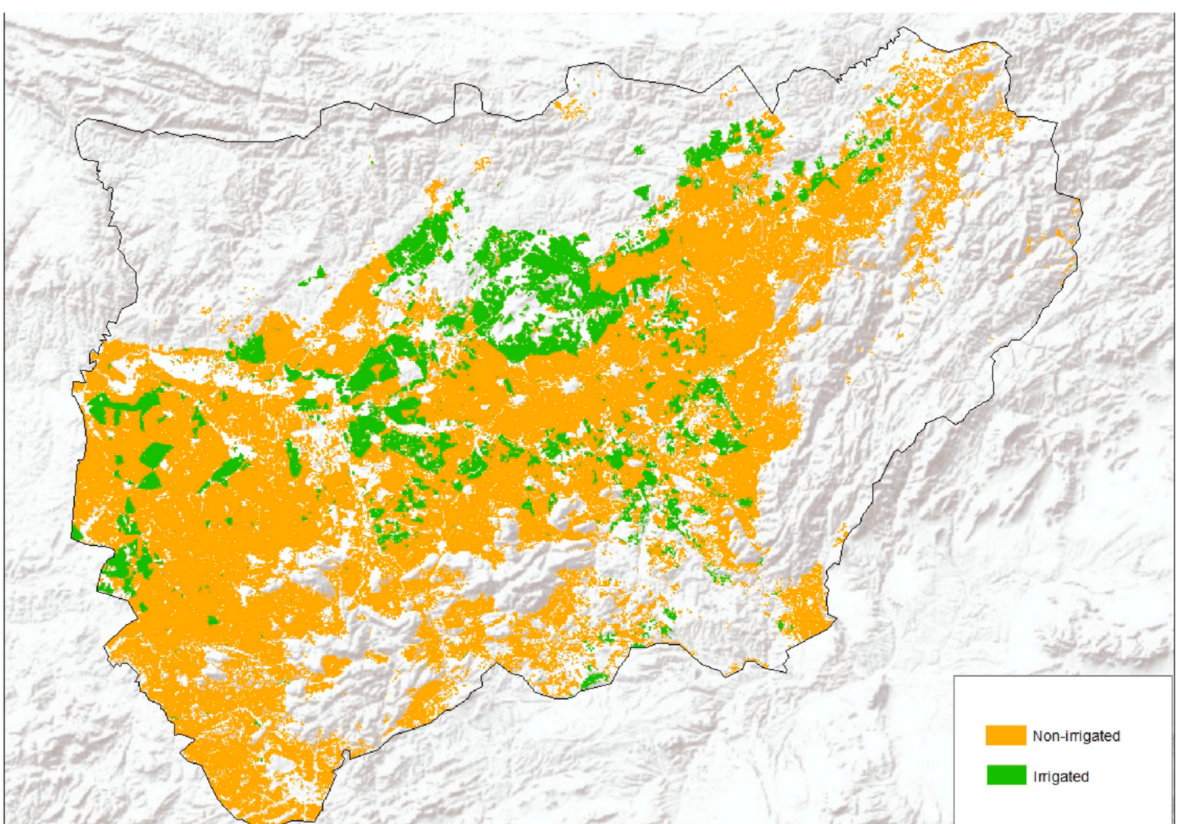

Fig. 6. Geographical distribution of exploitable olive crops in the province of Jaén.

socio-acceptability attributes that could be installed in the short-term without land use conflicts with olive crops corresponds to 0.6 GW (equivalent to 303 turbines of 2 MW and 0.2% of the surface of Jaén), which is 1.6 times more than the current total RE installed capacity for generating electricity in Jaén and 40 times more than the current wind installed capacity in this province. Those 0.6 GW could create about 1,943 direct jobs in the C&I stage and around 185 direct jobs for O&M tasks.

On the other hand, such wind technical potential would produce 911 GWh of electricity, which is 30% of the total electricity consumed in this province in 2019, meaning 34.6 times more than the electricity generated by the wind farm operating in Jaén in 2020. Finally, this wind energy potential would avoid the emission of 0.33–0.75 $MtCO_2$ to the atmosphere.

4.3. Biomass technical potential for generating electricity

Fig. 6 shows the exploitable areas with olive crops in the province of Jaén whose pruning residuals may be used for electricity generation. This exploitable area represents 98% of the total extent of the olive crop in Jaén. The useful terrain with non-irrigated (orange in Fig. 6) and irrigated (green in Fig. 6) olive crops amounts to 496,775 ha and 106,567 ha, respectively.

Based on the assumed biomass residuals generation index for each type of olive crop, there is a total of 745,163 tons/year of pruning residuals from non-irrigated and 175,836 tons/year from irrigated, which are available for generating electricity in biomass power plants up to 683 GWh, which represents 25% of the total electricity consumed in this province in 2019 and 2.9 times more than the electricity generated by the existing biomass power plants operating in Jaén in 2020. Furthermore, such an amount of biomass generated electricity would avoid the emission of 0.25–0.56 $MtCO_2$ to the atmosphere.

On the other hand, the estimated biomass generated electricity potential would imply a total of 88 MW of installed capacity, which is 2.4 times more than the current biomass installed capacity in Jaén in 2020. This is also equivalent to about six plants of 15 MW and 15 of 6 MW, which are the sizes of the biomass power plants currently operating in Jaén. Those 88 MW could create around 1,235 direct jobs in the C&I phase and circa 25 direct jobs for O&M tasks.

5. Discussion

The proposed spatial approach for the calculation of the short-term implementable potential with economic and social-acceptability attributes of the three RE technologies considered is based on validated assumptions. As it was detailed in the methodology section, the techno-economic assumptions are based on real data and considerations from profitable power plants already operating in Jaén, and, the social-acceptability attributes are based on lessons learned from published articles.

Once the proposed multi-criteria GIS-based approach have been applied, it is highlighted that the province of Jaén has a significant RE technical potential that could be implemented in the short-term; even considering the worst case scenario of discarding those PV and wind sites that may conflict with olive crops.

Table 5 shows a summary of the results obtained by technology, but excluding those PV and wind potentials that may get in conflict with olive crops. The technical potential for annual electricity generation (10.5 TWh), composed of solar PV, wind and biomass power plants, is 3.8 times greater than the total electricity consumption in Jaén in 2019. This potential would require 1.5% of the total surface of this province. Moreover, such RE potential could create more than 88,000 direct jobs in the C&I stage and around 4,700 direct jobs for O&M purposing, and would avoid the emission of 3.78–8.61 $MtCO_2$ to the atmosphere. These results reveal that only the solar PV technology would generate 85% of the electricity, avoiding 85% of the CO_2 emissions and may create 96% of the direct jobs.

Table 5
Technical power and electricity potential, job creation and CO_2 avoided emissions by technology.

	Unit	Solar PV	Wind energy	Biomass	Total
Power potential	GW	6.6	0.6	0.088	7.3
Electricity generation	TWh	8.9	0.911	0.683	10.5
Job creation in C&I	Jobs	85,000	1,943	1,235	88,178
Job creation in O&M	Jobs	4,500	185	25	4,710
Avoided emissions	$MtCO_2$	3.2–7.3	0.33–0.75	0.25–0.56	3.78–8.61

Despite the fact that the proposed multi-criteria GIS-based approach is consistent with most of the criteria applied by others spatial publications that assess the sites suitability for more than two RE technologies, the results obtained in this research have significant differences. Martínez-Martínez et al. (2022) reported that the suitable sites for solar PV and wind are 44% and 52% of the total surface of the study area, respectively. Nadizadeh Shorabeh et al. (2021) found that the highly suitable sites for solar PV and wind are 23% and 19% of the total surface of the study area, respectively. And, Díaz-Cuevas et al. (2019), reported that the suitable sites for solar PV and wind are 25% and 21% of the total surface of the study area, respectively, and also found that the highly suitable sites are 8.7% and 3.9% of the total surface of the study area, respectively. Instead, our results show that the suitable sites for solar PV and wind are 6.3% and 0.9% of the total surface of the study area, respectively, and reveal that the solar PV and wind implementable potential in the short-term would occupy 1.3% and 0.2% of the total surface of the study area, respectively. The differences of results between these works with the study carried out in this research lie on the economic and social-acceptability attributes that are considered in the spatial constrains of the technical and geographical criteria. This would imply that the proposed approach is more realistic, in terms of the short-term implementation of the assessed RE technologies. In addition, these works have not calculated the electricity generation potential of each technology and the job creation by technology of the implementable RE potential has not been reported. Furthermore, comparing the approach of this manuscript with a previous work applied to the province of Jaén which calculated the electricity generation potential for solar PV, wind and biomass energy technologies (Ruiz-Arias et al., 2012), similar differences are found, as it neither considers socio-acceptability attributes nor job creation potential have been reported.

Therefore, the spatial approach proposed in this manuscript implies that, the results are not only the technical potential economically feasible to be installed in the short-term, but should also not face strong opposition from the local community. This kind of approach can be easily applied to other regions of Spain or at the country level, and it can be of application to other parts of the world. Nevertheless, an important aspect to consider for the replication of this multi-criteria GIS-based approach is the use of real data and considerations from existing local power plants and, such as lessons learned on social acceptance from previous studies.

The results obtained from the proposed spatial approach are of relevance, as they could be useful for the energy and electric grid expansion planning as well as for enabling decision-makers to accelerate the implementation of the RE technologies under analysis in a specific region. However, in practice, the RE potential that could really be implemented in the short-term in Jaén will also rely on some additional aspects that are discussed below.

In any case, the wind and biomass energy results are within the same range as those suggested by Ruiz-Arias et al. (2012), though the solar PV one differs. Those 8.9 TWh of solar PV electricity per year generated by 6.6 GW of installed systems that we found could be implemented in the short-term are 19.8 times less than the technical potential reported by these authors. This is because of a lack of either technical constraints with economic attributes or geographical limitation with social-acceptability attributes in such research, but, at the same time, our results are 13.5 times more than their proposed implementation, since only 12 areas were selected for implementing solar PV plants were finally selected. Additionally, it is important to highlight that these 12 solar PV facilities of 35 MW of installed capacity each one suggested by Ruiz-Arias et al. (2012) may encounter social acceptance barriers, according to the reasons detailed below based on the RE project size.

The first reason is related to the trend that has been experimented in the province of Jaén when it comes to the installation of solar PV plants, which are relatively small. In fact, the largest existing solar PV power plant in this province is 11.8 MW and most of the solar PV systems connected to the electric power grid have a range of installed capacity within 0.1–10 MW. This means that the local community is currently familiar with solar PV systems that are as a minimum 3.5 times smaller than a 35 MW solar PV power plant.

The second reason is related to Spanish scientific and civil society concerns associated with potential environmental and socio-economic negative impacts. On the one hand, a group of Spanish researchers from different institutions have highlighted the threats to biodiversity on high ecological value lands that large-scale solar PV plants and wind power farms could cause in Spain (Serrano et al., 2020). On the other hand, more than 180 Spanish civil organizations have publicly expressed these environmental concerns and called for a more distributed and fair energy transition for regional development. Therefore, the implementation of solar PV and wind energy projects should be decentralized and participative, in order to benefit the rural population and people in general, instead of multinational companies only.

Based on these two aforementioned reasons, it is possible that large-scale solar PV and wind energy projects could encounter social barriers for their acceptance, which have not been analysed in this work. Therefore, further investigation on social acceptance at the local level, specifically with regard to the size of RE projects should be carried out in future works. Nevertheless, large-scale wind farms should receive special attention in further studies. This is mainly due to it encounters more social opposition than solar PV plants in Europe in general and in Spain in particular, not only for environmental concerns (Ferrer et al., 2012; Heuck et al., 2019; Sanz-Aguilar et al., 2015; Voigt et al., 2015), but also because of the visual and aesthetic landscape impacts (Frolova et al., 2019, 2020). In this regard, the quantity and distance for their implementation is a paramount parameter for public acceptance that also needs to be addressed by energy planning processes (Betakova et al., 2015), in order to avoid social resistance related to visual impacts of this technology and speed up its implementation.

Another limitation of this work is a compatibility analysis of the olive crops with the implementation of wind turbines and solar PV systems, which open future research directions. On the one hand, considering that, normally, productive olive trees do not exceed the 4 m of high, it could be possible to install wind turbines of 80–100 m of axial-high on a site with olive crop. On the other hand, the trend of agrivoltaic applied to the olive crops and floating solar PV systems added to the irrigation pond of these crops could be also analysed. If such a compatibility exists, the installable wind energy and solar PV technical potential in Jaén can increase significantly and could trigger an additional income to the olive crop owners, which will vary depending on the business model applied.

In another way, a new Spanish trend on change of land use from crop farms to solar PV plants (el País, n.d.) could also be investigated in the case of olive crops in Jaén. In this case, the question should answer what is more profitable in, for example, 1 ha: an olive crop or a solar PV plant of 388 kW. For sure, that last option would swap the olive pruning residual production for electricity generation that should be included in the analysis as well.

With regard to biomass power plant projects, cultural habits in term of potentially providing or denying olive pruning residues for electricity generation purposes could also be a sociocultural barrier that needs further investigation. In any case, this kind of facilities could be less conflictive due to their installation in existing olive oil plants.

Nevertheless, some biomass power plant projects have not been implemented in the province of Jaén due to the lack of adequate capacity of transmission lines for the evacuation of electrical energy. In this regard, although the analysis of the electricity evacuation capacities of the power grid in Jaén is outside of the scope of this work, the results can be useful as an input to planning eventual expansion of the existing transmission lines capacities in this province. In addition, rooftop solar PV systems is another type of installation that have not been included in this work but should be considered since it could also contribute to decarbonize the energy mix at the city level. This is due to rooftop solar PV with battery storage can generate significant amounts of electricity that will reduce the need for large power grids (Child et al., 2019). Furthermore, the impact in the electrical grid caused by the intermittent production of solar PV and wind energy facilities can be reduce by a smart operation planning of the biomass power plants (Lehtveer and Fridahl, 2020).

Finally, although it inherently has an impact, the analysis of the RE potentials have not been linked with the Sustainable Development Goals (SDG). In this regard, a future study for evaluating the RE potential based on SDG in a similar way that the work carried out by Sreenath et al. (2021) is suggested.

6. Conclusions

This work proposes a multi-criteria spatial approach based on GIS that includes environmental, technical (with economic attributes) and geographical (with social-acceptability attributes) constraints, together with existing local power plants considerations and lessons learnt to estimate the short-term implementable potential of solar photovoltaic (PV), wind and biomass energy technologies, in a given territory. As far as the authors are aware, this is the first spatial approach that address the calculation of the short-term implementable potential for three RE technologies at the same time considering social-acceptability attributes, and, that reports jobs creation estimations of the implementable potentials by technology.

According to the results obtained with the proposed methodology, the potential for electricity generation based on solar PV, wind and biomass power plants are: 6.6 GW (8.9 TWh/year), 0.6 GW (911 GWh/year) and 88 MW (683 GWh/year), respectively. The total annual electricity production potential is 3.8 times greater than the amount of electricity consumption in Jaén in 2019. Such RE potential could create more than 88,000 direct jobs in the C&I stage and around 4,700 direct jobs for O&M purposing, avoiding the emissions of 3.78–8.61 $MtCO_2$ to the atmosphere. Also, the solar PV and onshore wind implementable potential would require 1.3% and 0.2% of the total surface of the study area, respectively. These results are between of 7.4–43% and 3.7–52% (for solar PV and wind, respectively) less required area compared to those reported by other spatial approaches. This mean that the proposed research offers more realistic results since it assures its chance of rapid implementation of RE power plants based on three main aspects implicit in the approach: i) the use of real data and consideration from existing local power plants that are already profitable in the study area; ii) the avoidance of land use conflict, and; iii) procurement the minimisation of social opposition. Therefore, the proposed approach will be useful for energy planning processes and for allowing decision-making to accelerate the implementation of RE power plants in a given territory, in order to achieve climate goals with social support.

However, due to the recent social barrier that large-scale power plants are facing for their implementation in Spain and provided that the size of power plants has not been assessed in this work, further research on social acceptance and to what extent the sociocultural and socio-economic aspects may affect the integration of the implementable potential in a determinate territory is still needed. Also, we recommend carry out future studies to evaluate the complementarity of solar PV systems and wind turbines with olive crops and the floating solar PV potential on irrigation pond. All of this can help to reduce social-acceptance barriers in a given territory, in order to speed up the transition towards a more environmentally friendly, decentralized and just energy systems.

Funding

This paper was elaborated in the scope of the research carried out within the project "Adaptation to sustainable energy transition in Europe: Environmental, socio-economic and cultural aspects (ADAPTAS)" (Ministry of Economy, Industry and Competitiveness and State Research Agency of Spain, and European Regional Development Fund, CSO2017-86975-R).

CRediT authorship contribution statement

Juan Carlos Osorio-Aravena: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Francisco Javier Rodríguez-Segura:** Methodology, Data curation, Visualization, Writing – original draft. **Marina Frolova:** Formal analysis, Project administration, Writing – review & editing. **Julio Terrados-Cepeda:** Formal analysis, Writing – review & editing. **Emilio Muñoz-Cerón:** Supervision, Formal analysis, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The first author thanks the Vice-Rectorate of Research of the University of Jaén for the "Acción 4" scholarship: "Ayudas predoctorales para la Formación de Personal Investigador".

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