Study of Sustainability of Renewable Energy Sources through GIS Analysis Techniques

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Abstract. In an integrated vision of the problems concerning energy policies, the use of renewable energy sources should assume a significant role. The 2009/28/EC Directive of the European Parliament and Council has indicated ambitious energy and climate change objectives for 2020: greenhouse gas emissions reduction for 20%, renewable energy increase for 20%, improvement in energy efficiency for 20% [1].

The aim of this paper is to present a GIS based methodology able to support decision-making in energy supply from Renewable Energy Sources (RES). To decide what type of renewable energy font is the best choice for a specific territory, it's important to know the local energetic situation, exploring the potential renewable energy sources available in that specific area, deciding what is the more territory compatible/sustainable among them, and if it's exploitable by suitable environmental and economic point of view.

The methodology is largely directed towards the development of a tool to support siting decision.

Keywords: Renewable Energy Sources, GIS, sustainable development, solar radiation.

1 Introduction

In recent years, both by necessity and in response to international policies, interest towards alternative energy forms, i.e. not derived from conventional sources like fossil fuels, has considerably grown. Photovoltaic, solar thermal, wind, biogas, biomass, geothermal are commonly used terms and the associated technologies are reaching very high expertise standards, with considerable interest in world markets. The spirit that leads towards such technologies comes from to answer a real sustainable development need as well a rational resources use [2, 3].

One of the most interesting renewable sources features is their dispersion in the territory. This characteristic is on the one hand a strength, because potentially everywhere it is possible to exploit solar energy, wind power, etc., on the other is a limiting factor, because the energy concentration is reduced. Moreover, the diffuse nature of

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renewables can combine energy production with the fight against land depopulation and degradation phenomena, supporting the technological and economic development of small urban and rural reality. Renewable Energy Sources (RES) exploitation implies a more direct communities and local administrations involvement in finding the best solution for each energy source, use and location [4], promoting the concept of thinking globally and acting locally. In this perspective, and in a modern land management, it is also necessary to take into account potential and actual impacts due to installations for renewable sources production, privileging the *landscape ecology* assessing [5].

Changes in landscape take continuously place, with significant repercussions on quality of life and natural habitat ecosystems, mainly through their impacts on soil and ecosystems [6]. Landscape planning is strongly related to sustainable development issues, especially considering that landscape is both an influencing factor and a resulting product of the people-place relationship [7]. As pointed out in the European Landscape Convention [8], the analysis of landscape can allow to understand the wellbeing/discomfort condition of population in relation with their environment. A significant problem for some types of production plants, mainly those solar and wind, is related to their possible negative effects in terms of visual impact. A careful planning of single plant integration and the choice of devices less "visible" could reduce the problem, but certainly not eliminate it.

In this framework, the use of Geographic Information Systems (GIS) represents the most significant technological and conceptual approach to spatial data analysis, in order to provide reliable information for both planning and decision-making tasks. The GIS tool fits perfectly in this kind of survey and assessment, providing the mean to combine several features as ecological, territorial, socio-economic aspects, etc. useful to support landscape analysis to deal with issues concerning environmental impacts [9].

Moreover, projections for 2020 indicate that renewables could cover, for that date, from 20% to 30% of the world's energy needs [1]. A set of effective actions to achieve those objectives should include the use of new tools and methodologies to be implemented in a modern vision of territory governance [10, 11]. This requires the implementation of rules aimed at protecting the land primary productive function, so as to facilitate the development and exploitation of potential sources of energy therein. Therefore proposals for a judicious planning, land management, knowledge, location and accessibility of resources constitute the core for an efficient and sustainable governance.

2 Objectives

The main objective of this research is to find a methodology, territory related, able to support decision-making processes in choosing energy supply from renewable sources. The methodology, through a series of *informants*, will make the planner able to *read* the potential of a given area to house plants from renewables, and to identify what and how many renewable energy can be compatible and applicable to environmental, social, cultural, economic realities located on that territory [12].

The description of the potential energetic vocation of a place, requires a more detailed study composed of several variables and their combination. In fact, to precisely define an area potentially adapted to housing a plant from photovoltaic (PV), it is necessary to carry out a series of thematic maps quantifying the effective usable area. Several thematic maps like Parks, Sites of Community Importance (SIC), Special Protection Areas (SPA), areas of natural scenery constraint, urban, humid areas, particular appreciate habitat, and so on, are created and combined in order to define the remaining areas of possible production from RES. The types and the *forms* of intervention in the territory, for the production of energy, are multiple and similar to linear and areal infrastructures of anthropogenic nature. It follows that the *environment consumption* is one of the main phenomena found at different levels, which add to the already growing soil consumption. Unlike purely anthropic settlements, the energy production installations from RES, in a global vision, have a positive value because they are intended to produce energy in a sustainable way and in order to reduce the causes of deterioration and consumption of natural resources. Their inclusion in the territory should be considered in light of two fundamental aspects:

1. one hand, the environmental cost of their implementation, expressed in terms of consumption of resources, habitat loss, land use;
2. the other, the real energetic vocation of a territory in terms of potential energy obtainable.

Fig. 1. Study area: Abruzzo region in Central Italy

This paper provides a framework for analysing the sustainability of renewable energy sources using GIS and presents a case-study for the Abruzzo region in Italy (Fig. 1). The region is situated at the centre of the Italian peninsula facing the Adriatic sea, with a 150 km long coastline. With an area of 10,763 km^2 and bordered on the east by the Adriatic and on the west by the Apennines, it is one of the most mountainous regions in Italy (the Corno Grande in the Gran Sasso massif, at 2,914 m, is the highest summit in the Apennines). The rivers, although numerous, are all seasonal except for the biggest, the Pescara and the Sangro. In the interior are the 500 km^2 of the Abruzzo National Park, where rare examples of Mediterranean flora and fauna survive (chamois, wolves, bears, golden eagles). The climate is varied: warm and dry on the coast, an alpine climate in the mountainous interior. Major roads and railway lines link the region to the south, west and north of Italy (Abruzzo western border lying less than 80 km due east of Rome).

3 GIS-Based Spatial Analysis

The production of electric energy from renewable source plants, being constituted by complex infrastructures that *need space*, can produce impacts on the natural environment. The clean energy quantification, that such technologies can produce, represents the value of sustainability that they have, in relation to interferences that they produce. The general methodology for analysis of solar radiation using GIS approach is summarised in Fig. 2. The time span, for which the average values of solar radiation have been calculated, goes from 1994 to 1999.

As a matter of fact, GIS techniques are efficiently exploited to analyse the effects of various factors, including the above mentioned thematic maps.

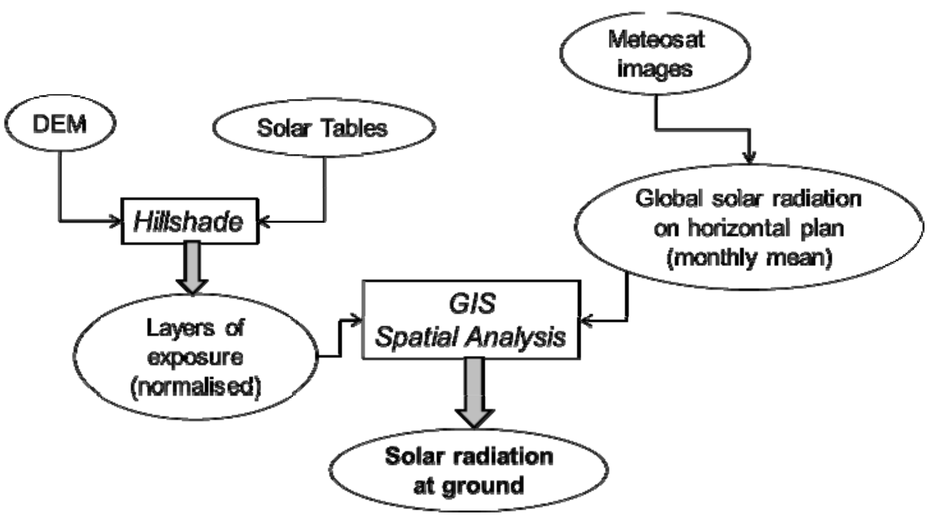

Fig. 2. General methodology schema

3.1 Spatial Distribution of Global Solar Radiation at Ground Level

The estimation method is based on the fact that the amount of solar radiation [13], reaching a certain portion of the land surface [14], is statistically correlated to the cloud cover on it. In addition, topographical characteristics such as latitude, slope, aspect and shadow cast, can affect solar radiation. In general, insolation is the result of the interactions between all these factors [15]. To determine solar radiation over an entire region, different approaches have been developed and described in literature [16, 17, 18, 19 and 20]. These studies create spatial databases of solar radiation using different interpolation techniques or calculate solar irradiance directly from meteorological geostationary satellites (e.g. the European based Meteosat).

In order to define the coverage of solar radiation on the ground, has been implemented a spatial analysis of land detected values by the program "The global solar radiation on the ground in Italy" compiled by ENEA [21], a specific database, extended at national level and offering free online access. The global solar radiation on Italy was estimated by processing images transmitted from the satellite Meteosat secondary band in the visible.

The monthly mean values of daily radiation on an horizontal plane thus estimated, were compared with those obtained from data measured by ground stations of the Central Office for the Italian Air Force Meteorological and of the agro meteorological National Network of Ministry of Agriculture. The average annual difference between the two sets of values is of 6-7%.

For this work are provided monthly data on Italy's radiation and monthly average daily values for the Abruzzo municipalities. The spatialisation of ground solar radiation data [2, 22] was a necessary step to implement the methodology discussed in this study.

The basic data required for the study are listed below:

- **DEM** (Digital Elevation Model), spatial resolution 20 m (Fig. 3).
- **Basic geographical layers:** vector databases, such as urban areas, road network, hydrography network, municipal boundaries, regional boundaries, etc.
- **Solar tables and charts:** data collection of the basic parameters of the solar azimuth angle and solar altitude angle, necessary to develop the basis of exposure.
- **Solar radiation:** data and results coming from the activity carried out by ENEA for the estimation of global solar radiation on a horizontal plane in Italy through the development of secondary images transmitted by satellite in the Meteosat visible band.

Digital elevation model has provided the structural basis for constructing thematic maps of solar radiation. The digital elevation model used in this work is derived from remote sensing data and is supplied in raster format: digital images in which each cell contains the altitude average value of the represented area.

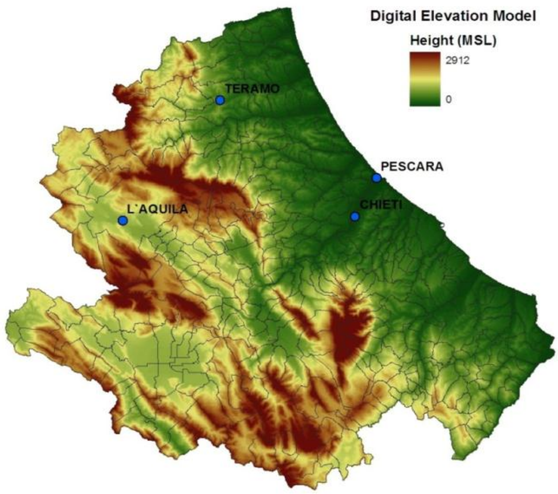

Fig. 3. Digital Elevation Model of Abruzzo region

3.2 Calculation of Average Slope

The *hillshade* GIS function [23], derived from Digital Elevation data Model, is a method to determine the hypothetical illumination of a surface, modelling the exposure surface using the shaded topography. On the setting of a hypothetical light source position, *hillshade* creates a hypothetical illumination of the topography and calculates the illumination level for each pixel. It's possible to compute the duration and intensity of insolation in a certain area, based on parameters of azimuth and altitude of the sun. In the table 1, 2 and 3 are shown the values used for the calculation.

Table 1. Solar Tables sunshine (Sshine) and sunset (Sset) values

Day	Sshine (CET)	Sset (CET)	Length of the day	Time equation	Eccentricity factor
Jan-17	7h 36'	16h 53'	9h 17'	-9'20"	10.340
Feb-16	7h 06'	17h 32'	10h 26'	-14'14"	10.251
Mar-16	6h 22'	18h 07'	11h 45'	-9'21"	10.108
Apr-15	5h 30'	18h 40'	13h 10'	-0'14"	6,897222
May-15	4h 49'	19h 13'	14h 24'	3'56"	6,790972
Jun-11	4h 33'	19h 35'	15h 02'	0'48"	6,729861
Jul-17	4h 47'	19h 34'	14h 47'	-6'01"	6,717361
Aug-16	5h 17'	19h 02'	13h 45'	-4'41"	6,76875
Sep-15	5h 48'	18h 13'	12h 24'	4'39"	6,865278
Oct-15	6h 21'	17h 20'	10h 59'	14'25"	10.059
Nov-14	6h 59'	16h 41'	9h 42'	15'20"	10.222
Dec-10	7h 28'	16h 27'	8h 59'	7'08"	10.319

Table 2. Solar altitude angle values

	Jan-17	Feb-16	Mar-16	Apr-15	May-15	Jun-11	Jul-17	Aug-16	Sep-15	Oct-15	Nov-14	Dec-10
03:00 CET												
04:00 CET												
05:00 CET					1°48'	4°21'	2°02'					
06:00 CET				5°25'	12°17'	14°34'	12°16'	7°38'	2°12'			
07:00 CET			7°01'	16°29'	23°12'	25°20'	23°03'	18°37'	13°15'	7°00'	0°13'	
08:00 CET	3°50'	9°12'	17°44'	27°27'	34°16'	36°22'	34°05'	29°40'	24°02'	17°10'	9°47'	4°51'
09:00 CET	12°30'	18°34'	27°41'	37°55'	45°07'	47°22'	45°05'	40°24'	34°04'	26°13'	18°04'	12°59'
10:00 CET	19°34'	26°26'	36°15'	47°12'	55°08'	57°49'	55°30'	50°12'	42°40'	33°29'	24°32'	19°22'
11:00 CET	24°27'	32°06'	42°32'	54°09'	63°01'	66°32'	64°16'	57°54'	48°44'	38°08'	28°32'	23°27'
12:00 CET	26°39'	34°52'	45°29'	57°06'	66°19'	70°40'	68°52'	61°33'	50°59'	39°23'	29°33'	24°48'
13:00 CET	25°52'	34°15'	44°25'	55°00'	63°13'	67°28'	66°37'	59°37'	48°47'	37°00'	27°28'	23°14'
14:00 CET	22°12'	30°22'	39°36'	48°37'	55°26'	59°10'	58°59'	52°59'	42°44'	31°26'	22°32'	18°58'
15:00 CET	16°06'	23°49'	31°59'	39°38'	45°28'	48°52'	49°00'	43°41'	34°10'	23°31'	15°23'	12°26'
16:00 CET	8°08'	15°20'	22°36'	29°19'	34°38'	37°54'	38°08'	33°10'	24°09'	14°04'	6°35'	4°12'
17:00 CET		5°35'	12°12'	18°23'	23°34'	26°50'	27°04'	22°10'	13°22'	3°39'		
18:00 CET			1°16'	7°19'	12°38'	16°01'	16°09'	11°08'	2°18'			
19:00 CET					2°09'	5°43'	5°41'	0°23'				
20:00 CET												
21:00 CET												

Table 3. Azimuthal angle values

	Jan-17	Feb-16	Mar-16	Apr-15	May-15	Jun-11	Jul-17	Aug-16	Sep-15	Oct-15	Nov-14	Dec-10
03:00 CET												
04:00 CET												
05:00 CET					113°52'	117°30'	117°25'					
06:00 CET				97°54'	104°11'	108°05'	107°49'	102°00'	92°31'			
07:00 CET			80°44'	87°52'	94°38'	98°53'	98°29'	92°11'	82°19'	72°07'	65°00'	
08:00 CET	56°58'	63°27'	69°59'	77°09'	84°26'	89°13'	88°43'	81°47'	71°20'	61°03'	54°23'	52°48'
09:00 CET	45°50'	51°50'	57°48'	64°41'	72°27'	77°58'	77°29'	69°44'	58°35'	48°21'	42°25'	41°29'
10:00 CET	33°15'	38°27'	43°16'	48°57'	56°36'	62°58'	62°48'	54°20'	42°52'	33°24'	28°45'	28°42'
11:00 CET	19°05'	22°58'	25°36'	28°12'	33°19'	39°39'	40°48'	33°07'	23°11'	15°58'	13°27'	14°31'
12:00 CET	3°44'	5°42'	5°06'	2°21'	0°36'	2°53'	7°05'	4°55'	0°07'	-3°02'	-2°50'	-0°33'
13:00 CET	-11°52'	-12°04'	-16°05'	-24°02'	-32°21'	-35°24'	-29°53'	-24°43'	-22°58'	-21°42'	-18°54'	-15°36'
14:00 CET	-26°41'	-28°47'	-35°15'	-45°46'	-55°58'	-60°24'	-55°54'	-48°17'	-42°42'	-38°23'	-33°41'	-29°41'
15:00 CET	-40°03'	-43°31'	-51°13'	-62°15'	-72°00'	-76°11'	-72°40'	-65°15'	-58°26'	-52°34'	-46°44'	-42°21'
16:00 CET	-51°50'	-56°12'	-64°25'	-75°09'	-84°04'	-87°47'	-84°52'	-78°10'	-71°12'	-64°41'	-58°11'	-53°35'
17:00 CET		-67°18'	-75°44'	-86°05'	-94°18'	-97°36'	-95°01'	-88°57'	-82°13'	-75°24'		
18:00 CET			-86°05'	-96°11'	-103°52'	-106°49'	-104°24'	-98°52'	-92°25'			
19:00 CET					-113°32'	-116°10'	-113°51'	-108°44'				
20:00 CET												
21:00 CET												

To each pair of values (altitude angle of the sun and solar azimuth angle) respectively in table 2 and table 3, corresponds a precise position of the sun across the sky, and so all surfaces are more or less illuminated, depending on their position relative to the sun. The solar radiation coming from space, for the purposes of our analysis, can be considered constant. The angle of incidence on the earth's surface, depurated of all those factors definable atmospheric and climatological, determines the effective power. So the objective of the study has been to develop surfaces of daily illumination where the exposure average values were expressed.

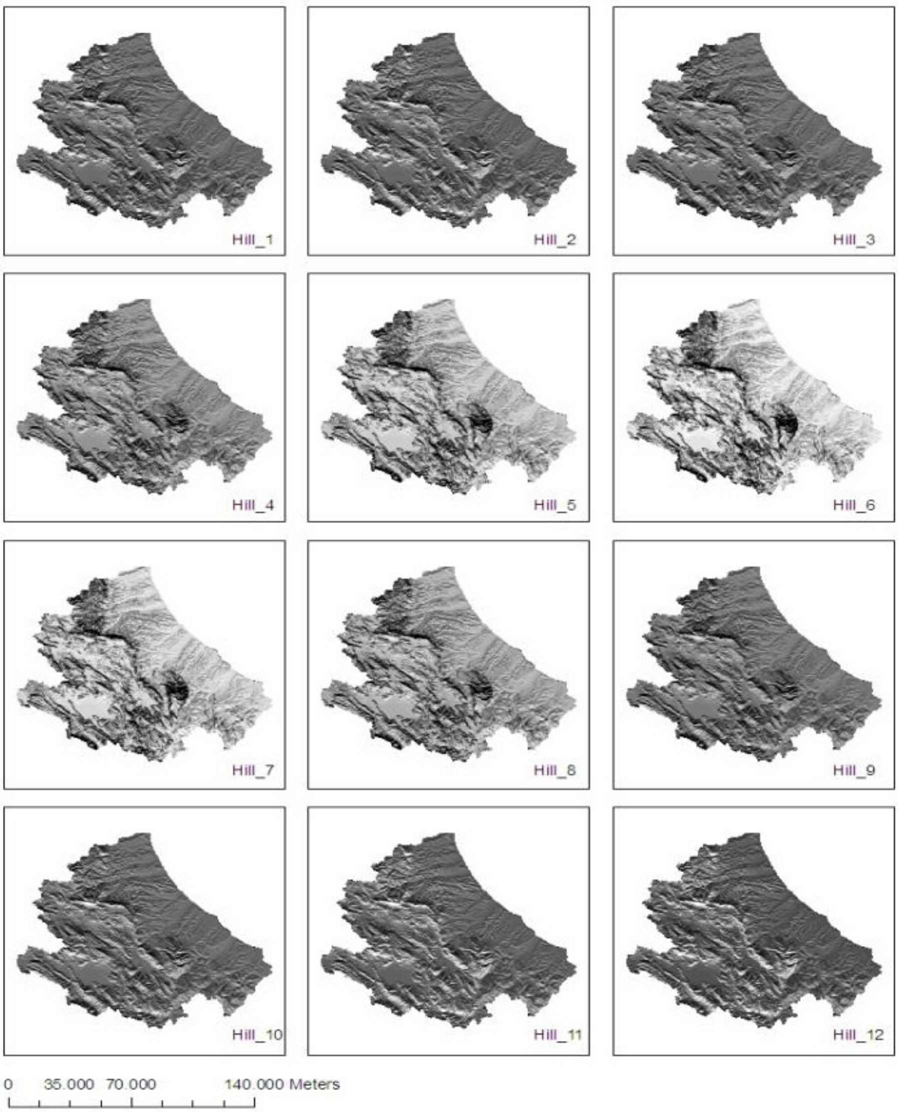

Fig. 4. Monthly exposure maps produced for a reference year

The thematic layers processing has been completed in ESRI ArcGIS environment [23], using spatial analysis and Map Algebra procedures: thematic maps on average daily values of radiation for the month they relate have been produced. In particular, the computing procedure used, has allowed the creation of 12 basic maps (Fig. 4) coming from the processing of 146 raster layers of exposure (according to the values reported in Tab. 1 and Tab. 2). These thematic maps have been obtained as result of the application of the *hillshade* function to DEM layer information.

To obtain the spatialisation of solar radiation values the maps of Fig. 4 were intersected with data of global solar radiation, that has been estimated processing secondary images transmitted from the satellite Meteosat [18] on visible band for the reference period from 1994 to 1999 [21]. Such data on solar radiation are available for all the national territory, for municipalities with at least 10,000 inhabitants and smaller municipalities with at least 5,000 inhabitants in sparsely populated places.

3.3 Estimation of Solar Electricity Potential

In order to estimate the potential solar electricity generation *E* [kWh], by PV configuration, the following formula has been used:

$$E = INS * SUP * \mu * v * K \quad \text{[kWh]} \tag{1}$$

This formula, derived from the one proposed by Šúri et al. [24], has been customised for our research purposes and with the intention to fit a real local situation. The following parameters have been made explicit:

- *INS* is the value of daily, monthly or annual insolation;
- *SUP* is the surface (expressed m^2) taken up by solar module (the values are derived from the dimensions declared by the manufacturer);
- μ is the average yield of photovoltaic cell (16%);
- v is the yield of the photovoltaic system (defined as a set of panels, inverters and electrical panels), usually ranging from 0.70 and 0.86;
- *K* is the reduction coefficient, defined to take into account possible shading effects (approximately ranging from 0.95 and 0.97) [25].

4 Results

The distribution and values of solar radiation on the ground are the results of analysis definable of fundamental importance for assessing the energetic potential of a territory. Knowledge of resources and their location represents a key step in planning for sustainable development [26].

Operatively several GIS layers (in raster format) have been produced, containing information about solar radiation at ground for the entire territory of Abruzzo region.

Starting from the processing of available data (1994-1999 interval), the relative thematic maps, reporting the average monthly values of solar radiation at ground, have been produced for each month of a reference year (Fig. 5).

Then, all the information obtained according the above described procedure have been synthesised in a single thematic map, reporting the values of solar radiation at ground for a whole year (Fig. 6). Once obtained the solar radiation values at ground, it has been possible to estimate the potential production from photovoltaic system, by applying the formula (1).

The map in Fig. 8 represents the potential solar electricity potential energy production from photovoltaic systems, assuming installations of 3 kW_p installed peak power. Moreover, from this map, it is possible to locate the areas potentially eligible to home an energy production plant from PV. To this end, the present study has evolved in defining where and how much it's possible to exploit this energy source, without constraints due to land use and local regulations.

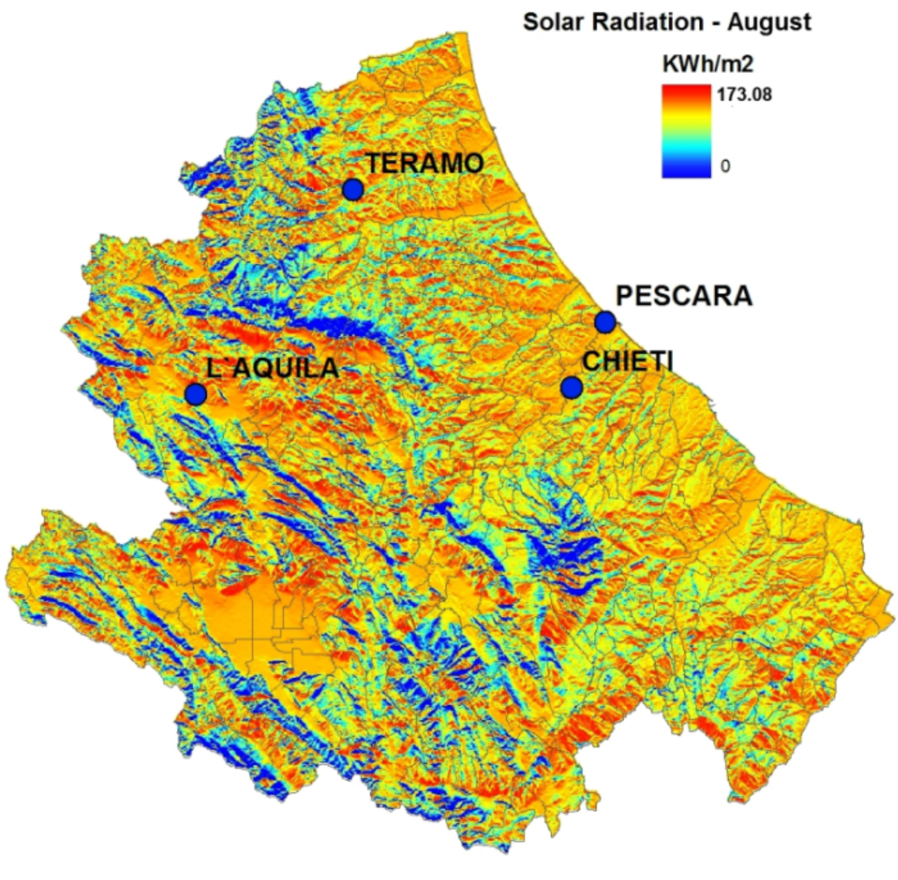

Fig. 5. Solar radiation at ground map for Abruzzo region: August month values

First of all, have been identified the places (*energy areas*) potentially suitable for the installation of a photovoltaic plant, net of all possible constraints. The constraints concern valuable areas such as parks, SPA, SIC, archaeological areas, landscaping, etc., and concern also areas of ascertained use like agricultural land areas, residential areas, infrastructures such as factories, highways, etc.. The remaining areas have been combined with the map of the solar radiation.

Subsequently, have been consulted planning tools like Urban Master Plans (at municipal level) and specific zoning laws, Landscape Plan, Energy Plan (at regional level) to produce the final potential energetic map. In fact, information about constraints reported in these documents, have been used inside GIS environment, in order to eliminate those areas not meeting the criteria of selection. The remaining areas (not subject to any kind of limitation) have been combined with the thematic map of the solar radiation at ground. After identifying these areas, it's necessary add another selection criteria, dictated by the terrain topography (northern exposure, steep slopes, etc.).

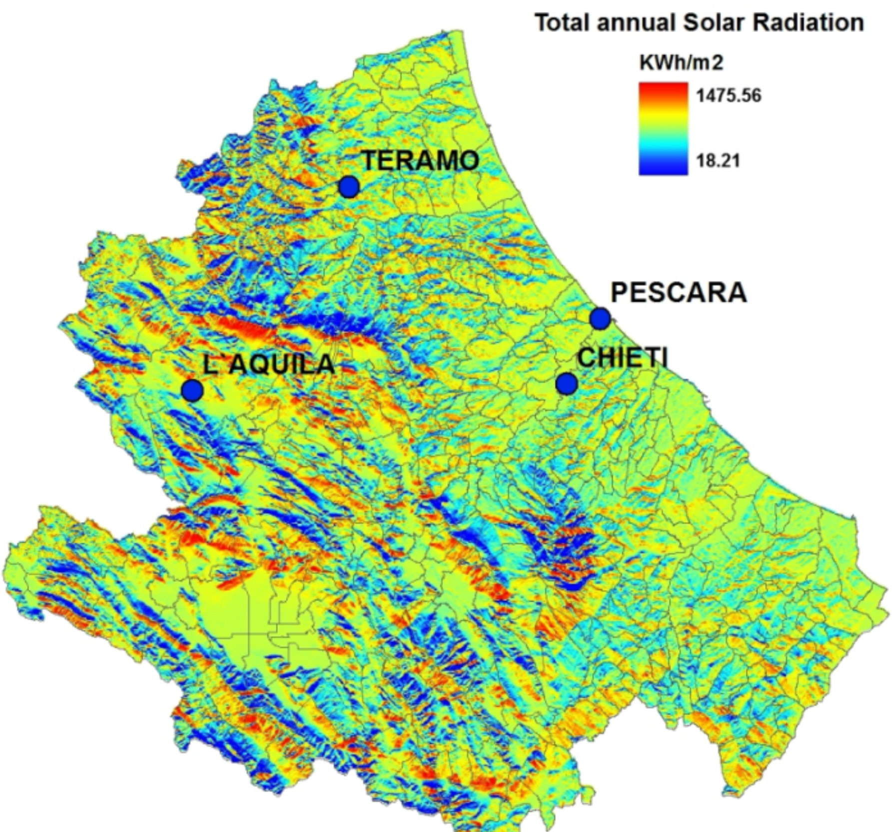

Fig. 6. Solar radiation at ground map for Abruzzo region: total annual values

To verify the real situation at the ground and to assess the feasibility of installations, the produced map has been checked using a set of thematic layers, such as DBPrior10K [27] GIS data (Administrative boundaries, Road network, Railways, etc., at 1:10,000 scale), Regional Technical Maps (RTM, at 1:10,000 scale) and digital aerial ortho-photos (available for consultation and visualization at the Italian National Geoportal [28], PCN). These layers have been used not only as reference and control, but also to take into account the presence of urbanized areas and other infrastructures (Fig. 7).

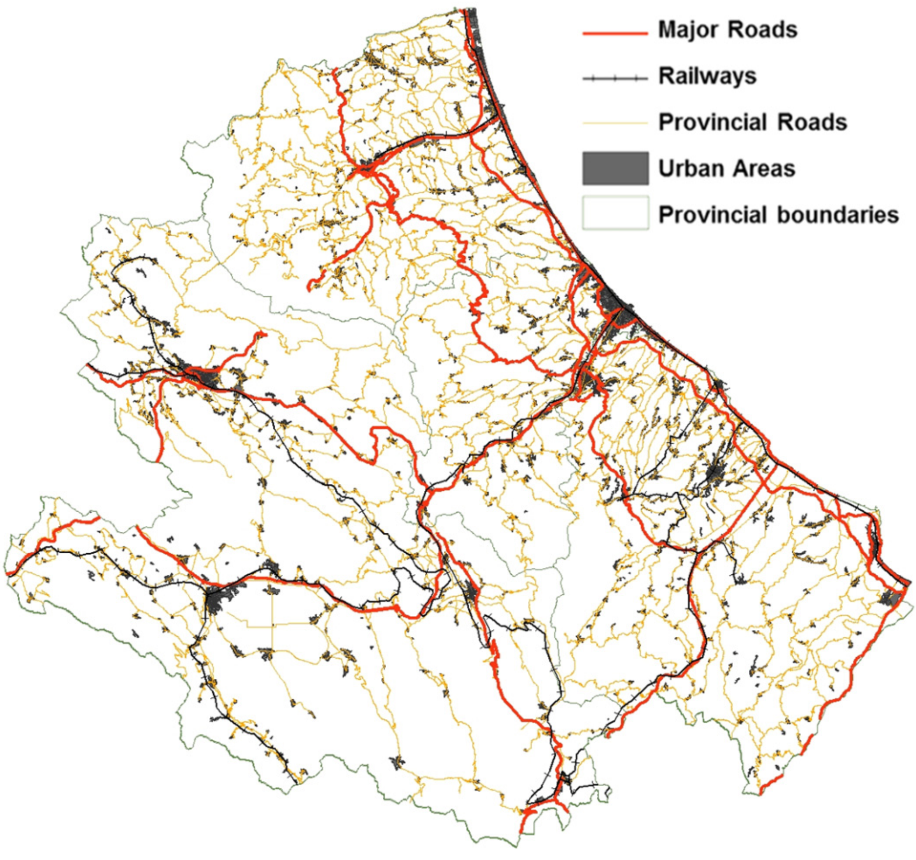

Fig. 7. Map of Urban areas and transportation network in the Abruzzo Region

An additional test was aimed to analyse the situation of the potential energy area both from the point of view of viability and of proximity to the electricity network (MV / LV network). The latter factor is fundamental to evaluate the capability to enter the energy produced in the national distribution network.

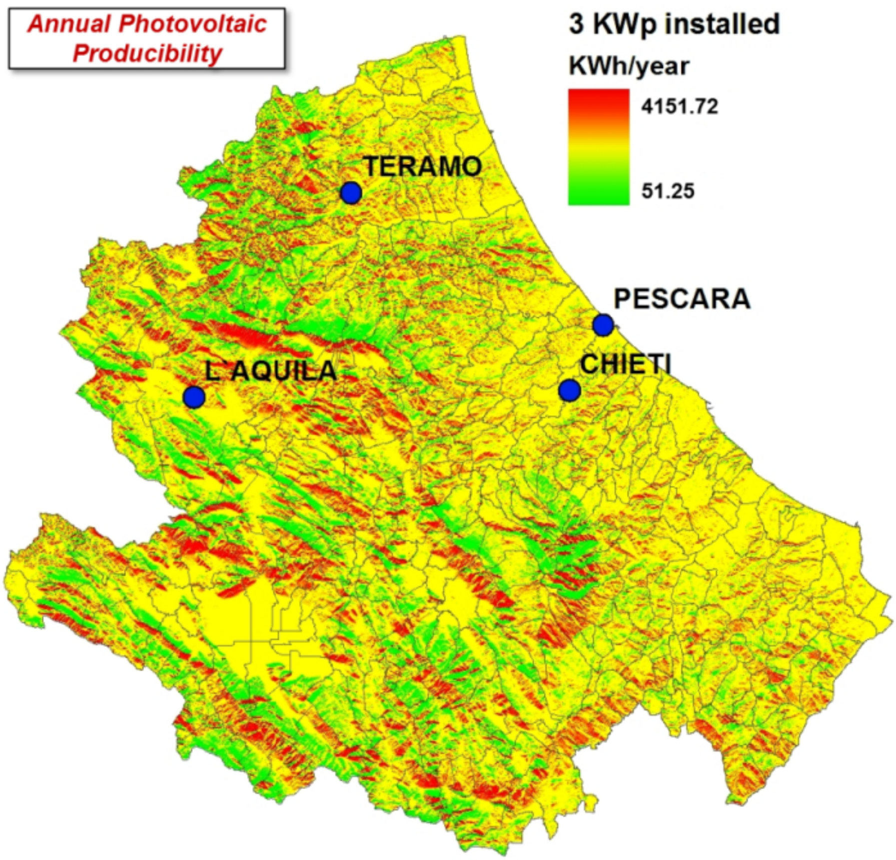

Fig. 8. PV potential production map

In particular, the distance analysis from existing energy production plants represents one of the future research directions, utilising - among others - VHR satellite images and digital cartography (RTM) in order to better evaluate the feasibility of the installations within the study area.

Finally, at the end of this further selection, the thematic layer enclosing only the areas potentially suitable for housing electricity production plants from PV has been obtained (Fig. 9).

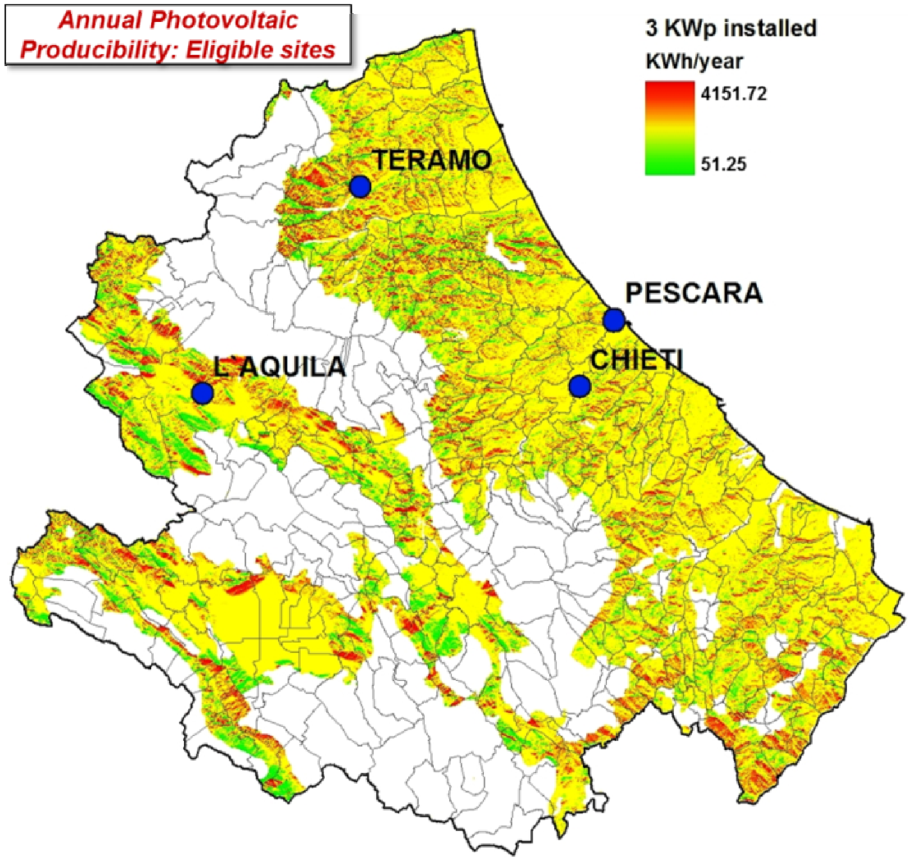

Fig. 9. Eligible sites for siting production plants from PV

5 Conclusions

In an overview of the issues that revolve around energy policy, the use of renewable energy sources has become a priority [29]. In fact, as already outlined by the 2009/28/EC Directive of the European Parliament and Council [1] (climate change objectives for 2020), all European countries are called to bring down the level of emissions of greenhouse gases in the atmosphere.

Many international bodies, as the UN Commission for Sustainable Development (UNCSD), the European Environmental Agency (EEA), the Organization for Economic Cooperation and Development (OECD), Eurostat (Statistical Office the European Community) and the IEA (International Energy Agency) are working on development plans in this direction [30].

The informatics layers realized for this study have proven a valuable tool for the analysis of the critical environmental purposes, and also at detailed scale a good result has been obtained. An accurate analysis of the environmental study has actually allowed to draw up clear and detailed entities and locations of possible with the ecosystem. The infrastructures insertion, both linear and areal, determines not only land consumption, due to the permanent occupation of the installations, but also produces influences on surroundings although minimum.

The greatest risk that could derive from insertion of the infrastructures, for the energy production from renewables, might be a micro-fragmentation and a micro-consume of the natural habitat. That circumstance doesn't show strong interference values, when analysed individually, but when considered in its entirety and cumulatively to all possible interventions in the area, could results in a high risk of degradation.

The development of information layers on the values and distribution of solar radiation is an important step for the evaluation of planning type both in energy and environmental field.

In conclusion we can say that through this study it was shown how GIS-based tools are able to analyse, interpolate and locate all the information necessary to make a complex environmental research [31]. Of course, the quality of input data determine the degree of survey accuracy and is a necessary condition to develop, in an appropriate way, environmental studies.

References

1. European Union: Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0028:EN:NOT
2. Šúri, M., Huld, T.A., Dunlop, E.D.: PV-GIS: A web-based solar radiation database for the calculation of PV potential in Europe. International Journal of Sustainable Energy 24(2), 55–67 (2005)
3. Pearce, J.M.: Photovoltaics: a path to sustainable futures. Futures 34(7), 663–674 (2002)
4. Hiremath, R.B., Shikha, S., Ravindranath, N.H.: Decentralized energy planning; modelling and application—a review. Renewable and Sustainable Energy Reviews 11(5), 729–752. Elsevier (2007)
5. Benson, J.F., Roe, M.H.: Landscape and sustainability, p. 423. Spon Press - Taylor & Francis Group, London (2000)
6. Antrop, M.: Changing patterns in the urbanized countryside of Western Europe. Landscape Ecology 15(3), 257–270 (2000)
7. Fichera, C.R., Modica, G., Pollino, M.: GIS and Remote Sensing to Study Urban-Rural Transformation During a Fifty-Year Period. In: Murgante, B., Gervasi, O., Iglesias, A., Taniar, D., Apduhan, B.O. (eds.) ICCSA 2011, Part I. LNCS, vol. 6782, pp. 237–252. Springer, Heidelberg (2011)
8. Council of Europe: European Landscape Convention, CETS No.176, Florence (2000), http://conventions.coe.int/Treaty/Commun/QueVoulezVous.asp?CL=ENG&NT=176 (retrieved on February 2012)
9. Ŝúri, M., Hofierka, J.: A new GIS-based solar radiation model and its application to photovoltaic assessments. Transactions in GIS 8(2), 175–190 (2004)
10. Caiaffa, E.: Geographic Information Science in Planning and in Forecasting. In: Institute for Prospective Technological Studies (eds.) Cooperation with the European S&T Observatory Network. The IPTS Report, vol. 76, pp. 36–41. European Commission JRC-Seville (2003)

11. Caiaffa, E.: Geographic Information Science for geo-knowledge-based governance. In: 8th AGILE Conference on Geographic Information Science, pp. 659–664. IGP Istituto Geografico Portugues, Estoril Portugal (2005)
12. Huld, T.A., Šúri, M., Kenny, R.P.: Estimating PV performance over large geographical regions. In: Conference Record of the IEEE Photovoltaic Specialists Conference (2005)
13. Zaksek, K., Podobnikar, T., Ostir, K.: Solar radiation modeling. Computers & Geosciences 31, 233–240 (2005)
14. Joint Research Centre (JRC) - Institute for Energy and Transport (IET): Photovoltaic Geographical Information System (PVGIS), `http://re.jrc.ec.europa.eu/pvgis/` (retrieved on February 2012)
15. Duffie, J.A., Beckman, W.A.: Solar Engineering of Thermal processes, 2nd edn. John Wiley & Sons, USA (1991)
16. Hutchinson, M.F., Booth, T.H., McMahon, L.P., Nin, H.A.: Estimating monthly mean values of daily total solar radiation for Australia. Solar Energy 32, 277–290 (1984)
17. Beyer, H.G., Czeplak, G., Terzenbach, U., Wald, L.: Assessment of the method used to construct clearness index maps for the new European solar radiation atlas (ESRA). Solar Energy 61(6), 389–397 (1997)
18. Zelenka, A.: Combining METEOSAT and surface network data: a data fusion approach for mapping solar irradiation. In: Proceedings 10th Meteosat Scientific Users Conference, Switzerland, pp. 515–520 (1994)
19. Pellegrino, M., Caiaffa, E., Grassi, A., Pollino, M.: GIS as a tool for solar urban planning. In: Proceedings of 3rd International Solar Energy Society Conference-Asia Pacific Region (ISES-AP 2008), Sydney, Australia, November 25-28 (2008)
20. Cebecauer, T., Huld, T., Šúri, M.: Using high-resolution digital elevation model for improved PV yield estimates. In: Proceedings of the 22nd European Photovoltaic Solar Energy Conference, Italy, pp. 3553–3557 (2007)
21. Italian Atlas of solar radiation, `http://www.solaritaly.enea.it/index.php` (retrieved on February 2012)
22. Hofierka, J., Šúri, M.: The solar radiation model for Open source GIS: implementation and applications. In: Proc. of the Open Source GIS GRASS Users Conference, Italy (2002)
23. ESRI ArcGIS Resource Center, `http://resources.arcgis.com/`
24. Šúri, M., Huld, T.A., Dunlop, E.D., Ossenbrink, H.A.: Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy 81, 1295–1305 (2007)
25. Liu, B.Y.H., Jordan, R.C.: The Long-Term Average Performance of Flat-Plate Solar Energy Collectors. Solar Energy 7(2), 53–74 (1963)
26. Carriona, J.A., Estrelaa, A.E., Dolsa, F.A., Torob, M.Z., Rodriguez, M., Ridaob, A.R.: Environmental decision-support systems for evaluating the carrying capacity of land areas: Optimal site selection for grid-connected photovoltaic power plants. Renewable and Sustainable Energy Reviews 12, 2358–2380 (2008)
27. DBPrior10K GIS layers, `http://www.centrointerregionale-gis.it/DBPrior/DBPrior.asp` (retrieved on February 2012)
28. Italian National Geoportal, `http://www.pcn.minambiente.it` (retrieved on February 2012)
29. Sims, R.E.H.: Renewable energy: a response to climate change. Solar Energy 76(1-3), 9–17 (2003)
30. International Energy Agency (IEA): Key World Energy Statistics. International Energy Agency. OECD Publication Service, Paris (2008)
31. Muselli, M., Notton, G., Poggi, P., Louche, A.: Computer aided analysis of the integration of renewable energy systems in remote areas using a geographical information system. Applied Energy 63(3), 141–160 (1999)