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ORIGINAL PAPER
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THE TERRITORIAL ORDERING FOR THE DIVERSIFICATION OF THE ELECTRICAL SYSTEM. CASE STUDY: ISLA DE LA JUVENTUD

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ABSTRACT

In the year 1882 when the first power plant designed by Thomas Edison began operations in Wisconsin, United States, the price of fuels was little more than symbolic and there was no knowledge about the environmental damage caused by the energy exploitation of fossil fuels. Currently the situation is completely different, with an unstable and expensive oil price, as well as an environmental awareness forged in the consequences of the over-exploitation of natural resources, the structuring of a sustainable energy matrix constitutes a challenge that is sustained in the use of renewable energies available territorially. For this, it will be necessary to bring the techniques and tools of territorial planning closer to the tasks of energy development, on the basis of achieving adequate planning of the space for the use of the endogenous energy resources of the territories. The objective of the work consists of proposing the application of a methodology for the study of the application of renewable sources, starting from determining the viable physical areas for their introduction, applying techniques of land use planning through a GIS. The Isla de la Juventud is a special municipality of the island of Cuba with significant renewable potential, however, the limitations inherited from traditional development models restricts the sustainable development of the territory from being achieved. In the period from 2010 to 2014, two projects were carried out to contribute to the diversification of the energy matrix, through the application of a territorial energy development model. This article takes up the main results of these projects, considering that they are currently valid. In this sense, an analysis of the

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energy matrix on the Isla de la Juventud was carried out at present and the projections until 2030, from a perspective of land use planning; with the aim that can get constituted as a guide for organization and planning of the integrative process of the renewable energies, in the diversifying process of the energetic matrix of Cuba.

Keywords: territorial ordering, geospatial planning, Renewable Energy Sources (RES), sustainable development, Geographic Information Systems (GIS)

INTRODUCTION

The phenomenon of climate change affects all continents, especially in poor and developing countries, the situation is usually more dramatic as it is linked to the high degree of poverty. The gradual increase in temperature derived from global warming influences the progressive melting of glaciers and polar ice caps and with it the progressive increase in sea level, with a succession of phenomena and meteorological events that are increasingly violent. The desiccation and acidity of the soils go hand in hand with the limitations for access to drinking water and agricultural irrigation, to create an unstable situation in access to food. These factors combined with economic instability create a very complex situation for human beings (ONU, 2021a).

The report of the expert group notes that climate change is a widespread phenomenon, manifesting rapidly and gradually intensifying on a global scale. Every day changes are observed in the Earth's climate in all regions and in the climate system as a whole. Some of the changes are unprecedented in human history and the situation is practically irreversible. However, it is suggested that the sustained decrease in greenhouse gas emissions can limit the catastrophic effects of climate change (ONU, 2021b).

Human activity has been responsible for the increase in environmental temperature by 1.1°C compared to pre-industrial times. It is a situation that is bringing devastating consequences for the environment. The high temperatures recorded in the last decade would not have been possible without human influence on the climate system. The anthropic influence on the warming of the atmosphere, the ocean and the land is undeniable (Carrere, 2021).

For Latin American and Caribbean countries with deep structural poverty and low availability of financial resources, the current and future situation to face the consequences and the necessary adaptation to the consequences derived from climate change is overwhelming.

The anthropic use of energy is closely associated with the causes that trigger climate change. On average, for each MWh of energy, 0.25 tons of oil is consumed, and 0.9 tons of CO_2 are emitted into the atmosphere (Berrio-Monsalve et al., 2015; Ihobe, 2013; Montesino & Frejo, 2012).

The use of renewable sources is not a new topic. Its use is linked to the struggle of human beings to satisfy their energy needs and currently constitutes an alternative to sustain sustainable development and face the energy crisis of recent years (Pereira, 2015).

The global crisis caused by COVID-19 has severely hit the fossil fuel industry and in this situation the use of renewable sources has reached its point of greatest profitability, according to a report by the United Nations Program For the environment. The report reflects that in 2019 the capacity of non-hydro renewable sources of more than 50 MW grew by 184 GW, 12% more than in 2018. This increase was achieved with investments of 282.2 billion dollars. The costs of electricity generated with photovoltaic systems for the second half of 2019 were 83% lower than the previous decade (ONU, 2020).

Specifically, Cuba is a Caribbean country that has an estimated population of 11,326,616 people and a population density of 103 inhabitants per km^2 (Banco Mundial, 2020). Subjected to a strong political, economic, and cultural blockade since in 1961 the president of the United States of America Dwight Eisenhower decreed an economic embargo that in the

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following years has been intensified in such a way that at present it is extraterritorially prohibited that any country in the world carries out commercial actions with Cuba (Padinger, 2021).

The block established by the United States for Cuba accumulates damage in six decades amounting to 147,853 million dollars (ONU, 2021c). With an affectation that plunges the Caribbean country into a deep economic crisis and that despite this has not managed to bend the political system chosen by Cuban society. Under difficult economic and social conditions, Cubans have had to work and survive, where the supply of electrical energy constitutes a real challenge to satisfy the growing demand for electricity posed by the economic and social sectors.

In 2018, the Cuban electricity system generated 15,549.4 GWh, of which 6,373.8 GWh were consumed by the public sector and 9,326.5 GWh by the private sector. The residential sector consumed 58% of the energy generated in the Country (ONEI, 2019). 94% of the energy generated is made using fossil fuels and 6% comes from the participation of renewable energy sources. 48% of the fuels used in generation require their importation, at prices that in addition to the product include premium values imposed by the suppliers, to compensate for the risk of being sanctioned by the laws derived from the extraterritorial US blockade, to which add up the costs of freight and insurance. In most cases, the fuel must be transported from places far away to the Country (Menéndez-Ramos & Iglesias-Martínez, 2019).

It is fair to point out that Cuban thermoelectric plants account for 59% of the country's generation and some of them have been in operation for several years, so that nowadays the occurrence of technical interruptions that affect the reliability of the electricity service is frequent. For the maintenance and repair of these plants, it is necessary to acquire the parts and components in the international market, subject to the same limitations imposed by the fierce extraterritorial blockade applied by the United States of America.

For the reasons previously analyzed, it is a priority for Cuba to move towards a sustainable energy matrix, which manages to reduce the consumption of fossil fuels and gradually increase the use of renewable sources, which is an objective that is included in the development policy of renewable sources of energy and energy efficiency. This program defines the strategy of the electricity sector until 2030 and includes the National Electricity System Development Plan and the Oil Program aimed at increasing national oil production.

The need to achieve energetically sustainable territories and localities requires the solution of complex problems in the energy scheme, which lead to the search of alternatives for the use of energy sources that reduce environmental incidents and been less expensive. The use of renewable energy sources constitutes a different option, in the search for sustainable solutions to the energetical development of the territories. Despite this, it is not intended to ignore the importance that traditional systems still have in the supply of energy, to the point of underestimating them or proposing their total replacement by the renewables; it is about incorporating a model of energetical development with an integrative vision, that it seeks to relieve the enormous weight that rests today in the conventional fuels for the energy production.

When it comes to Renewable Energy Sources (RES), an adequate assessment is fundamental when dealing with coupling power supply with energy demand. Spatial and temporal variability play a crucial role in this process. In addition, the integration of a technology has always an important territorial impact, which is not easily detected by a merely technical approach. Therefore, the wide geographical dispersion that characterizes RES and the importance of evaluating their integration at a regional level fit perfectly with the potential of GIS analysis (Domínguez, 2002).

The use of GIS in the planning of energy infrastructures require the handled of different data sources, like line network topologies, weather data, land cover, land use, demographic data, and others. These tasks are tedious and large consumers of time and resources, being usually compromised by the lack of information, which is often not available or comes from sources with different characteristics. However,

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these data sources are often restricted by the data providers, limiting the possibilities of the analysis methods and the accuracy of the results (Díaz-Cuevas et al., 2021; Korkovelos et al., 2019; Resch et al., 2014). In the case of Cuba, the Enterprising Group GEOCUBA, has the purpose to elaborate and to commercialize information, technologies, products and services in the spheres of: geodesy, photogrammetry, remote sensing, hydrography, cartography, and other activities; in order to satisfy needs of the market related with the study and utilization of the geographic medium (EcuRed, 2020).

There are numerous examples where GIS has been used to support the planning process of renewable energy infrastructure. GIS can be used as an effective tool to carry out projects aimed at energy planning in territories, especially when it comes to diversifying the energy matrix from the use of renewable sources. They constitute a powerful informative tool in the process of sustainable structuring of the energy system in the medium term (Rodríguez, 2012).

There are experiences on the application of GIS on an international scale (IES, 2018). In 2000, the Center for Energy, Environmental and Technological Research located in Madrid, Spain, developed an application based on a GIS linked to the use of RES, with the aim of evaluating the regional potential of various types of decentralized electrification systems for their introduction in regional integration (Guerra & Domínguez, 2000).

In 2011, a group of researchers from the Institute of Electrical and Electronic Engineers (IEEE) used a GIS to integrate renewable energies into the electrical grid and make their use for transport, heat, cold and others feasible (Jacobson & Delucchi, 2011).

In the Latin American area, some projects have been developed related to the use of GIS for sustainable development, by combining RES with traditional systems. In Colombia, an integrated modeling platform was applied for sustainable energy planning (Quijano, 2012). The possibility of combining renewable self-consumption systems and those designed to provide energy directly to the grid, can reduce the costs of electricity service to users, preserve non-renewable natural resources that are used to generate electricity and help reduce the environmental impact derived from the use of fossil fuel in power generation.

Other projects similar to the previous one was carried out in Chile aimed at sustainable development through the use of renewable sources. In Costa Rica, these systems were used to project the demand for electricity in a distribution system. Countries like Mexico and Venezuela have also introduced GIS to develop the use of renewable resources. In Cuba it was used for energy planning with renewable sources and its integration with the traditional electrical system (Agostini et al., 2016; Jácome, 2008; Miranda et al., 2003; Rodríguez et al., 2011; Rodríguez et al., 2013).

Furthermore, in the identification of suitable places for wind (Díaz-Cuevas, 2018; Effat, 2014; Höfer et al., 2016) and solar farms (Díaz-Cuevas, et al., 2018b), as well as the mapping of renewable energy resources (Díaz-Cuevas et al., 2018a; Díaz-Cuevas et al., 2021).

In other cases, geospatial information and GIS software has been employed to support the decision making for renewable energy planning in rural areas. Some examples of those planning efforts are: OnSSET (Korkovelos, 2020; Mentis, 2017), REM (Ciller, 2020; Ciller et al., 2019), IntiGIS (Domínguez Bravo & Pinedo-Pascua, 2009; Torres-Pérez et al., 2021), Network Planner (Kemausuor et al., 2014; Ohiare, 2015), GEOSIM (Innovation Énergie Développement, 2021), RE2nAF (Moner-Girona et al., 2016) and (Bertheau et al., 2017; Blechinger et al., 2019).

In the period from 2010 to 2014, two projects were carried out[1] in order to contribute to the diversification of the energy matrix of the Isla de la Juventud, through the application of a territorial energy development model. This article pursues two

[1] Territorial energy planning with RES using GIS (SIGFRE) and ICT in territorial planning, studies of their impacts (environmental, natural, economic and social disasters) and the introduction of the regulatory framework of legal and technical standards (PR-0287); and Generation and commercialization of modern energy services based on renewable energies, case Isla de la Juventud (GP/CUB/05/001)

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objectives, first to reintroduce the main results of these projects, considering that they are currently valid. Second, to carry out an analysis of the energy matrix of the Isla de la Juventud at present and the projections until 2030, from a perspective of territorial ordering; in order that they can be constituted as a guide for the organization and planning of the integrating process of renewable energies, in the diversifying process of Cuba's energy matrix. The article does not focus on the present and future energy needs to be supplied by the different proposed systems, neither in the energy costs involved by each source or evaluation of the type of technology.

To meet the objective, this paper is structured as follows: first, the current situation of the Isla de la Juventud electro-energy generation system and the projections until 2030, are presented. Then, the main results of the two aforementioned projects are exposed: maps of the behavior of renewable resources (solar, wind, water and biomass), the study of protection standards and natural barriers existing in the territory for the implementation of photovoltaic systems connected to the grid in the Isla de la Juventud, the Geoportal and the territorial energy development model. Finally, the conclusions and a series of recommendations are presented based on the experiences in the projects.

MATERIALS AND METHODS

A GIS study is proposed to manage the viable space that exists in the territory of Isla de la Juventud to diversify the energy matrix by introducing renewable energy sources. It will be made from several thematic maps with polygonal, linear and punctual layers, which collects administrative information and that related to the energy management of the territory.

Study Area

Isla de la Juventud is the second largest island in the Cuban archipelago, occupying a territorial space of 2,419.27 km², including its keys and islets. It is geographically located in the southwestern part of the big island (see Fig. 1), in the Canarreos sub-archipelago, at a distance of 48.4 km from the Gulf of Batabanó (island of Cuba), which is the closest point to the main island (ONEI Isla de la Juventud, 2019). This position places it in the corridor of the hurricanes that annually hit the Caribbean region, classifying itself as a territory highly threatened by extreme hydrometeorological phenomena, among which are the tropical cyclones of great intensity, being frequently impacted by the destructive consequences of these meteorological events: the strong winds and the penetrations of the sea caused by the upwelling (Poder Popular I.J., 2010).

The island's population is around 83,801 inhabitants, and approximately 75% of the population is concentrated in three main settlements, Nueva Gerona, which is the capital, the town of La Fé and La Demajagua, which are located in the northern part of the territory and where there is the highest energy demand (ONEI Isla de la Juventud, 2019). In total, it has an installed capacity equivalent to 42 MW, depending in a high percentage of fossil fuels for its production. The supply of fuels, lubricants and other technological inputs necessary for generation is not available in the territory and they need to be transported to the Island from the island of Cuba.

In addition, the generation of electricity in the territory from the combustion of hydrocarbons is responsible for the annual emission of 47,377 tons of CO_2 into space (Alves et al., 2009; Poder Popular I.J., 2010), constituting the most pressing environmental monitoring element, since its production is constantly diametric to the generation of electricity. The island's power plants store and manage a daily capacity of approximately 450 m^3 of diesel fuel, 100 m^3 of fuel oil and 400 m^3 of lubricants (Rodríguez et al., 2017). The danger of environmental pollution caused by the consumption and management of hydrocarbons during the generation of electricity requires the permanent and rigorous application of a set of regulations and protection measures, which involve dedicating considerable human and material resources.

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Fig. 1. Location of the Isla de la Juventud (Cuba)
Source: own preparation based on Google (2021a, 2021b).

Taking on the alternatives of the renewables sources implies a challenge in terms of the structure of the current energy matrix, because it requires the gradual and progressive diversification of the system, based on the adequate use of the renewable resources existing in the territories. Also requires gradually transforming the philosophy and the traditional energy practice, promoted and sustained in a centralized format, towards a distributed generation and consumption way, more economical, efficient and respectful with the natural environment.

Regardless of whether the Cuban legal framework establishes energy management as a matter of strategic development of the Country with direct authority from the State, it must be borne in mind that from a technical point of view, the sustainable diversification of the energy matrix is a related matter. directly with the development and territorial ordering and therefore must be treated with the techniques and tools of this discipline. In many cases, the image possessed by the technicians and personnel in charge of making decisions about the territory does not correspond to the physical reality of the space. GIS can play an important role in promoting an approach on the notion of space to the physical, geographical, and social reality of territorial dynamics.

The work is descriptive and correlational cross-sectional, which will allow the collection of data and spatial information on the territory of Cuba and especially on the Isla de la Juventud, to analyze its impact on the sustainable management of the energy matrix. At the same time to investigate and describe the values that are related between energy management and the availability of renewable resources offered by the natural environment.

The introduction of technologies that take advantage of renewable sources requires an analysis of the availability of space and the relationships that take place during energy management to meet the growing needs demanded by the economic and social development of the territory.

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Current situation of the electric power generation system the of Isla de la Juventud

The Isla de la Juventud does not have deposits or sources of supply of conventional energy resources, having to incur considerable expenses for their transfer by sea, in order to guarantee the operation of the installed Power Plants (PP). However, there are renewable potentials that are distributed throughout the territory and that could be used for energy purposes, this will be analyzed in the next sections. The energy matrix (see Fig. 2) shows a prevalence of fossil fuel use of 95%. Wind energy represents 1%, biomass, with very low rates, does not affect the matrix, and solar only contributes 4%. Being isolated from the National Energy System, the cost of generation is very high due to the transportation of the raw material, and as the installed technology is imported in more than 90%, the sustainability of the system becomes difficult (Díaz, 2021).

The energy development strategy in this special municipality aims to achieve 24% penetration into the local system through Renewable Energy Sources (RES) by 2030, essentially with photovoltaic solar and forest biomass. In a first phase from 2020 to 2025, the intention is to increase the participation of the RES to 19%, after achieving stability in the network through the increase of another 14 Megawatts peak (MWp) of photovoltaic energy, and the installation of systems of accumulation for four Megawatts (MW) (Díaz, 2021).

In the second stage (2025 to 2030) 7 MWp and 6 MW of accumulation will be installed, which added to the previous ones complete the strategy of reaching 24%, as required by the country's policy; by then with greater stability, so it does not affect the service (Díaz, 2021). Even if the national energy matrix with clean energy is increased by 24%, the greatest weight of electricity production will continue to be from fossil fuel.

In the Fig. 3 can be seen the characteristics of the island's electro-energy system, where all the possibilities of using wind and solar energy are not yet exploited, generation is not used from the hydraulic potential that, although small, exists, as shown in the next section.

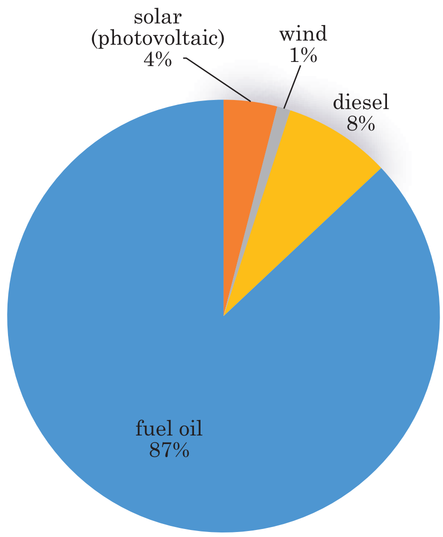

Fig. 2. Energy matrix of the Isla de la Juventud for the year 2020

Source: own preparation based on UNE Isla de la Juventud & Díaz (2021).

Materials

The employed materials are results of the projects, the first directed by the Centro de Investigaciones y Pruebas Electroenergéticas (CIPEL) and the second by the United Nations Industrial Development Organization (UNIDO).

The maps of the potentials are presented: solar, wind, water resources and biomass that exist in the Isla de la Juventud and that offer the possibility of being used for the energy diversification of the territory.

Solar radiation maps were got from published by the Solar and Wind Energy Resource Assessment (SWERA), with a resolution of 10 kilometers. The wind data were also obtained from SWERA, and contains a detailed high-resolution (1 km^2) wind energy resource at 20 meters of height (SWERA, 2005). The water potential (INRH, 2009). Finally, the Biomass potential map of Isla de la Juventud were acquired from GEOCUBA (GEOCUBA, 2006).

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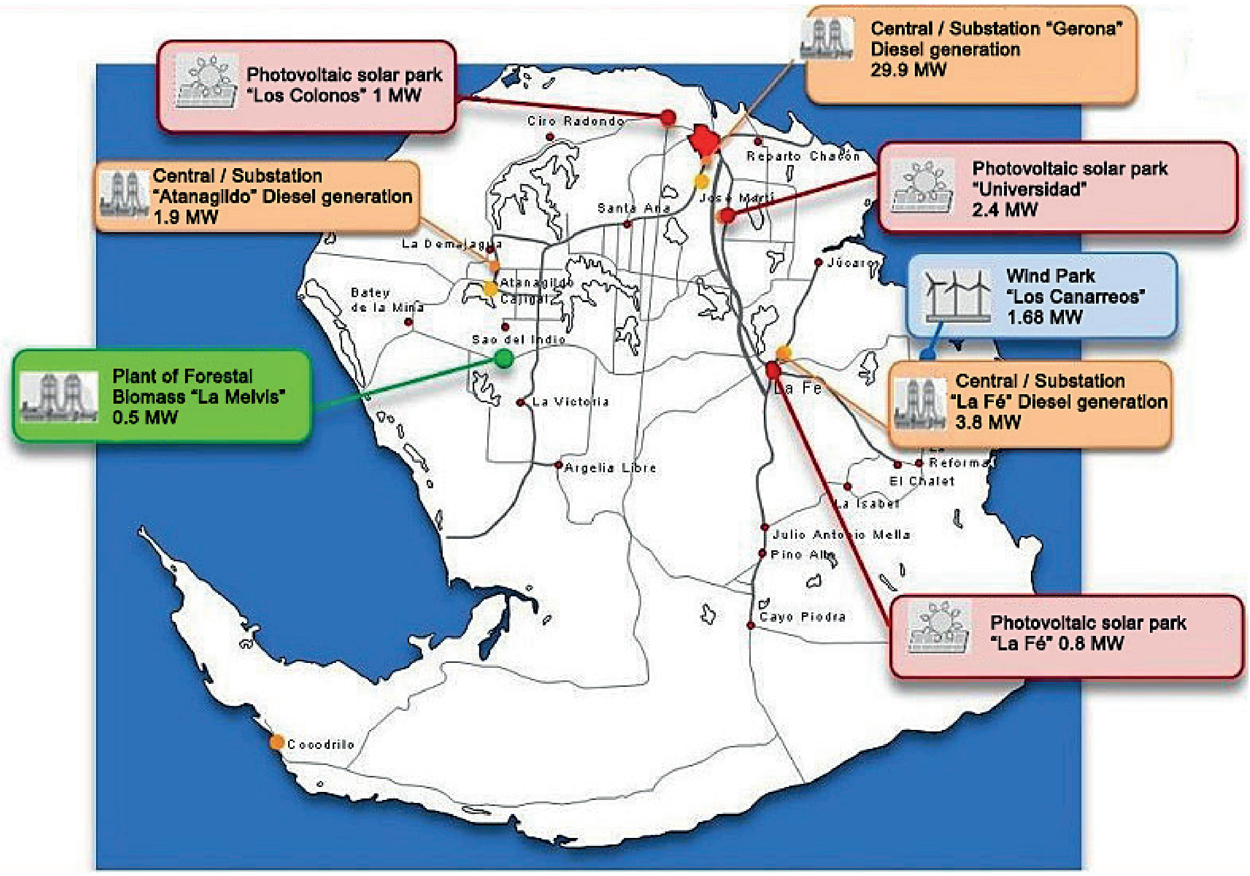

Fig. 3. Characteristics of the electrical system in the Isla de la Juventud
Source: adapted from UNE Isla de la Juventud & Díaz (2021).

The maps corresponding to the different criteria employed to delimit the viable and nonviable zones are described later in the Table 1. Concerning to the GIS in the projects above-mentioned, the ArcGIS VII software was used due to its wide-ranging spatial analysis capabilities. In the present investigation was employed the software QGIS 3.12 for the adaptations of the maps and the review of the results obtained in the two projects. Also was used the plugin ExamZonas (Torres-Pérez et al., 2019) in QGIS 2.18, for the examination of the non-viable areas.

Research background and methodology

As background there is the investigation of (Rodríguez, 2011), in which a methodology was defined that, through the use of a GIS, allows to obtaining the maps for the territorial ordering of renewable energy sources and calculating the viable areas for the application of each type of energy on the island of Cuba (without including the Isla de la Juventud).

The methodology (see Fig. 4), comprises five stages, that are used in a progressive way from the first to the following stages; allowing the representation of the zones of protection, the delimitation of zones of relative viability, and the generation of maps of potential of energy for every one of the studied energy sources.

In 2011, the methodology for the study of the territorial ordering of renewable energy sources was applied on the island of Cuba (Rodríguez, 2011). In 2012 it was applied for the management and planning of renewable sources in the municipality of Guamá (Rodríguez, 2012). In 2013, it was applied for

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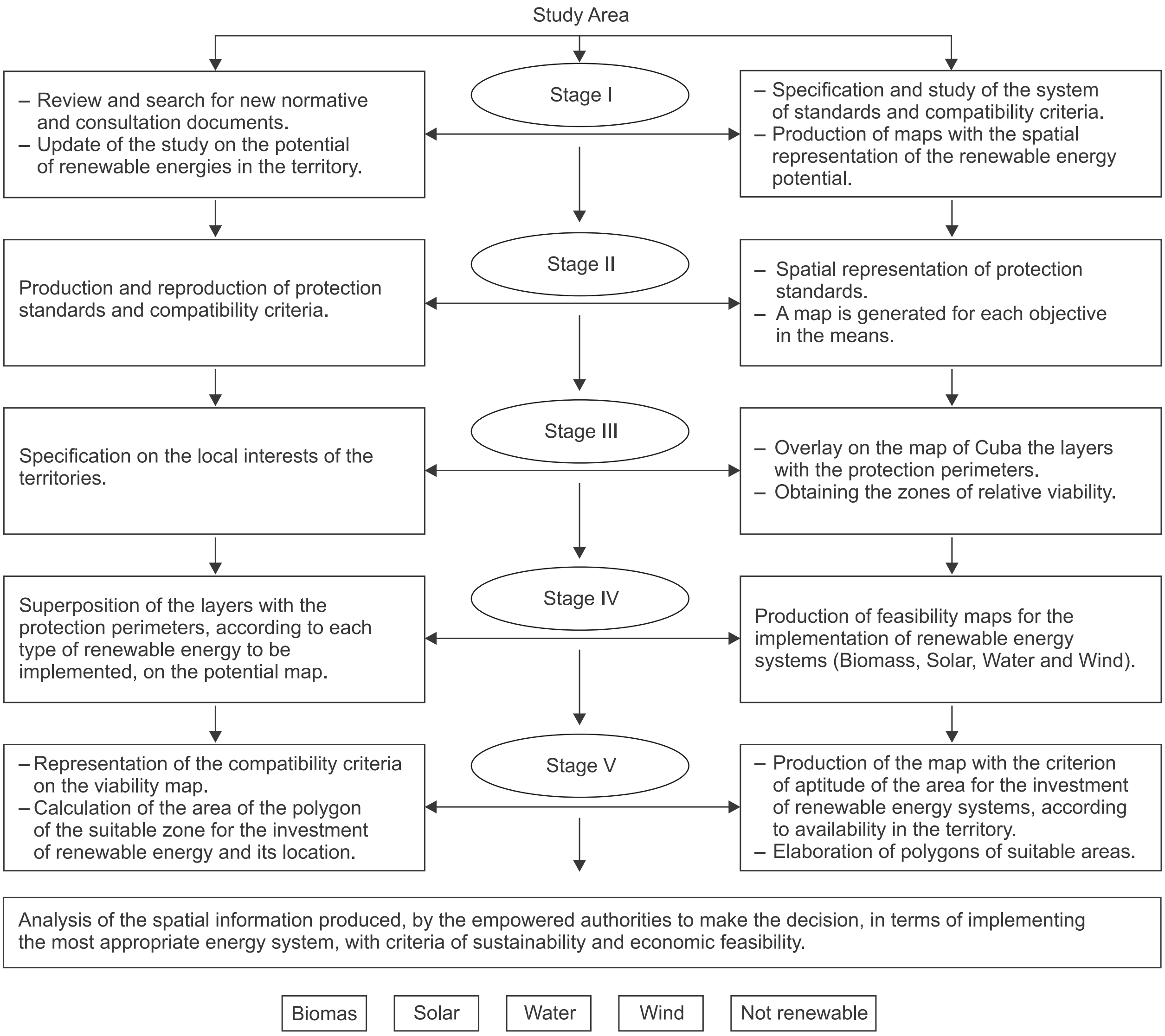

Fig. 4. Methodology for the territorial ordering of renewable energy sources in Cuba
Source: adapted from Rodríguez (2011).

a proposal for the territorial planning of photovoltaic energy in the mode of distributed generation in Cuba (Rodríguez et al., 2013).

The methodology was applied in the province of Las Tunas by (Torres-Pérez, 2018). Where also was developed a QGIS plugin (Torres-Pérez et al., 2019) with a functionality that allows the implementation of the phases I, II and III of the previously mentioned methodology.

APPLICATION OF THE METHODOLOGY IN THE ISLA DE LA JUVENTUD

Stage I: Behavior of renewable resources: solar, wind, water, and biomass

The territorial energy development model predisposes the use of the territorially available renewable resource, to satisfy a certain energy, need

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for economic and social development, alleviating the weight that the use of fossil fuels has in generation today. This requires a process of study and analysis on the behavior of the renewable resource, its location, disposition, possibilities of its use, type of technology, environmental impacts, demand adjustment, degree of social acceptance and other necessary aspects.

Solar potential

The solar potential of the Isla de la Juventud has values similar to the rest of the country; but in its northern region the radiation reaches values between 5.43 and 5.69 kWh/m^2 day, these are especially above the national average (between 5 and 5.17 kWh/m^2 day). The area of solar potential studied is 2,251.8 km^2, it is influenced by radiation values between 5.16 and 5.70 kWh/m^2 day. This potential represents an energy equivalent to 12,224.48 GWh/day, with an average power of 1.09 kW/m^2 (Rodríguez et al., 2017).

The measurements made by SWERA dating from 2005, with a resolution of 10 kilometers, have been taken as a model for the study of the solar potential of the territory, and a 1: 100000 scale cartography was used for the representation (Rodríguez et al., 2012). The results of the study of the solar potential of the island (see Fig. 5), suggest an attractive perspective regarding the analysis for the introduction of photovoltaic systems connected to the grid, mainly in the northern part, where the highest radiation values affect and the highest demand for electricity in the territory is concentrated.

Wind Potential

Studies carried out on the Isla de la Juventud have shown that winds predominate from the east direction, with average speeds between 9–12 km/h. The geographical location of the island implies that the trade winds are influenced by the sea breezes. In the first edition of the Cuba Wind Potential Map, it is reflected that in the territory there are about 49 points that present a potential qualified as Good, Excellent with wind speeds between 6.8 and 8.2 m/s that can generate an equivalent power of approximately 298 MW. These are located in a narrow coastal strip from Punta de los Barcos (located in the northern region), to Punta Rancho Viejo (located in the southeast of the island) near Punta del Este, as well as in the Sierras de Colombo and the Caballos. At the same way, there are other 26 points qualified as Good with wind speeds between 6.8 and 7.5 m/s, with the possibility of generate an equivalent power of approximately 31 MW, these are located in the Sierras de Casas and de la Cañada (Roque-Rodríguez & Soltura-Morales, 2020).

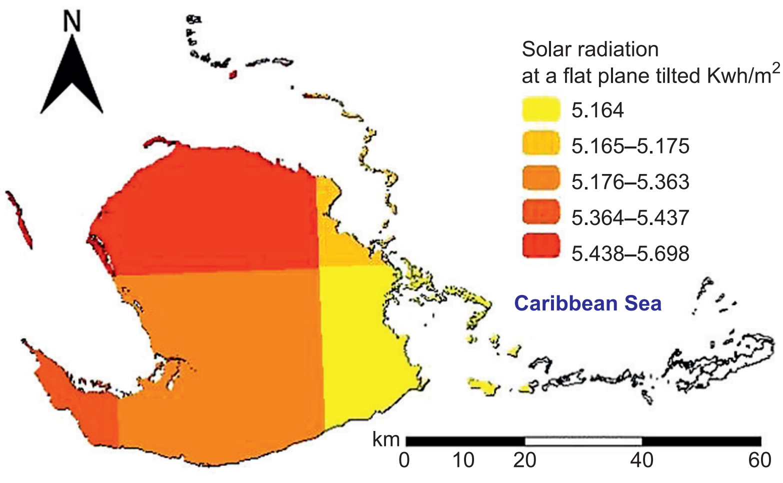

Fig. 5. Global solar potentials of the Isla de la Juventud
Source: adapted from Rodríguez et al. (2017).

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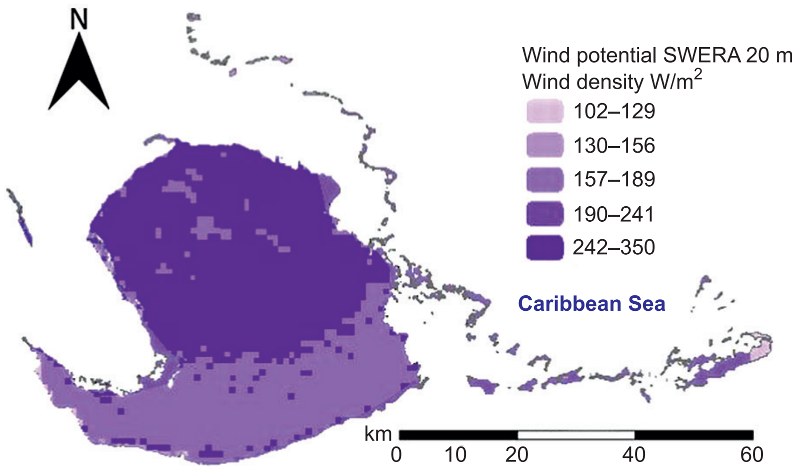

Fig. 6. Wind potential of the Isla de la Juventud
Source: adapted from Rodríguez et al. (2017).

In the Fig. 6, it is possible to observe the behavior of the wind potential that affects the territory of the Isla de la Juventud. This renewable energy is the one that presents a more complete study and application model, being the one that until now has energy levels delivered to the system and the one that has allowed to quantify the economic impact of its application in saving consumption and transportation of fuels and lubricants. As well as in the reduction of associated expenses for concepts of environmental impacts, corroborating the certainty regarding to the role that territorial renewable resources can play in the effort to achieve energy self-sufficiency.

The analysis of the behavior of the wind variable has made it possible to determine that it is feasible to use wind energy on a large scale, mainly in the northern and southeastern part of the territory, either to produce electricity by installing wind turbines or by implementing mills for pumping water in agricultural farms, small rural aqueducts, hydroponics, and plant production centers, as well as in nursery and aquaculture production centers.

Water potential

The territory of the Isla de la Juventud is permanently irrigated by about 20 rivers of short courses and small flow, as well as the existence of 10 permanent streams and 1,203 streams and canyons that intermittently appear as tributaries of the main rivers. There are a total of 784 small lagoons, ponds, and reservoirs, as well as 14 small dams, 52 channels and 323 ditches, of which 6 of them remain dry in dry weather. In the center east there are 27 underground water conductors (Lamyser, 2010). In the Fig. 7 the behavior of the hydric potential of the territory can be appreciated.

So far, the studies of the water potential in order to be used for the production of electricity have been carried out in 7 dams and reservoirs, with a total flow of 3.40 m^3/s, these are located in the northern and central region of the Island, where the greatest demand for electricity is concentrated. It can be verified that the installation of mini-hydroelectric plants is feasible, which in total can provide an installed power of 200 kW. This energy production is capable of releasing 293 tons of fuel from year consumption, avoiding that 1,069.45 tons of CO_2 being emitted into the atmosphere (Peña Pupo & Fariñas Wong, 2020).

The conditions of existence of the water component not studied, characterized by a significant number of small sources, implies the continuation of specific studies of the potential that could be used for the contribution of energy to the system. Also, constitute an attractive development variant, because among the renewable energies, this is the one with the least

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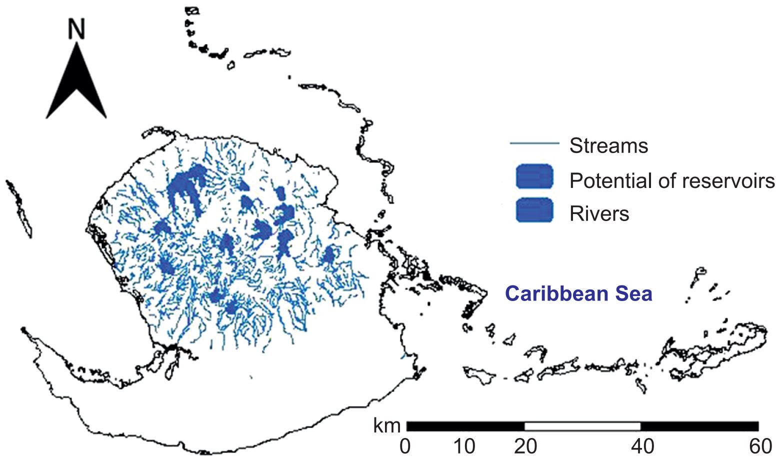

Fig. 7. Water potential of the Isla de la Juventud
Source: adapted from Rodríguez et al. (2017).

economic implication in the investment process for the territory. In addition to the use of this resource based on the production of electricity, it is feasible to use it in other applications such as hydraulic rams for pumping water in the agriculture.

Biomass potential

The Isla de la Juventud is distinguished by the presence of the wood energy resource (61% of the territory), this characteristic is determined by its main economic line, which is agricultural and wood production, as well as nature tourism. Biomass potential studies have made it possible to determine the distribution of the wood energy resource, corresponding to 20,180 ha of forests, 24,463 ha of mangroves, 16,053 ha of weed, 85,802 ha of fruit orchards and 1,090 ha of coffee plantations (GEOCUBA, 2006). In the Fig. 8 the behavior of the biomass potential of the territory can be appreciated.

The presence in volume and type of the wood energy resource in the territory, suggests the feasibility

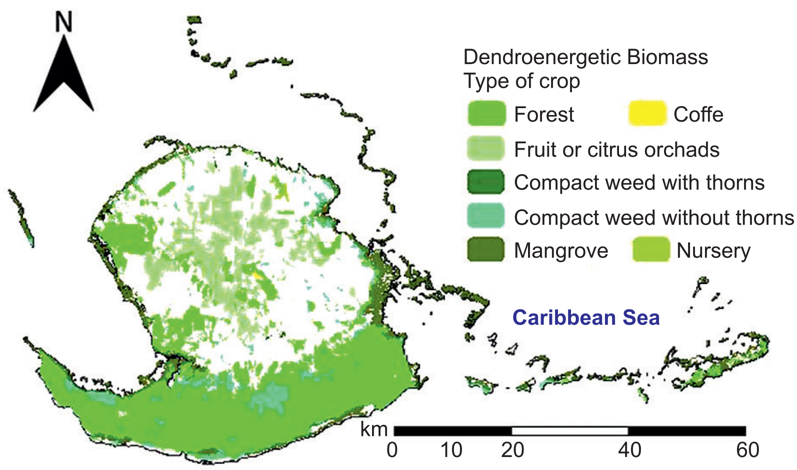

Fig. 8. Biomass potentials of the Isla de la Juventud
Source: adapted from Rodríguez et al. (2017).

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of its use on a large scale to produce electrical energy. In the development plans of this technology, the installation of a power of 50 kW in the community of Cocodrilo with an autonomous work regime has been valued (Curbelo, 2010).

Studies carried out have allowed to calculate the possibility of installing up to 1 MW of power, with a specific consumption of dry wood energy biomass of 0.55 kg/kWh. Also, this power can be double, with the simultaneous creation of a sowing backup of 2,600 ha of energy forests (Poder Popular I.J., 2010).

Other attractive proposals are derived by the use of biomass in energy applications from the solid waste of 11 entities of the agricultural sector that are in the territory (Poder Popular I.J., 2010). These can generate certain volumes of solid waste, with the possibility of being used in the production of biogas, which would be employed for consumption in activities that today are demanded from the island's electrical system.

Results of the study for the introduction of photovoltaic systems connected to the grid

The study of the solar potential of the Isla de la Juventud, allowed to determine that radiation values affect the northern region of the territory, which constitute a special attraction for the implementation of photovoltaic systems connected to the grid, since in these areas is located the greater demand for electrical energy in the territory.

With the interest of implementing photovoltaic systems during the diversification process of the Cuban Electric System were fallowed the principles outlined in the Model of Energy Efficiency for Cuba, regarding to the study of the submitted requirements for the territorial ordering (Rodríguez, 2011).

Stage II: Application of land use planning criteria

For the introduction of renewable energies sources, were analyzed the spatial behavior of a set of protection standards that respond to the requirements of national and international standards, established in the Regulatory framework provided in Laws, Decree Laws, Cuban Standards, International Standards, regulations, manuals and other documents in this regard (Rodríguez, 2011). Below, in the Table 1, are presented the criteria employed to delimit the viable and nonviable zones for the implementation of the photovoltaic systems connected to the grid.

In the same way, were analyzed the incidence of a set of existing natural barriers represented in the space at a scale of 1: 100000, which determine the location of investments. The protection standards

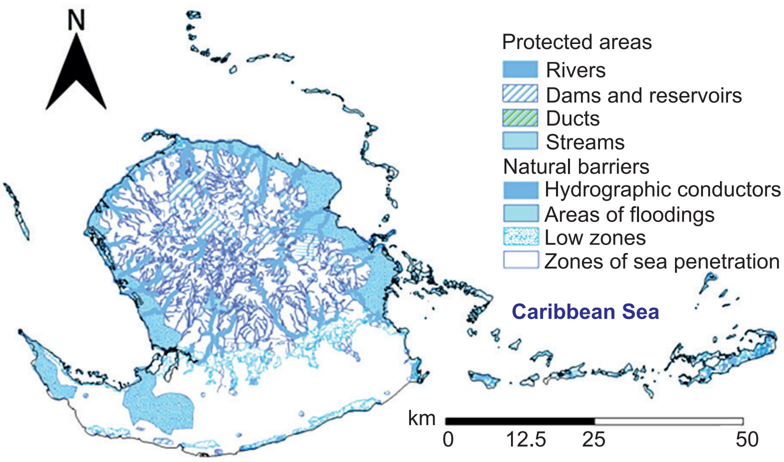

Fig. 9. Zones occupied by areas of protection and natural barriers of origin hydric
Source: adapted from Rodríguez et al. (2017).

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Table 1. Criteria to delimit the viable and nonviable zones for the implementation of the photovoltaic systems connected to the grid

Variables	Protection Perimeters (m)	Description	Normative Documents
Natural barriers of origin orographic	0	Slopes in the terrain, Elevations +30 degrees, Deposits (GEOCUBA, 2006)	12 Cuban standards and 3 national normative documents (Rodríguez, 2011)
Natural barriers related with roads	150	Roads, highways, streets of cities and towns, terrepleins, pathways, airdromes (GEOCUBA, 2006; Rodríguez, 2011)	19 international standards y 6 national normative documents (Rodríguez, 2011)
	100	Railway lines	
Natural barriers of origin hydric	300	Natural Barriers: hydrographic conductors, areas of flooding, low zones, and zones of sea penetration (GEOCUBA, 2006; Rodríguez, 2011)	19 international standards and 6 national normative documents (Rodríguez, 2011)
	1000	Protected areas: rivers, dams and reservoirs, ducts and Streams	10 Cuban regulations and 3 national legislative documents (Law 81 of the Environment, 1997; Rodríguez, 2011)
Natural barriers related with the vegetation layer	0	Forest and other cultivations (GEOCUBA, 2006)	(Decree No. 268, 1999; Law 81 of the Environment, 1997)

Source: own study, start from: Decree No. 268 (1999), GEOCUBA (2006), Law 81 of the Environment (1997), Rodríguez (2011).

are intended to protect the objectives that generate them, as well as to preserve the electrical installations that are implemented.

In accordance with the above, the influence they exert on the viability of the territory to undertake investments was analyzed, and in particular those of hydric (see Fig. 9), orographic origin (see Fig. 10), those related to the vegetation layer (see Fig. 11) and roads (see Fig. 12). In the particular case where is analyzed the feasibility for the introduction of photovoltaic technology, the populated areas do not constitute barriers. These systems can be adequately implemented within the limits of cities and towns, even taking advantage of the roofed surfaces of buildings and houses or incorporated into their structures.

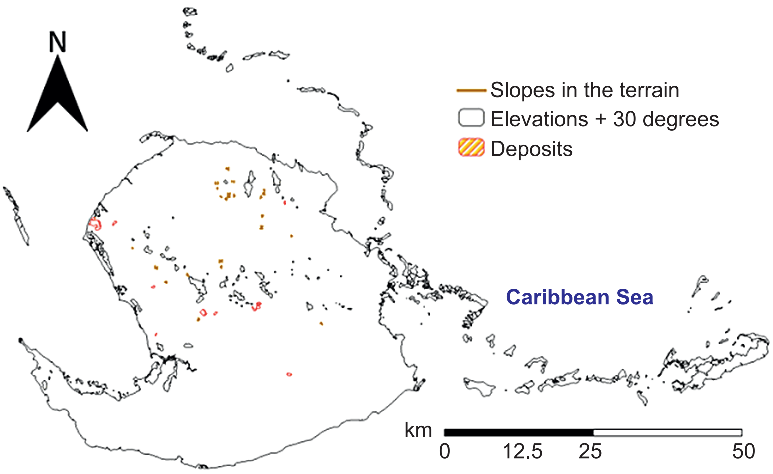

Fig. 10. Zones occupied by areas of protection and natural barriers of origin orographic
Source: adapted from Rodríguez et al. (2017).

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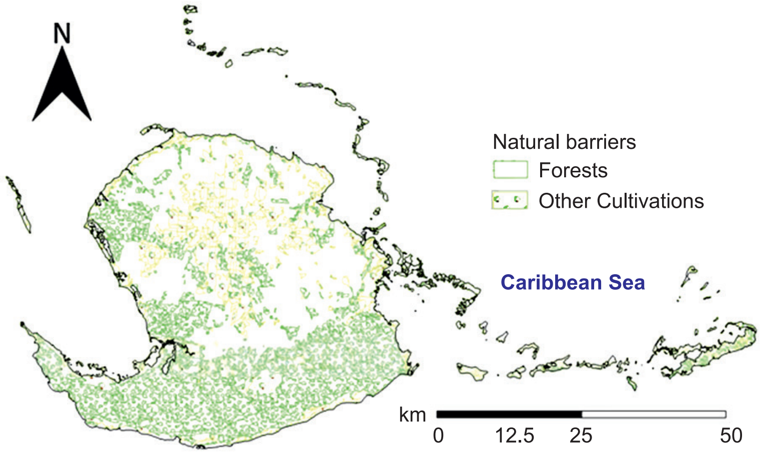

Fig. 11. Zones occupied by areas of protection and natural barriers related with the vegetation layer
Source: adapted from Rodríguez et al. (2017).

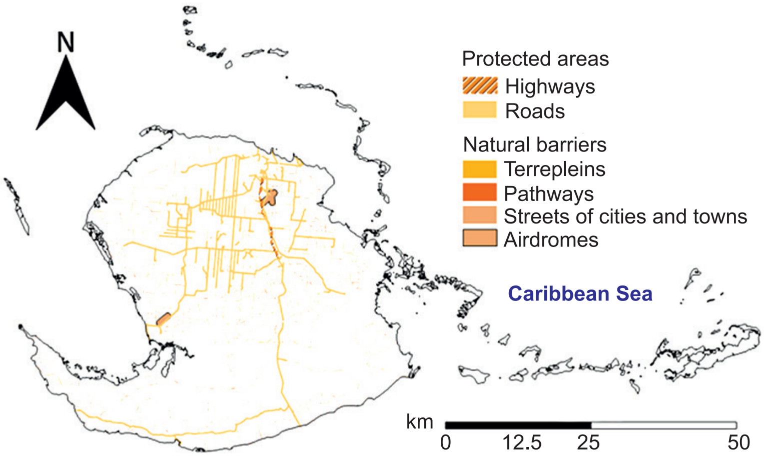

Fig. 12. Zones occupied by areas of protection and natural barriers related with roads
Source: adapted from Rodríguez et al. (2017).

Stage III: Viability criteria of the territory of the Isla de la Juventud for the introduction of photovoltaic systems connected to the grid

The evaluation of the influence that the protection criteria and the previously studied natural barriers exert on the space of the territory, has allowed the deduction of non-viable areas for the introduction of photovoltaic systems connected to the electricity grid (see Fig. 13). The analysis of the information contained in the system's database has made it possible to calculate that the non-viable areas occupy a total area of 2,004 km^2, which represents 83.6% of the island's territorial space (Rodríguez et al., 2017).

Renewable energy resources are distributed and incorporated into the geographical area of the island; hence the importance of studying the feasibility criteria, due to the influence they exert on the possibility of using the territory to undertake investments related to photovoltaic systems connected to the grid.

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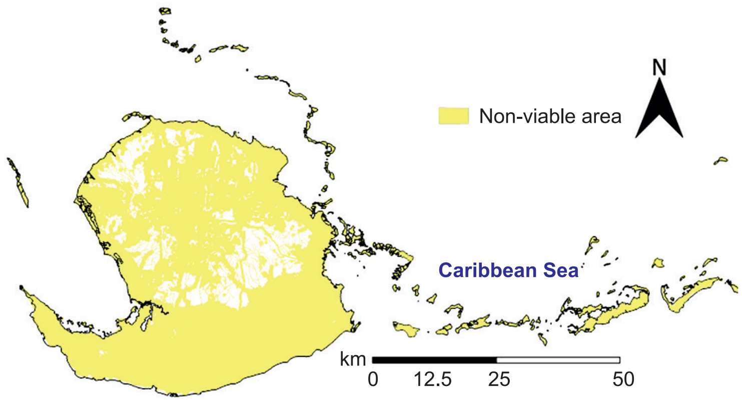

Fig. 13. Non-viable areas for the installation of photovoltaic systems connected to the electricity grid
Source: adapted from Rodríguez et al. (2017).

Stage IV: Viable areas for the introduction of photovoltaic systems

Once the viable areas have been determined and the information of the global solar potential has been prepared, can be carried out the analysis of these data in terms of the development of the systems. The management of the data submitted to the analysis process, allowed to study an area equivalent to 376 km^2 and to determine that the areas with the best solar radiation are in the northern region, with values between 5.43 and 5.70 kWh/m^2 day. In the central

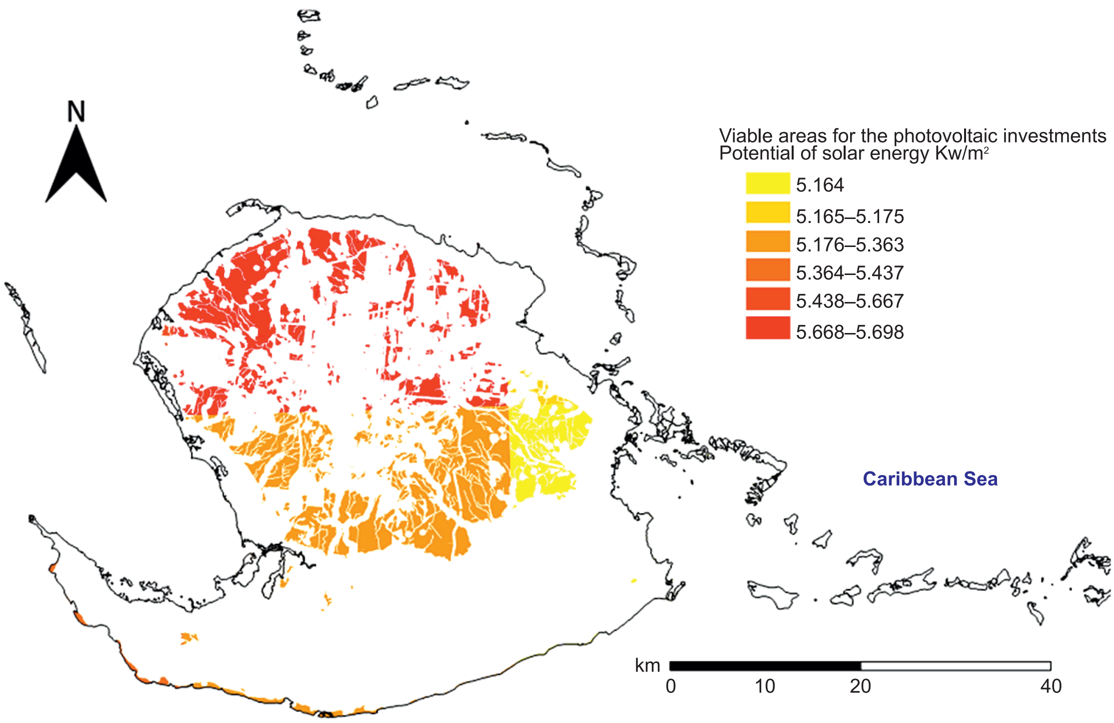

Fig. 14. Influence of the feasibility criteria in the use of the solar potential of the Isla de la Juventud
Source: adapted from Rodríguez et al. (2017).

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region the radiation values correspond between 5.16 to 5.36 kWh/m^2 day.

It has also been possible to calculate that in these areas there is a solar potential capable of generating energy equivalent to 2,053 GWh/day, with an average of 5.46 kWhm^2/day and a power of 1.092 kW/m^2 (Rodríguez et al., 2017). In the Fig. 14, the influence of the criteria of territorial viability can be observed, in function of evaluating the behavior of the global solar potential, that affects the territory of the Isla de la Juventud.

The components of the economic study of projects for the implementation of photovoltaic systems connected to the grid are very diverse, among these, the connectivity analysis is of special importance, due to its influence on the achievement of the efficiency of the systems. This element predisposes the realization of an analysis of the electrical network system, its category, technical state and the distance of these to the places where it is intended to introduce the photovoltaic system.

From the distance of the systems to the network, depends on factors with a high economic impact due to the construction of new lines, substations and other structures or components that have higher costs in the market. For example, the current cost of one kilometer of power lines including their components oscillates in flat terrain at 20,833 USD and in mountainous terrain at 22,916 USD.

Another problem to be taken into account is related to the reduction of losses due to the transportation and distribution of the electrical energy, considering

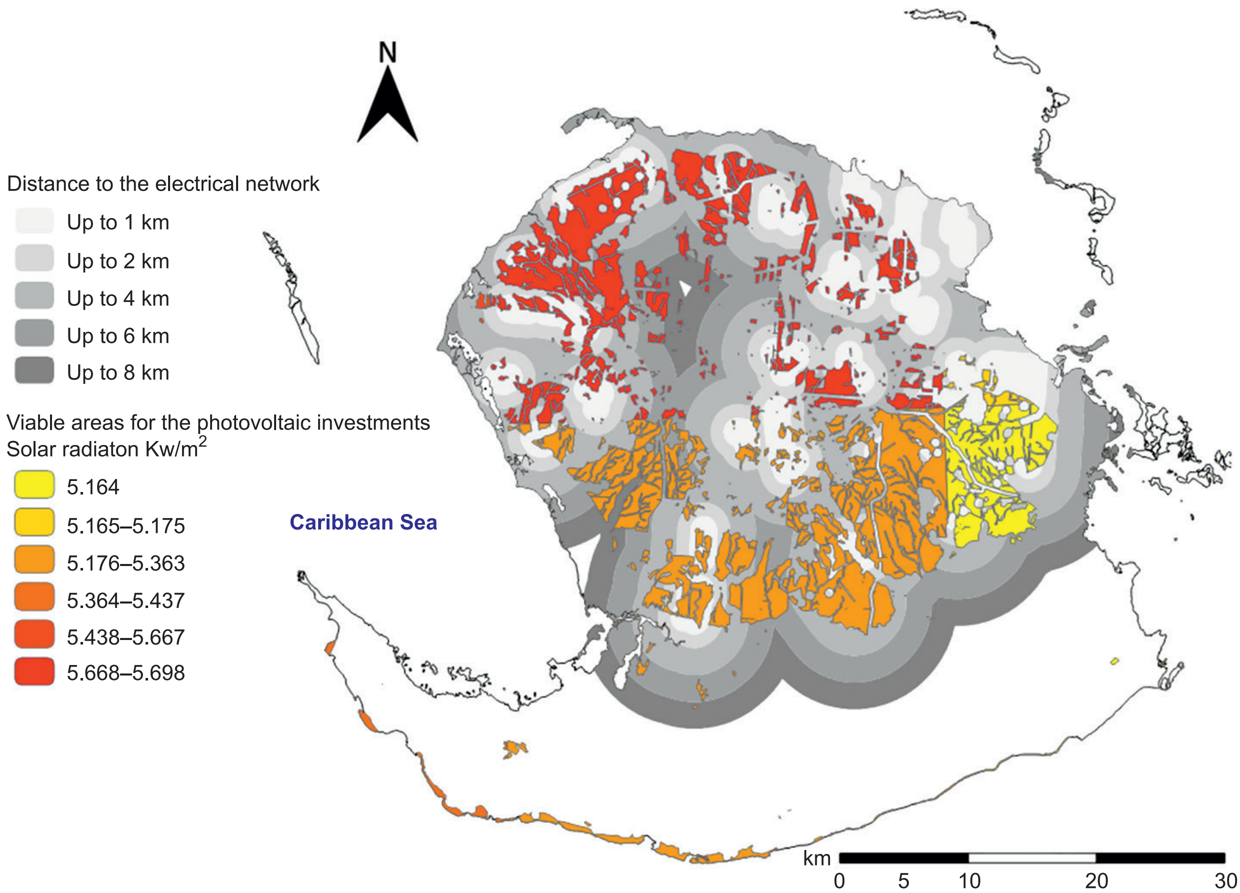

Fig. 15. Efficiency for the installation of photovoltaic systems connected to the grid in relation to power lines
Source: adapted from Rodríguez et al. (2017).

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that the losses increases to greater distances from the power plant to the grid. The above is a very sensitive aspect if it is involved photovoltaic investments, which requiring in their application of measures that guarantee high energy efficiency of the generation system and connectivity to the grid, due to its high investment costs and low returns on solar cells.

In this sense, it has been considered as an acceptable distance for the territory of the Isla de la Juventud, in the case of small photovoltaic plants a distance not greater than 4 km, for medium plants up to 6 km and for large plants up to 8 km (Rodríguez, 2011). In the Fig. 15, can see the chromatic scale model of the distances from the electrical networks at 1, 2, 4, 6 and 8 kilometers; taking as a reference the existing networks and the relationship between these and the viable areas for the implementation of photovoltaic systems connected to the network.

Could be resolved, that in the places close to the electrical grid system, there are 376 km^2 of viable areas for the installation of photovoltaic plants connected to the grid, where affects an average solar radiation 5.46 kWh/m^2 day, with an equivalent energy at 2,053 GWh/day and an average power of 1.092 kW/m^2 (Rodríguez et al., 2017). Therefore, there are feasibility conditions for the introduction of this technology on a large scale, mainly in areas up to 4 km away from power lines. The Table 2 display a summary of statistical data about the territorial feasibility and the behavior of the solar potential for investments in photovoltaic systems connected to the grid, in areas close to the electrical networks.

Table 2. Statistical summary on the territorial feasibility and the behavior of the solar potential for investments

Areas close to the electrical networks	Viable areas (km^2)	Average solar radiation ($kWh/m^2/day$)	Total energy Incident (GWh/day)	Power that affects (kW/m^2)
Grand Total	376	5.46	2,053	1.098
1 km	102	5.44	552	1.088
2 km	109	5.46	561	1.092
4 km	118	5.49	647	1.098
Subtotal Small PV plants	322	5.46	1,760	1.093
6 km Medium PV power plants	46	5.44	25	1.088
8 km Large PV plants	8	5.49	42	1.098

Source: adapted from Rodríguez et al. (2017).

Stage V: Determination of the efficiency level of photovoltaic systems, considering the existing distribution system in the territory

Another element that can influence the analysis of the economic feasibility for the introduction of photovoltaic technologies connected to the grid is its proximity to the existing electrical energy distribution system. In this sense, is possible to take advantage of the existing structures and the PP in operation, for saving the investment for this concept and to reduce the environmental impact associated with the execution of new works.

Distribution systems are important elements of economic expenses during the investment process. The PPs that are in operation offer connectivity conditions to the energy system that can be generated with photovoltaic plants, even higher than the parameters provided by the electrical networks. This scenario favors the introduction of photovoltaic systems, reducing investment costs and the level of environmental impact. It is only possible to analyze the convenience of extension or adaptation of the substations, depending on the increase in power or some changes to be introduced that are necessary.

From the aforesaid, the importance of the analysis can be inferred, for ensuring the reduction of energy losses during its distribution and transmission, from the photovoltaic plant that is projected to the point of consumption. It is recommended for the territory of Isla de la Juventud, to maintain the following acceptable distance: for small photovoltaic plants a distance not greater than 4 kilometers to the connection point, for medium plants up to 6 kilometers and for large plants up to 8 kilometers.

It is also possible to study the organizational, technical and management feasibility offered by

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the structures created in the PP that are operating. When conceiving the installation of photovoltaic systems in areas very close or close to the PP, could be assessed the subordination of the renewable systems to the diesel plants. Consequently, avoiding the creation of new positions, mainly management and services personnel, requiring only the training and improvement of existing personnel in the management of this technology.

In the Fig. 16 can be appreciated the viable areas that can be used for the installation of photovoltaic plants connected to the grid, as well as the color scale value of the incident radiation in a radius of 1, 2, 4, 6 and 8 kilometers close to electric power plants. This information constitutes the starting point, in the complex decision-making process by the authorities of the territory and Cuba, for the implementation of photovoltaic systems connected to the grid.

Energy planning and the Energy Geographic Information System of the Isla de la Juventud

In order to promote strategic planning coordinated with land use planning, the Isla de la Juventud Geographical Information System (GIS) was developed (see Fig. 17), in the form of a geoportal. This contained the inventory of the renewable potentialities and the total elements that conformed the electrical infrastructure. At the same time, the cartographic record of all the elements associated with the land use planning was carried out, which are useful during

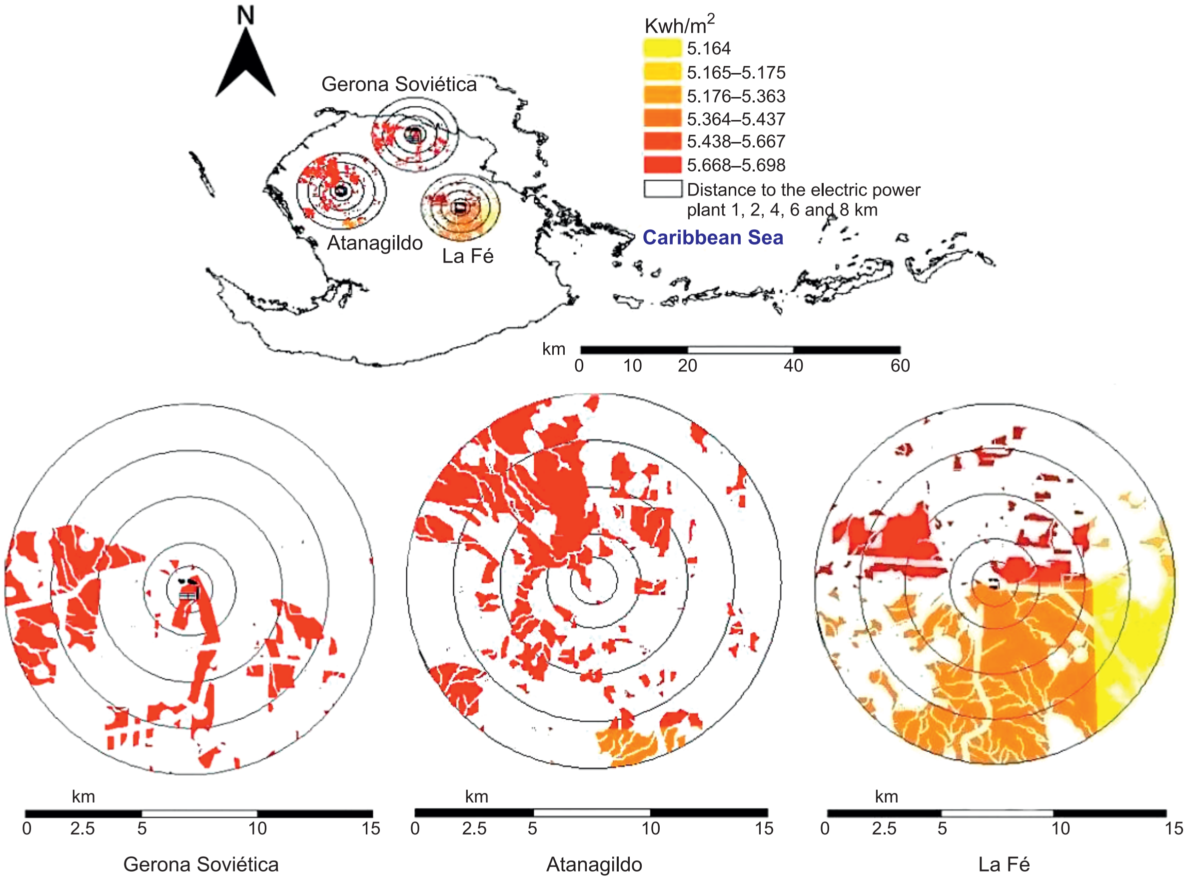

Fig. 16. Viable areas and the behavior of the solar potential near the Power Plants
Source: own preparation, adapted from Rodríguez et al. (2017).

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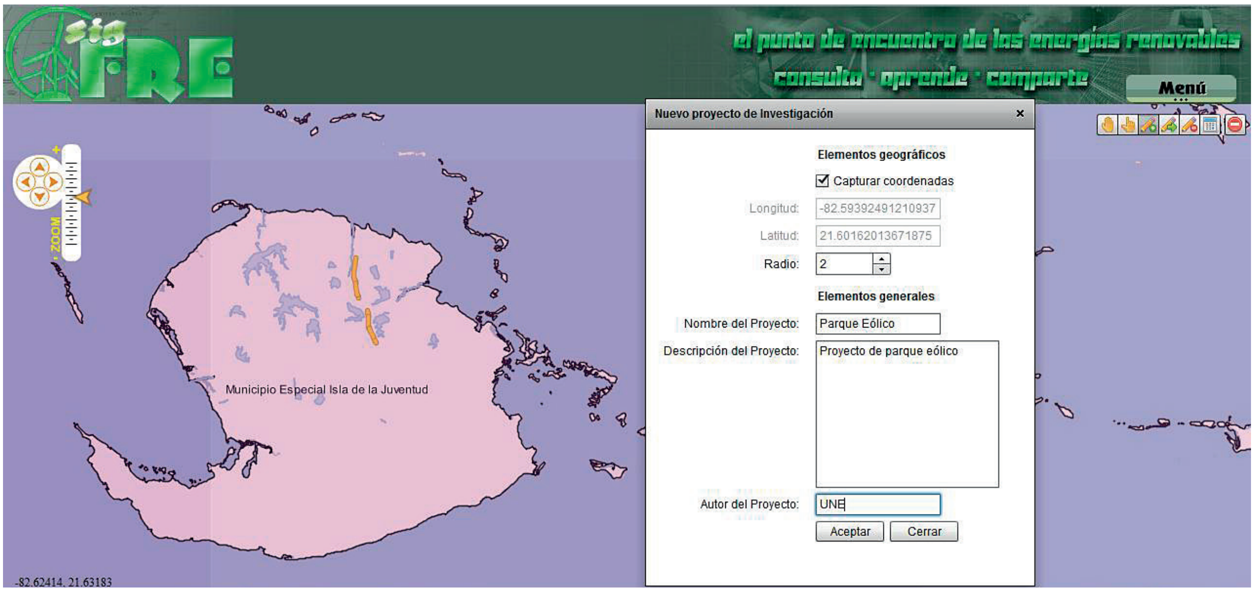

Fig. 17. Geographic Information System of energy of the Isla de la Juventud
Source: adapted from Rodríguez et al. (2017).

the energy planning process and decision-making by the territorial authorities.

With the geoportal, the results were shown interactively through maps (images) compatible with vector and matrix data. In addition, it made it possible to publish the results, carry out technical consultations, generalize experiences, propose novel solutions regarding the energy profile, as well as maintain an adequate level of consultation on issues related to the introduction of renewable energies and other information and data of interest. The geoportal was put into operation, but it is not currently online.

Model for the territorial energy development

The public awareness of the serious problems derived from the unsustainable use of energy and the difficulties that are causing the environment with the acceleration of climate change, offers the opportunity to fight for a new energy model. This model (see Fig. 18) is based on diversification in sources, rationalization, efficiency, savings in consumption and respect for the environment, not being considered an isolated energy strategy.

It constitutes a fundamental element of development to promote the improvement of the environment and socioeconomic development, based on the possibility of the territory to choose and develop appropriate technologies to its needs, resources, environment, balanced growth, and context of cultural development among others and differentiated way, on sustainable bases in the use of natural resources.

DISCUSSION

The study of the viable areas for investment in solar energy allows knowing the information required to carry out the territorial energy planning process, ensuring that the territory adequately manages the natural resources it possesses, planning energy self-sufficiency in the short, medium and long term, without putting at risk or contradicting the interests and macro-objectives of sustainable and integrated national development from solar energy.

Geospatial planning and GIS are instruments that allow the management of the territory in an integral way, managing to incorporate the factors that affect the sustainable development of the regions and

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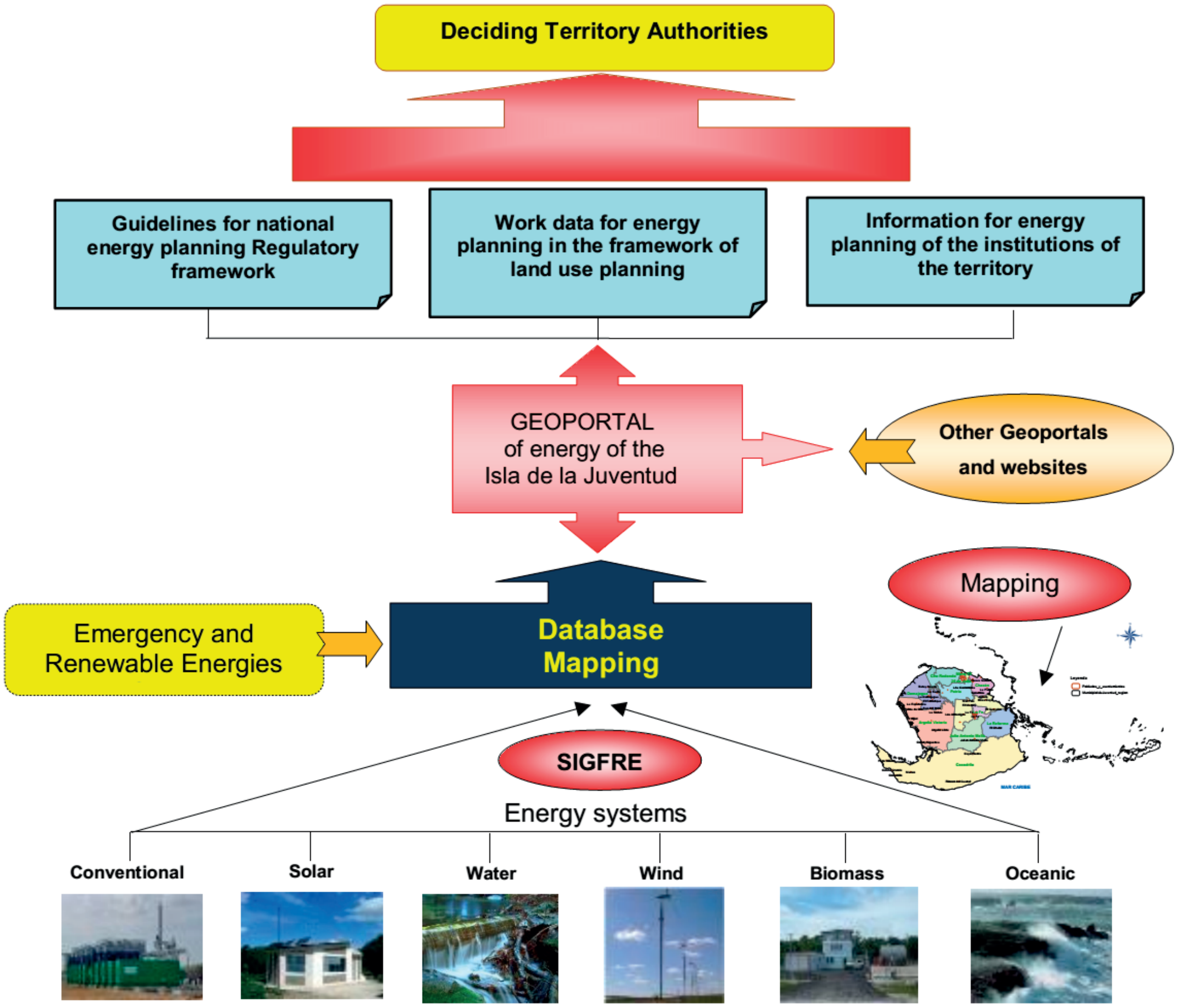

Fig. 18. Model for the Territorial Energy Development
Source: adapted from Rodríguez et al. (2017).

provide adequate knowledge that helps decentralize the power generating systems using the solar potential at the local level, where consumption and demand are integrating and necessary elements in improving the efficiency to produce energy.

One of the main challenges in the integration of energy systems models and GIS is the diversity of data structures and formats. The aforesaid involves difficulties like data integration methods and lacking standardization in data exchange, data availability and proprietary data formats. In this sense, the implementation of the geoportal of the Isla de la Juventud, could contribute to enhance the infrastructure of space data that has Cuba, that at present is scarce (see www.iderc.cu). The benefits of the model and the geoportal are clear, but their effective implementation depends of the commitment from the authorities and the actors involved.

From the point of view of land use planning, this special municipality has sufficient viable areas for the development of photovoltaic plants connected to the grid in close and very close areas to power lines,

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as well as in areas of the substations that are part of the electrical system. This can bring immediate economic results, which is materialized through the reduction of expenditures for fuel and lubricants, a reduction in the management of environmental impacts and the readjustment of maintenance, repairs and technological inputs of conventional power plants, contributing to the energy sustainability of the territory.

Also, the studies of this nature must be complemented with a techno-economic analysis that deepens into the elements related with the energy needs to be supplied by the different proposed systems, the energy costs involved by each source and the evaluation of the type of technology that corresponds.

CONCLUSIONS AND NEXT STEPS

The present study covers the GIS and territorial ordering assessment of Isla de la Juventud's potential for the diversification of the electrical system, with focus on the introduction of photovoltaic systems connected to the grid. The result indicated that 83.6% of the island territory is found unsuitable for the location of those systems.

The geographical location of Isla de la Juventud, its climate, vegetation, and orography, favor the stable existence of other renewable energy sources, besides the solar, that can be used for the diversification of the current energy matrix, achieving sustainable alternatives for the economic and social development of the territory.

The consolidation of the territorial energy development model of the Isla de la Juventud will serve as a guide in the organization and planning of the integrating process of renewable energies, in order to promote a diverse energy matrix, with a broad vision of the sustainability of the system. In addition, the study methodology exposed and the territorial energy development model, can become an energetical guide for other similar studies.

The present work contributes to the aims to achieve 24% penetration into the local system of the Isla de la Juventud through RES by 2030, essentially with photovoltaic solar. Currently a project is being carried out with the intention of making the Isla de la Juventud to be 100% renewable. In next papers we will continue deepen in the analysis presented in this work, through the introduction of systems based in other renewable energy sources besides the solar.

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