Sustainable Development Solved by Using Multicriteria

A. Gil-de-Castro, A. Moreno Muñoz, M.A. López Rodríguez
Departamento A.C., Electrónica y T.E.
Escuela Politécnica Superior. Universidad de Córdoba.
Córdoba, Spain
p32rogia@uco.es

J. J. G. de la Rosa
Área de Electrónica. Dpto. ISA, TE y Electrónica
Universidad de Cádiz
Algeciras-Cádiz, Spain

Abstract— **Cordoba is an inland province of southern Spain. This paper presents the quantity of power that will be necessary to install for covering the electrical consumption of Cordoba's population. Multicriteria has been the followed method with selection of criteria and options for the new and renewable energy technologies assessment based on the analysis and synthesis of parameters under the information deficiency method.**

Keywords-component; Energy supply; Multicriteria decision-making; Renewable energy technologies; Sustainable energy development.

I. Nomenclature

SD: Sustainable Development
DG: Distributed Generation
CHP: Combined Heat and Power
RES: Renewable Energy Sources
DER: Distributed Energy Resources
CSP: Concentrated Solar Power
PQ: Power Quality
MCDM: Multi-Criteria Decision-Making
PER: Plan de Energias Renovables
PV: Photovoltaic
MAED: Model Analysis for Energy Demand
ELECTRE: Elimination Et Choix Traduisant la REalité

II. Introduction

Worldwide energy consumption has risen 30% in the last 25 years, and the International Energy Agency expects to rise of about 60% in 2030. Today, the world's energy system is based mainly on oil, gas and coal, which together supply around 80% of our primary energy. Only around 0,5% of primary energy comes from renewable sources such as wind, solar and geothermal. The present production and use of energy is causing depletion of resources and serious environmental problems. In Europe the dependency on imported primary energy increases from year to year. Nowadays most of Europe's energy needs are supplied from shrinking fossil fuel resources (oil, gas and coal), largely imported into the European Union. As energy demand continues to grow, this external dependence could grow from 50 to 70% in 25 years or less.

Nowadays, the threat of global climate change, high fuel import dependence, and rapidly rising electricity demand levels have intensified the quest for more sustainable energy systems [1]. Accordingly, more and more countries are examining a whole range of new policies and technology issues to make their energy futures "sustainable". Nowadays achieving sustainable development (SD) is an overarching target to be achieved on every society. SD has been defined by the Brundtland Commission as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs [2]. SD affects not only energy, but all sectors of activity, both at the local and national levels.

Almost all the electricity currently produced in the western economies is generated as part of a centralised power system designed around large fossil fuel or nuclear power stations. At present, many technologies known as Distributed Generation (DG) have become available; for instance Combined Heat and Power (CHP; cogeneration; or cooling, heating, and power) or by the different renewable sources. Usually situated close to the electricity consumers, the amount of energy converted is relatively small compared to the ratings encountered in large centrally dispatched power plants. But it is hard to tell where the limit of DG technology is situated. Its definition is heavily debated, but in general most people understand it as electricity generation systems of small to moderate size (less than a few MW), usually implemented in the electricity distribution system and not necessarily owned nor controlled by utilities.

Due to the negative impact on the environment of traditional power-generating methods, especially coal and oil-fired power stations, the interest in DG has emerged in the energy market [3]. On-site power production circumvents transmission and distribution costs for the delivery of electricity. These costs average about 30% of the total electricity cost. This share, however, varies according to customer size. For very large customers, taking power directly at transmission voltage does not suppose excessive cost. Nevertheless, for a small household consumer, network charges may constitute over 40% of the price. However, the emphasis for DG has shifted over the last few years towards Renewable Energy Sources (RES). Thus, it has been coined term Distributed Energy Resources (DER), which could include a wide range of energy sources apart from the traditional hydroelectric, including wind, concentrated solar power (CSP), biomass, solar photovoltaic, solar chimneys, wave energy and storage, which are not necessarily generation in the traditional utility sense.

DER has increased in popularity because have a large potential to contribute to the SD of specific territories by providing them with a wide variety of socioeconomic and environmental benefits, including [4]: a decrease in external energy dependence; a boost to local and regional component manufacturing industries; promotion of regional engineering and consultancy services specialising in the use of renewable energy; increased R&D; increase in the level of services for the rural population; and creation of local employment. Some of the intrinsic characteristics of many territories make them particularly suitable to benefit from renewable energy investments, such as relatively large share of rural, dispersed population, high dependence on a declining agricultural sector (in a context of reduced agricultural subsidies), high unemployment rates, scarcity of regional development alternatives, declining populations and aging of the remaining population [5]. However the extensive exploitation of DER will require the judicious use of resources, technology, appropriate economic incentives and strategic planning. Energy supply must adhere to the criteria of rationality, efficiency and reliability. However, the integration of DER into existing networks brings up several economical, regulatory and technical questions, some of them closely related with Power Quality (PQ) [6].

Presently, most DGs only produce power, and they do not contribute to the ancillary services required to control the power system and ensure stable operation. What is more, the outputs of RES such as those from solar power, wind and wave energy, are intermittent, and often do not match the energy demands of consumers. This characteristic means that the maximum percentage that a particular technology could provide to generation system remains as a technical doubt that hinders the DER support [7]. However, at present intermittency is not a serious technical constraint as long as the energy sources are diverse and amount to a small share of total supply. Several studies have addressed this issue. The main options currently contemplated to cope with the changes caused by the variable output of the intermittent generations are the following [8], [9]: power plants providing operational and capacity reserve, electricity storage, interconnection with other grid systems, demand-side response, forecasting and aggregation.

In the last few years different approaches have been implemented in different countries to move towards SD [10], [11], [12], [13]. To facilitate this process around the province of Cordoba (Spain) (see Fig. 1) in this paper, we propose a novel methodology that supports spatial planning in relation to renewable energy. Cordoba is an inland province of southern Spain, in the north-central part of the autonomous community of Andalusia. In order to predict production development and energy consumption, various models are applied for analysis of energy needs. The spatial location of renewable plants has been based on the use of Multi-Criteria Decision-Making (MCDM). These methods provide better understanding of inherent features of decision problem, promote the role of participants in decision making processes, facilitate compromise and collective decisions and provide a good platform to understanding the perception of models and analysts in a realistic scenario. The methods help to improve quality of decisions by making them more explicit, rational and efficient. Negotiating, quantifying and communicating the priorities are also facilitated with the use of these methods [14].

The remainder of the article is organised as follows: Section 2 outlines the basic analysis of the province of Cordoba and of its renewable energy sources. Section 3 includes the methodological approach on which we base our analysis, specifying the multicriteria method that has been used. Results obtained from the whole process follow in Section 4. Section 5 concludes.

III. The Study Area and Analysis of its Renewable Energy Sources

Cordoba is an inland province of southern Spain, in the north-central part of the autonomous community of Andalusia. The area of Cordoba is 13,769 km², (2.73% of the total surface of Spain). Its population is 792,182 (2007), of whom more than 40% live in the capital, Cordoba, and its population density is 57.5. The province of Cordoba contains 75 municipalities and 8 regions (comarcas in Spanish). Due to its geographical features, Cordoba has substantial reserves of renewable energy sources, especially in biomass, hydroelectric and solar energy. More than 80% of this production was supplied by biomass sources, including municipal solid waste, animal waste and agricultural by-products.

To achieve the GHG reduction targets, to contribute to sustainable development and to improve the competitiveness of the economy by increasing the use of RE and improving the energy efficiency are the main objectives that Spanish policy has for the support of RES. To this end, policy is focus on promote RES in Spain with some renewable energy promotion plan, such as “Renewable Energy Plan 2005-2010 (PER)” [15] which says that, by 2010, at least 12% of the energy consumed in this country will come from renewable sources. For this purpose, we want to satisfy the electrical demand by using renewable energy according to the marked aim by PER. Consequently, knowing the electrical consumption of the population is necessary to calculate the proposed renewable power to be installed.

For instance, the “Andalusian Environmental Plan 2004-2010” aspires at supporting technological development, as well as sustainable production and consumption. More concretely, the “Andalusian Energy Plan 2003-2006” aims at a 15% of the total Energy demand to be produced by renewable sources by 2010 [16].

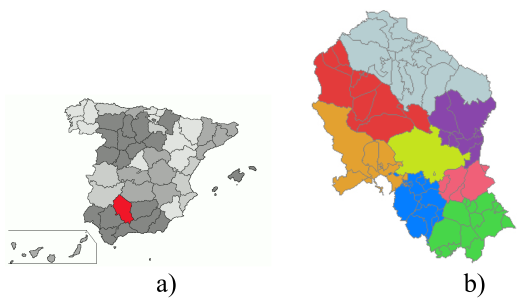

Figure 1. Geographical location of the Regions of a) Spain, b) Cordoba.

The photovoltaic (PV) capacity in Cordoba was totally 150 MW (in year 2008) [17] and in Andalusia was 659 MW. Cordoba is the second region with most installed PV power and this quantity has increased 39.73% in only four months. In the province, out of the PV capacity, 30 MW is in the north, 60 MW in the centre and 60 MW in the south. Installed capacity from thermo solar is 300 MW. And with respect to biomass, our province has a huge potential of this product, by considering olive and by products from olive tree. It is also usable agricultural by products, forest-derived and industrial biomass.

MAED [18] is a simulation model for evaluating the energy demand implications (in the medium and long term) of a scenario describing a hypothesized evolution of the economic activities and of the lifestyle of the population. This model links together specific energy needs for production of different goods and services with sets of social, economical, and technological factors which have influence on these needs. By using MAED we have predicted the electricity consumption in the province of Cordoba up to 2012.

In *Vega del Guadalquivir* are available 99,123 ha which can yield 89,211 tons of biomass. All the electricity can be supply with biomass because the demand for year 2012 is traduced in 79,137 tons. For satisfying 55.47 GWh with PV, it would be necessary 92.46 ha, negligible surface if it is considered the whole surface of the region. Likewise, it is supply the demand with Solar-thermal because to cover the demand it would be needed 97.06 ha. The surface of growing installed in *Subbetica* is 121,871 ha which can totally yield 109,684 tons of biomass, and because it would be needed 217,635 tons to produce 152.548 GWh, only 50% could be met. Both PV and solar thermal could satisfy the electricity demand. *Cordoba* has 29,446 ha of growing and that is equivalent to 26,501 tons of biomass. Because to cove 391.618 GWh with only biomass in this region it will be needed 558,708 tons of biomass; so that a total of 4.7% of this electricity demand could be satisfied. Both PV and solar thermal could be use. In *Guadajoz y Campiña Este* there are 54,217 ha of growing which can yield 48,795 tons of biomass, and because it is necessary 42.678 GWh of electricity, it is translated in 60,887 tons of biomass, so that only 80% of the electric energy could be satisfied with biomass. Solar thermal and PV could satisfy the whole demand of electricity. In *Campiña Sur* it is necessary 56.694 GWh to satisfy the demand of electricity so it would be needed 80,883 tons of biomass. Because only there are in this region 59,818 ha and that is equal to 53,836 tons of biomass, it could be satisfy 66% of the total quantity. *Alto Guadalquivir* has 84,657 ha of growing which can yield 76,191 tons of biomass, consequently only 82% of the demand could be satisfy with biomass because it is needed 92,750 ha to satisfy 65.012 GWh. Both PV and solar thermal could be use to yield the electricity needed for this region. Only a small surface it would be enough.

TABLE I. ELECTRICITY CONSUMPTION IN 2012

	Electricity yield 2012 (GWh)	Increase of electric energy (GWh)
Vega del Guadalquivir	326.755	55.47
Subbetica	660.953	152.548
Cordoba	1952.826	391.618
Guadajoz y Campiña Este	170.060	42.678
Campiña Sur	385.925	56.694
Alto Guadalquivir	285.22	65.012

IV. METHODOLOGY

The decision making process is the closing link in the process of analysing and handling different types of information: environmental, technical, economic and social. Such information can play a strategic role in steering the decision maker towards one choice instead of another. Some of these variables (technical and economic) can be handled fairly easily by numerical models whilst others, particularly ones relating to environmental impacts, may only be adjudicated qualitatively (subjective or not). Multi-criteria methods provide a flexible tool that is able to handle and bring together a wide range of variables appraised in different ways and thus offer valid assistance to the decision maker in mapping out the problem. Among existing methods, the Elimination Et Choix Traduisant la REalité (ELECTRE) method was chosen because of its relation with the distributed energy renewable [19].

To make this method, the data must be organized in a decision matrix. We have chosen this method because of a similar example made by Rogers [20], who employed the ELECTRE III methodology in a group decision making setting to analyze eleven strategic alternatives and to decide on the optimum waste incineration strategy for the eastern Switzerland region in future.

Criteria are the tools that enable alternatives to be compared from a specific viewpoint. Undoubtedly, selecting criteria is the most delicate part in formulating the problem before the decision maker, and thus it is required the utmost care and attention. The number of criteria is heavily dependent on the availability of both quantitative and qualitative information and data. Here, from the variety of criteria that were considered during the preliminary investigation, five criteria were finally taken into account. All of them are qualitative and come from studies made on Andalusia. The criterion called “Operating and Maintenance costs” includes all the costs relating to plants, employees’ wages, materials and installations, transport and hire charges, and any ground rentals payable (Euros). The criterion called “Investment costs” includes all costs relating to the purchase of mechanical equipment, technological installations, to construction of roads and connections to the national grid, to engineering services, drilling and other incidental construction work (Euros). The criterion called “Area” represents land requirement and is expressed as m^2/kW of installed power. The criterion called “Efficiency” is the output of the plant. Finally, the criterion called “Life cycle” is the life of the plant and it is measured in years.

The chosen alternatives are the different feasible technologies that are better to be installed in the province of Cordoba. They are biomass, solar thermal and PV energy. For electricity generation from Hydro Power no major increase is expected as most large hydro resources are already in use today. Wind energy neither has been considered due to actual technology doesn't work in an appropriated way to produce energy considering the Cordoba's wind speed.

A. Biomass

The source of biomass energy is a form of plant-derived material such as wood, herbaceous crops and forest residues. Biomass is produced by photosynthesis. The main biomass technologies presently used are: direct firing of biomass and co-firing of biomass [21], [22].

In general, investment costs for biomass installations are higher than conventional installations because not only for the lack of series system production developments of some components but also the special characteristics required by equipment have influence in the use of the biomass in an efficient way.

The main component of the operating cost is the purchase of biomass. The costs come from biomass supply vary depending on the quantity demanded, the distance of transport and the possible treatments to improve its quality such as to dry the wood, to take metal out of the wood or by producing pellets. Moreover, it is necessary to add the availability of the fuel, its seasonality and the change of the prices linked to the behavior of the crop.

B. Photovoltaic

The solar cell costs are important elements of the PV economic viability. The modules account for about 50% of cost of a PV power plant. The solar cells themselves for account for about half of the module cost, or 20% of the total system cost. Thin film polycrystalline technology may make it possible to have an electricity price of 6 cents/kWh. This is only a planning target for 10% efficiency. With the increase of efficiency to 20% the target will be 4 cents/kWh.

The production of the solar cells themselves leads to the emission of greenhouse gases. Taking a life cycle perspective of a PV plant, it will produce more electric energy during its life than it takes to build it [21], [22]. On the other hand, over the years the costs have decreased from 9,500 €/kWp installed in year 1999 to 6,000 €/kWp in year 2008 [15]. The considered life cycle is 25 years.

TABLE II. ELECTRIC GENERATION WITH BIOMASS

Electric generation with forest and agricultural by products	
Power capacity	5 MW
Life cycle	20 years
Output	21.6%
Quantity of used biomass	53,500 ton/year
Fuel cost	4.4942 cents/kWh
Operating and maintenance cost	0.9306 cents/kWh
Investment cost	1,803 €/kWh
Electric generation	37,500 MWh/year

TABLE III. ELECTRIC GENERATION WITH PHOTOVOLTAIC

Electric generation with photovoltaic		
	Grid connected. Following the sun	***Grid connected. Fixed***
Power capacity	6.12 kWp	6.12 kWp
Equivalent operating hours	1,644 hour/year	1,250 hour/year
Investment cost	5,938 €/kWp	5,700 €/kWp
Price paid per kilowatt-hour	42.1498 cents/kWh	42.1498 cents/kWh
Operating and maintenance cost	2.37 cents/kWh	3.00 cents/kWh
Generation cost	37 cents/kWh	37 cents/kWh

C. Solar thermal

Solar–thermal technologies work by converting the sun's energy into heat, which is then used to produce steam for driving a turbine and generator. The thermal efficiency of the plant is about 15% of the sun's energy. There are limited data on installation and electricity cost, so for this experiment the cost data are evaluated from the central receiver power plant. This system requires a large land area but has no other environmental impact [21], [23]. The chosen equipment has been parabolic trough technology.

V. RESULTS

Our multi-attribute decision making problem has 5 criteria and 3 alternatives. A standard feature of multi-attribute decision making methodology is the decision table shown in Table IV. From A1 to A5 represent the five criteria. The first, second and forth criteria are used to maximize; nevertheless, the third and fifth criteria are used to minimize.

In the case of the *Vega del Guadalquivir*, after evaluating the concordance and discordance matrix, it can be concluded on one hand that biomass is preferred to PV and solar thermal, and on the other hand, PV is preferred to solar thermal. Moreover, it isn't advisable to rule out neither PV nor solar-thermal. To sum up, whenever possible it is preferred to install biomass but without taking into account PV neither solar thermal, being PV better than solar thermal. The same that in the before region, in *Alto Guadalquivir* it can be concluded that because biomass is preferred to the others, the objective will be the installation of 7.5 MW (82% of the total energy demand). Because there is still 18% of the demand, we use preferably PV but without forgetting solar thermal in some cases. In *Guadajoz y Campiña Este*, due to biomass is preferred to PV and solar thermal, it is proposed the installation of 4.5 MW (80% of the total energy demand). And the odd 20%, it will be covered with solar thermal, and also with PV.

TABLE IV. ELECTRIC GENERATION WITH SOLAR THERMAL

Parabolic trough technology	
Life cycle	25 years
Power capacity	50 MWp
Equivalent operating hours	2,596 hours/year
Investment cost	5,000 €/kW
Price paid per kilowatt-hour	21.99 c€/kWh
Operating and maintenance cost	4.24 c€/kWh
Generation cost	20 c€/kWh

TABLE V. DECISION TABLE

	A1	A2	A3	A4	A5
Biomass	5.42	1,803	21.6	1.6	20
PV solar	2.685	5,819	13	25	25
Solar Thermal	4.24	5,000	19	40	25

In *Campiña Sur*, it is recommended to use biomass for covering 66% of the new demand, and it would be desirable that the remaining 34% be covered with solar thermal; nevertheless, when dealing with large facilities both in power and area required, it should not be excluded that PV contributed equally. In *Subbética* 50% of electrical demand (11 MW) will be covered with biomass, and the remaining 50% be covered with solar thermal; nevertheless, the same as the previous region, when dealing with large facilities it should not be excluded that PV contributed equally. Finally, in *Cordoba* 4.7% of electrical demand will be covered with biomass, and the remaining 95.3% be covered both solar thermal and PV. Because it is a high quantity of electricity, it should be desirable directing efforts towards the establishment of thermo solar facilities.

VI. CONCLUSION

The results obtained from multicriteria are the following ones. If we examine the concordance and discordance matrix, we can appreciate that in all of the regions, all the considered technologies are feasible to install. In the case of the biomass technology, we can use it in every region, being the percentage higher in one region than in other. For example, in *Subbetica* we should install almost 11 MW of power coming from biomass and in *Guadajoz and Campiña Este* would be enough only 4.5 MW. Although solar thermal is recommended in all of the regions, only two of them are better to install (*Cordoba* and *Subbetica*) because such technology requires flat floor, water, closed connexion to an electrical substation and a huge demand for electricity. These requirements are only achieved in such regions.

Last but not least it has to be pointed out that this significant contribution of the renewable electricity sector will not come by itself. Without increased political support, especially in the field of fair grid access and regulatory measures to ensure that the current electricity system is transformed to be capable to absorb these amounts of Renewable Electricity, these predictions will not come about.

Finally, with this report we don't rule out the installation of some technology near the resulting points of increase of energy. We only propose the supply in the same place in where energy is going to be used because of its better quality, minimize loses, and to be into account the possible impacts that would happen the movement of energy from some places to another. Here we propose the best solution, without being the only feasible.

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