Multicriteria selection aiding of photovoltaic plants on farming fields in Corsica Island: a real case study in the ELECTRE outranking framework

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Abstract

Corsica island has been subjected to an unprecedented abundance of photovoltaic plant projects since its energy policy has become focused on renewable resources. Concerned public institutions require specific tools to select the most relevant projects among numerous projects proposed in a transparent and prudent way.

To this end, a multicriteria decision aiding method was developed to select among sixteen projects that have been proposed for farming fields in Corsica. This report details all of the steps in the multicriteria methodology, including criteria and constraint definition, criteria weight set calculations, threshold and concordance level determination and the implementation of the chosen multicriteria model, ELECTRE IS. Thus, considering different points of view from ecological to financial, eight criteria have been defined, one of which is optional, and three constraints were determined. The methodology applied to the reviewed data allowed building six weight sets, while a concordance level of 2/3. Using this methodology, based on our criteria sets and according to the weights and concordance levels determined by the backer, four projects were selected among the sixteen initial ones, with the robustness of these results being tested through all criteria weight sets and different concordance level applications.

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Introduction

International and European agreements refer to important energy issues aimed at the reduction of greenhouse gas emissions, including energy savings, increased efficiency, supply safety and increasing the use of renewable energy sources. In 2007, renewable energy systems (RESs) contributed 18.2% of world electricity production (Observ'ER, 2008). In Europe, RESs are also considered an engine for increasing economic competitiveness and a way to reduce dependency on fossil fuel importation. The European Union has seen growth in the rate of green electricity production, which increased from 14.5% in 2004 to 15.7% of the total energy production in 2006 according to European Community Commissions[b] (ECCs). Despite this, the target of reaching 21% of renewable energy production specified in the 2001/77/CE directive will not be achieved in 2010. Therefore, the 2009/28/EC directive[c] related to the promotion of RES use and the elaboration of a common model of national actions plans[d] ratified in 2009 set new constraining targets of producing 20% of the total energy consumed from RES and at least 10% in the transport sector through the use of biofuels. According to the ECCs, the first objective requires a maximum level of RES electricity production equal to 33%. The new directive highlights the local advantages of transitioning to decentralized and renewable production: local resource use, increased supply security, shorter transport distances and a reduction of electricity losses, local public institution development, social cohesion and new income sources and job creation.

France must achieve a level of 23% of RESs in its total energy consumption in 2020 according to this new legislative framework, considering that RESs represented 6.3% of its total energy consumption in 2006. Clean electricity production increased by 18.94% from 2006 to 2008, with production of 74.019 TWh[e] in 2008. In France, grid-connected photovoltaic electricity production has increased considerably starting in 2008. The accumulated power of installed plants quadrupled compared to 2007 to achieve 56 MW with the launch of the first capacity installations. Despite this progression,

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[b]http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0192:FIN:EN:PDF

[c] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

[d] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:182:0033:0062:EN:PDF

France is ranked number six among European countries in photovoltaic energy production, far behind Spain and Germany, where photovoltaic parks generated 3.7 GW and 5.2 GW in 2008, respectively. In some French regions, photovoltaic electricity production was only approximately 26 GWh in 2008, representing 0.04% of total electricity production, making these regions are very attractive for businesses in this sector. This is the case for Corsica island. The island benefits from considerable solar potential, estimated at 1,400 TEP/Ha/yr (Poggi and Notton, 2005), and specific and profitable purchasing conditions for photovoltaic electricity: a 20-year guaranteed tariff of 40 Cts/kWh, compared to 30 c€/kWh in continental France. Thus, investing in a photovoltaic plant has an estimated profitability rate of approximately 6.5% (ADEME, 2006). In this context, the island is the subject of numerous substantial proposals related private photovoltaic plants: 74 project files had been submitted to the economic development office of Corsica (Agence de Développement Economique de la Corse, ADEC) before June 2009. Together, these projects represent a cumulative potential power generation potential of 257 MW_c, whereas the current installation potential has been assessed at 46 MW_c (Collectivité territoriale de Corse, 2010).

The Collectivité Territorial de Corse (CTC) and the Chambre d'Agriculture Départementale de Haute-Corse (CA2B) are public institutions that are solicited for their opinions about each photovoltaic plant project. They have stressed the necessity of a multicriteria evaluation process. Thus, the CTC has developed a photovoltaic development charter and a process for project assessment that were voted on June the 29th, 2009 by the Corsica assembly. Additionally, the CA2B, which is required to provide an opinion particularly on projects that may be implemented in farming fields, has ordered an evaluation study on 16 projects from the University of Corsica with the aim of basing its opinion on rigorous arguments.

The first part of this evaluation is related to the energy context on Corsica island. It is specific from the policy point of view, considering that Corsica's public institutions have more competence concerning energy policy than those in other French regions, as well as from the technical viewpoint because the weakly interconnected grid with France and Italy is a consequence of its insular situation. The

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[e] http://www.developpement-durable.gouv.fr/energie/renou/textes/se_bilan.htm

presentation of this context allows the introduction of the following problem: the use of multicriteria tools to select the most appropriate private photovoltaic plant projects among numerous proposals. In the second part of the evaluation, the multicriteria method is developed through the presentation of alternatives, the definition of criteria and constraints and the construction of performance tables, and the model used is also presented.

Insularity and Corsica's energy context

Energy framework of insular territories

A large majority of the islands in the world have a vulnerable economy in which the energy supply weighs strongly, particularly as demand grows due to demographic pressure and tourism development. Thus, islands face specific problems constraining their energy policies (Commission des îles CRPM, 2001):

- connection to continental production sources, such as nuclear or gas, is impossible in the majority of cases, and the infrastructure for continental connection is extremely expensive in other cases;
- energy is so expensive that if the price was totally born by the users, the competitiveness of local industries and the standard of living of island inhabitants would be highly impacted;
- a high level of dependence on imported fuel makes most islands highly vulnerable to fuel price fluctuations;
- there are numerous considerable demand fluctuations due to seasonal tourism;
- generally, the narrowness of these markets prevents the coordination of local energy distribution;
- the remoteness and topography of islands make energy supply even more difficult.

Considering these limits together with the abundance of renewable energy sources and the high integration capacity of islands, large-scale development of renewable energy production on islands seems to be timely. Thus, "*islands have become genuine laboratories of the future of energy sustainability*" (C Marin *et al*, 2005).

The governments of insular territories are increasingly characterized by the goal of achieving energy autonomy through sustainable use and consumption control. Thus, they are actively involved in the fight against global warming through the limitation of greenhouse gas emissions. These complex and essential tasks require the definition of an energy strategy and the implementation of rigorous planning specific to the island environment. The numerous stakeholders involved in these processes, including economic, ecological and social, make the use of appropriate tools indispensable, such as multicriteria analysis and multicriteria decision aiding.

Multicriteria analysis allows decision makers because it requires many years to make explicit, rational and efficient choices incorporating the best compromises related to electricity production (Pohekar and Ramachandran, 2003). Numerous studies have illustrated the uses of this methodology to solve energy planning problems in an island context. For example, it supported the selection of a strategy for energy supply among numerous alternatives ranging from high level renewable energy production to continental interconnection on Crete island (Greece) (Georgopoulou et al., 1997). It also allowed the determination of the penetration ratio of renewable energy production in this island's electrical system (Mourelatos et al., 1998).

Additionally, multicriteria decision aiding assisted in choosing the renewable energy technology best adapted among all technologies existing in Sicilia (Cavallaro, 2005) and Sardinia (Beccali et al., 2003), where each alternative was studied according to different priorities from three points of view.

Furthermore, an appropriate mix of energy production means has been selected through the use of multicriteria tools in Crete (Tsoutsos et al., 2009) and in the Greek islands of Karpathos and Kassos (Papadopoulos and Karagiannidis, 2008).

In other cases, determining the size and locations of renewable energy installations has been conducted using multicriteria decision aiding methodology. Thus, the size of a wind farm with a photovoltaic plant in the Eolian islands was determined (Italy) (Cavallaro and Ciraolo, 2005), and the location of a wind farm in Corsica (Oberti, 2006) and thermal plant installations in northern Africa (Barda, 1990) were selected by multicriteria decision aiding.

Energy resources in Corsica

On Corsica in 2008, nearly the half of the 587 MW of electrical power generated came from oil thermal plants. At the same time, 22.15% of the electricity was imported from Italy or Sardinia through the high voltage SARCO (SARdinia-COrsica) and SARCOI (SARdinia-COrsica-Italy) links, whereas RESs represented 29% of electricity production of the total energy production with 25.2% results from hydraulic production (Fig. 1).

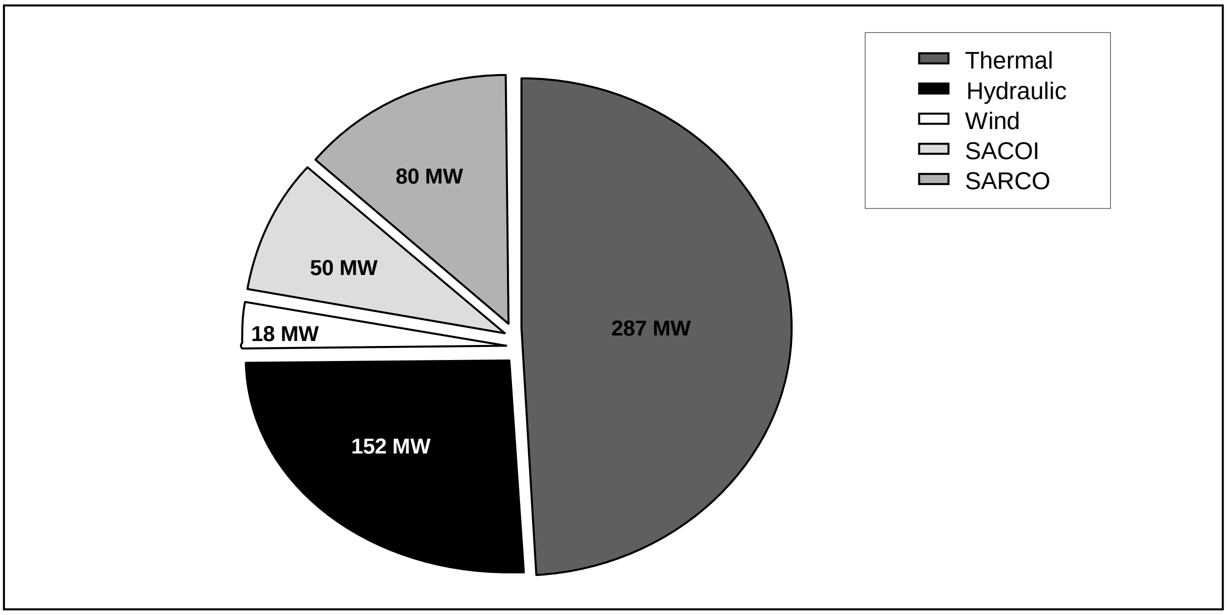

Figure 1: Power (MW) and resource partitioning in the electrical production in Corsica

Despite an important wind potential with an estimated workable layer of 433 MW for a mean wind speed over 7 m/s at a height of 10 m and an economically viable potential of a 100 MW (Poggi & Notton, 2005), only 18 MW of the energy on the island are wind produced, representing 3.1% of electricity production.

Finally, photovoltaic electricity production on the island is nil, despite the high solar potential of over 1,400 Tep/Ha/yr: the daily global horizontal irradiation reaches 4.41 kWh/$m^2$for more than 2720 hours of sunshine in Ajaccio (Poggi and Notton, 2005).

Corsica's energy competencies

Corsica's status, as defined in 1982, entrusts the CTC with the responsibilities of increasing energy fields and development. Subsequently, CTC's energy competencies were determined by a law passed on the 13th of May, 1991, and were strengthened in 2002. These competencies concern RES development, actions related to energy consumption control and participation in a demand coverage guarantee plan in collaboration with "Electricité de France" (EDF). They are developed according two axes:

- A specific competence in the creation and the definition of an energy resource prospecting, exploiting and valorizing program, which concerns installations powered by less than 8,000

KW. This competence has been solidified through the adoption of energy strategy determination laws, such as Corsica's energy plan for the period 2005 to 2025. This plan defines regional policy aims and is centered on an "energy tripod" that foresees

  - basic production means renewal,
  - interconnection reinforcement,
  - RES development.

  Thus, the CTC adopted an RES development and a plan for energy consumption control in 2007 to achieve the goal of 30% of electricity production by RESs. This text is the reference for the energy actions of the CTC during the period of 2007 to 2013.

- The second competence axis concerns the arrangement of territories and the possibility of making installation choices and creating implantation proposals for the island electric supply. It defines the advisory role of the CTC in all RES installation projects: the CTC is to be systematically consulted by the administrations entrusted with granting permission for every new project. Thus, the CTC adopted charters for wind farm development in 2003 and wind farm controlled development in 2005 and the Corsica photovoltaic development charter in 2009. These charters enforce the authority of the CTC through a transparent and fair-minded approach and allow dealing with to the considerable inflow of installation projects.

Outranking multicriteria decision aiding (MCDA) for photovoltaic plant selection on farming fields

Operational research has provided models for the treatment of decision problems for decades. The classical approach to these models, consisting of optimizing a single function with possible constraints, has the benefit of leading to clear, well-expressed mathematical models adapted to mono-criterion decisions. Cost-benefit analysis and other simple and widely employed tools, such as sums or arithmetic means, illustrate this case. However, these processes have generally been proven to be unsuitable to treat complex decisional problems for which decision makers look for various and more or less controversial targets. This reasoning assumes two main difficulties in determining real multiple criteria and multi-actor decisions. They impose a single and common evaluation scale (monetary, utilitarian) to judge the alternatives for the performance on each criterion. This constraint does not allow the participation of a variety of actors with their own systems of values and information.

The aggregation of alternative evaluations can be highly compensatory. It can be considered acceptable that losses on a criterion match gains on another criterion. It dilutes winners and losers in an arithmetic result, which promotes sectoral logic, and a technically optimal solution may not be accepted. Thus, the modern approach in operational research, which has been employed for approximately the past forty years, is to develop multicriteria decision aiding (MCDA) methodologies that compensate for the weaknesses of the classical process.

Among MCDA, the ELECTRE outranking approach (Roy, 1996) (Bouyssou and Roy, 1993) (Figueira et al., 2005) is a mathematical tool that tests comparisons between different alternatives according to several criteria that are often controversial. This context generally leads to an absence of an optimal solution and to a study of a satisfactory solution. Thus, this framework makes its contributions through decision-aiding science. It formulates recommendations, while decision makers completely maintain their freedom to make choices: the final decision belongs to the decision makers with respect to how to interpret the scientific conclusions. Numerous energy studies have MCDA ((Cavallaro, 2005), (Beccali et al., 2003), (Tsoutsos et al., 2009), (Papadopoulos and Karagiannidis, 2008), (Cavallaro and Ciraolo, 2005), (Oberti, 2006), (Barda, 1990)).

Study context

Institutional actors and decision makers, on whom there is a great deal of pressure in judging the relevance and feasibility of individual projects, have the aim of providing transparent and informed opinions. The Haute-Corse departmental Agriculture Chamber (CA2B) consulted Corsican University researchers with the aim of enlightening this public institution and gaining advice in project selection through the application of MCDA. The present study deals with the concrete problem of the selection of photovoltaic plant projects among 16 projects that have been developed and submitted by industries to local decision makers. Our priorities were the following:

- Use conflict risks have to be evaluated, particularly because the planned installations are to be placed on farm fields and could potentially use up to 311 Ha of cultivated ground.

- A limit of renewable energy source installations connected to a regional-scale electrical network has to be respected. No more than 30% of renewable energy can be injected into an electrical network to ensure its stability. This ratio corresponds to 100 MW_c in Corsica, but a recent decree set the renewable production limit at approximately 83 MW_c. Existing plants (three wind farms) already produce 18 MW_c, and accepted wind farm and PV projects represent 19 MWc, so only an additional 46 MW_c of renewable energy can be integrated into the network (Assemblée de Corse, 2009). The studied group of projects represents a 93.5 MW_c potential of accumulated power for the Haute Corse department alone, which exceeds the maximum calculated for the whole Corsican region.
- Territorial over-abundance of electricity production has to be avoided. The geographic concentration risk of the energy projects has to be considered to avoid sudden declines in production due to climatic or technical factors. The set of projects is dispersed over three restricted geographic zones, and it concerns only four electrical linking posts. Projects that are intended to be linked to the electrical network through the same linking post were analyzed simultaneously to fulfill the over-abundance shunning demand, so our recommendations are expressed for each electrical post.
- Social acceptability has to be taken into account. Negative and positive impacts, both visual and financial, due to such installations on local populations must be studied.
- Ecological impacts must be evaluated. Photovoltaic plants are assumed to represent sustainable alternatives for electrical production, but such important plants also have an ecological cost that must be evaluated to ensure their ecological benefits.
- Economic and financial impacts at regional and local levels must also be aken into account.

Finally, project evaluations were based on data files and criteria that were informed by a targeted reading without field visits.

The photovoltaic projects proposed in Haute-Corse

The new energy policy context in Corsica aimed at renewable energy has increased the attractiveness of this region for PV industrials. The Corsica island is considered as the metropolitan region of France with the most important for photovoltaic plants installation.. Thus, numerous photovoltaic plant projects are consequently relevant to Corsica.

The study described in this aim deals with the evaluation of data files of 16 proposed photovoltaic plant projects (Table 1) that are likely to be implemented on agricultural fields in the oriental plain and Bastia's neighborhood (Fig. 2).

Electrical linking post	Projects	Sites	Village	Power (MW_c)	Annual Production (GWh/an)	Rent area's surface (Ha)	Efficient surface (Ha)
Oletta	a_5	Malpergo	Rapale	10.26	12.82	40	9.86
	a_8	Griolo	Oletta	3.43	5.15	11.1	3.41
	a_{11}	Mignalojo	Oletta	3.55	5.32	14.3	3.5
Taglio	a_4	Querci	Penta di Casinca	11.06	16.5	41.5	10.4
	a_{10}	Citrinche	Venzolasca	4.5	5.85	12	3
Cervione	a_9	Farinaccio & Sandali	Linguizzetta	8.5	10.16	29.48	8.43
	a_{14}	Sbiri	Linguizzetta & Talonne	8	10.4	23	5.9
Ghisonaccia	a_1	Tozze	Aghione	11.64	17.5	36.68	11.5
	a_2	Alzolu	Prunelli Di Fiumorbo	1.27	1.62	3.6	1.3
	a_3	Casa Calva	Prunelli Di Fiumorbo	3.05	4.585	14.3	5.7
	a_6	Mortella	Ghisonaccia	3.89	5.179	11.5	2.86
	a_7	Maison Pieraggi	Pietroso	1.83	2.414	5.79	1.37
	a_{12}	Manalotte	Pioggio Di Nazza	4.5	5.85	17.43	3.1
	a_{13}	Chisacca	Serra Di Fiumorbo	8	10.4	17	5.1
	a_{15}	Niellone	Prunelli Di Fiumorbo	4.02	5.378	10.8	3.54
	a_{16}	Acqua di l'Asino Les Cigales	Ventiseri	10.65	14.995	30.21	10.25

Table 1: Characteristics of the 16 photovoltaic plant projects

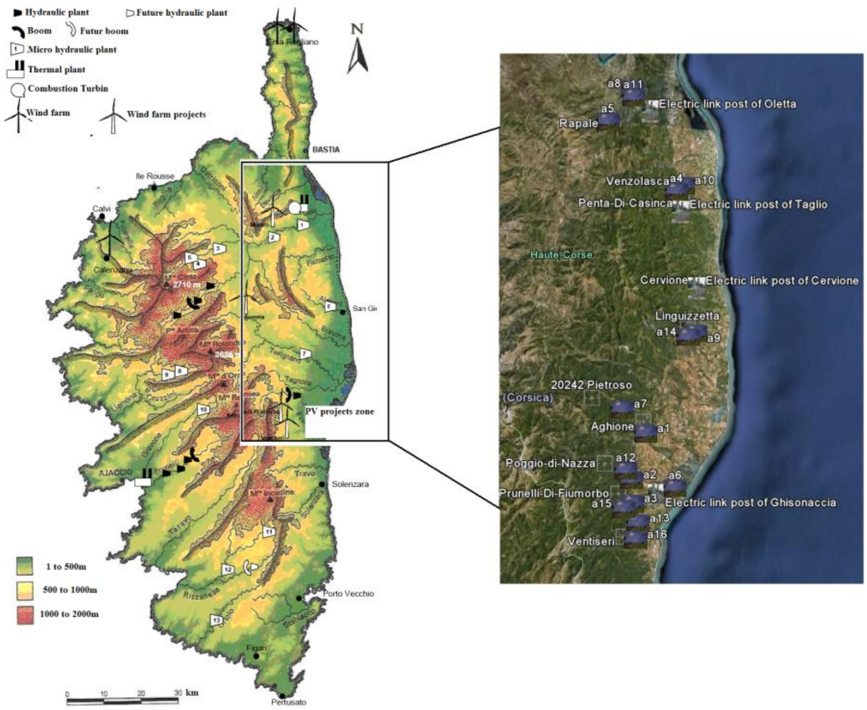

Figure 2: Geographic location of electricity production means in Corsica and areas concerned by photovoltaic plants.

Pre-selection constraints are defined as conditions of acceptability or eligibility that actors must satisfy to be candidates for the decision or/and the multicriteria study (Oberti, 2004). Three constraints have been determined in this study framework (Table 2).

Constraints	Definitions
C_1	**Plant dismantling guarantee**: plant dismantling must be guaranteed in the exploitation contracts.
C_2	**Area's ecological classification**: concerned areas must not be classified by Natura 2000 or as wetlands
C_3	**Area's topography**: an areas' slopes must not exceed 10%[f]

Table 2: Constraint definitions

Evaluation criteria of PV projects

A criterion is a tool created to evaluate and compare potential actions from a particular point of view (Roy, 2000). The construction of a set (or family) of evaluation criteria is the outcome of a progressive

f Value usually used by industries.

process with debates between actors. This approach is not supposed to maintain numerous criteria with associated risks of redundancies or antagonisms. It must offer complementary and coherent comparative points of view, even considering lacking information.

Seven evaluation criteria have been elaborated to incorporate the information available in all files and to compare the PV projects from different points of view related to energy, economic, ecological, visual and territorial uses. An eighth optional criterion also intervenes: the annual additional incomes from a communal budget per inhabitant, which represents a financial concern related to professional taxes. This criterion is optional because of uncertainty about these taxes in the future in France and the difficulties of calculating them, as their costs can vary greatly between files for similar projects. Thus, our multicriteria models will be implemented twice: first considering the initial seven evaluation criteria without the financial considerations and second with financial considerations included.

Table 3 presents the pertinent criteria developed for this specific study and listed by the Haute-Corse chamber of farming (CA2B) in cooperation with the University of Corsica (SPE and LISA laboratories).

Point of view	Code	Criteria title	Criteria creation principle	Scale terms	Preference aim
Energy	g_1	Net production	Energy production evaluation	GWh annual	Maximize
Geo-economic	g_2	Rent area unoccupied by the installation	Ratio between free area of productive land and the total	%	Maximize
Ecological	g_3	Study of the potential ecological degradation in the files	Weighted sum	Points	Maximize
Visual impact	g_4	Relevance of visual impact presentation in the files	Weighted sum	Points	Maximize
Visual impact	g_5	Observer-plant minimum distance	Measures from cartography	km	Maximize
Territorial use	g_6	Use conflicts risks	Weighted sum	Points	Maximize
Financial effect	g_7	Economic activity and inhabitants' financial benefits related to RES facilities	Weighted sum	Points	Maximize
Financial effect	g_8	Financial incomes at the communal level	Ratio between professional duty evaluation and the communal population	€/yr/inhab	Maximize

Table 3: Photovoltaic project criteria

Net production

This criterion (coded g_1) to be maximized aims to incorporate the annual production estimations in GWh/year calculated by the industries in each file.

Rent area unoccupied by the installation

This criterion (coded g_2) to be maximized is the relative difference between the total rent plot area (RA in Ha) and the total photovoltaic module area (EA in Ha) calculated by the industries and published in the files as $\frac{RA - EA}{RA}$. The aim is to provide information about the free area between the PV arrays that is able to be used for agricultural activities. This is an alternative to limit the loss of farming fields. In Germany, for example, the Bavaria solar park and the Pöking and Strasskirchen parks take in sheep for gazing, whereas on the French island of La Réunion, photovoltaic modules are used as hothouses for vanilla culture (Quattrolibri, 2009).

Study of the potential ecological degradation in the files

This criterion (coded g_3) to be maximized is evaluated in points (score) according to a notation table (Table 4). Its purpose is to determine the rigor of the ecological impact studies in the files and the compensatory actions proposed by the industry following DIREN PACA recommendations (DIREN PACA, 2009). This table has been divided into four categories.

- Impact definition: The ecological impact must be determined following a rigorous approach and methodology. It requires objective and measured knowledge of ecological assets justifying the production of field flora and fauna inventories. This category’s evaluation is based on the existence of inventories and the quality in the files, as well as species quantification and descriptions of physical field characteristics. Impact qualification and quantification evaluations are not carried out based on their importance but rather on the existence of these qualifications and quantifications in the files.
- Compensatory actions: These actions intervene as an offset against accepted residual damage. Their aim is to achieve a neutral ecological balance or global site improvement of ecological

value. The aim is to avoid a net diversity loss to slow down its decline. This category represents the compensatory actions proposed in the files. It reports whether the files present a budget because we consider that a budget presentation indicates a more important commitment from the industry putting forth the project.

- Demonstration of equivalence impacts/compensatory actions: Impacts are translated into surface terms by multiplying the impacted surface area by a ratio calculated from the quantifications and qualifications of impacts according to the principle "the greater the importance of the impact, the larger the surface for compensation". The surface equivalent of compensatory actions must be at least equal to the equivalent surface of the impacts. This category reports a demonstration of the impact/compensatory action equivalence existence in the files to evaluate the rigor and relevance of compensatory actions.
- Artificializing fields: This last category reports the additional artificializing imposed on the field, such as concrete foundations, access roads and earthworks.

	Appreciation elements	Score
	Impact definition	10
Species description	Rigorous species listing (carried out by naturalists)	4
	Incomplete species listing	1
	No species listing	0
Habitat description	Rigorous habitat listing (carried out by naturalists)	4
	Incomplete habitat listing	1
	No habitat listing	0
Species number	Species number count	1
	No species number count	0
Field specificities	Description of field characteristics	1
	No description of field characteristics	0
	Impact measurement and quantification	4
Impact intensity	Informed	1
	Not informed	0
Surface impact	Informed	1
	Not informed	0
Impact duration	Informed	1
	Not informed	0
Impact frequency	Informed	1
	Not informed	0
	Impact qualification	4
Protection laws	Informed	1
	Not informed	0
Impact's global biological incidence	Informed	1
	Not informed	0
Impacted species and habitat multiplicity	Informed	1
	Not informed	0
Species resilience capacity	Informed	1

	Not informed	0
	Compensatory action definitions	10
Species circulation freedom	limits fit with budget	4
	limits fit without budget	1
	Not informed	0
Fauna survey	Fauna survey, environmental management with budget	4
	Fauna survey, environmental management without budget	1
	Not informed	0
Flora and habitat protection	Habitats protected and reinforced with budget	3
	Habitats protected and reinforced without budget	1
	Not informed	0
	Impacts/compensatory actions	10
	Equivalence demonstration	10
	No equivalence demonstration	0
	Site artificializing	7
Access roads	No creation, no reinforcement	3
	Weak road reinforcement	1
	Road creation or/and strong reinforcement	0
Concrete basis	No concrete foundation	3
	Concrete foundation for buildings	1
	Concrete foundation for both PV module tables and buildings	0
Earthwork	No need for earthwork	1
	Need for earthwork	0

Table 4: Evaluation scale to study the potential ecological degradation in the files

Relevance of visual impact presentation in the files

The exteriors of the projected installations are considerable enough to be visible from a great distance. Although the evaluation of the visual impact of such installations is still strongly subjective, being negative for some and neutral for others, it appears to be preferable to attenuate it.

This study, which was based on project file reading, did not allow measurements of visual impacts to be made. Thus, we evaluated how the industries presenting the proposals had studied this impact, as opposed to the impact itself. Therefore, this criterion (coded g_4) to be maximized is assessed in points (score) according to a notation table (Table 5). It takes into account the treatment presented in the files according to three elements:

- the proposed viewpoints determine the relevance. Here, we consider whether important viewpoints are present (from roads, homes and villages);
- the presence of visual impact cartography produced from a geographical information system presenting the locations from which the photovoltaic plant would be visible;

- the definition of compensatory actions.

	Appreciation elements	Score
	Visual impact study relevance	10
Viewpoint set	Relevant viewpoint set	2
	Body of relevant viewpoints (from neighbor villages, roads or homes)	0
Visual impact cartography	Visual impact cartography presented in the file	4
	No visual impact cartography	0
Compensatory actions	Compensatory actions with budget	4
	No compensatory actions, or compensatory actions without budget	0

Table 5: Evaluation scale of visual impact study relevance in the files

Observer-plant minimum distance

The object of this criterion (coded g_5), which is to be maximized and measured in km, is to take into account the inconvenience caused by such an installation on the surrounding neighborhood. It has the aim of penalizing those installations that are in close proximity to residences. This distance was generally not specified in the files, so it has been measured from maps.

Use conflicts risks

The sites that are supposed to receive the photovoltaic plants are farming fields, which have the desirable characteristics of being large-sized, relatively level and already artificialized places. However, their current status as agricultural sites results in a use conflict problem.

This criterion (coded g_6) to be maximized is assessed in points based on a notation table (Table 6), which takes into account the present use of the field and the characteristics of its neighborhood according to

- the present site uses and development: the chosen sites are not necessarily used for farming at present, so it is important to precisely present the type of use and whether it includes irrigation structures;
- the cultural and economical interests of the neighborhood: this parameter deals with the evaluation of the agricultural, tourist, or archaeological interest in the neighborhood.

	Appreciation elements	Score
	Field usage	
Agricultural classification	No classification	18

	Agricultural field		8
	Biological agriculture field		0
Agricultural usage	Fallow field		16
	Neglected cultivation or relocation possibility of the culture		9
	Grazing		4
	Exploited culture		0
Irrigation	No irrigation		18
	Irrigation		9
Future of the agricultural activity	Possibility to conserve an agricultural activity		13
	Not informed		0
	Geographic zone characteristics		
Agricultural development	Undeveloped zone		12
	Sparsely developed zone		5
	Developed zone		0
Tourist interest	Undeveloped zone		12
	Developed zone or proximity of hiking paths		0
Archaeological interest	No archaeological interest acknowledged		12
	Archaeological interest not acknowledged	Preventive excavations suggested	7
		If any findings, abeyance of the project	4
		Not informed	1
	Archaeological interest acknowledged		0

Table 6: Evaluation scale of use conflict risks

Economic activity and financial benefits to inhabitants from RES facilities

This criterion (coded g_7) to be maximized reports the economic activity generated for Corsican firms during the building stage and eventual creation of employment during the exploitation stage. The notation table (Table 7) allows the evaluation of the projects with respect to this criterion in points. It integrates the eventual will of industries to allocate financial aid for RES facilities to local inhabitants.

	Appreciation elements	Score
Work stage	Activity for Corsica-based firms	6
	Corsica-based firm intervention with budget	6
	Corsica-based firm intervention without budget	1
	Not informed	0
Exploitation stage	Employment	3
	Defined employment creation	3
	Undefined employment creation	1
	Not informed	0
	Financial benefit from RES facilities to local inhabitants	6
	Financial benefit with budget	6
	Not informed	0

Table 7: Evaluation scale of the economic activity and financial benefits to inhabitants for RES facilities

Financial income at the communal level

This optional criterion (coded g_8) to be maximized is measured in €/yr/inhab. It designates the additional fiscal income for the municipality provided through the professional duty divided by its population. Thus, we prefer installations to be placed in low socio-economic stratus communities, which are generally poorer.

The professional taxes were specified by the industries in the submitted files, whereas the included populations were gathered from the Institut de la Statistique et des Etudes Economiques (INSEE) database.

Performance table

A performance table summarized the usefulness information set for an outranking multicriteria calculation, with the exception of a few internal technical or economical model-specific parameters. This table is usually composed of three informational parts: the evaluation of each alternative on each criterion, criteria weights and thresholds on criteria.

The existence of several criteria weight sets lead to building an expanded performance table. This table allows the condensation of the presentation of information and avoids repeating the same elements in several classical tables. However, the existence of an optional criterion (g_8) implied that two expanded performance tables should be constructed: a first table including and the second table excluding this criterion. Both performance tables are presented together in this aim (Table 8).

Criteria	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8
Units	GWh/an	%	Points	Points	km	Points	Points	€/yr/inhab
Optimization					Maximization			
Projects – Sector of Oletta								
a_5	12.82	75.35	10	4	0.05	46	1	512.82
a_8	5.15	69.28	13	10	0.1	46	2	79.43
a_{11}	5.32	75.52	14	10	0.625	58	2	79.43
Projects – Sector of Taglio								
a_4	16.5	74.94	12	8	0.35	47	2	89.57
a_{10}	5.85	75	27	6	0.2	38	7	41.32
Projects – Sector of Cervione								
a_9	10.16	71.4	12	8	0.2	65	1	148.51
a_{14}	10.4	74.4	30	6	1	64	6	102.27
Projects – Sector of Ghisonaccia								
a_1	17.5	68.7	9	6	0.2	52	2	1033.06
a_2	1.62	63.89	20	2	0.3	55	4	8.38
a_3	4.585	60.14	29	6	0.1	48	2	30.93
a_6	5.179	75.13	8	0	1	33	4	42.88
a_7	2.414	76.34	8	0	0.1	43	2	249.1
a_{12}	5.85	82.02	27	4	0.5	89	7	388.89
a_{13}	10.4	70	26	4	0.05	77	6	453.02
a_{15}	5.378	67.2	22	6	0.3	32	7	-
a_{16}	14.995	66.08	26	10	0.05	30	7	152.84
Criteria weights								
Set I z=4	14.28%	19.05%	19.05%	19.05%	4.76%	19.05%	4.76%	-
Set II z=3.8	14.3%	18.935%	18.935%	18.935%	4.98%	18.935%	4.98%	-
Set III z=4.2	14.27%	19.1525%	19.1525%	19.1525%	4.56%	19.1525%	4.56%	-
Set IV z=4	12%	17%	17%	17%	4%	17%	12%	4
Set V z=3.8	12.51%	16.565%	16.565%	16.565%	4.36%	16.565%	12.51%	4.36%
Set VI z=4.2	12.49%	16.76%	16.76%	16.76%	3.99%	16.76%	12.49%	3.99%
Criteria thresholds								
Indifference	10%	4	2	0	0.35g5(.)+0.15	3	0	20.57%
Preference	91.7%	4	10	0	0.35g5(.)+0.15	13	1	188.52%
Veto	-	-	20	-	-	43	-	-

Table 8: Expanded performance table

Finally, the projects were grouped according to the post where they are supposed to be linked because our selections were made by electrical linkage posts.

Outranking multicriteria aggregation

State of the art surveys have shown a wide variety of approaches in multiple MCDA. Among these, ELECTRE outranking methods (Figueira et al., 2005) are relevant when the stakeholder (for example, the decision maker) wants to include in the model at least three evaluation criteria (up to thirteen) and when at least one of the following cases is verified:

- for one criterion or more, actions are evaluated on an ordinal scale or on a weak interval scale;
- strong heterogeneity related to the nature of the values exists among the criteria;
- compensation of the loss of a given criterion by a gain in another one may not be acceptable for the decision maker;
- small differences in evaluations are not significant in terms of preferences for at least one criterion, while the accumulation of several small differences may become significant.

In our study:

- seven or eight criteria are considered (Table 3);
- no common scale of values is used (Table 3 and evaluation criteria of PV projects)
- compensatory possibilities are limited by veto thresholds defined on criteria g_3 and g_6 (Table 8);
- differences of a maximum of two or three points for g_3 and g_6, respectively, are compatible with indifference situations between two PV projects, but greater differences become significant in terms of weak or strong preferences.

Thus, ELECTRE outranking framework was appropriate.

Particularly, the ELECTRE IS method was chosen according to the problematic types encountered, the analysis of imperfect knowledge and its scientific rigor. The problematic type refers to the way in which decision aiding is envisaged in the MCDA: i.e., to achieve conformity with the evaluation command, what type of results should the analyst try to obtain? Currently, three reference problematic types are practiced: ranking (complete or partial preordering of the set of actions), sorting (assignment of each action to the most appropriate predefined category of a family) and choice (selecting a small subset of the most satisfying actions in such a way that a single action may finally be chosen). The request of the client (CA2B) was clear: select a few PV projects among the numerous projects proposed, with installations on roofs being preferred instead of those on closed agricultural space on the ground. For this reason, the choice problematic type was suitable, and the relevant methods of the ELECTRE family are ELECTRE I, ELECTRE Iv and ELECTRE IS. Only this last method provides a pseudo-criteria-based procedure of selection to take into account imperfect knowledge through discrimination thresholds. This distinction was appropriate for the present study because the evaluations focus on PV projects and not on photovoltaic plants with observable impacts. Finally, the ELECTRE IS method is an extension of the previous methods and is the most well-developed model for processing the choice problematic type because it is scientifically more refined (Aït Younes et al., 2000) and includes a rigorous robustness analysis of the results.

Consequently, the performance table values (Table 8) were aggregated by this chosen outranking model. Each criterion may have its own scale term, and the actions (alternative projects here) are compared by ordered pairs in the ELECTRE framework.

Basic mathematical elements

We consider $A = \{a_1, a_2, ..., a_i, ..., a_n\}$ as a finite set of n alternatives and $a_i \in A, a_k \in A : a_i \neq a_k$ as two different alternatives.

We define the outranking hypothesis $a_i S a_k$ applied to the ordered pair (a_i, a_k) as follows: either "a_i is not worse than a_k" or "a_i outranks a_k". $F = \{g_1, g_2, ..., g_j, ..., g_m\}$ is a coherent family of m evaluation criteria.

The weight of the criterion g_j is $w_j \in]0;1[$, and the criteria weights are normalized as follows: $\sum_{j=1}^{m} w_j = 1$.

The evaluation or value obtained by alternative a_i related to the criterion g_j is $g_j(a_i)$, and $g_j(a_k)$ provides the evaluation of a_k on g_j.

$\Omega_j(a_k, a_i) = \begin{cases} g_j(a_k) - g_j(a_i), \text{ if } g_j \text{ has to be maximized} \\ g_j(a_i) - g_j(a_k), \text{ if } g_j \text{ has to be minimized} \end{cases}$ defines the advantage of a_k over a_i for the criterion g_j.

Discrimination and veto thresholds

Preference modeling of an actor on the action set A for a criterion of the family F is based on pseudo-criterion formalization (Bouyssou and Roy, 1993). It allows more realistic comparisons by distinguishing indifferent, weak and strict preference situations between actions due to the introduction of two discrimination thresholds (indifference and preference). Thus, the pseudo-criterion model takes into account margins of imprecision, ill-determination and uncertainty about the evaluations of actions. We note that there are no true values for thresholds but only chosen values that are the most convenient and accepted to express imperfect knowledge.

$q_j \geq 0$ is the g_j criterion's indifference threshold so that an advantage $\Omega_j(a_k, a_i)$ is judged not significant if $|\Omega_j(a_k, a_i)| \leq q_j$. Then there are no preferences between a_i and a_k. For example (Table 8), concerning the study of potential ecological degradation in the files (g_3), a difference of two points was considered negligible $(q_3 = 2)$. Consequently, the PV projects a_3 and a_{12} are indifferent.

p_j is the preference threshold of criterion g_j, so an advantage of $\Omega_j(a_k, a_i)$ is judged significant if $\Omega_j(a_k, a_i) > p_j$. a_k will then be strictly preferred to a_i. For example, project a_2 has a significant advantage over a_1 as follows: $\Omega_3(a_2, a_1) = 11 \geq p_3 = 10$, and a_2 is strictly preferred to a_1.

Then, $C(a_k Q a_i) = \{g_j \in F : q_j < \Omega_j(a_k, a_i) \leq p_j\}$ is the criteria set, so a_k is weakly preferred to a_i, and its advantage is neither significant nor non-significant. For example, project a_3 is weakly preferred to a_2 because $q_3 = 2 < \Omega_3(a_3, a_2) = 9 \leq p_3 = 10$.

Finally, an alternative a_i can result in an insufficient evaluation for criterion g_j in comparison with another one, a_k, such that the preference of a_i over a_k is unacceptable when all criteria are considered. A veto threshold v_j can be valued to set a limit on the compensation of the bad performance of a criterion by good performances of other criteria. Thus, an advantage $\Omega_j(a_k, a_i)$ above this value of v_j cannot be matched by an advantage $\Omega_{j'}(a_i, a_k)$ for another criterion $g_{j'} \in F - \{g_j\}$. This fact leads to the rejection of the hypothesis $a_i S a_k$. For example (Table 8), project a_6 does not outrank project a_3 ($not(a_6 S a_3)$) because criterion g_3 gives $\Omega_3(a_3, a_6) = 21 > v_3 = 20$.

The thresholds are defined in such a way that $v_j \geq p_j \geq q_j \geq 0$ and $v_j - p_j \geq q_j$. They can be constants or variables (affine functions) in the value scale of g_j (Aït Younes et al., 2000). For example (Table 8), variable thresholds were considered for criteria g_1, g_5 and g_8.

Several techniques can be used to assign values to such thresholds (Figueira et al., 2005), such as direct elicitation, when the parameter definition is intelligible to the queried actor, and indirect elicitation, which can be used based on a dispersion approach. A dispersion threshold translates the plausible difference due to over- or under-estimations that affect the evaluation and takes into account probable, pessimistic and optimistic values or the lower and upper bounds of the values.

In our case study, the indifference threshold value of the criterion g_1 was directly assigned by a physicist who studies RESs as an error of estimation related to net production according to this individual's experience and from reading publications and self-evaluations. In contrast, the preference threshold was indirectly assessed. Thus, it takes into account the ratio between the power maximum and minimum (Table 1) and the indifference threshold for the purpose of not placing small PV plant projects at a clear disadvantage compared with larger ones. Thus, we obtained $p_1 = \frac{11.64\,MW_c}{1.27\,MW_c} \times q_1 = 91.7\%$. This value excludes situations of strict preferences between projects.

Additionally, the threshold for criterion g_2 of $q_2 = p_2 = 4\%$, dealing with the imprecision around the surface measures, was indirectly valued by a mapping study. Finally, we note that variable thresholds of $q_5 = p_5 = 0.35\,d + 0.15$ were defined for the criterion g_5. Thus, we consider that the indifference threshold increases with the distance (d) between an observer and the PV plant projects.

Criteria weights

In the ELECTRE outranking framework, the importance coefficients of the criteria are intrinsic weights; they cannot be interpreted as substitution rates but should be interpreted as voting power accorded to each criterion. The revised procedure of Simos (Figueira and Roy, 2002), as implemented in SRF software, provides normalized weights of the criteria. Before computing these, the analyst questions the actor about

- the ranks of the criteria, from the least important (rank 1) to the most important (last rank); ex aequo is accepted;
- the differences of importance between successive ranks;
- the ratio (z) between the most important criterion and the least important one in the ranking.

These two last stages are facilitated by an adaptation of the procedure presented in Poli (2009).

Briefly, for a criterion g_j of rank r, its normalized weight is $w_j = \frac{100}{K'} k_j$, where:

m is the number of criteria; $\overline{m}$ is the number of ranks; e'_r is the difference of the importance between criteria of ranks r and $r+1$, $e_r = e'_r + 1 \quad \forall r = 1,..., \overline{m} - 1$, $e = \sum_{r=1}^{\overline{m}-1} e_r$, $u = \frac{z-1}{e}$ for 6 decimal places;

$k_j = 1 + u(e_1 + ... + e_{r-1})$ is the non-normalized weight; and $K' = \sum_{j=1}^{m} k_j$.

Table 8 presents the six sets of normalized weights obtained with the participation of the CA2B. Two evaluation sets (I and IV) were computed with or without the integration the criterion g_8. The four other weight sets were built based on ±5% variations of the importance ratio z.

ELECTRE IS outranking test and kernel

ELECTRE IS (Aït Younes et al., 2000) (Figueira et al., 2005) is a model inspired by the voting process. It tests the outranking hypothesis $a_i S a_k$ through the following conditions:

- Concordance condition (majority principle): a considerable majority of the criteria must verify $a_i S a_k$. Formally, $c(a_i, a_k) \geq s \in \left[0.5, 1 - \min_j w_j\right]$,

  where $c(a_i, a_k) = \sum_{j \in C(a_i S a_k)} w_j + \sum_{j \in C(a_k Q a_i)} w_j \varphi_j(a_i, a_k) \in [0;1]$ is the global concordance index; $\varphi_j(a_i, a_k) = \dfrac{p_j - \Omega_j(a_k, a_i)}{p_j - q_j} \in \left]0;1\right[$ is the concordance for the g_j criterion, calculated by linear interpolation; and s is the demanded majority level;

- Non-veto condition (minority respect): no minority criterion coming into conflict with $a_i S a_k$ must cause the occurrence of an amplitude of disagreement justifying a veto. Formally, $\forall g_j \in D(a_i S a_k), \Omega_j(a_k, a_i) \leq v_j - q_j \times \eta_j(a_i, a_k)$,

  where $D(a_i S a_k) = \{g_j \in F : \Omega_j(a_k, a_i) > p_j\}$ is the criteria set at odds with $a_i S a_k$, and $\eta_j(a_i, a_k) = \dfrac{1 - c(a_i, a_k) - w_j}{1 - s - w_j} \in [0;1]$.

In summary, the $a_i S a_k$ hypothesis test can be expressed through the outranking binary relationship S_s, so that

$$a_i S_s a_k \Leftrightarrow \begin{cases} c(a_i, a_k) \geq s \\ \forall g_j \in D(a_i S a_k), \Omega_j(a_k, a_i) \leq v_j - q_j \times \eta_j(a_i, a_k) \end{cases}.$$

The S_s relationship can be illustrated by the outranking graph $G_s = (A, U_s)$, where A is the vertices (or nodes) set and U_s is the set of arcs oriented from a_i to a_k when $a_i S_s a_k$ is verified. Thus, G_s is a particular directed graph (or digraph). To select the most restrictive subset of alternatives, the ELECTRE IS model searches for the outranking graph's kernel, $A_s^{'} \supseteq A$, verifying the two internal and external stability conditions (respectively $\forall a_i \in A'_s$, $\forall a_k \in A'_s$, $a_i R_s a_k$ and $\forall a_l \notin A_s^{'}, \exists a_i \in A_s^{'}, a_i S_s a_l$). Thus, the kernel elements do not outrank themselves, and each out-of-kernel element is outranked by at least one kernel element. The existence and uniqueness of the kernel is guaranteed only if the outrank graph is without a cycle. The algorithm for transformation to a cycle graph (final graph) is detailed in Aït Younes et al. (2000).

Principal results

The ELECTRE IS method was applied to 72 cases combining the four sectors (electrical link posts) with six weight sets (Table 8) and three majority levels. The client (CA2B) directly assessed the concordance threshold $s = 2/3$ defined by the President of CA2B and the President's councilors corresponding to a practical realistic level. The two other values of this parameter have been indirectly determined to test the sensitivity of the results. The two nearest values of $2/3$ that exceeded 50% were chosen in the computed concordance matrix, for example, 0.66 and 0.67 (Table 9a).

Concerning the Ghisonaccia sector, where set A of n=9 photovoltaic projects was considered, we obtained the following concordance matrix (Table 9a), discordance matrix (Table 9b) and outranking graph (Fig. 3) using our 7 evaluation criteria.

	a_1	a_2	a_3	a_6	a_7	a_{12}	a_{13}	a_{15}	a_{16}
a_1	1.00	0.76	0.81	0.71	0.81	0.38	0.57	0.76	0.57
a_2	0.48	1.00	0.50	0.62	0.74	0.12	0.14	0.62	0.52
a_3	0.65	0.88	1.00	0.71	0.81	0.49	0.43	0.75	0.43
a_6	0.48	0.43	0.43	1.00	0.87	0.19	0.24	0.57	0.43
a_7	0.55	0.40	0.44	0.76	1.00	0.00	0.24	0.43	0.43
a_{12}	0.67	1.00	0.81	1.00	1.00	1.00	0.88	0.81	0.67
a_{13}	0.71	1.00	0.79	0.76	0.81	0.54	1.00	0.76	0.70
a_{15}	0.67	0.81	0.69	0.76	0.66	0.55	0.62	1.00	0.62
a_{16}	0.80	0.81	0.79	0.76	0.62	0.57	0.81	1.00	1.00

Table 9a : Global concordance matrix between the Ghisonaccia sector PV projects

	a_1	a_2	a_3	a_6	a_7	a_{12}	a_{13}	a_{15}	a_{16}
a_1	0	0	0	0	0	*	*	0	*
a_2	*	0	*	*	0	*	*	*	*
a_3	*	0	0	0	0	*	*	0	*
a_6	*	*	*	0	0	*	*	*	*
a_7	*	*	*	0	0	*	*	*	*
a_{12}	0	0	0	0	0	0	0	0	0
a_{13}	0	0	0	0	0	*	0	0	0
a_{15}	0	0	0	0	*	*	*	0	*
a_{16}	0	0	0	0	*	*	1	0	0

Table 9b: Discordance matrix between the Ghisonaccia sector PV projects

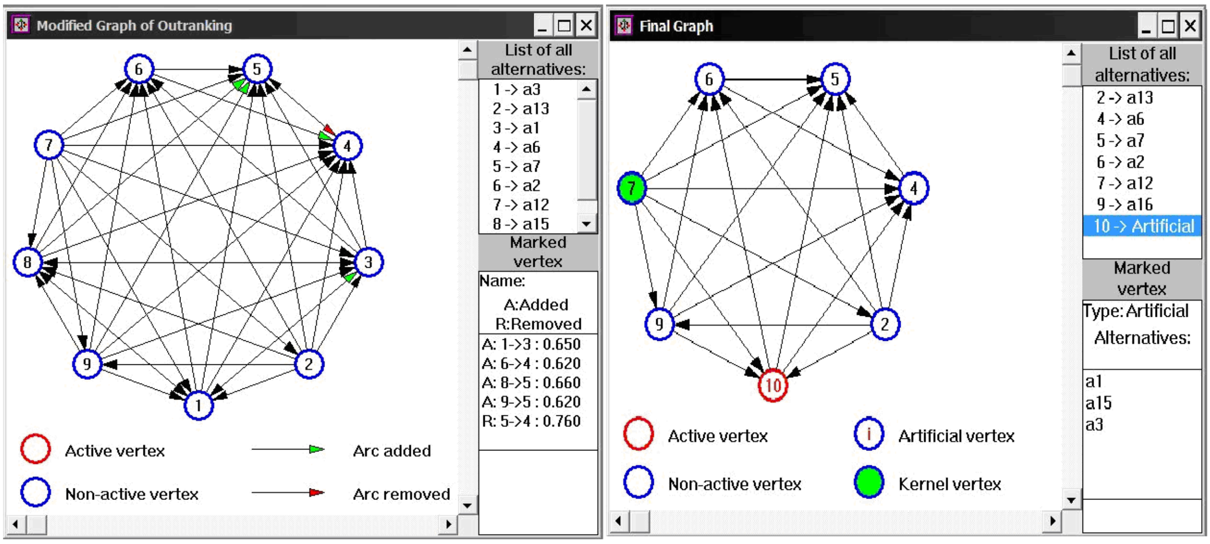

Figure 3: Outranking graphs and PV project selection for the Ghisonaccia sector

The concordance matrix gives the values of $c(a_i, a_k)$ for all ordered pairs of projects. For example, $c(a_{12}, a_2) = 1$ is interpreted as unanimity (100%) of agreement of the criteria with hypothesis "a_{12} outranks a_2". $c(a_{16}, a_7) = 0.62$ indicates that the criteria are in agreement to a degree of 62% with the outranking hypothesis $a_{16} S a_7$. When a majority (2/3 here) is not achieved, the discordance test is not performed, and '*' is inserted in the matrix. Otherwise, a 0 value expresses the absence of veto (the no veto condition is true), and a value of 1 indicates the existence of at least one veto (the no veto condition is false). The kernel of the outranking graph is composed of only the a_{12} project (node or vertex 7), which is the best compromise.

The other three sectors were analyzed in the same way. Finally, four among the sixteen photovoltaic plant projects studied for the Haute-Corse department were selected using the outranking model ELECTRE IS. Table 10 summarizes the recommended project set, while the map (Fig. 4) presents their geographic locations.

Electrical linkage posts	Selected photovoltaic projects	Power (MW_c)	Occupied surface (Ha)
Ghisonaccia	a_{12}	4.5	17.
Cervione	a_{14}	8	23
Oletta	a_{11}	3.5	14.3
Taglio	a_4	11.1	41.5
Total	**4 projects on 16**	**27.1**	**96.2**

Table 10: Selected PV projects

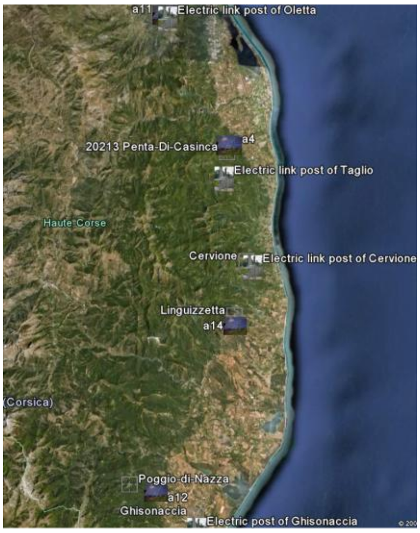

Figure 4: Geographic localization of selected projects.

Based on the reference criteria set, the a_{12}, a_{14}, a_{11} and a_4 alternatives are unanimously within the kernel of the outranking graph, while some other projects are selected only in specific cases. Thus, alternative a_1, in the Ghisonaccia sector, is only accepted after the g_8 criterion integrates the criteria set. The a_5 and a_8 alternatives, in the Oletta sector, and the a_{10} alternative, in Taglio's zone, are accepted only when the concordance (or majority) level is lowered. Moreover, the results are confirmed despite which weight set is used, definitively rejecting the hypothesis of a unique weight set and demonstrating the selection stability of the model.

Discussion

The results presented above came from power struggles between the favorable majority and the opposite minority of criteria according to each outranking hypothesis tested. We highlight some of these struggles, especially concerning the Ghisonaccia sector. It can be observed that the concordance condition is seldom verified for the a_2 , a_6 and a_7 projects (Fig. 9a). The 2/3 required majority is, indeed, met only once for each of these projects. Notably, a_{12} outranks the other PV projects by a majority and outranks the a_2 and a_7 projects unanimously. With respect to the minority criteria being strongly opposite to some outrankings, only g_3 and g_6 have veto power (Tab. 8). The criterion g_3 (study of potential ecological degradation in the files) rejects the "a_6 outranks a_3" and "a_7 outranks

a_3" hypotheses, whereas the use conflict risk criterion is in opposition to the "a_6, a_{15} or a_{16} outranks a_{13} or a_{12}" hypothesis and also rejects the "a_7 outranks a_{12}" hypothesis. Thus, in these power struggles between majority and minority, the a_{12} project outranks the other projects without being outranked (Fig. 3)

For each of the four studied sectors, the ELECTRE IS model application allows making a conclusion about the selection of each project in 18 cases considering two criteria sets, each of which is combined with three weight sets and the three majority values. Thus, a sensitivity analysis was performed with or without taking into account the criterion g_8 and assigning different values to the parameters. Such recommendations should be elaborated from robust conclusions: "A *conclusion ... is said to be robust with respect to a domain ... of possible values for the preference and technical parameters, if there is not a particular set of parameters ... which clearly invalidates the conclusion ...*" (Figueira et al., 2005). The sensitivity analysis was supplemented with a study of the degree of robustness for each outranking situation using the $\rho(a_i, a_k) \in [0;1]$ indicator defined in Aït Younes et al. (2000) and Roy and Bouyssou (1993). This indicator allows the assessment of whether modifying the $a_i S_s a_k$ conclusion is justified. If $\rho(a_i, a_k) = 0.5$, adding an arc is as justified as removing it. Otherwise, a complex algorithm compares an additional cost of $0.5 - \rho(a_i, a_k)$ with a removal cost of $\rho(a_i, a_k) - 0.5$.

Concerning the Ghisonaccia sector, the robustness matrix is presented in Table 11.

	a_1	a_2	a_3	a_6	a_7	a_{12}	a_{13}	a_{15}	a_{16}
a_1	1.00	0.76	0.40	0.71	0.81	0.12	0.36	0.76	0.36
a_2	0.48	1.00	0.50	0.62	0.74	0.09	0.14	0.62	0.52
a_3	0.65	0.88	1.00	0.71	0.81	0.23	0.39	0.75	0.43
a_6	0.48	0.43	0.05	1.00	0.87	0.00	0.04	0.57	0.21
a_7	0.55	0.40	0.06	0.76	1.00	0.00	0.09	0.43	0.21
a_{12}	0.67	1.00	0.81	0.95	1.00	1.00	0.88	0.81	0.67
a_{13}	0.71	1.00	0.79	0.76	0.81	0.54	1.00	0.76	0.70
a_{15}	0.67	0.81	0.69	0.76	0.66	0.00	0.19	1.00	0.62
a_{16}	0.80	0.81	0.79	0.76	0.62	0.00	0.30	1.00	1.00

Table 11: Robustness matrix of outranking results between the Ghisonaccia sector PV projects

For example, it can be observed that $\rho(a_{13}, a_k) = c(a_{13}, a_k) \forall a_k \in A$, reflecting very robust results for the $a_{13} S a_k$ outranking hypothesis. Consequently, the result is completely stable despite whether the PV project a_{13} (vertex 2) outranks a_k. No modification was made (no arc added and no arc removed) concerning this alternative in the modified graph (Fig. 3). However, adding an arc from node 1 to node 3 transforms the $\{1, 8, 3\} = \{a_3, a_{15}, a_1\}$ circuit; these three projects are then considered to be equivalent and are brought together in the artificial node 10. This transformation based on robustness and costs leads to the final graph, from which the kernel can be determined.

Considering all of the sectors, the robustness analysis allows maintaining our previous conclusions and the recommendation to select projects a_{12}, a_{14}, a_{11} and a_4.

Conclusion

Energy policy in an island environment is a complex and essential task that requires rigorous planning and appropriate tools of evaluation to aid in decision making.

Its considerable potential for renewable energy production makes Corsica island very attractive for a number of industries, and numerous photovoltaic plant projects that have been proposed for farming fields are relevant to this topic. Only a limited number of projects can be selected by local policy makers due to technical constraints because of the necessity of electrical network stability and considering the desire to prevent geographical over-abundance of electrical production to meet the requirements of social acceptability and field use conflict avoidance.

Our study related to PV project selection was carried out using the ELECTRE IS outranking multicriteria method. This process allowed us to choose the four most relevant projects among the sixteen projects presented to the CA2B.

The selected project set covers an area of 96.2 Ha (on 310 Ha) of farming fields and represents a cumulative power of 27.1 MW_c (on 96.17 MW_c). Thus, the 46 MW_c limit is not exceeded, and the Haute-Corse department would contribute to renewable energy development at 58.9% of the PV potential limit (46 MWc). If these recommendations were to be implemented in the whole of Corsica, 18.9 MW_c of renewable systems remains to be installed. Territorial over-abundance is also avoided because the four selected projects concern four different electrical linkage posts (2) and the maximal power to each link is 11.1 MW_c.

The multicriteria methodology used here can be implemented in a more participative context, with protagonists advocating various concerns with different degrees of controversy (Froger, Oberti, 2002) (Oberti, 2004).

Furthermore, the CTC has carried out its own valuation of all of the proposed projects concerning this region (Haute-Corse and Corse-du-Sud). The use of 8 constraints and 39 criteria allowed presenting a favorable opinion for 17 of the 74 submitted projects. With respect to the value scales of the criteria, a rigorous methodology for criteria weighting has been implemented, whereas the weighted arithmetic mean used for the aggregation of the assessments is strongly compensatory. Moreover, the CTC methodology controlling for lakes increased the file treatment times.

The relevance of these recommendations concerning Corsica's energy future depends on the adapted multicriteria models used to synthesize our assessments of technologies, scenarios, policies and projects. A research partnership with the CTC is suggested to further inform this analysis to a much greater degree.

ELECTRE outranking methods offer an adequate analytical framework related to RES integration on islands, where technological, economic, social and political constraints are plentiful.

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