# Chapter 2
# Photovoltaic Plants Selection on an Insular Grid Using Multicriteria Outranking Tools: Application in Corsica Island (France)

**Pascal Oberti, Marc Muselli and Pierrick Haurant**

**Abstract** Sustainable energy systems involve a multiplicity of stakes more or less conflicting. Multiple criteria decision analysis (MCDA) offers a broad methodological framework in which the ELECTRE-based outranking approach is suitable for searching good compromise solutions. Particularly, the RUBIS methodology offers new tools that we have used successfully for photovoltaic (PV) plants selection aid in Corsica island, a real case study from a research agreement between the University of Corsica and the Agriculture Chamber of the Haute-Corse department. This chapter will focus on the following points: outranking approaches and the choice problematic in MCDA, the RUBIS method and the RUBIS D3 web server, the insular power grid of Corsica and the studied case, the main results and their robustness, a comparison with the ELECTRE IS method.

## 2.1 Introduction

Sustainable energy systems are presented as alternative solutions to fossil fuels (Dinçer and Zamfirescu 2012), to provide better efficiency, better cost-effectiveness, better resources use, better design and analysis, better energy security, and better environment. This multiplicity of objectives requires scientific evaluation tools, testing the comparison of solutions in order to find good compromise, and multiple criteria decision analysis (MCDA) offers a broad methodological framework (Figueira et al. 2005a, b).

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Renewable and sustainable energy reviews highlight that MCDA methods are part of the assessment and Simulation tools. Notably, about alternative methodologies for analyzing off-grid electricity supply, Bhattacharyya (2012) identifies five main tools based on worksheet, optimization, multicriteria decision making, system-based participatory, and hybrid approaches to take advantage of strengths and weaknesses of these different tools. More particularly, MCDA deals with renewable and sustainable energy planning (Baños et al. 2011; Wang et al. 2009; Løken 2007; Pohekar and Ramachandran 2004). The main MCDA tools are AHP method and the families of outranking methods namely PROMETHEE and ELECTRE.

Numerous case studies with an insular context and renewable energy were processed using MCDA tools. For example, in Crete island (Greece), ELECTRE III method supported the Ranking of alternative strategies for energy supply ranging from high-level renewable energy production to continental interconnection (Georgopoulou et al. 1997). Furthermore, an appropriate mix of energy production means has been analyzed with PROMETHEE I and II methods (Tsoutsos et al. 2009), as in the Greek islands of Karpathos and Kassos with ELECTRE III (Papadopoulos and Karagiannidis 2008). In Sardinia (Italy), this method assisted in ranking the renewable energy technology best adapted (Beccali et al. 2003), and PROMETHEE I and II methods were implemented in Sicily (Cavallaro 2005). Moreover in the Eolian islands (Italy), the size of a wind farm with a photovoltaic plant was determined by combining NAIADE and PROMETHEE methods (Cavallaro and Ciraolo 2005). In Corsica island (France), participative location of a wind farm projects (Oberti and Paoli 2013) was implemented with ELECTRE III method, and photovoltaic plants selection (Haurant et al. 2011) has been computed with ELECTRE IS.

The aim of the research is to deal with a multicriteria choice problem under electrical and geographical constraints: it intends to select the best projects of PV plants among 16, developed by industries on farmlands and submitted to local decision-makers in Corsica island, while preserving the power grid stability (i.e., at most 30 % of intermittent renewable energies can be injected) and without spatial concentration of solar power parks (i.e., to avoid sudden declines in electric production due to climatic or technical factors). In MCDA, this problem refers to the choice problematic (Roy 1985, p. 57): … *to aid the decision maker by the choice of a subset that is as small as possible so that a single action can eventually be chosen. This subset contains best actions (optima) or, perhaps, satisfactory actions (satisficing solutions).*

Technically, the real case study has been solved in three main stages. Over a first phase was collected information to take into account the aforementioned constraints. To avoid spatial concentration of projects were located the points of connection to the power grid, and for each of them was defined the set of PV plants to be connected. Thus, the 16 alternatives were assigned to 4 different sets geographically distant. Also, to preserve the power grid stability was considered an additional power of maximum 46 MWp from the selected candidates. Over a second phase for each set of projects was computed the subset[1] of the best (or satisficing) PV plant. With this aim in view was applied the ELECTRE outranking framework, particularly the suitable ELECTRE IS and RUBIS methodologies (method and software). In this chapter the focus is on the RUBIS D3 web server, a tool used to solve the case. Over a final phase, the stability constraint was checked; the total power of the 4 selected projects should not exceed the above-cited threshold.

The key findings of this study are methodological. They arise from special features of the energy context and of the Sustainable development perspective. First, the installation constraints of intermittent renewable energies on the small power grid, such as in Corsica island (see Sect. 3.1), have taken part upstream (phase one) and downstream (phase three) of the multicriteria aggregation procedure. Thus, the decision problem must be well defined to integrate the MCDA method in the energy context. Second, the complexity of multicriteria evaluation in energy real case studies justifies a well-established methodology. Compensatory logic of the aggregation procedure and the robustness analysis of the results are significant issues for MCDA of sustainable energy systems. The ELECTRE outranking framework provides an operational research toolbox for a relevant selection of one best compromise solution; especially the RUBIS methodology based on the RUBIS method (Bisdorff et al. 2008) implemented in the RUBIS D3 web server to solve a choice problem. This non-compensatory approach, in the tradition of ELECTRE IS method, leads to the same robust selections of PV plant projects, with modern MCDA tools.

To study the subject of this chapter, two sections are developed. First of all, is presented an overview of the outranking approaches. The leading reasons to retain the RUBIS methodology are underlined, and the MCDA used tools are described commented. The second section focuses on the real case study and the results. Five subsections are considered. First, the insular power grid of Corsica is characterized, and second the research context is explained. In a third time the PV plants projects are listed, the family of evaluation criteria is presented and the performance table is presented. In sub-section four are produced the main results of the RUBIS outranking computations. Finally, a discussion concerns the robustness of the choice, a comparison with the ELECTRE IS method, and a possible solution to make explicit and improve the criterion about estimated net production of a PV plant.

[1] Called kernel within the ELECTRE IS method and hyperkernel within the RUBIS method.

## 2.2 An Outranking-Based Approach of Multicriteria Selection: the RUBIS Framework

### *2.2.1 About Outranking Approaches*

The overall purpose of outranking approaches is to aid in preference modeling computed on ordered pairs of solutions (called actions, alternatives or not) for the search of compromise, into processes with multiple criteria involving real decision maker(s). State of the art surveys on MCDA (Figueira et al. 2005a, b) have differentiated three classes of outranking approaches.

The first one is the family of ELECTRE methods (i.e., acronym stands for ELimination Et Choix Traduisant la REalité, designating ELimination and Choice Expressing the Reality), based on the pioneering work of Bernard Roy in the mid-1960s. The first method called ELECTRE I (electre one) becomes widely known and applied after its publication in Roy (1968). This tool for choosing the best solution(s) from a given finite set (or **choice problematic**), was devised to overcome the drawbacks of the classical weighted-sum based technique when applied to a concrete multiple criteria real-world problem. Thereafter, the contribution of outranking binary relation to preference modeling was highlighted by Roy (1974).

ELECTRE IS (electre one esse) appeared subsequently (Roy and Skalka 1984) as an extension of the previous method to take into account imperfect data with pseudo-criteria. Also, robustness analysis of the results was developed in Aït Younes et al. (2000). Let us note that ELECTRE IS remains the most rigorous tool for choice problematic within the ELECTRE family, and it inspired the RUBIS method used in this chapter. Meanwhile, other ELECTRE methods have emerged to deal with the ranking problematic (i.e., ranking solutions from the best to the worst), the most advanced tool being ELECTRE III (electre three) (Roy 1978; Roy et al. 1986), which inspired ELECTRE IV (electre four) (Roy and Hugonnard 1982) usable when relative criteria importance coefficients are not required. All these earlier researches were completed by a MCDA methodology established (Roy 1985) and a presentation of the outranking approach in ELECTRE methods (Roy 1991). More recently, ELECTRE TRI (electre tree) method (Yu 1992) was designed to deal with the sorting problematic (i.e., assigning each solution to one of the pre-defined and ordered categories) using boundary profiles. A comprehensive presentation of ELECTRE methods (among others) was collected by Vincke (1992) and (Roy and Bouyssou 1993).

A brief history of ELECTRE methods in given Figueira et al. (2005a, b), and methodological advances (Figueira et al. 2010) remain topical notably:

- About ELECTRE TRI-B method: pure-inference-based approaches for valuing model parameters from holistic judgments (i.e., alternative assignable to a category by the decision-maker) that should be combined with inference-robustness based approaches to derive some robust conclusion about assignments of solutions into categories; pseudo-robustness based approaches with Monte Carlo simulation for analyzing the stability of some parameters.

- New concepts for robustness measure of results obtained when using ELECTRE III and ELECTRE IV methods, but also new axiomatic analyses, evolutionary approaches, decision rules using dominance-based rough set approach.
- Improvements for modeling three different types of interaction among criteria and an outranking credibility index with reinforced preference thresholds and counter-veto thresholds.
- Recent ELECTRE-like methods: ELECTRE TRI-C generalized to ELECTRE TRI-NC where each category is defined by a set of reference characteristic actions; $\text{ELECTRE}^{\text{GMS}}$ which consider all sets of parameter values compatible with the preference information provided by a decision-maker to give recommendation based on robust ordinal regression, with an adaptation for group decision making called $\text{ELECTRE}^{\text{GMS}}$-GROUP method; the RUBIS method in the tradition of ELECTRE IS, presented later in this chapter, introducing a bi-polar outranking selection procedure to choose a single best solution.

Thus, over the four decades, a wide body of research in the field of ELECTRE family methods appeared mainly in Europe.

The second class of outranking approach is the family of PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) methods (Brans and Mareschal 2005), with the GAIA (Geometrical Analysis for Interactive Assistance) tool, also called PROMETHEE-GAIA methodology. In 1982 appeared the PROMETHEE I (partial ranking) and PROMETHEE II (complete ranking) methods published in Brans et al. (1986). The main novelty concerns a typology based on six criteria preference functions of the decision maker, particularly the Gaussian type. These PROMETHEE methods, very simple to understand, were completed by the GAIA visual interactive module (Mareschal and Brans 1988) which provided geometrical representations for sensitivity analysis of results.

Further extensions were produced, notably the PROMETHEE V procedure (Brans and Mareschal 1992), devoted to identify a subset of alternatives satisfying segmentation constraints, the PROMETHEE VI module (Brans and Mareschal 1995) which is a sensitivity tool to detect soft or hard decision problems to revolve, and finally a GDSS (Group Decision Support System) PROMETHEE procedure (Macharis et al. 1998) for providing decision aid to a group of decision makers and to visualize conflicts between them. For a comprehensive book on PROMETHEE-GAIA methodology, see Brans and Mareschal (2002).

The third class of approaches collects other outranking methods (Martel and Matarazzo 2005), more or less related to the principles of concordance or/and of discordance, with or without outranking binary relation, and dealing mostly with performance table of total preorders (one by criterion) on a finite solutions set (these are evaluated according to their ranks).

Outranking methods constitute one of the most fruitful approaches in MCDA. This leads to several software implementations of tools.[2] Let us note the Decision-Deck (D2) project,[3] providing a collaborative open source platform.

### 2.2.2 Why Implement the RUBIS Methodology?

In this plethora offer of outranking tools was first applied the ELECTRE IS method for analyzing the case study (Haurant et al. 2011), because it was necessary to deal with a multicriteria choice problem: select the best photovoltaic plant projects developed and submitted by industrial enterprises to local decision makers in Corsica island. Also, as outlined in the previous point, ELECTRE IS was the most rigorous method devoted to such problematic. Moreover, the ELECTRE I method could not be implemented because it considers only true criteria (i.e., criteria without imperfect data). Finally, the software implementation of ELECTRE IS was a great help to compute results and their robustness.

After delivering the final study report, new MCDA tools from the RUBIS methodology became available, which also deal with the choice problematic and pseudo-criteria (i.e., criteria with indifference and preference thresholds to consider imperfect data). Besides, this innovative framework includes the RUBIS method developed in the tradition of ELECTRE IS. Thus, it was scientifically interesting to compare the selections of photovoltaic plant projects resulting from these two outranking methods, with the same input data (i.e., performance table and parameter values). The robustness analyses of results (i.e., the best projects to be selected) were performed within each two MCDA tools and compared after.

Moreover, the new methodology provides a RUBIS MCDA-web service, for submitting a choice problem and requesting the single best solution in a finite set of alternatives. The benefits are substantial including open source software, no specific acquisition costs, an independence from the operating system (no problem of compatibilities), an easy access with a recent standard internet browser, the high quality of the output data well structured and presented, access to source code of the no black-box RUBIS method.

Furthermore, the real case study required to implement a non-compensatory aggregation method (i.e., no possibility of offsetting a disadvantage considered criterion by a sufficiently large advantage on one other criterion at least). RUBIS method allows to grant (or not) a veto power for each criterion, using veto thresholds. This possibility is useful in a sustainable development view, for searching potential compromise solutions, but also to penalize decision alternatives with value profiles which neglect certain dimensions of the problem.

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[2] http://www.inescc.pt/~ewgmcda/Software.html; http://www.lamsade.dauphine.fr/

[3] www.decision-deck.org

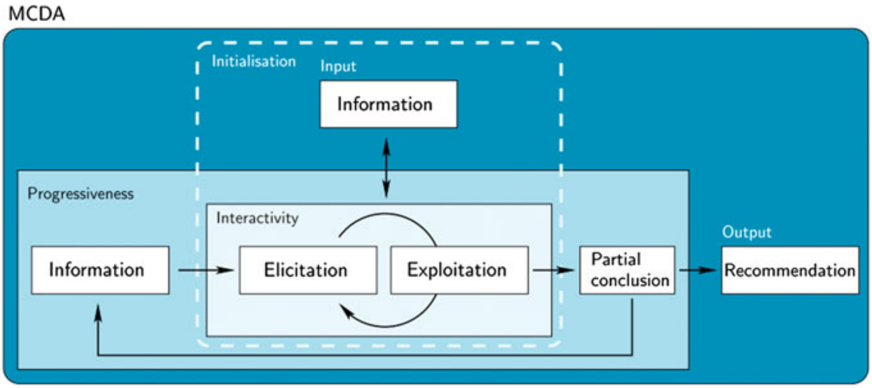


**Fig. 2.1** General scheme of a progressive MCDA process (Meyer 2009)

Finally, let us note that the RUBIS methodology deals with a **progressive decision-aiding process** (Meyer 2009) (see Fig. 2.1), justified notably by prudence,[4] economic constraints,[5] and a constructive approach to the problem.[6] New foundations for a progressive choice decision aiding methodology were laid by Bisdorff et al. (2008), according to five pragmatic principles presented to the next point.

### 2.2.3 *An Overview of the RUBIS MCDA Method*

RUBIS (Bisdorff et al. 2008) is a new best choice method in the tradition of ELECTRE IS. This recent development is considered as a methodological contribution to the ELECTRE outranking approach of MCDA (Figueira et al. 2010).

RUBIS method focuses on the problem of selecting a single best decision alternative in a considered set of decision objects, on the basis of their performances (see example Tables 2.1 and 2.2) on a consistent (or coherent) family of criteria (Roy 1985). Methodologically, are performed pairwise comparisons of alternatives leading to a bipolar-valued outranking digraph, on which are determined the hyperkernels where is finally extracted the solution called RCR (RUBIS Choice Recommendation) in a progressive MCDA process (Meyer 2009). The main theoretical concepts and formulas of the method, and a few personal adjustments to expand the evaluation exercise[7] will be briefly outlined.

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4 The ultimate recommendation does not necessarily have to be reached in one step.

5 At a given moment, only limited financial or temporal resources may be available.

6 Elicitation of decision maker's preferences and final recommendations are constructed via small steps.

7 Each criterion and discrimination threshold (indifference, preference) can take their values out of $[0, 1]$; each veto threshold (weak, strong) can take its values out of $[0, 1] \cup \{2\}$. Each evaluation criterion can be to maximize or to minimize.

**Table 2.1** The photovoltaic plant projects on farmlands in Haute-Corse

| Sets of projects | Projects | Farmland sites | Villages | Powers (MWp) | Estimated net productions (GWh/yr) | Rented surfaces (ha) |
|---|---|---|---|---|---|---|
| Oletta | $a_5$ | Malpergo | Rapale | 10.26 | 12.82 | 40 |
| | $a_8$ | Griolo | Oletta | 3.43 | 5.15 | 11.1 |
| | $a_{11}$ | Mignalojo | Oletta | 3.55 | 5.32 | 14.3 |
| Taglio | $a_4$ | Querci | Penta di Casinca | 11.06 | 16.5 | 41.5 |
| | $a_{10}$ | Citrinche | Venzolasca | 4.5 | 5.85 | 12 |
| Cervione | $a_9$ | Farinaccio, Sandali | Linguizzetta | 8.5 | 10.16 | 29.48 |
| | $a_{14}$ | Sbiri | Linguizzetta, Talonne | 8 | 10.4 | 23 |
| Ghisonaccia | $a_1$ | Tozze | Aghione | 11.64 | 17.5 | 36.68 |
| | $a_2$ | Alzolu | Prunelli di Fiumorbo | 1.27 | 1.62 | 3.6 |
| | $a_3$ | Casa Calva | Prunelli di Fiumorbo | 3.05 | 4.59 | 14.3 |
| | $a_6$ | Mortella | Ghisonaccia | 3.89 | 5.179 | 11.5 |
| | $a_7$ | Maison Pieraggi | Pietroso | 1.83 | 2.414 | 5.79 |
| | $a_{12}$ | Manalotte | Poggio di Nazza | 4.5 | 5.85 | 17.43 |
| | $a_{13}$ | Chisacca | Serra di Fiumorbo | 8 | 10.4 | 17 |
| | $a_{15}$ | Niellone | Prunelli di Fiumorbo | 4.02 | 5.378 | 10.8 |
| | $a_{16}$ | Acqua di l'Asino, les Cigales | Ventiseri | 10.65 | 14.995 | 30.21 |
| Total | – | – | – | 98.15 | – | 318.69 |

**Table 2.2** The family of evaluation criteria (presented with RUBIS D3-web application)

| Identifier | Name | Comment | Weight[a] | Scale | | | Thresholds | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Direction | min | Max | Indifference | Preference | Veto |
| $g_1$ | Estimated net production | GWh/yr | 14.28 (12) | Max | 0 | 17.50 | 0.00 + 0.10x | 0.00 + 91.70x | 20 |
| $g_2$ | Rent area unoccupied by the installation | % | 19.05 (17) | Max | 0 | 82.02 | 4.00 | 4.00 | 101 |
| $g_3$ | Study of the potential ecological degradation in the files | 45-point scale | 19.05 (17) | Max | 0 | 30.00 | 2.00 | 10.00 | 20 |
| $g_4$ | Relevance of visual impact presentation in the files | 10-point scale | 19.05 (17) | Max | 0 | 10.00 | 0.00 | 0.00 | 11 |
| $g_5$ | Observer-plant minimum distance | km | 4.76 (4) | Max | 0 | 1.00 | 0.15 + 0.35x | 0.15 + 0.35x | 1.1 |
| $g_6$ | Use conflicts risks | 101-point scale | 19.05 (17) | Max | 0 | 101.00 | 3.00 | 13.00 | 43 |
| $g_7$ | Economic activity and financial benefits to inhabitants from RES facilities | 15-point scale | 4.76 (4) | Max | 0 | 15.00 | 0.00 | 1.00 | 16 |
| $g_8$ | Financial income at the communal level | €/yr/inhab | (12.00) | Max | 0 | 1033.06 | 0.00 + 0.21x | 0.00 + 1.89x | 1100 |

[a] In brackets are inserted the weight values when 8 criteria are considered

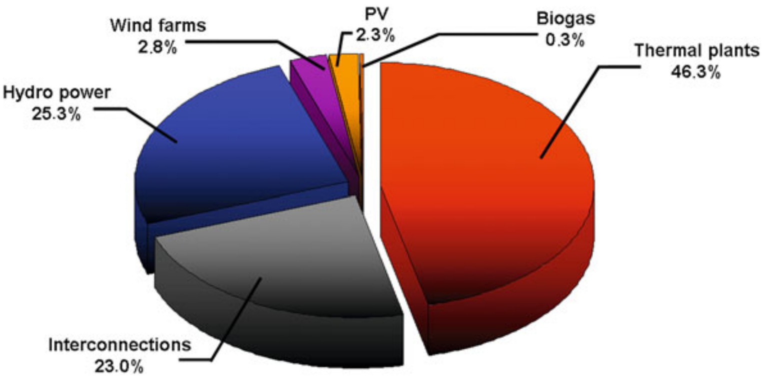


**Fig. 2.2** Distribution of the power supply means in Corsica for June (EDF, 2011)

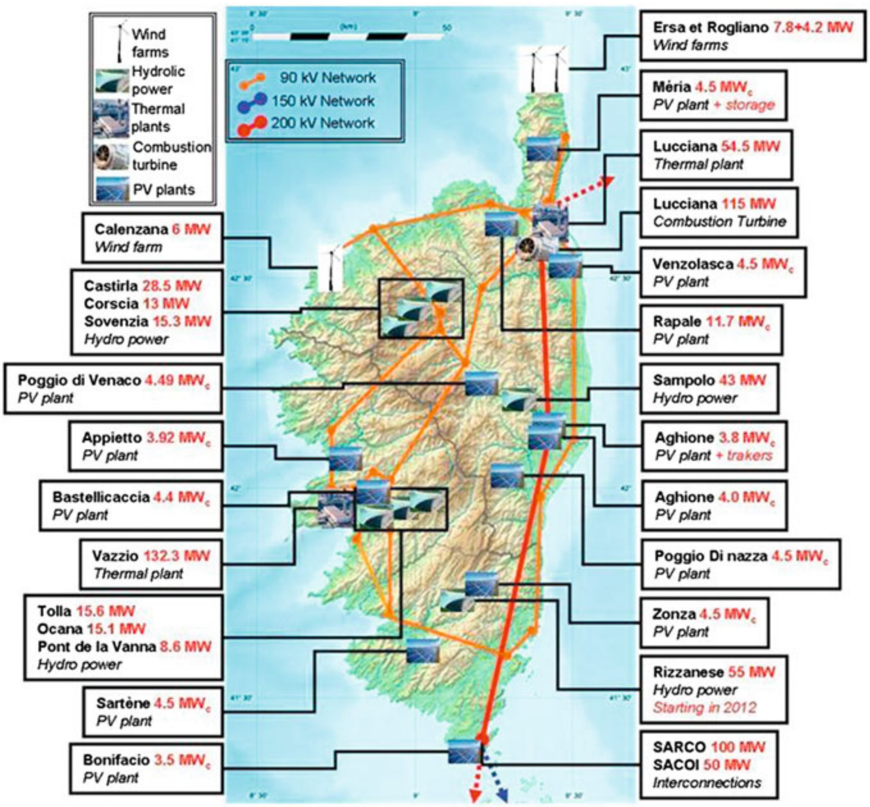


**Fig. 2.3** Geographical dispersion of power supply means in Corsica

Let $X = \{x, y, \ldots, z\}$ be a finite set of $z \geq 2$ alternatives (or decision objects) evaluated on a finite family $F = \{g_1, \ldots, g_j, \ldots, g_p\}$ of $p \geq 2$ criteria. Each criterion $g_j$ takes its values on an ordinal scale or on a weak interval scale (Bouyssou et al. 2006). For all ordered pairs of different elements $x$ and $y$ of $X$ is tested the preferential statement "$x$ is at least as good as $y$", or for short "$x$ outranks $y$" that is the classical outranking situation $xSy$ with $S \subseteq X \times X$ the binary relation of outranking. The founding principle of modeling $S$ (Roy 1985) is to test if (concordance condition) a sufficient majority of criteria which supports $xSy$ and if (non-veto condition) no criterion which raises a veto against it. RUBIS gives formal definition that allows to assign a valuation $\tilde{S}$ to each element of $S$ in a so-called rational credibility scale $\mathcal{L} = [-1, 1]$. The more $\tilde{S}(x, y)$ is close to 1 (resp. $-1$), the more the assertion $xSy$ is validated (resp. non-validated); the median value $\tilde{S}(x, y) = 0$ means this assertion remains undetermined.

Let $g_j(x)$ and $g_j(y)$ be the evaluations (or performance) of two alternatives $x$ and $y$ of $X$ on criterion $g_j$, and $\Delta_j(x, y)$ the difference of the two values such that:

$$\Delta_j(x, y) = \begin{cases} g_j(x) - g_j(y), & \text{if } g_j \text{ is to be maximized} \\ g_j(y) - g_j(x), & \text{if } g_j \text{ is to be minimized} \end{cases} \tag{2.1}$$

To each preference scale of a criterion is associated thresholds (variable or constant), to determine whether the difference $\Delta_j(x, y)$ is significant (preference and veto thresholds) or not (indifference threshold). Threshold functions are supposed to verify the standard non-decreasing monotonicity condition (Roy and Bouyssou 1993, p. 56). Also, more formally $v_j(g_j(x)) \geq wv_j(g_j(x)) \geq p_j(g_j(x)) \geq q_j(g_j(x)) \geq 0$, with $q_j(g_j(x))$ the indifference threshold, $p_j(g_j(x))$ the preference threshold, $wv_j(g_j(x))$ the weak (or potential) veto threshold, and $v_j(g_j)$ the strong veto threshold. Thus, for each criterion it is possible to:

- define $q_j(g_j(x))$ as the largest difference of values compatible with a situation of indifference (no preference) between alternatives $x$ and $y$;
- define $p_j(g_j(x))$ as the smallest difference of values from witch a situation of a preference for $x$ or to $y$ is clearly established;
- grant or not a veto power, and determine if it can alone reject or not the preferential statement $xSy$.

If an actor of the evaluation process deems necessary the absence of compensation effects (a good performance of an action in one criterion does not hide a poor performance in another), then at least one criterion $g_{j'}$ will have a positive veto threshold (weak or/and strong) value greater than the preference threshold value but also smaller than $\text{Max}\{g_{j'}(i); \forall i \in X\} - \text{Min}\{g_{j'}(i); \forall i \in X\}$ or than the magnitude of the criterion scale. In contrast, if all actors agree this compensation between performances, none of the criteria will have different values of preference and veto thresholds ($v_j(g_j(x)) = wv_j(g_j(x)) = p_j(g_j(x))$). In these two ways, it is possible to set the compensatory logic of the MCDA method.

Several elicitation techniques can be used to assign values to such thresholds (Figueira et al. 2005a, b).

Let $w_j$ from $[0, 1]$ be the relative weight of the criterion $g_j$. All weights of criteria are normalized, such that $\sum_{j=1}^{p} w_j = 1$, and can be computed with the revised Simos' procedure (Figueira and Roy 2002) implemented in the SRF software.

In order to formalize the concordance and non-veto conditions of an outranking situation $xSy$, are defined the following functions:

- the criterion concordance index $C_j : X \times X \rightarrow \{-1, 0, 1\}$ such that

$$C_j(x,y) = \begin{cases} 1 & \text{if } \Delta_j(x,y) > -q_j(g_j(x)) \\ -1 & \text{if } \Delta_j(x,y) \leq -p_j(g_j(x)) \\ 0 & \text{otherwise} \end{cases} \tag{2.2}$$

$C_j(x, y) = 1$ (resp. $-1$) denote that the criterion $g_j$ agree or is concordant with (resp. disagree or is discordant with) the preferential statement $xSy$. $C_j(x, y) = 0$ in case it cannot be determined whether $xSy$ or not.

- the global (multicriteria) concordance index $\tilde{C} : X \times X \rightarrow [-1, 1]$, such that:

$$\tilde{C}(x,y) = \sum_{j \in F} w_j \cdot C_j(x,y) \tag{2.3}$$

$\tilde{C}(x, y)$ aggregates all weighted criterion concordance indexes (i.e., solely balance rational significance weights) and indicates the concordance degree of the criteria family $F$ with the preferential statement $xSy$.

- the criterion veto index $V_j : X \times X \rightarrow \{-1, 0, 1\}$, such that:

$$V_j(x,y) = \begin{cases} 1 & \text{if } \Delta_j(x,y) \leq -v_j(g_j(x)) \\ -1 & \text{if } \Delta_j(x,y) > -wv_j(g_j(x)) \\ 0 & \text{otherwise} \end{cases} \tag{2.4}$$

$V_j(x, y) = 1$ reflects a veto situation observed on the criterion $g_j$ when the difference $\Delta_j(x, y)$ gives a strong disadvantage of $x$ over $y$. $V_j(x, y) = -1$ when no veto appears. $V_j(x, y) = 0$ is an undetermined response to $xSy$.

- the negated criterion-based veto index, $-V_j(x, y)$, such that $-V_j(x, y) = -1$ (resp. 1) when a (resp. no) criterion veto is observed.

Thus, the global (multicriteria) outranking index $\tilde{S} : X \times X \rightarrow \mathcal{L} = [-1, 1]$, is as follows:

$$\tilde{S}(x,y) = \min\{\tilde{C}(x,y), -V_1(x,y), \ldots, -V_p(x,y)\} \quad (2.5)$$

The min operator translates the conjunction between the global concordance index and all the negated criterion-based veto indexes, according to the founding principle of an outranking situation (Roy 1985). Analogously to the ELECTRE methods, $\tilde{S}$ is a function representing the **credibility of the validation or non-validation of an outranking situation** for each ordered pair of alternatives. More particularly in the RUBIS framework, "$\tilde{S}$ is called the bipolar-valued characterization of the outranking relation $S$, or for short, the ***bipolar-valued outranking relation***" (Bisdorff et al. 2008, p. 147) or also "***bipolar outranking index***" (Figueira et al. 2010). The maximum value $\tilde{S}(x,y) = 1$ is obtained in the case of unanimous concordance (all criteria are agree with $xSy$, i.e., $C_j(x,y) = 1, \forall g_j \in F$). The minimum value $\tilde{S}(x,y) = -1$ is reached either in the case of unanimous negative concordance ($C_j(x,y) = -1, \forall g_j \in F$), or when exists a strong veto situation on at least one criterion ($\exists g_j \in F : V_j(x,y) = 1$). The median value $\tilde{S}(x,y) = 0$ represents a case of indeterminateness: either the arguments in favor of $xSy$ are compensated by those against it or a positive global concordance in favor of this outranking is outbalanced by a weak (potential) veto situation ($\exists g_j \in F : V_j(x,y) = 0$). The other cases of values occur when a sufficient majority of criteria or criteria coalition of positive significance (i.e., gathering more than 50 % of the global criteria significance weights) is more favorable than unfavorable to $xSy$ ($\tilde{S}(x,y) \in [0,1]$) or vice versa ($\tilde{S}(x,y) \in [-1,0]$). For example, computed values (in percentages) from our real case study are collected in Table 2.3 and rounded in Tables 2.4, 2.5.

The semantics linked to $\tilde{S}$ are such that for any two alternatives $x$ and $y$ of $X$:

- $\tilde{S}(x,y) = -1$ means that $xSy$ is clearly non-validated (cases of unanimous negative concordance or of strong veto situation for one criterion at least);
- $\tilde{S}(x,y) < 0$ means that $xSy$ is more non-validated than validated, for a sufficient majority of criteria;

**Table 2.3** Performance table restricted to the Ghisonaccia set of projects (presented with RUBIS D3-web application)

| Alternative | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ | $g_7$ | $g_8$ |
|---|---|---|---|---|---|---|---|---|
| $a_1$ | 17.50 | 68.70 | 9.00 | 6.00 | 0.20 | 52.00 | 2.00 | 1033.06 |
| $a_{12}$ | 5.85 | 82.02 | 27.00 | 4.00 | 0.50 | 89.00 | 7.00 | 388.89 |
| $a_{13}$ | 10.40 | 70.00 | 26.00 | 4.00 | 0.05 | 77.00 | 6.00 | 453.02 |
| $a_{15}$ | 5.38 | 67.20 | 22.00 | 6.00 | 0.30 | 32.00 | 7.00 | - |
| $a_{16}$ | 14.99 | 66.08 | 26.00 | 10.00 | 0.05 | 30.00 | 7.00 | 152.84 |
| $a_2$ | 1.62 | 63.89 | 20.00 | 2.00 | 0.30 | 55.00 | 4.00 | 8.38 |
| $a_3$ | 4.58 | 60.14 | 29.00 | 6.00 | 0.10 | 48.00 | 2.00 | 30.93 |
| $a_6$ | 5.18 | 75.13 | 8.00 | 0.00 | 1.00 | 33.00 | 4.00 | 42.88 |
| $a_7$ | 2.41 | 76.34 | 8.00 | 0.00 | 0.10 | 43.00 | 2.00 | 249.10 |

**Table 2.4** Pairwise outranking significance degrees in the range −100.00 to 100.00 (without the optional criterion g8)

| $\tilde{S}(x,y)$ | $a_1$ | $a_{12}$ | $a_{13}$ | $a_{15}$ | $a_{16}$ | $a_2$ | $a_3$ | $a_6$ | $a_7$ |
|---|---|---|---|---|---|---|---|---|---|
| $a_1$ | 0.00 | −23.82 | 14.28 | 14.28 | 14.28 | 52.38 | 0.00 | 42.86 | 61.90 |
| $a_{12}$ | 47.62 | 0.00 | 47.62 | 100.00 | 100.00 | 100.00 | 61.90 | 100.00 | 100.00 |
| $a_{13}$ | 47.62 | −14.29 | 0.00 | 100.00 | 100.00 | 100.00 | 42.85 | 100.00 | 61.90 |
| $a_{15}$ | 9.52 | 0.00 | 0.00 | 0.00 | 28.57 | 61.90 | 4.75 | 52.38 | 42.85 |
| $a_{16}$ | 47.62 | 0.00 | 0.00 | 100.00 | 0.00 | 61.90 | 42.85 | 52.38 | 23.80 |
| $a_2$ | 9.52 | −57.15 | −57.15 | 38.10 | 19.05 | 0.00 | 28.57 | 38.10 | 47.62 |
| $a_3$ | 0.00 | −9.52 | 0.00 | 0.00 | 0.00 | 71.43 | 0.00 | 100.00 | 100.00 |
| $a_6$ | 9.52 | −100.00 | −100.00 | 14.28 | 0.00 | −14.30 | −100.00 | 0.00 | 42.85 |
| $a_7$ | 28.57 | −100.00 | −38.10 | 0.00 | 0.00 | −4.77 | −100.00 | 28.58 | 0.00 |

**Table 2.5** Scale of condorcet robustness degrees

| Unanimously concordant | 3 |
|---|---|
| Ordinal majority concordant | 2 |
| Cardinal majority concordant | 1 |
| Balanced concordance and discordance, or weak veto | 0 |
| Simple majority discordant | −1 |
| Ordinal majority discordant | −2 |
| Unanimously discordant, or veto | −3 |

- $\tilde{S}(x,y) = 0$ means that $xSy$ is undetermined (neither the validation, nor the invalidation may be assumed) at this stage of the decision-aiding process;
- $\tilde{S}(x,y) > 0$ means that $xSy$ is more validated than non-validated, for a sufficient majority of criteria;
- $\tilde{S}(x,y) = 1$ means that $xSy$ is clearly validated (case of unanimous concordance: all criteria are agree with $xSy$).

For example in Table 2.3, are denoted that:

– $\tilde{S}(a_6, a_{12}) = -100\,\%$, i.e., the outranking statement “PV project $a_6$ outranks PV project $a_{12}$” is clearly non-validated;
– $\tilde{S}(a_1, a_{12}) = -23.82\%$, i.e., the outranking statement “PV project $a_1$ outranks PV project $a_{12}$” is more non-validated than validated;
– $\tilde{S}(a_1, a_3) = \tilde{S}(a_3, a_1) = 0\,\%$, i.e., the outranking statements $a_1 S a_3$ and $a_3 S a_1$ are undetermined at this stage of the decision-aiding process;
– $\tilde{S}(a_1, a_{13}) = 14.28\,\%$, i.e., the outranking statement “PV project $a_1$ outranks PV project $a_{13}$” more validated than non-validated;
– $\tilde{S}(a_{12}, a_{15}) = 100\,\%$, i.e., the outranking statement “PV project $a_{12}$ outranks PV project $a_{15}$” is clearly validated;

To give an abstract representation of the outranking situations supported by a criteria coalition of positive significance (i.e., gathering more than 50 % of the global criteria significance weights), is used the concept of **bipolar-valued crisp outranking digraph** which is the ordered pair $\tilde{G}(X, \tilde{S})$ comprising the set $X$ of alternatives associated to $\tilde{S}$ such that $\tilde{S}(x, y) > 0$ (i.e., in the graph, an black arc or arrow is directed from $x$ to $y$). In this way, the **crisp outranking binary relation** $S$ is a strict 0-cut relation modeled as follows: $xSy \Leftrightarrow \tilde{S}(x, y) > 0$.

An illustration of the bi-polar crisp outranking digraph is given in Fig. 2.4. Lets us note that are added in this digraph the indeterminate outranking situations ($\tilde{S}(x, y) = 0$), identifiable by empty arrows heads, because the credibility degree 0 represents a temporary delay in characterizing the validation or non-validation of the outranking statement. Thus, *In the framework of progressive decision aiding, this feature allows us to easily cope with currently undetermined preferential situations that may eventually become determined to a certain degree, either as validated or non-validated, in a later stage of the decision aiding process.* Bisdorff et al. (2008, p. 145). A purpose of the progressiveness is to resolve undetermined cases.

To compute the **best choice recommendation** (**BCR**) in bipolar-valued digraphs, mathematical and algorithmic results were obtained in Bisdorff et al. (2006). RUBIS choice recommendation (RCR) verifies five following pragmatic principles funding the progressive MCDA:

1. *Non-retainment for well-motivated reasons*: each non-retained alternative is eliminated without missing any potentially best alternative;
2. *Minimal size*: the number of alternatives retained in a BCR set is as small as possible;
3. *Efficient and informative refinement*: at each step of the progressive decision aiding is delivered a stable refinement of the previous BCR;
4. *Effective recommendation*: a BCR does not correspond simultaneously to a best as well as a worst choice recommendation;
5. *Maximal credibility*: the BCR is as credible as possible with respect to the preferential knowledge available in the current stage of the decision-aiding process.

A formal translation of these principles is given in Bisdorff et al. (2008) and leads to a new graph theory-related object, the **maximally determined strict outranking hyperkernel**, which is considered as an appropriate RCR (i.e., solution) in a progressive MCDA context. For example, from our real case study, only the PV project $a_{12}$ is selected (see Fig. 2.4 the yellow alternative in the outranking digraph).

The RCR algorithm, thoroughly presented and discussed by the authors, is implemented in the Python programming language within the digraphs Python solver module accessible via the RUBIS MCDA-web service presented hereafter.

### 2.2.4 The RUBIS D3 Web Server

RUBIS method is available in the Decision-Deck (D2) software package (Bisdorff 2008). The D2 project,[8] started in early 2006, provides a collaborative open source software platform pertaining to the field of MCDA. Typical end-users of D2 are MCDA researchers, MCDA consultants or practitioners, and teachers in academicals institutions. The platform architecture includes a distributed web server (D3) at the University of Luxembourg, serving implemented MCDA methods such as RUBIS.

The D3-Web application allows to submit an online XML encoded RUBIS problem description (XMCDA input data file) and to visualize the RUBIS solver's response and the solution (output data file) in a recent Internet browser session. XMCDA is a data standard[9] which allows representing MCDA data elements in XML according to a clearly defined grammar. To validate an input data file, see the current XML schema approved[10] by the specifications committee of the D2 project. The main steps for using the RUBIS D3 web server and solving a choice problem are the following:

1. Go to the webpage http://ernst-schroeder.uni.lu/d3/.
2. Enter login and password provided.
3. Online submission of a problem description file (XML encoded data for RUBIS):

    3.1 Click on "Remote".
    3.2 Click on the "My Jobs" icon.
    3.3 Click on the "Add…" button.
    3.4 Select the XML file (input data).
    3.5 Upload this XML file on the server by clicking the green arrow.

4. Save a new job:

    4.1 Click on the "Register new job" icon.
    4.2 Fill in the form "Method properties":

        4.2.1 Give a problem description.
        4.2.2 Select the uploaded XML file (if it not appears, click on "Refresh the list" button).
        4.2.3 Select the MCDA Method "Rubis Choice XMCDA-2.0".
        4.2.4 Select service to use.
        4.2.5 Submit the form (success if appears "Job successfully saved").

8 www.decision-deck.org

9 http://www.decision-deck.org/xmcda/index.html

10 http://www.decision-deck.org/xmcda/current.html

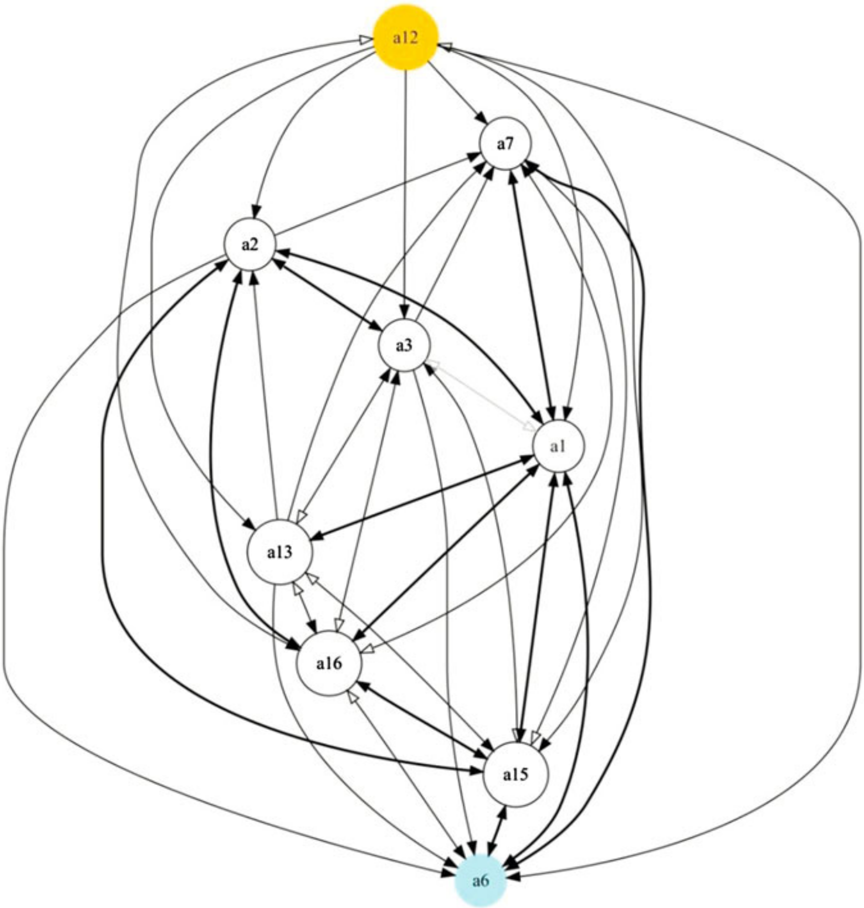


**Fig. 2.4** Significantly concordant outranking graph (Ghisonaccia set of projects)

5. Interact with remote service:

   1.1 In the list of jobs, click right on the saved job and on "Submit problem" (success if appears "Remote invocation succeeded").

   1.2 Click on the "Refresh" button: the saved job status is changed from "pending" to "waiting" (i.e., the problem has been submitted).

   1.3 In the list of jobs, click right on the saved job and on "Request solution" (success if appears "Remote invocation succeeded").

   1.4 Click on the "Refresh" button: the saved job status is changed from "waiting" to "solved" (i.e., the problem has been successfully solved).

6. Visualization of the RUBIS solver's response in a standard internet browser session: click right on the saved job and on "view solution", then select the desired output format (Raw XML or HTML).

To compute a robustness analysis of the results, the selected MCDA method should be "Robust Rubis XMCDA-2.0.0 Choice Loew" in step 4.2.3.

Let us present the real case study and implement it on the RUBIS D3 web server.

## 2.3 Real Case Study in Corsica and Results of the PV Plants Selection Procedure

The study was requested by the Agriculture Chamber of the Haute-Corse department (CDA2B, http://www.chambragri2b.fr/), which is an advisory and professional actor for agricultural interests with public authorities. This stakeholder wanted an informed opinion about PV plant projects which would affect farmland, economic, ecological, and social issues, under electrical and geographical constraints. Let us present before the electric network of the island.

### *2.3.1 The Insular Power Grid of Corsica*

The electricity supply in Corsica is constrained by insularity, particularly a small electrical grid which is weakly interconnected to continental sources. Also, the demand fluctuates considerably with the tourist pressure especially during summer. The distributions of electricity generation means in Corsica are presented in Figs. 2.2 and 2.3. The total amount of production in Corsica represents about 651 MW (EDF 2011). The thermal power plants and the energy imported are the main production sources (respectively, 46.3 and 23 %), while other technologies are used for periods of peak demand. The electricity is transported by two power lines (200 kV primary net and 90 kV high voltage).

About thermal power plants:

- the fuel plant of Bastia-Lucciana supplies 132.3 MW thanks to 7 diesel engines of 18.9 MW;
- the plant of Ajaccio-Vazzio produces 54.5 MW with 5 engines of 10.9 MW;
- a 40 MW turbine and 3 turbines of 25 MW were installed in Lucciana and started in November 2008. They are used for peak demands.

Furthermore, 23 % of the total power is imported from Italy (Tuscany and Sardinia) through two submarine transmission lines. The line SACOI (line Sardinia—Corsica—Italy, connecting Tuscany, Elba, and Sardinia via Corsica) provides a maximal power of 50 MW in 200 kV direct current, while the line SARCO (line between Sardinia and Corsica) supplies 100 MW of alternative current (EDF 2011).

Renewable energies represent 30.6 % of the means, 25.3 % are waterpower stations (Fig. 2.2) cumulating 139.1 MW (EDF 2011) and installed in different valleys (Prunelli, Golo, and Fium'Orbo) (Fig. 2.3). There are many micro-hydro plants around the island whose production is fatal for the grid. Also, in spite of a significant exploitable wind potential, valued at 433 MW for a wind speed above 7 m/s at 10 m over the ground (Notton et al. 2005), only 18 MW are generated by three farms in the territories of Balagne and Cap Corse:

- the Ersa Wind farm is composed with 13 wind turbines of 600 kW, representing 7.8 MW and produces 20 GWh per year;
- the wind park of Rogliano, with 7 wind generators of 600 kW, represents 4.2 MW and produces 10 GWh per year;
- the Calenzana wind farm supplies 6 MW with 10 turbines of 600 kW and produces 15 GWh per year.

The wind generated power accounts for only 2.8 % of the electric production in Corsica. Finally, PV power represents not even 2.3 % of the total production (Fig. 2.2) despite a workable capacity of 1400 TEP. In May 2011, Corsica had only 15 MWp of grid connected PV (EDF 2011). Also new PV plants have emerged (Fig. 2.3) and the power achieved in July 2012 is 58.31 MWp.

Let us note that a power constraint for intermittent renewable energies is established with the modified ministerial decree of April 23, 2008: all production means of at least 3 kVA could be disconnected to the Corsica grid by its administrator once 30 % of the injected total power is delivered by such resources. This threshold should be achieved in 2012 (EDF 2011). Despite of this, plant projects are still studied and developed. Another solution to avoid intermittence is to couple energy storage with wind and solar power generation. Two examples are the PV plant with a storage unit located in Meria (Fig. 2.3) and the R&D Platform MYRTE located in Ajaccio that combines a PV array and a storage system based on hydrogen (Thibault et al. 2012). Also the national electricity supplier "Electricité de France" (EDF) foresees that smart grids will constitute an alternative for integrating massively intermittent renewable energies into an insular grid, and the experimental project called Millener was officially launched in Corsica during 2011.

### *2.3.2 Context of the Study*

This real case study (Haurant et al. 2011) was the subject of a research agreement achieved between University of Corsica Pasquale Paoli (UCPP), the Agriculture Chamber of the Haute-Corse department (CDA2B) and the French National Center

**Table 2.6** Outranking and condorcet robustness degrees between PV projects

| | $a_1$ | $a_{12}$ | $a_{13}$ | $a_{15}$ | $a_{16}$ | $a_2$ | $a_3$ | $a_6$ | $a_7$ |
|---|---|---|---|---|---|---|---|---|---|
| $a_1$ | 0 (0) | −23 (−2) | 14 (2) | 14 (2) | 14 (2) | 52 (2) | 0 (−3) | 42 (2) | 61 (2) |
| $a_{12}$ | 47 (2) | 0 (0) | 47 (2) | 100 (2) | 100 (2) | 100 (3) | 61 (2) | 100 (2) | 100 (3) |
| $a_{13}$ | 47 (2) | −14 (−2) | 0 (0) | 100 (2) | 100 (2) | 100 (3) | 42 (2) | 100 (2) | 61 (2) |
| $a_{15}$ | 9 (2) | 0 (−3) | 0 (−3) | 0 (0) | 28 (2) | 61 (2) | 4 (1) | 52 (2) | 42 (2) |
| $a_{16}$ | 47 (2) | 0 (−3) | 0 (−3) | 100 (3) | 0 (0) | 61 (2) | 42 (2) | 52 (2) | 23 (2) |
| $a_2$ | 9 (2) | −57 (−2) | −57 (−2) | 38 (2) | 19 (2) | 0 (0) | 28 (2) | 38 (2) | 47 (2) |
| $a_3$ | 0 (0) | −9 (−2) | 0 (0) | 0 (0) | 0 (0) | 71 (2) | 0 (0) | 100 (2) | 100 (2) |
| $a_6$ | 9 (2) | −100 (−3) | −100 (−3) | 14 (2) | 0 (0) | −14 (−1) | −100 (−3) | 0 (0) | 42 (2) |
| $a_7$ | 28 (2) | −100 (−3) | −38 (−2) | 0 (0) | 0 (0) | −4 (−2) | −100 (−3) | 28 (2) | 0 (0) |

for Scientific Research (CNRS). The aim was to aid this public institution in formulating a recommendation about the selection among 16 photovoltaic plant projects on farmlands, developed and submitted by industries to local decision makers. The actors' preoccupations and constraints listed hereafter were considered:

- The use conflict risks, particularly because the planned installations could potentially use up to 318.69 ha of cultivated grounds.
- The Social acceptability: had to be studied negative and positive impacts, both visual and financial, due to such installations on local populations.
- The ecological impacts: their definitions, the compensatory actions, the demonstration of equivalence between impacts and compensatory actions, the artificiality of farmland.
- The economic and financial impacts at regional and local levels: activity for Corsica-based firms, employment, financial aid to local inhabitants for renewable energy systems facilities, additional fiscal income per capita for the municipality.
- At most 30 % of intermittent renewable energies can be injected into the Corsica power grid in order to preserve its stability (see the aforementioned decree). This ratio corresponded to an additional power of maximum 46 MWp (Assemblée de Corse 2009a, b) but the studied PV plant projects represented a total of 98.15 MWp, which justifies a selection.
- No geographic concentration of PV plants is requested, to avoid sudden declines in production due to climatic or technical factors.

These last two constraints implied that the number of selected photovoltaic plant projects should be as small as possible. This type of intended outcome corresponds to the choice problematic in MCDA (Roy 1985). Thus, the 16 candidate projects (see Table 2.6) were assigned to 4 sets[11] each defined by the common point of connection to the power grid, and **the selections of a single best**

[11] Namely: Oletta, Taglio, Cervione and Ghisonaccia.

**project were separately computed on each set of alternatives**. In other terms, among the 16 alternatives, only 4 will be selected with the RUBIS and ELECTRE IS methods under the above constraints. Also, in this way maximum 41.46 MWp could be achieved.

Finally, let us note that project evaluations were based on data files.

### 2.3.3 PV Plant Projects, Criteria Family and Performance Table

The 16 projects, divided into 4 sets separately analyzed to find a single best solution for each of them are characterized in Table 2.6. All of them satisfied three preselecting constraints, about guarantee of plant dismantling, farmland out of ecological classifications (Natura 2000, wetlands) and area's topography (slopes must not exceed 10 %).

A family of 8 criteria to be maximized (Table 2.1) has been constructed to evaluate each alternative project (Table 2.2). The criteria family was worked out in dialog with the two actors (CDA2B, UCPP), directly involved in the decision aid process: the Stakeholder CDA2B requesting the study, the researchers of the UCPP specialized in multicriteria analysis of renewable energies and Sustainable development. Criteria were chosen to take into account the preoccupations of these actors about the consequence of the PV plant projects. More particularly, the risk of conflicts between farmland uses and PV plant projects, specific stake of the CDA2B, was considered with the criteria $g_2$ and $g_6$. Let us note that $g_6$ also considers tourist and archeological interests. In contrast, all other criteria translate common preoccupations of CDA2B and UCPP, based on energy production ($g_1$), ecological degradation ($g_3$), social issues ($g_4,\ g_5$), economic and financial effects ($g_7,\ g_8$). Let us also note that criterion $g_8$ was optional because based on very uncertain information (i.e., keeping or not of professional tax in France) or too different data (i.e., professional tax amounts vary considerably between files for similar projects). Also, only criteria $g_3$ and $g_6$ have veto powers (i.e., each veto value is lower than the magnitude of the criterion scale), according to the sensitive preoccupations which are associated. A fuller description is given in Haurant et al. (2011). Moreover, no distinction is done between weak veto thresholds and strong veto thresholds.

Based on these evaluations (performance, weights and thresholds on criteria), the RUBIS methodology can be implemented to aid in selecting the best alternative PV plant project.

### 2.3.4 Main Results of RUBIS Outranking Computations

As presented in Haurant et al. (2011), detailed results are given for the PV plant projects which composed the set called Ghisonaccia, because it is the main case (9 alternatives, 48.85 MWp and 490.7 ha concerned). The selection is mainly based without the optional criterion g8. Its consideration is discussed later. Also, for the three over sets of projects, finals results (i.e., robust RUBIS choice recommendations) are stated in the discussion. The reader can compute all the cases using the RUBIS D3 web server, as presented above. Here are the main results.

About Fig. 2.4, let us recall that from an alternative $x$ to an alternative $y$: a black arrow (or arc) is directed if "$x$ outranks $y$" ($\tilde{S}(x, y) > 0$). For example, $a_{12}$ outranks all over projects. Also, an empty arrow head indicates an indeterminate outranking situation ($\tilde{S}(x, y) = 0$) at this stage of the decision-aiding process. It is the case for the ordered pair $(a_3,\ a_{13})$, or even between $a_3$ and $a_1$. Moreover, a thick arrow means an indifference situation between these two alternatives, because $x$ outranks $y$ and $y$ outranks $x$ ($\tilde{S}(x, y) > 0$ and $\tilde{S}(y, x) > 0$). For example are indifferent $a_6$ and $a_7$, $a_7$ and $a_1$, $a_6$ and $a_1$. Finally, the case with a black arrow from $x$ to $y$ and no arrow from $y$ to $x$ means a preference situation of $x$ over y. For example, $a_{12}$ is preferred to $a_7$, $a_2$, $a_3$, $a_{13}$, $a_1$ and $a_6$.

The RCR algorithm implementation leads to the result that **project $a_{12}$ is selected as the best choice: it is the RUBIS choice recommendation** (yellow alternative in the outranking digraph). It is a good compromise of criteria. Intuitively (see Tables 2.1 and 2.2), this result can be found by reading performance (taking into account the thresholds) in the descending order of criteria weight. Indeed, on the most important ($g_2$, $g_3$, $g_4$ and $g_6$), the project $a_{12}$ is the best (or is indifferent to the best) except for $g_4$ where the alternative obtains the median rank. For the criteria of second-rank importance ($g_1$ or optionally $g_8$), $a_{12}$ gets a rank higher than median. Considering the least important criteria ($g_5$ and $g_7$), project $a_{12}$ is the best or the second.

Let us note that the RUBIS D3 web server also delivers the non-retained alternatives, called potentially bad choices, outranked by at least one alternative of the choice recommendation translating the aforementioned principle of non-retainment for well motivated reasons. Therefore, **project $a_6$ is the worst bad choice** (blue alternative in the previous outranking digraph), then $a_7$, and finally $\{a_1,\ a_3\}$.

### *2.3.5 Discussion*

Hereafter are discussed the following points: robustness analysis of the preceding results, introduction of the optional criterion $g_8$, RUBIS final recommendations with a comparison to the ELECTRE IS method, and the estimated net production (criterion $g_1$).

Regarding the uncertainty of the input data, it was necessary to assess the robustness of the results (i.e., best choice, indeed bad choice). It can be easily computed within the RUBIS D3 web server which provides a tool called "Robust Rubis XMCDA-2.0.0 Choice Loew" for implementing a Condorcet robustness of a RUBIS Best Choice Recommendation [and also robustness of the bad choice(s)].

The assessment scale shown in Table 2.4 is applied to each outranking significance degree (see Table 2.5). Pairwise outranking significance degrees are in the range $[-100, 100]$ and Condorcet robustness degrees are shown in brackets. Thus, is obtained the Robustly Concordant Outranking Graph (Fig. 2.5).

Thus, it allows resolving the indeterminate outranking situations associated to lowest Condorcet robustness degree (−3). From the Significantly Concordant Outranking Graph (Fig. 2.4) are removed 5 empty arrow heads concerning the following ordered pairs of alternatives: ($a_{16}$, $a_{12}$), ($a_{15}$, $a_{12}$), ($a_1$, $a_3$), ($a_{16}$, $a_{13}$), ($a_{15}$, $a_{13}$). Therefore, at this new stage of the decision-aiding process providing the Robustly Concordant Outranking Graph (Fig. 2.5), **the robust RUBIS choice recommendation is still the project** $a_{12}$. Let us note that project $a_6$ remains a robust bad choice. It is also the case of projects $a_7$ and {$a_1$, $a_3$}, which is an additional results that can be obtained with the RUBIS D3 web server.

Moreover, by introducing the optional criterion $g_8$ into RUBIS computations, a new robust bad choice appears: the project $a_{15}$. Thus, in considering the full criteria family, 5 of 9 alternatives would be rejected and the robust good choice remains the project $a_{12}$.

Consequently, taking into account the results and their robustness, the RUBIS final recommendation is the PV plant project $a_{12}$. It was also the obtained conclusion by implementing the ELECTRE IS method (Haurant et al. 2011).

Considering now the four sets of projects (see Table 2.6; see Table 8 in Haurant et al. 2011), separately analyzed to compute on each the single best solution, the selected PV plants were finally $a_{11}$, $a_4$, $a_{14}$, and $a_{12}$. They are all robust best choices recommended with the two outranking methods. This final selection covers 96.2 ha (on 318.69 ha concerned) of farmlands in Haute-Corse and represents a total power of 27.1 MWp (on 98.15 MWp submitted by industries to local decision makers). As expected at the point 3.2, the regional limit of 46 MWp additional is not exceeded and no geographic concentration of PV plants is obtained (Haurant et al. 2010). The actor CDA2B requesting the study was satisfied with the clarifications made by the outranking multicriteria selection aid of projects, well taking into account his preoccupations. In contrast at a regional level, during the real decision making process led by the Assembly of Corsica, let us lay the stress on the fact that only the Stakeholder ODARC (Agricultural and Rural Development Office of Corsica) has expressed his opinion on value of agricultural land.

More broadly, are to be considered some elements of **discussion about the ELECTRE-based methods for the choice problematic**. In the progressive search for a single best alternative, the outranking kernel(s) of an outranking digraph are taken as BCRs within the methods ELECTRE I and ELECTRE IS. Nevertheless, as shown by Bisdorff et al. (2008), the kernel may be too restrictive in certain cases and either no recommendation may be performed, or obvious BCRs may be left out. To overcome this problem, the authors have defined the concept of outranking hyperkernel which can always be found in any bipolar-valued outranking digraph. Thus, with the RUBIS method, the authors introduced new operational instruments which contribute to enrich the set of multicriteria decision-aiding tools for the

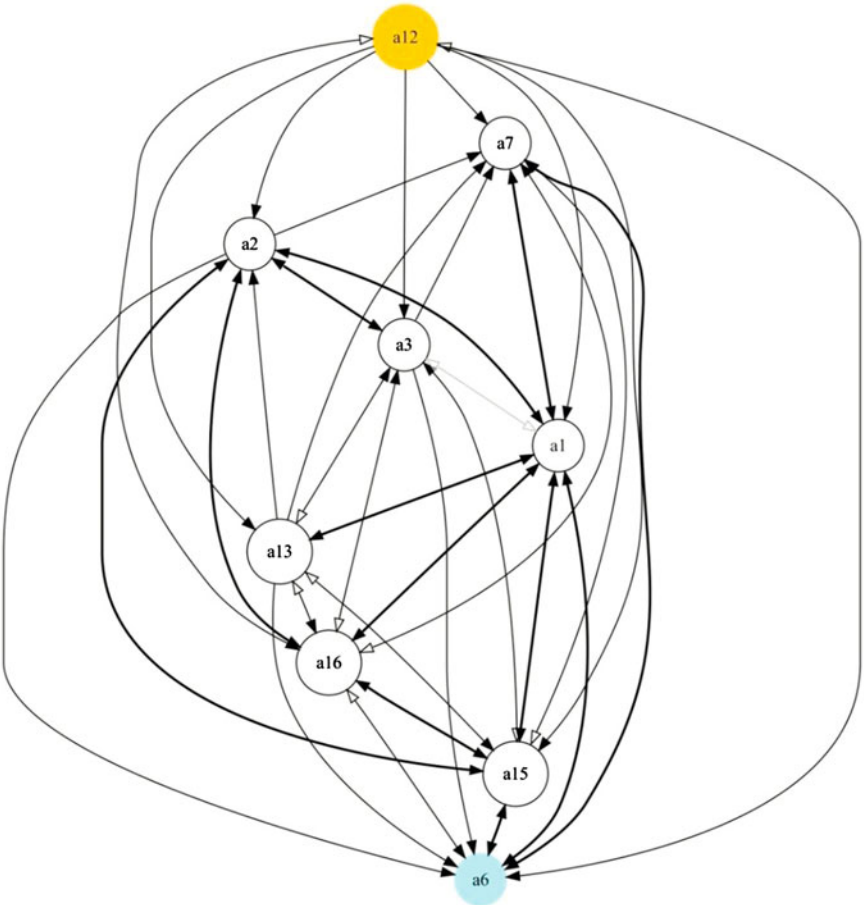


**Fig. 2.5** Robustly concordant outranking graph (Ghisonaccia set of projects)

choice problematic. Also, the method appears intelligible, because the bipolar valuation of the outranking relation is solely based on sums and differences of weights of individual criteria. Similarly, the steps of the RCR algorithm seem clear. However, the analyst must be computer-aided both with the methods RUBIS and ELECTRE IS, because the complexity of calculus (digraphs processing and Robustness analysis of the results) increases in real cases studies. Let us note the advantage of RUBIS to be implemented in a solver web service at the University of Luxembourg, thereby removing the constraint of incompatibility due to a change of operating system. In addition, the RUBIS method delivers enriched conclusions such as the bad choice alternative(s). In contrast, ELECTRE IS method offers the possibility to parameter the so-called sufficient majority of criteria to test an outranking statement. In the RUBIS method is considered a strict

0-cut outranking relation, corresponding to more than 50 % of the global criteria significance weights. A more general crisp relation could be considered, to apply other values of majority.

Finally, as pointed upstream, the evaluations of PV plant projects were based on data files provided by industries to local decision makers. The estimated net production, given by the criterion $g_1$, was directly extracted. The lack of detail on the calculations has left us sceptical. Consequently, have been defined threshold values to avoid cases of strict preference between projects. Also, the actor CDA2B requesting the study has given a median rank of importance to this criterion. Thus, its role was somewhat restricted. Recently and after submission of the study report, we have developed a mapping of solar potential in Corsica (Haurant et al. 2012), based on sub-pixel disintegration method, reducing the errors of radiation estimates and improving the spatial resolution. This advance would reassess projects on this criterion.

## 2.4 Conclusion

Was successfully implemented the RUBIS methodology confirming the results previously obtained with the ELECTRE IS method for aiding to select photovoltaic plants on farmlands in the Haute-Corse department of the island (Haurant et al. 2011). Moreover, let us assert that the basic ELECTRE I method is still applied especially to support an investor in choosing the best alternative to develop a small photovoltaic park, in the Greek PV market (Siskos and Houridis 2011). All these operational researches dealing with the choice problematic are performed within the ELECTRE outranking-based approach and they implement robustness analysis of the results (i.e., the best solution(s) to be selected). The complexity of MCDA in energy real case studies justifies well-established scientific methods and a computer-aided analyst. This combination is possible within the RUBIS methodology, as outlined in this chapter. In summary, it offers an operational research toolbox, coherent, modern, and transparent, to deal with the choice problematic in MCDA. The main three innovative tools are a new graph theory-related object (i.e., the maximally determined strict outranking hyperkernel), the outranking method RUBIS in the tradition of ELECTRE IS and the RUBIS D3 web server for computing and solving a choice problem with Cordorcet robustness analysis of the results.

In contrast, at a regional level (i.e., the Haute-Corse and Corse-du-Sud departments), the Assembly of Corsica has carried out its own multicriteria evaluation (Assemblée de Corse 2009a, b) of all the 74 proposed PV plant projects (on farmlands or not) with a simplistic framework (weighted arithmetic mean strongly compensatory, no rigorous tool for weighting the 39 qualitative criteria, no robustness analysis of the recommendations). Sustainable energy systems in Corsica island must be evaluated in a more formalized framework for a relevant multicriteria selection.

More broadly, assessment and simulation tools in MCDA must meet a variety of methodological challenges, including in particular the four following: coupling with GIS (Oberti and Bollinger 2013) notably for site selection (Defne et al. 2011) (Van Haaren and Fthenakis 2011) focusing on the compensatory logic of the data aggregation and on the robustness of mapping results; participatory approach (Oberti and Paoli 2013) to sustainable energy futures (Kowalski et al. 2009); dealing with the sorting problematic such as the outranking ELECTRE TRI-based methods notably implemented to biogas plants (Madlener et al. 2009) and energy efficiency (Neves et al. 2008); and finally delivering new MCDA- web application such as the Decision Deck collaborative open source software platform (www.decision-deck.org).

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