Chapter 15
Choosing a Voting Procedure for Assessing the Readiness of Technology for Generating Energy

Abstract This Chapter presents an illustration of the framework for choosing a voting procedure applied to the context of assessing the Readiness of Technology for Generating Energy. The illustration is based on Morais et al. (Math Probl Eng (Online), 1–11, 2015) and is used in order to prioritize technologies that are critical for power generation in the Energy Sector. This problem was tackled in response to a request from CGEE (*Centro de Gestão e Estudos Estratégicos*, in English, the Center for Management and Strategic Studies) which is a Center that offers support to decision-making processes related to topics in science, technology and innovation. It does so by undertaking research and conducting strategic assessment studies based on a wide-ranging collaboration with experts and institutions of the Brazilian System of Science, Technology and Innovation with a view to promoting collaboration between the education and business sectors.

15.1 Assessing the Readiness to Generate Energy

Technology Readiness or critical technology can be understood as an in-country domain of technology which will generate economic development and, as a result, the technology will no longer need to be supplied from outside that country (Melo et al. 2003). In this context, technology means forming a rationale for acquiring know-how and this is designed in response to new demands and social requirements, thus changing a whole set of values and attitudes and ends up being aggregated to the culture of an organization or country (Veraszto et al. 2008). Therefore, critical technology is a top priority when planning change within an organization or a country.

Some technologies can be selected as a priority or as being critical for an organization or a country, when related to a specific area of interest. In order to evaluate the strategic condition of technology, Technology Readiness Assessment (TRA) is applied. TRA uses methods and processes to evaluate the technology itself and by specific metrics verifies the status of its development, i.e., measures the maturity of the technology assessed (Schot and Rip 1997).

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When developing a new technology, an effective TRA should also incorporate some metrics that provide a consistent assessment of the "degree of risk" (Mankins 2009). An effective TRA includes the following main features:

- *Performance Objectives.* These include aspects of engineering and operational performance measures, with a view to ensuring that the performance objectives of the new technologies and/or the capabilities of the system are clearly understood.
- *Technology Readiness Level—TRL.* This concept was introduced by NASA (National Aeronautics and Space Administration), in the mid-1970s. It is a metric that evaluates the maturity level of a specific new technology more effectively. It consists of a 9-level scale: TRL1 is the lowest level of maturity and TRL9 is the highest. The TRL scale is simple and easy to operate and has been applied in many fields such as aeronautics, astronautics and energy resources (Wei-gang et al. 2013). However, this tool also contains some weaknesses, especially because it depends on qualitative assessment, which is derived from the professional knowledge of experts, whose assessment is prone to high subjectivity and low objectivity.
- *Degree of Difficulty of Research and Development.* During the formal TRA, it is important to develop a clear understanding of the barriers to be faced and the difficulties related to whether the new technologies can be successfully developed.

The TRA for energy consists of two phases: diagnosis and implementation (as shown in Fig. 15.1). First of all, a search for new technologies that could be developed is made in the diagnostic phase. Thereafter, using TRL metrics, the maturity level of that technology is analyzed. When a specific technology is chosen, then a new

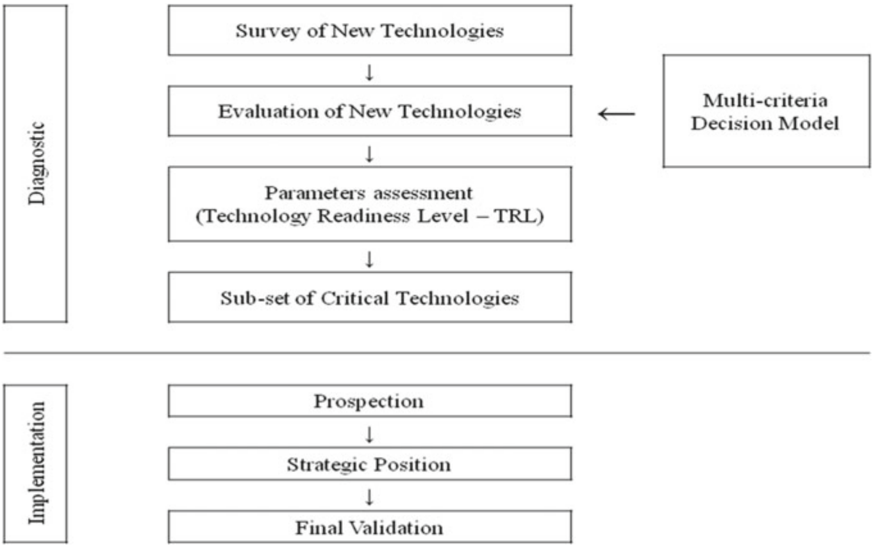

Fig. 15.1 Flowchart of the TRA and position of the multicriteria decision evaluation (Morais et al. 2015)

search on a subset of critical technologies is conducted and only after the results of this have been analyzed should the implementation phase begin.

Note that, based on these steps of the TRA, a multicriteria decision model can be applied in both phases, either in the diagnostic phase, when evaluating new technologies, or in the implementation phase, when evaluating the subset of critical technologies. Nevertheless, this study focuses on the first and most strategic part of the TRA of generating energy in order to aid how best to evaluate new technologies.

It is worth noting that some authors have conducted studies to contribute to TRA in order to improve the process for evaluating critical technologies: Chen et al. (2012), Wei-gang et al. (2013), Hoffmann et al. (2013), Li and Zhu (2011), Demirkiran (2012), Goetghebeur et al. (2012), Thokala and Duenas (2012). It is important to bear in mind that this kind of evaluation is complex and normally involves many actors in the process. However, none of these studies deal with aggregating the individual preferences of a group of decision-makers (DMs).

In this perspective, in order to take the DMs' multiple perspectives and objectives into account, this study aims to develop a group multicriteria decision model for the purpose of analyzing the strategic problem of evaluating technologies for the Brazilian energy matrix. It is worth mentioning that investments in this area are huge and an appropriate multicriteria model is necessary in order to ensure adequate efficiency in making a decision on which technology should be fostered. Also, an adequate voting process to aggregate the individual DMs' results is needed.

For this kind of strategic problem, the DMs should establish their objectives in order to analyze the alternatives (technologies). In this case, a multicriteria analysis can be a useful way to compare the technologies when using different criteria, which are important enough to disallow any kind of compensation. Therefore, this kind of decision problem has a non-compensatory rationality. However, for a non-compensatory rationality, DMs need to be able to give weights for criteria that represent their relative importance, and this task can be very hard for them.

Therefore, there are some cases in which the DM is neither able to provide such information nor feels comfortable about doing so but he/she may be able to rank the criteria by their importance. Having obtained such a ranking from the DMs, the use of surrogate weights can be considered. Therefore, it is proposed that surrogate weights could be used with the PROMETHEE method (Morais et al. 2015). The authors proposed a model for assessing the readiness of technology to generate energy a PROMETHEE-ROC method. De Almeida-Filho et al. (2018) argue that, according to their analysis, the surrogate weights approach that most faithfully represents a DM's value system is the ROC procedure.

In this Chapter, the real application conducted by Morais et al. (2015) regarding the strategic problem of TRA was adapted to incorporate the perspectives of different DMs and also, in order to illustrate the application of the Framework for choosing a Voting Procedure.

Figure 15.2 shows the group decision model to evaluate critical technology for generating energy and thereby to analyze which technology for power generation should be recommended. This model was developed in order to support DMs in choosing, with greater efficiency, the technology to be implemented in the sector.

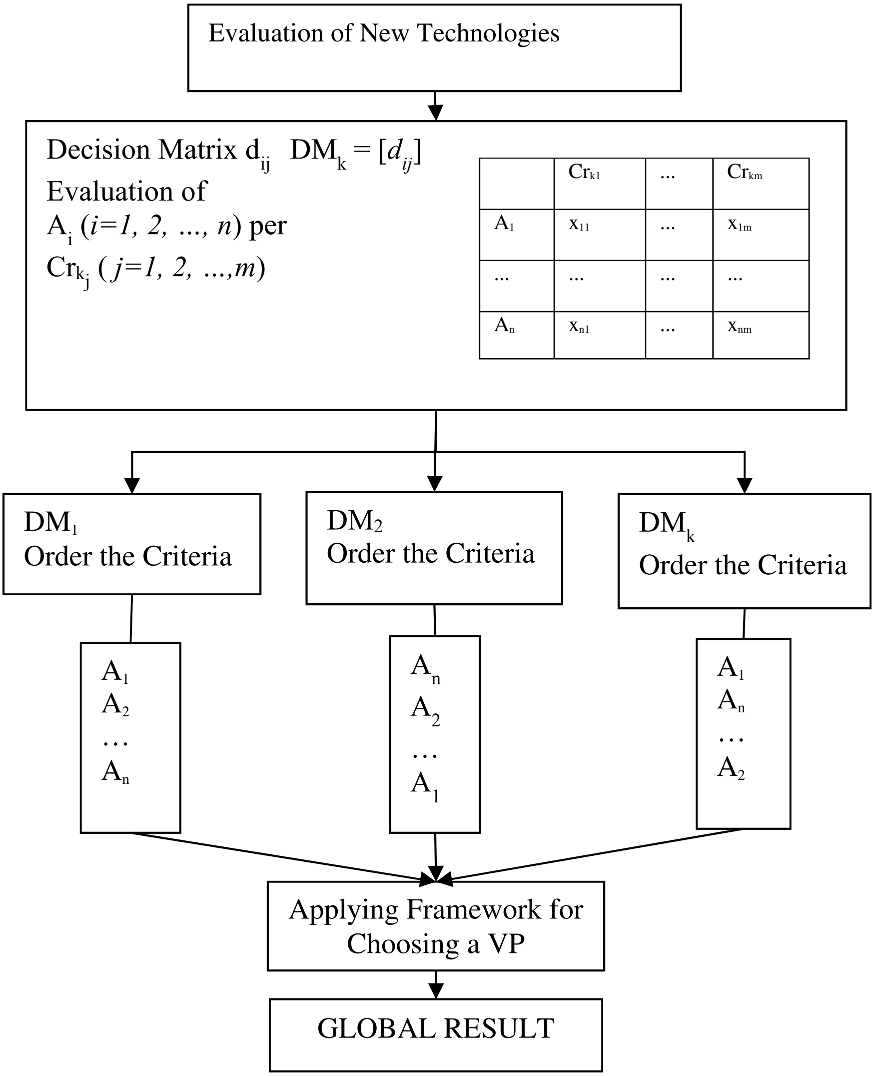

Fig. 15.2 Overview of the group decision model incorporating the framework for choosing a VP

The individual analyses take into account all the members' preferences and their perceptions about relative importance among criteria, i.e., only ordinal information. The individual evaluation explores the matrix of alternatives per criteria per DM and the individual ranks are obtained by applying the PROMETHEE-ROC method. To find the collective decision, the Framework for choosing a VP was taken into account Based on the chosen VP, the group decision-making process obtains the collective result by aggregating the results from the individual analysis.

The following sections present the application of the group decision model. First, the DMs' perspectives, their objectives and criteria are given, and the set of critical technologies to be considered as alternatives are established. On applying the PROMETHEE-ROC with each DM, the individual results are then found. Thereafter, the framework for choosing the VP that is appropriate for this problem is applied. Finally the global result is presented.

15.2 Structuring the Problem

The first step of the model consists of bringing together all members involved in the decision-making process. We call these members DMs. Thus, there is a group of DMs comprising k members, which is the set of $DM = \{DM1, DM2, \ldots, DMk\}$.

It is important to have a facilitator who will conduct the discussion process, but this person can be a member of the group, when it is not possible to have an external person. This member is called the Supra-decision-maker, i.e., the member of the group who has the most experience of and knowledge about the problem and, in conflict cases, he/she may have greater weight in the final decision and/or also establishes the DMs' priority as to calculating the final ranking. The problem of assessing the readiness of technology for generating power energy in Brazil considered there were three DMs in the process, namely, DM1, DM2 and DM3:

- DM1 is the representative concerned about environmental issues, e.g., the impacts on soil fertility, air, water, temperature and sound;
- DM2 is the representative concerned about social issues, e.g., local development, the quality of jobs generated and the know-how competence that needs to be developed;
- DM3 is the representative concerned about government issues, e.g., the development of national industry and the strategic impact on the energy matrix of the country.

15.2.1 Establishing Objectives and Criteria Based on Decision-Makers' Perspectives

The set of the objectives and criteria identified for the process of evaluating critical technologies is presented in Table 15.1 per DM. This table also shows the criteria codes, whether the interest is in minimizing or maximizing the criterion, and the unit or measurement scale for each criterion.

Table 15.2 presents the reference parameters for analyzing the critical technologies that are the units or measurement scales of the criteria. The details of these scales are shown below.

Table 15.1 Objectives and criteria

Decision-maker	Objectives	Criteria	Code	Min/Max	Unit/Scale
DM1	Environmental	Impact on soil fertility	Fert	Min	IS
		Impact on temperature	Temp	Min	IS
		Impact on sound	Soun	Min	IS
		Impact on water	Air	Min	IS
		Impact on air	Wat	Min	IS
DM2	Social	Impact on generating local or national employment	Emp	Max	IS
		Impact on the local development	Dev	Max	IS
		Impact on the quality of employment	QualEmp	Max	IS
	Knowledge	Impact on the synergy between boundaries of knowledge	Syn	Max	IS
		Impact on national competence (know-how)	Khow	Max	IS
	Economic	Period of time of interesting the market	PMar	Max	TS
		Impact of current demand in the domestic market	DDMar	Max	IS
		Impact of current demand in the global market	DGMar	Max	IS
		Impact on the growing of the national market	NaM	Max	IS
		Impact on the growing of the global market	GloM	Max	IS
DM3	Industrial	Impact on production capacity	Cap	Max	IS
		Impact of the availability of inputs	Inp	Max	IS
	Strategic	Condition for curtailing its development	Curt	Min	CS
		Impact on the energy matrix	Mtx	Max	IS

IS impact scale; *TS* time scale; *CS* curtailment condition scale

Table 15.2 Reference parameters for analyzing the critical technologies

Impact level	Value	
	Min	Max
a. Impact scale (IS) (Morais et al. 2015)		
No impact	5	1
Very low impact	4	2
Moderate impact	3	3
High impact	2	4
Very high impact	1	5
b. Time scale (TS) (Morais et al. 2015)		
Period of time		Value
Short term (up to 5 years)		1
Medium term (up to 15 years)		2
Long term (up to 30 years)		3
c. Curtailing condition scale (CS) (Morais et al. 2015)		
Curtailing condition		Value
The Energy Technology is not an important part of the development of another process		1
The Energy Technology is an important part of the development of another process		2

15.2.2 Establishing the Set of Critical Technologies

The process for selecting the set of alternatives was agreed to by all three DMs. They agreed to evaluate fourteen critical technologies, which are distributed in five technological areas. Table 15.3 shows the technological area and subarea, and the code of the critical technology.

15.3 Individual Results

Each DM has a decision matrix since each of them compares the alternatives from different perspectives. In order to evaluate the individual results, each DM considered in this study needed to establish the ranking of the criteria and computing their weights, based on ROC (Rank order centroid) weights (Vansnick 1986; Barron 1992). Table 15.4 shows the order and weights for the criteria per DM.

The next step is to build the consequence matrix, which evaluates the alternatives by criterion, using the scale shown in Table 15.2. The step of evaluating the critical technologies by criterion is supported by a decision support system and is illustrated in Figs. 15.3, 15.4 and 15.5.

Table 15.3 Set of alternatives

Technological area	Technological subarea	Critical technology	Code
Chemical	Physicochemical	Lithium-ion batteries	BIL
	Organic chemistry	Recycling	Rec
		Bioenergy	Bio
Optics	Photo-automation	Photosensors	FotS
	Photo-generation	Photo-voltaic panel	FotG
Telecommunications	Control and automation	Automation system	Aut
	Communication	Telecommunication systems using transmission power cables	Com
		Loading batteries by communication signals	Batt
Mechanics	Wind	Wind power	Wind
	Hydro	Hydro power	Hydr
		Small hydro power central unit	SHC
	Solar	Solar Energy	Solar
Electric	Battery	Advanced battery technologies	Acum
	System	Equipment and arrangements	EqAr

Source Morais et al. (2015)

All DMs considered the Usual preference function for all criteria, which indicates that any difference between alternative performances represents a strict preference. The use of ROC weights minimizes the effort that a DM needs to make in the process for indicating the degree of importance of the criteria. Based on the consequence matrix and the value of the criteria, the performance of the alternatives can be evaluated by implementing a multicriteria method. Table 15.5 shows the individual results per DM regarding their preferences. The result is shown as the order of preference of the alternatives by DMs (1 being the most preferable and 14 the least preferable).

The critical technologies are evaluated based on PROMETHEE-ROC. The mathematical structure of the multicriteria method offers the first recommendation per DM and obtains the ranking of the alternatives.

In accordance with the results, the DMs do not agree with each other about which critical technology must be prioritized. Besides, note that there is a great divergence between DM 2 and DM3, since the first alternative of DM3 is the 11th alternative for DM2. Thus, the next step is to evaluate which Voting Procedure should be used in order to aggregate these individual results.

Table 15.4 Criteria order and weights by DMs

Decision-maker	Criteria code	Order of the criteria	ROC-weights
DM1	Fert	3	0.1567
	Temp	5	0.0400
	Soun	4	0.0900
	Air	2	0.2567
	Wat	1	0.4567
DM2	Emp	4	0.0900
	Dev	5	0.0400
	QualEmp	2	0.2567
	Syn	1	0.4567
	Khow	3	0.1567
	PMar	6	0.0606
	DDMar	5	0.0828
	DGMar	8	0.0262
	NaM	3	0.1477
	GloM	7	0.0421
DM3	Cap	4	0.1106
	Inp	9	0.0123
	Curt	2	0.2032
	Mtx	1	0.3143

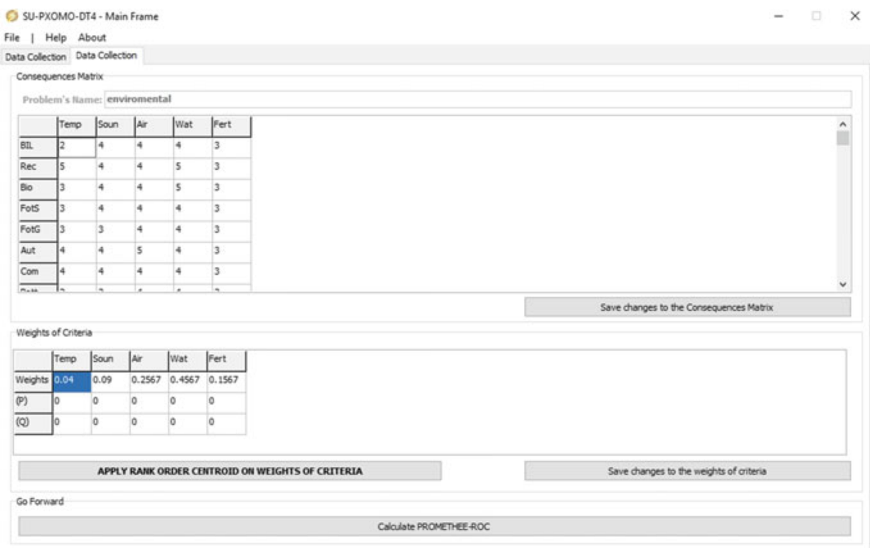

Fig. 15.3 Establishing the consequence matrix and the weights of criteria by DM1

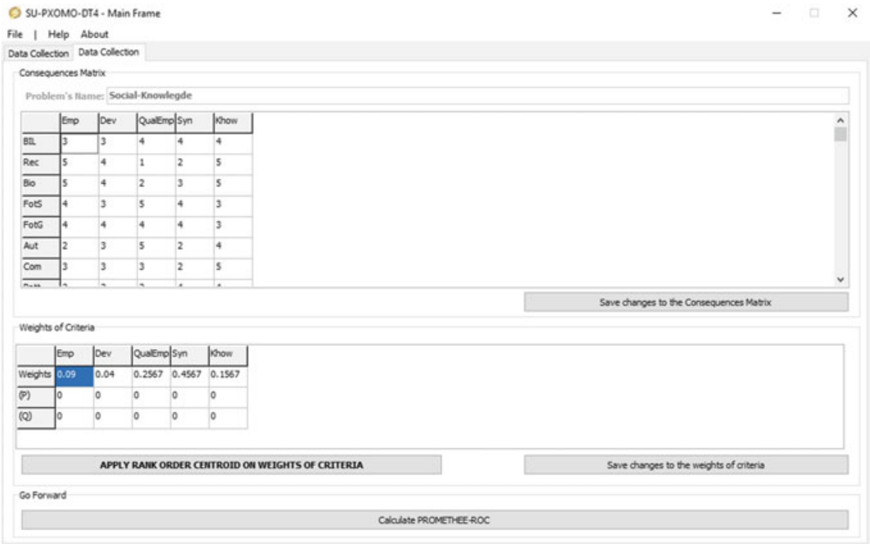

Fig. 15.4 Establishing the consequence matrix and the weights of criteria by DM2

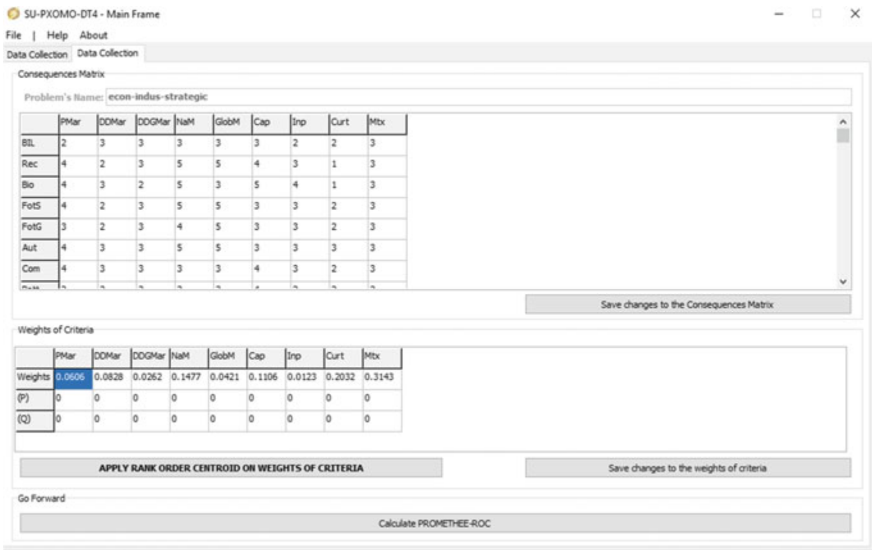

Fig. 15.5 Establishing the consequence matrix and the weights of criteria by DM3

Table 15.5 Ranking of the alternatives by DMs

Alternatives	DM1	DM2	DM3
BIL	9	2	14
Rec	1	12	9
Bio	3	7	7
FotS	8	1	6
FotG	11	3	11
Aut	4	11	1
Com	7	13	8
Batt	13	4	13
Wind	10	6	2
Hydr	5	5	3
SHC	12	10	12
Solar	14	9	4
Acum	2	8	5
EqAr	6	14	10

15.4 Applying the Framework for Choosing a VP

In this session, the focus is on choosing which Voting Procedures (VPs) can be used to evaluate the specific problem of evaluating the Readiness of Technology for Generating Energy. The process is based on the Framework presented on Chap. 14 of this book. The main aspect of this kind of problem may be the type of input required by a VP. Based on the characteristics of this problem, the input was the VP rankings of alternatives, while the VPs that were considered adequate were: Amendment, Copeland, Dogson, Minmax, Borda, Nanson and Hare.

The Criteria used to evaluate the VPs is in accordance with the context of the problem of Readiness of Technology for Generating Energy, and with the characteristics of the VP and how they affect the problem. Criteria are generated which are associated with the properties and other characteristics, such as paradoxes that may be relevant for consideration when analysing a VP.

In order to facilitate the process, the same multicriteria process (PROMETHEE-ROC) was applied to evaluate the VP. The DMs involved in this process agreed with the order of the criteria to evaluate the VP. Table 15.6 shows the order and weights of these criteria.

For the process of choosing a VP, the Usual preference function was applied for all criteria, since it is a binary evaluation of the VPs. Besides, based on the consequence matrix (binary evaluation as shown in Table 14.1—Chap. 14), the value function as considered in Eq. (14.1) (Chap. 14), and the weights of the criteria, the VP appropriate for this problem can be found. Figure 15.6 presents this result.

Table 15.6 Order of criteria to evaluate VP

Criteria	Condorcet winner	Condorcet loser	Strong Condorcet	Mono-tonicity	Pareto	Consis-tency	Chernoff	Invulnerability to the no-show paradox
Order	4	5	2	3	1	7	8	6
ROC-Weights	0.1106	0.0793	0.2147	0.1522	0.3397	0.0335	0.0156	0.0543

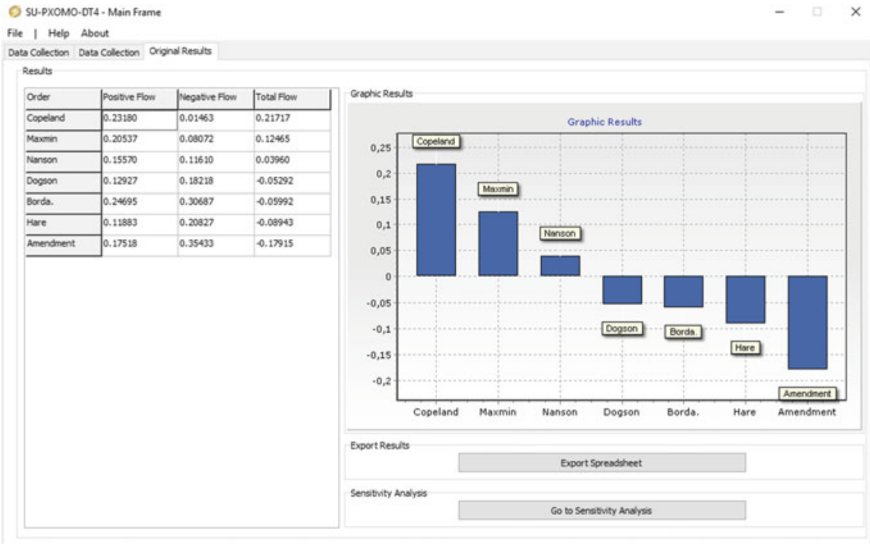

Fig. 15.6 Result of the VP chosen for the problem of evaluating the Readiness of Technology for Generating Energy

As can be observed, the Copeland method was identified as the most appropriate VP for the problem to aggregate the individual results from the DMs involved in the problem of evaluating the Readiness of Technology for Generating Energy.

15.5 Global Results

Since the Copeland method was considered the most appropriate voting procedure to conduct the aggregation of individual results for this problem. Table 15.7 shows the result of the aggregation of the alternatives using Copeland method.

In accordance with the results, the critical technology which must be prioritized in the first instance is Hydr, followed by Aut and Acum. The last position is taken by SHC and Batt. The reference to the name of the alternatives is shown in Table 15.3. This result reflects the aggregation of DMs' rankings after using the Copeland method.

Table 15.7 Global result by applying Copeland Method

Alternatives	BIL	REC	BIO	FotS	FotG	AUT	Com	Batt	Wind	Hydr	SHC	Solar	Acum	EqAr	Wins	Total
BIL	–	0	0	0	1	0	0	1	1	0	1	1	0	0	5	−3
REC	1	–	0	0	1	0	1	1	0	0	1	0	0	1	6	−1
BIO	1	1	–	0	1	1	1	1	0	0	1	1	0	1	9	5
FotS	1	1	1	–	1	0	1	1	1	0	1	1	0	1	10	7
FotG	0	0	0	0	–	0	0	1	0	0	1	1	0	0	3	−7
AUT	1	1	0	1	1	–	1	1	1	1	1	1	0	1	11	9
Com	1	0	0	0	1	0	–	1	0	0	1	0	0	1	5	−3
Batt	0	0	0	0	0	0	0	–	0	0	0	1	0	0	1	−11
Wind	0	1	1	0	1	0	1	1	–	0	1	1	1	1	9	5
Hydr	1	1	1	1	1	0	1	1	1	–	1	1	1	1	12	11
SHC	0	0	0	0	0	0	0	1	0	0	–	0	0	0	1	−11
Solar	0	1	0	0	0	0	1	0	0	0	1	–	0	1	4	−5
Acum	1	1	1	1	1	1	1	1	0	0	1	1	–	1	11	9
EqAr	1	0	0	0	1	0	0	1	0	0	1	0	0	–	4	−5
Loss	8	7	4	3	10	2	8	12	4	1	12	9	2	9		

15.6 Topics for Further Reflection

The problem presented used ROC weights to represent the importance of criteria in the decision problem, either during the individual phase or for the framework for choosing the VP. This model could be applied to other problems, since the DMs have a non-compensatory rationality and could not give complete information about the criteria, but they are able to give partial information about them.

If the DMs have a compensatory rationality, it is important to rank the criteria based on swing weights and also to use an additive multicriteria method.

In this Chapter, all DMs agreed with the order of criteria for choosing the VP. However, if this were not the case, a Supradecision-maker who is able to do this task should be appointed.

15.7 Suggestions for Reading

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