Chapter 17
Choosing a Voting Procedure to Identify Technology for Generating Renewable Electric Power

Abstract Among other worldwide concerns is that of choosing the technology for generating electric power that should comprise the electricity matrix of a country. In this kind of decision process, multiple actors are involved, and they need to consider not just the financial dimension but also the technical, socio-economic and environmental dimensions. This Chapter presents an illustration of the framework for choosing a VP to aggregate information from the profile of the various Decision-Makers involved in this process. This illustration is based on Kang et al. (2018) and Soares et al. (working paper) which presented how a decision model using the FITradeoff method was applied to aid a decision on identifying technology to generate electric power for the Brazilian electricity matrix.

17.1 Generating Renewable Electric Power

When electric power is generated centrally and the demand for electricity rises, an increase in generation occurs until capacity is reached. When capacity is exceeded, new generation units are created, thereby increasing the costs of transporting and distributing energy. As an alternative to such traditional systems for generating energy, Alanne and Saari (2006) argued that distributed energy generation systems offer an alternative that is more efficient, reliable and environmentally friendly.

This new trend of distributed energy generation means that energy conversion units are situated close to the consumers of energy, and large units are replaced with smaller ones. Besides, distributing the generation of energy is well adapted to regions that suffer from the supply of low-quality energy, such as rural regions, since this form of generation is relatively easy to develop locally and is cost-effective compared to other solutions for generating energy (Irena 2016).

In the context of distributed energy generation, it is important to periodically evaluate the most suitable solution for a country due to changes that may have occurred in different dimensions. In emerging countries, particularly those that are dependent on oil, it is essential to diversify energy sources in order to guarantee the supply of energy, to create jobs and to develop sustainable energy (Al Garni et al. 2016).

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The concept of sustainability, in general, means that scarce resources and economic opportunities regarding society and the environment should be distributed fairly (www.sustainablemeasures.com), and should take account not only of society's well-being today, but also in the future, as it is known that the resources consumed will be different in the future (WCED 1987). Based on the need for sustainable development, making use of renewable energy sources emerges as a good option.

According to De Melo et al. (2016), energy is said to be renewable when it is generated by using natural resources. Such sources of energy are continually replenished by nature and derived from the sun, wind, hydropower, the photosynthetic energy stored in biomass or from other natural movements in and mechanisms of the environment (such as geothermal and tidal energy) (Ellabban et al. 2014). Renewable energy technologies turn these natural energy sources into usable forms of energy, namely electricity, heat, and fuels.

Therefore, renewable energy meets the dual goals of reducing greenhouse gas emissions, thereby limiting future extreme weather and climate impacts, and ensuring the reliable, timely, and cost-efficient delivery of energy (Ellabban et al. 2014). Although these sources enhance the economy of a country (da Silva et al. 2016; Pohekar and Ramachandran 2004), renewable energy technologies are more expensive than conventional ones (Balezentis and Streimikiene 2017).

In Brazil, most electricity is generated by hydropower (de Melo et al. 2016; Aquila et al. 2016). The main technologies that generate electric power and comprise the electricity matrix of Brazil are shown in Table 17.1.

The predominance of hydroelectric sources for power generation in Brazil can be explained by Brazil's topography (Aquila et al. 2016). Nevertheless, since this kind of generation is dependent on hydrological conditions (da Silva et al. 2016) and has significant socio-environmental impacts, it is prudent to evaluate other sources of power generation that would form ideal energy policies for Brazil, especially of renewable energy sources (Strantzali and Arovossis 2016) to ensure that this kind of generation makes up a high share of the total resources in Brazil's electricity matrix (da Silva et al. 2016).

Thus, making decisions in this context is of high complexity. Multiple factors should be considered when deciding on how best to generate energy. This is not

Table 17.1 Brazilian electricity matrix as at 2015

Source	Percentage (%)
Hydropower	64
Natural Gas	13
Biomass	8
Petroleum	5
Coal	4
Wind	4
Nuclear	2

Adapted from Kang et al. (2018)

only related to energy production and consumption but is also associated with social, economic and environmental aspects (Zografidou et al. 2016). From this perspective, multiple actors are involved in this kind of decision process and they have the complex task of considering all these aspects, and thus to ensure a balance of sources or to make a tradeoff between them (Balezentis and Streimikiene 2017). Therefore, the impact of this decision process affects not only a region or a country, but it is a worldwide concern (Al Garni et al. 2016).

Nonetheless, another important characteristic of this type of problem is that the set of alternative solutions depends on the values and desires of the actors involved in the decision process. In the energy sector, there are a large number of actors, each of whom brings different perspectives on and a different set of values regarding power generation.

As can be observed, this kind of decision-making cannot be treated as an optimization problem that can use a single dimension (commonly the economic one). Thus, in order to analyze the problem as a complex system, the most appropriate approach for considering all the conflicting dimensions appears to be one that uses multicriteria decision-making/aiding (MCDM/A) methods (Zhang et al. 2015).

Given the need to diversify Brazil's electricity matrix by investing in technologies that complement hydroelectric generation, and taking into account the multiple aspects that need to be considered when making such decisions, Kang et al. (2018) proposed a MCDM/A model to evaluate different electrical energy technologies, both renewable and non-renewable ones, that comprise Brazil's current electricity matrix under (financial, technical, environmental and socio-economic) dimensions of sustainability.

In this Chapter we use this model as an illustration of applying the framework for choosing a VP. However, we focus only on renewable sources of energy, based on the working paper of Soares et al. (w.p.).

The MCDM/A model proposed by Kang et al. (2018) focused on situations where there is not enough data regarding the parameters related to some criteria that are important for the decision context or where the available information is incomplete. This is a very relevant aspect in the area of renewable technologies for distributed electric power generation. Taking this perspective, they proposed applying the Flexible and Interactive Tradeoff (FITradeoff) method (de Almeida et al. 2016). This method requires less cognitive effort from the decision-maker (DM) when eliciting his/her preferences, since it is based on incomplete (or partial) information. The FITradeoff DSS (Decision Support System) can be downloaded on request at http://fitradeoff.org/.

The dynamic procedure to build this MCDM/A model followed the de Almeida et al. (2015), framework, which consists of three main phases subdivided into twelve steps, within a flexible sequence, where the DM can go back to previous steps when necessary, thereby enhancing learning and generating insights during the process.

In the first phase of the model, the preliminary information is defined, such as identifying the actors of the decision process (henceforth called DMs), their objectives and the related set of criteria, and the viable alternatives. In the second phase, which considers the characteristics of the problem and the DM's preference structure, an MCDM/A method is chosen and applied (de Almeida et al. 2015), in this case, the FITradeoff method. Finally, in the third phase, the alternatives are evaluated, and a sensitivity analysis is conducted.

For this Chapter, a fourth and fifth phase were added. These phases deal with applying the framework for choosing a Voting Procedure (VP) and the global result, respectively. In order to choose the VP, it is important to evaluate the properties of the desired VP and also which VP is appropriate for this decision context. Once the VP is chosen, then it is applied using the ranking obtained from the DMs during the first three phases. Figure 17.1 shows the flowchart of the model for selecting the most appropriate form of renewable electric power generation in Brazil.

17.2 Structuring the Problem

In order to support the analysis of technology for renewable distributed electric power generation, first of all, what must be done is to identify who the DMs are, what the alternatives for this problem are and what the set of criteria to evaluate the alternatives should be. This application is based on Kang et al. (2018) and Soares et al. (w.p.), considering Brazil's electricity matrix.

17.2.1 Identifying the Decision-Makers

Many actors or pressure groups can be involved in this problem of looking for renewable technologies to generate electric power in Brazil. Each of them has their own perspectives and different value structures. For instance, technical and financial aspects may be emphasized by a utility company, which is interested in the performance of a plant and a return on capital. On the other hand, the community is interested in social and environmental impacts. Consequently, conflicts may exist and what is preferred by one group may not be by another (Stein 2013).

In this chapter, it was considered that there were four decision-makers (DMs), whom Kang et al. (2018) call different decision profiles. Table 17.2 shows the concerns of these DMs and their codes.

17.2.1.1 Decision Profile A: Energy Production

This DM is primarily concerned with the operational performance of the renewable electric power generation plant. The technical dimension is his/her focus. This profile is especially interested in the efficiency of generation, the capacity factor and controllability.

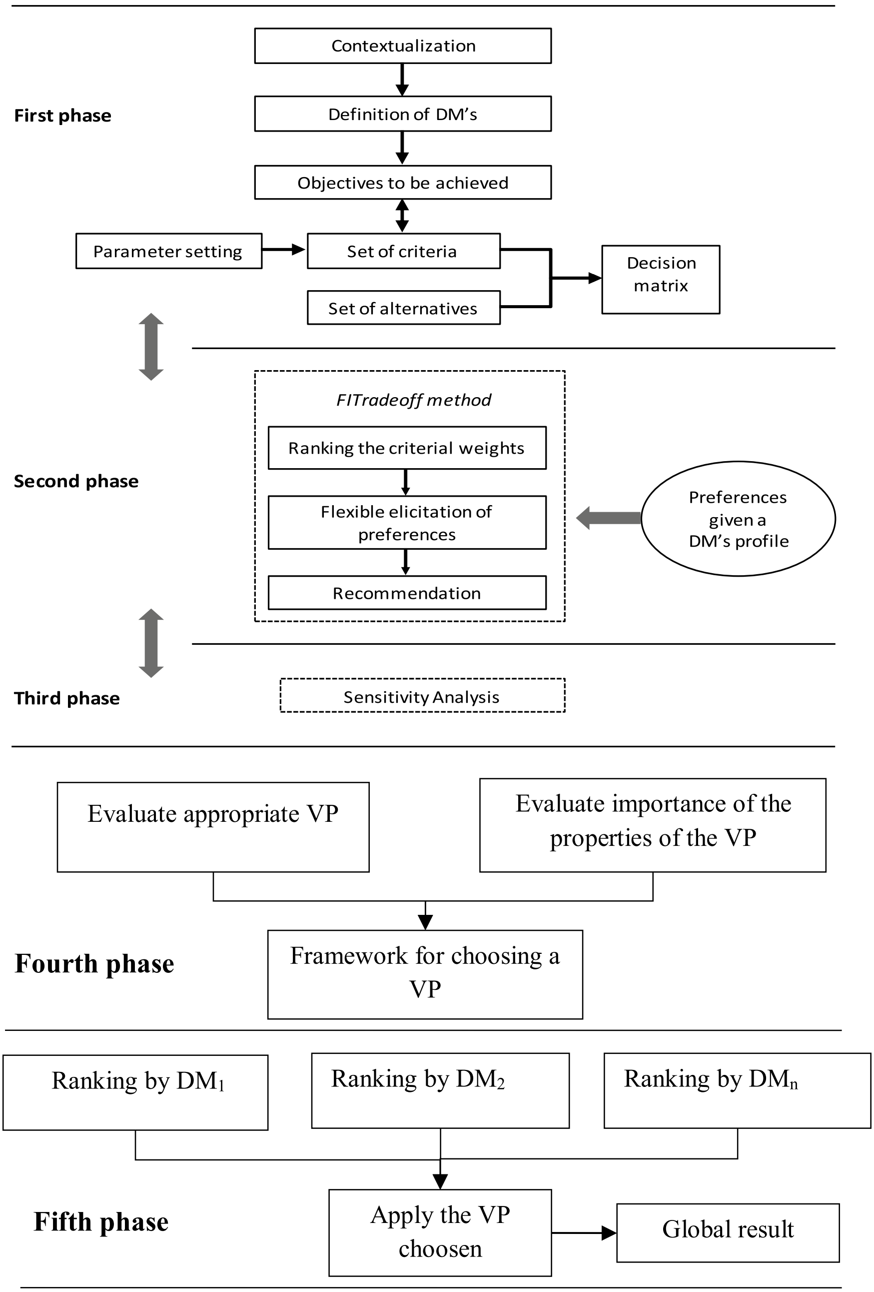

Fig. 17.1 Flowchart of the proposed MCDM/A model (adapted from Kang et al. 2018)

Table 17.2 Decision-makers considered in this problem

Decision-maker	Code	Concerns
Profile A	DM $_{A}$	Energy production
Profile B	DM $_{B}$	Return on investment
Profile C	DM $_{C}$	Environmental impact
Profile D	DM $_{D}$	Job creation

17.2.1.2 Decision Profile B: Return on Investment

This DM is concerned with the financial performance of the renewable electric power generation plant. The electric power technologies are evaluated from a financially-oriented perspective. The DM would prioritize the cost of investment and the average cost of operation and maintenance costs.

17.2.1.3 Decision Profile C: Environmental Impact

This DM is concerned with the environmental impacts and their interference in people's lives, and therefore seeks clean, renewable and non-polluting forms of energy.

17.2.1.4 Decision Profile D: Job Creation

This DM is concerned with the socioeconomic and political impact and creating jobs by setting up a renewable electric power generation plant. The number of jobs created is evaluated in the construction and installation phases, in the manufacturing phase, and during the operation and maintenance of the system.

17.2.2 Establishing the Set of Potential Alternatives

The set of potential alternatives, i.e., the set of viable alternatives, consists of four renewable electric power generation technologies that comprise Brazil's electricity matrix (Tolmasquim 2016). These alternatives are the technologies defined by ANEEL Normative Resolution No. 482/687 (ANEEL 2014, 2015). Table 17.3 shows the alternatives considered and their respective codes.

Table 17.3 Set of alternatives

Renewable electric power generation technology	Code
Wind power	WP
Solar photovoltaic	SPV
Small hydroelectric power plant	SHP
Biomass	Biofuels

According to (Ellabban et al. 2014), wind power results from using wind turbines to convert the energy from wind into electricity, using windmills for mechanical power, using wind pumps for pumping water or for drainage, or using sails to propel ships. Generating electricity from the wind requires that the kinetic energy of moving air be converted to mechanical and then to electric energy, thus challenging the industry to design cost effective wind turbines and power plants to perform this conversion. At the beginning of the 20th century, the first wind turbines for electricity generation were developed, and this technology has gradually improved since the early 1970s. Nowadays, wind energy has re-emerged as one of the most important sustainable energy resources.

A solar photovoltaic (PV) system is a semiconductor device (PV cell) that converts solar energy into direct-current electricity. PV cells are interconnected to form a PV module, typically up to 50 to 200 W. The PV modules, combined with a set of additional application-dependent system components (e.g., inverters, batteries, electrical components, and mounting systems), form a PV system. PV systems are highly modular, i.e., modules can be linked together to provide power ranging from a few watts to tens of megawatts (Ellabban et al. 2014).

Hydropower is a power derived from harnessing the energy of moving water. Flowing water creates energy that can be captured and converted into electricity by using turbines. The most prevalent form of hydropower is associated with dams. On the other hand, a small hydroelectric power plant (SHP) can be created by developing hydroelectric power on a scale suitable for a local community and industry, or to contribute to distributed generation in a regional electricity matrix.

Biomass energy is the term used for all organic material originating from plants, trees and crops, and is essentially about collecting and storing solar energy as a result of photosynthesis. Biomass energy (bioenergy) is the conversion of biomass into useful forms of energy such as heat, electricity and liquid fuels (biofuels) (Ellabban et al. 2014).

While these alternatives are different sources of renewable energy, it should be noted that each source of renewable energy has its advantages, disadvantages and these include there being some negative impacts on the environment, as shown in Table 17.4.

17.2.3 Selecting Criteria for Evaluation

The selection of the criteria was based on four decision-makers' profiles, henceforth called sustainability dimensions: financial, technical, environmental and socio-economic. Table 17.5 shows the relationship between these profiles and the dimensions considered.

Each dimension represents a group of criteria. Table 17.6 shows these criteria and their respective parameters. Such parameters are fundamental for the model, since they represent the consequence that can be obtained for each alternative, considering a deterministic problem. As to the financial dimension, two natural aspects were

Table 17.4 Advantages, disadvantages and negative impacts on the environment of the renewable energy resources considered

Source	Advantages	Disadvantages	Potential negative impacts on the environment
WP	– Is a free source of energy – Produces no water or air pollution – Wind farms are relatively inexpensive to build – Land around wind farms can have other uses	– Requires constant and significant amounts of wind – Wind farms require significant amounts of land – Can have a significant visual impact on landscapes – Need better ways to store energy	– Noises in the area, landscape change, soil erosion, the blades of the turbines kill birds
SPV	– Potentially infinite energy supply – Causes no air or water pollution	– May not be cost effective – Storage and backup are necessary – Reliability depends on availability of sunlight	– Soil erosion, landscape change, hazardous waste
SHP	– Abundant, clean, and safe – Easily stored in reservoirs – Relatively inexpensive way to produce electricity – Offers recreational benefits like boating, fishing, etc.	– Can cause the flooding of surrounding communities and landscapes – Dams have major ecological impacts on local hydrology – Can be used only where there is a water supply	– Change in local eco-systems, change in weather conditions, social and cultural impacts
Biofuel	– Abundant and renewable – Can be used to burn waste products	– Burning biomass can result in air pollution – May not be cost effective	– May not be natural CO_2, may release global warming gases like methane during the production of biofuels, landscape change, deterioration of soil productivity, hazardous waste

Adapted from Ellabban et al. (2014)

considered: the investment cost and the operational and maintenance costs. For the technical dimension, four criteria related to operational performance and efficiency were considered: the efficiency of generation, the capacity factor, maintenance and the controllability of input. The environmental dimension is concerned with evaluating the emission of CO_2, land occupation, safety and social welfare. Finally, what is

Table 17.5 Decision profile versus dimensions of sustainability

Decision-makers	Concerns	Dimension	Relates to	Objectives
Profile A	Energy production	Technical	Technical aspects of a technology that influences the generation of energy	Maximize operational performance and efficiency of the production process
Profile B	Return on investment	Financial	Costs related to investing in technology for generating electricity	Minimize costs
Profile C	Environmental impact	Environmental	Impact that a technology has on the environment	Minimize negative impacts on the environment and the well-being of the population
Profile D	Job creation	Socio-economic	Socio-economic impact caused by implementing a technology	Maximize the socio-economic impact and the financial return

evaluated for the socioeconomic dimension is the lifespan, secondary gains, jobs created in the construction and installation phase, and jobs created in the manufacturing phase and during operation and maintenance.

Regarding the financial dimension, it is very objective and in order to parameterize its criteria, it is necessary to define the desired application, as to the location, and to consider the energy potential and consequent choice of the energy generating devices. In this case, for the investment cost criterion, the data were obtained from the literature review (Skystream 2018; ENERGIA 2018; Solar 2018; BGS 2018; Branco 2018). Moreover, for O&M, the fixed costs related to operating and maintaining the electrical power generation plant were considered (Tolmasquim 2016).

As to the technical dimension, two criteria are natural ones, namely Generation Efficiency and Capacity Factor. These are measured in percentage terms (%), with values for each technology being well established in the literature (Evans 2010; Tidball 2010; EIA 2013). The other criterion is related to the maintenance of the electricity generation system. It is important to notice that this criterion is fundamental for choosing a technology. However, as yet no data for distributed production have been established. In order to evaluate the maintenance needed for distributed renewable electricity generation technologies, Komor and Molnar (2015) presented a simplified Likert scale that uses generalist parameters (high, low or medium). In this

Table 17.6 Set of criteria

Code	Criteria	Definition	Unit
C1	Investment cost	Comprises the costs related to build and install a power generation plant	US$/kW
C2	O&M	Considers the costs related to operating and maintaining the electric power generation plant	US$/MWh
C3	Generation efficiency	Considers the conversion in electric energy capacity by each generation technology, i.e., establishes the relationship between electricity generated by the plant and the energy provided by the source	%
C4	Capacity factor	This refers to the time period in which the plant is actively generating electricity. Natural conditions that occur in places where the plants are located and scheduled stops for repairs and maintenance have to be considered	%
C5	Maintenance	This considers the facility/simplicity of carrying out maintenance on the generation devices	–
C6	Input controllability	The possibility of controlling both the availability of the source that generates power and storing this power	
C7	CO_2 $emission_t$	CO_2 is one of the gases that contribute to the greenhouse effect and that can be emitted as a result of the production process of generating electric power	gCO_2EQ/kWh
C8	Land occupation	This is a measure of the area available for a technology to work in	m^2/MWh
C9	Safety	This considers the degree of possibility of accidents occurring that are inherent to each power generation system	–
C10	Social welfare	This considers the impact of technologies on people's lives and well-being	–
C11	Lifespan	Length of time, in years, in which the plant can generate electricity in a sustainable way	Years
C12	Secondary gain	This considers what value-added by-products there may be as a consequence of generating energy	Years
C13	Jobs in the construction and installation phase	This considers how many jobs will be generated while devices and equipment of the power generation plant are being manufactured	Jobs/year/MW
C14	Jobs in the manufacturing phase	This considers the jobs generated when building the infrastructure and installing the devices and equipment of the electric power generation plant	Jobs/year/MW
C15	Jobs during operation and maintenance	This considers the jobs generated when operating and maintaining the devices and equipment of the electric power generation plant	Jobs/year/MWh

Adapted from Soares et al. (w.p.)

application, three basic aspects were used for this evaluation of maintenance: lubrication needs, availability of spare parts and the need for specialized labor. Table 17.7 analyzes the maintenance criterion.

Considering these aspects and influences, a five-point Likert scale was used to determine a qualitative evaluation of this criterion, as shown in Table 17.8.

The last criterion of the Technical dimension is Input Controllability, which considers if it is possible to control the availability of the power source for generation, and of the storage of power. Table 17.9 shows its binary evaluation.

As to the environmental dimension, two aspects were considered: the emission of CO_2, as a greenhouse gas (GHG), and the external costs generated when producing electrical energy, such as land occupation, safety and social welfare.

Regarding the emission of CO_2, according to (Weisser 2007), all energy systems emit greenhouse gases (GHG) and therefore contribute to anthropogenic climate change. In the case of renewable energy technologies, the majority of GHG emissions typically occur as a result of producing and constructing the technology and/or its supporting infrastructure, although, for biomass systems, depending on the choice of biomass fuel, most emissions can arise during the fuel-cycle. With regard to GHG emissions from different energy technologies, Daniel Weisser (2007) conducted an interesting study. This compared and analyzed the results of the GHG emission life-cycle and reviewed and summarized this kind of emission for the renewable energy technologies. Moreover, the National Renewable Energy Laboratory (NREL) (Edenhofer 2011) conducted a similar review, by building a database to assess GHG in the life cycle of electricity. The NREL data were used in this application, and are within the range obtained in the studies of Weisser (2007).

Table 17.7 Maintenance criterion and its aspects and influences

Maintenance aspects	Possibilities
Availability of spare parts	– High availability – Low availability
Lubrication needs	– Needs lubrification – No need for lubrification
Need for specialized labor	– High complexity – Low complexity

Table 17.8 Maintenance criterion scale of evaluation

Description	Level
Low availability, lubrication and high complexity	1
High availability, lubrication and low complexity	2
Low availability, no lubrication and high complexity	3
Low availability, no lubrication and low complexity	4
High availability, no lubrication and low complexity	5

Adapted from Soares et al. (2018, w.p)

Table 17.9 Input controllability scale of evaluation

Description	Level
Non-controllable technology	0
Controllable technology	1

For the external costs, the environmental impact of a power generation plant on human populations and natural systems was considered. Such impacts should be measured considering not only their operation, but also all stages of the technology's life cycle. However, few studies about this issue have been conducted and there is very little information in Brazil. In fact, the only one available has no technical proof. Therefore, because of the generality of external cost data—since they do not consider the specificities for the Brazilian case, three representative criteria were proposed for the concept of external costs (considering their negative nature): land occupation, safety and social welfare.

– Land occupation: this considers the amount of area needed, directly and indirectly, for a technology to work. Neither how the land is used nor for how long it is used, nor if the technology damages the site are observed (Evans 2010). As to the generation of renewable energy, wind and solar photovoltaic typically use little space directly, although what is required is to disperse these technologies over large areas (Fritsche 2017). Other simultaneous uses of the land are often allowed, such as grazing and even arable farming, possible under or on wind and photovoltaic farms. In this application, due to its distributed characteristics, space is saved by considering only placing photovoltaic panels directly on the roof of buildings. As to hydropower, the use of land is more limited, since flooded areas preclude other uses of land (except recreation/fishing) and can create barriers to the migration of aquatic life. Nevertheless, for the SHPs, this application considers the solution to be to use shallow water as the source from which to derive the energy to drive turbines which avoids generating a flooded area. As to biofuel, the land occupation is close to zero, because this fuel is a by-product, since bioenergy can be obtained simultaneously from the same land with other products, for example, milk and beef, pork or poultry meat (Rafaj and Kypreos 2007). Other data on land use for the generation of electrical energy from renewable sources can be found in Evans (2010) and Fritsche (2017).
– Safety: this concerns the risk of accidents to the electric energy generation devices, considering the types of elements that they consist of and the different features of the technologies that generate energy. Three aspects of safety involving energy control are considered: kinetic energy (moving parts in relative motion), inertia energy (size and weight of components) and energy potential (height of the installation). For the safety criterion, a seven-point Likert scale of values was established, as shown in Table 17.10.
– Social welfare: considers the impact of each generation technology on people's lives. For the social welfare criterion, a four-point Likert scale was drawn up to conduct a qualitative evaluation. Table 17.11 shows the levels defined for the

Table 17.10 Safety evaluation scale

Description	Level
There are elements with low weight without relative movement and situated at a low height	1
There are elements with high weight, without relative movement and situated at a low height	2
There are elements with low weight, with relative movement and situated at a low height	3
There are elements with high weight, with relative movement and situated at a low height	4
There are elements with high weight, without relative movement and situated at a great height	5
There are elements with low weight, with relative movement and situated at a great height	6
There are elements with high weight, with relative movement and situated at a great height	7

Adapted from Soares et al. (2018, w.p)

Table 17.11 Social welfare scale of evaluation

Description	Level
No sound impact, no visual impact, no risk to animals, no direct risk to human beings	1
Low sound impact, no visual impact, no risk to animals, no direct risk to human beings	2
Low sound impact, low visual impact, no risk to animals, low risk to human beings	3
With sound impact, with visual impact, with risk to animals, with direct risk to human beings	4

Adapted from Soares et al. (2018, w.p)

consequences for this criterion, based on the impact of sound, the visual impact, the risk to animals and the risk to human beings.

Regarding the socioeconomic dimension, five criteria were considered to evaluate its impact: lifespan, secondary gain and the capacity to generate jobs in the different phases, including design, construction, operation and maintenance.

- Lifespan: This considers values available in the literature (Tolmasquim 2016) such as the service life based on the operating life of the devices and equipment of the energy generation plant.
- Secondary gain: considers the opportunity of obtaining a by-product with added economic value because of the generation of electric energy. Table 17.12 presents the evaluation scale for this criterion.
- Jobs: Those that are considered are the ones created when the devices are being constructed and installed; when devices and equipment of the electrical energy generation plant are being manufactured; and the ones generated during the operation and maintenance of these devices and equipment (Wei 2010). Due to the

Table 17.12 Evaluation scale for secondary gains when energy is generated

Description	Level
The technology does not generate any by-products	0
The technology generates a by-product	1

lack of data for the region of small scale electrical energy generation, data were based on a Greenpeace study (Greenpeace 2013), which compares the different electricity generation technologies associated with the capacity to generate jobs in Brazil.

17.3 Individual Results

The application of the model was developed in a case study carried out in a rural southeast region of Brazil in the State of São Paulo, chosen due to the availability of the data on the generation technologies to be analyzed. It corresponds to the area of the Mogiguaçu River Basin.

For each decision profile, the FITradeoff elicitation process was performed based on data from the decision matrix (Table 17.13), which therefore simulated the specific interests of different pressure groups regarding the problem.

Moreover, a different structure of preferences was assumed when ranking the criteria weights and expressing preferences. Then, the FITradeoff elicitation process was performed with each decision profile (here understood as a group of decision-makers) based on data from the decision matrix (Table 17.13). These decision profiles simulated specific interests of different pressure groups regarding renewable electric power generation. This led to different results. Table 17.14 shows the final rankings per decision profile, where w_j corresponds to the weight of a criterion c_j.

Table 17.15 presents the results found by FITradeoff for each decision profile. For each solution, there is an associated space of weights in which each criterion weight is limited by a minimum and a maximum value. This weight space was narrowed as more information, in the form of preference statements, was obtained from the DMs' responses. Column "Number of Questions" in Table 17.15 shows how many questions were answered, i.e., how many preference statements were given.

When analyzing the results for the four groups, SHP is considered the best option for two groups (A and B), but it is considered the worst for group D. While the Biofuel option is the best for group C and D, it is never considered as the worst alternative.

Table 17.13 Matrix of consequences for choosing power generation technology

Electric Power Generation Technology	Criteria														
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
	US$1.000/kW	US$/kW/ano	%	%	–	–	gCO_2EQ/kWh	m^2/MW_h	–	–	Year	–	Jobs/year/MW	Jobs/year/MW	Jobs/year/MW
Wind	3.23	85	35	43	1	0	12	1	7	4	20	0	7.7	3.3	0.6
Solar (FVT)	2.34	19	20	24	5	0	46	10	1	3	25	0	10.9	6.9	0,3
Hydropower	1.26	13	90	55	3	1	4	10	4	1	20	0	6	1.5	0.6
Biomass	1.119	22	25.3	60	2	1	18	0	3	2	20	1	14	2.9	1.5

Adapted from Soares et al. (2018, w.p)

Table 17.14 Ranking of criteria per decision profile

Group of DMs	Ranking of criteria
Profile A: Energy production	$w_3 > w_4 > w_6 > w_5 > w_7 > w_8 > w_9 > w_{10} > w_{11} > w_{12} > w_{13} > w_{14} > w_{15} > w_1 > w_2$
Profile B: Return on investment	$w_1 > w_2 > w_3 > w_4 > w_5 > w_6 > w_{11} > w_{12} > w_{15} > w_{14} > w_{13} > w_8 > w_9 > w_{10} > w_7$
Profile C: Environmental impact	$w_7 > w_{10} > w_8 > w_9 > w_{12} > w_{11} > w_{15} > w_{13} > w_{14} > w_3 > w_4 > w_5 > w_6 > w_1 > w_2$
Profile D: Job creation	$w_{15} > w_{14} > w_{13} > w_{12} > w_8 > w_{11} > w_3 > w_4 > w_5 > w_6 > w_1 > w_2 > w_7 > w_9 > w_{10}$

Table 17.15 Results for the group decision profiles

Ranking	Profile A: Energy production	Profile B: Return on investment	Profile C: Environmental impact	Profile D: Job creation
1	SHP	SHP	Biofuel	Biofuel
2	WP	Biofuel	SHP	WP
3	Biofuel	SPV	WP	SPV
4	SPV	WP	SPV	SHP
Number of questions answered	21	14	23	45

17.4 Applying the Framework for Choosing a VP

Since the decision profiles found a different ranking of the alternatives, in this stage of the model, the framework for choosing a voting procedure (VP) is used to aggregate the results of the decision profiles in order to find a global result which will be the best alternative for renewable power technology for a Brazilian region.

The characteristics of this problem reveals that there is a need for a voting procedure that deals with rankings, since the problem evaluated has only four alternatives and it is important to analyze how the decision profiles classified them. Thus, the VPs considered for this evaluation were: Copeland, Borda, Black, Nanson and Hare.

Another important aspect to consider is the voting proprieties to evaluate the VP. The proprieties analyzed in this application were: Condorcet winner; Strong Condorcet; Monotonicity; Consistency and Invulnerability to the no-show paradox. The proprieties of Condorcet loser and Pareto were not considered since all VPs analyzed satisfy these conditions. Similarly, the Chernoff and Independence of irrelevant alternatives were not considered since none of the VPs analyzed satisfies these conditions.

For this analysis, it will be present two ways of consequence matrix: binary outcome and discrete score.

17.4.1 Using the Consequence Matrix of Binary Outcome

The consequence matrix of the VPs and their proprieties based on a binary outcome (Chap. 14), is as shown in Table 17.16. In this table, "1" indicates that the VP satisfies the property and "0" that it does not. The value function is in Eq. 14.1 (Chap. 14). Also, Table 17.16 gives the weights of the five voting proprieties considered, where the DMs agreed about the weights considered.

Table 17.17 presents the results after applying the PROMETHEE II method to evaluate the decision matrix, using the usual preference function.

As can be observed, the result for the PROMETHEE II method is equivalent to that of the additive model, when using this binary outcome matrix (see Table 17.18).

Thus, the Borda voting procedure was identified as the most appropriate to aggregate the decision profile to find an alternative renewable power generation technology for a Brazilian region.

Table 17.16 Matrix of consequence of the VP considered

Voting system	Criteria/weights				
	Condorcet winner	Strong condorcet	Monotonicity	Consistency	Invulnerability to the no-show paradox
	0.1	0.1	0.2	0.35	0.25
Copeland	1	1	1	0	0
Borda	0	0	1	1	1
Black	1	1	1	0	0
Nanson	1	1	0	0	0
Hare	0	1	0	0	0

Table 17.17 Results after applying the PROMETHEE II method

Rank	VP	Phi	Phi+	Phi−
1	Borda	0.525	0.7	0.175
2	Copeland	0.025	0.175	0.15
2	Black	0.025	0.175	0.15
4	Nanson	−0.225	0.075	0.3
5	Hare	−0.35	0.025	0.375

Table 17.18 Results after applying the additive method

Voting system	Criteria/weights					Result	Rank
	Condorcet winner	Strong con-dorcet	Monotonicity	Consistency	Invulnerability to the no-show paradox		
	0.1	0.1	0.2	0.35	0.25		
Copeland	1	1	1	0	0	0.40	2
Borda	0	0	1	1	1	0.80	1
Black	1	1	1	0	0	0.40	2
Nanson	1	1	0	0	0	0.20	4
Hare	0	1	0	0	0	0.10	5

17.4.2 Using the Consequence Matrix of with Discrete Score

The consequence matrix of the VPs and their proprieties can also be evaluated by using a discrete score of three levels (0, 1, 2), instead the binary outcome. This score is elicited from an expert indicating the influence of that criterion on the VP. Table 17.19 shows what the score represents for the VP considered.

Considering these scores, it is obtained the following consequence matrix (Table 17.20), for the VP considered for this problem.

Table 17.19 Discrete score of the VP considered

Score	Description
0	It indicates that the VP satisfies the property
1	It indicates that the VP may satisfy with a medium frequency the property
2	It indicates that the VP does not satisfy the property

Table 17.20 Matrix of consequence of the VP with discrete score

Voting system	Criteria/weights				
	Condorcet winner	Strong condorcet	Monotonicity	Consistency	Invulnerability to the no-show paradox
	0.1	0.1	0.2	0.35	0.25
Copeland	0	0	0	1	1
Borda	1	1	0	0	0
Black	0	0	0	1	2
Nanson	0	0	1	1	2
Hare	1	0	1	2	1

Table 17.21 Results after applying the additive method for discrete score

Voting system	Criteria/weights					Result	Rank
	Condorcet winner	Strong con-dorcet	Monotonicity	Consistency	Invulnerability to the no-show paradox		
	0.1	0.1	0.2	0.35	0.25		
Copeland	1	1	1	0.5	0.5	0.70	2
Borda	0.5	0.5	1	1	1	0.90	1
Black	1	1	1	0.5	0	0.58	3
Nanson	1	1	0.5	0.5	0	0.48	4
Hare	0.5	1	0.5	0	0.5	0.38	5

At this point, the score has an outcome of decreasing preference, this leads to producing the marginal value $v(x_j)$ of the outcomes x_j related to criterion j. The following value function (see Chap. 14; Eq. 14.6) may be applied:

$$v_j(x_{ij}) = (y - x_i)/y$$

Where y is the highest level in the scale (for this case of three-level scale, $y = 2$).

Using the additive model, Table 17.21 shows the result and respectable rank.

As can be observed, also the Borda voting procedure was identified as the most appropriate to aggregate the decision process. So, for this case, the result using the discrete score is the same as using the binary outcome. However, it is possible to have a complete order. No ties were found between Copeland and Black VP.

17.5 Global Result

In order to find the global result, the Borda count is applied to the data presented in Table 17.15. Thus, the Borda voting procedure was identified as the most appropriate for aggregating the decision profile to find an alternative renewable power generation technology for a Brazilian region (Table 17.22).

Based on the ranking obtained by the Borda count, the Biofuel was the first alternative, followed by Small Hydropower, Wind power and finally Solar Photovoltaic.

17.6 Topics for Further Reflection

The results obtained by using the decision model based on the FITradeoff method applied to different decision profiles and then aggregated by a Voting procedure,

Table 17.22 Results for the group decision profiles

Alternatives	Points				
	Profile A:	Profile B:	Profile C:	Profile D:	Results
SHP	4	4	3	1	12
WP	3	1	2	3	9
Biofuel	2	3	4	4	13
SPV	1	2	1	2	6

shows the model has potential to assist a group of decision-makers to tackle complex problems related to energy planning.

17.7 Suggestions for Reading

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Soares Junior, A. M. C.; de Almeida, A. T.; Almdeida, J. The small distributed electric power generation: A multicriteria model for the analysis of technologies. Working paper, 2018.

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