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Assessment Tool For The Hybridisation Of Minigrids – Case Study In Niger

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Abstract

Minigrids are a great electrification strategy for developing countries. [1] Formerly operated only by diesel generators, they could be equipped with renewable energy and storage systems to become more reliable and competitive. Since resources are limited, it is not possible to hybridise all minigrids at the same time. An MS-EXCEL-based multi-criteria decision analysis (MCDA) tool offers a rational and impartial way of decision-making presenting the most eligible minigrids for a hybridisation. For the demonstration purposes, it is applied to the electricity sector of Niger.

Keywords: Minigrid; Hybridisation; PV-Battery-Systems, MCDA tool, Niger

1. Introduction

With technical progress and dropping prices of renewable energy technologies, rural electrification – being once an unprofitable business – is accelerating around the world. Especially wind power and photovoltaic energy are key technologies for increasing the access to affordable off-grid electricity. For remote villages, where a connection to the national grid is not planned, isolated minigrids are the most promising option. [1] Actually, if such a minigrid exists, it is often operated by diesel generators, for which diesel supply is usually an issue – both for logistic as well

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as for financial reasons. [2] Consequently, they could be equipped with additional power generation originating from renewable energy and also storage systems to become more reliable and competitive. Preferring a high share of renewable energy and storage systems, increases the independence from fossil fuels and the sustainability of the power supply.

In fact, every – so called – hybridisation can optimise the energy production and its costs. However, since resources are limited, it is not possible to hybridise all minigrids and for sure not at the same time. Therefore, a strategy for decision-making needs to be developed to be able to determine, the minigrids being the most eligible one for a hybridisation. Based on different criteria (technical, financial, environmental and social), a multi-criteria decision analysis (MCDA) tool was developed being easily adoptable to any other case and location with similar or even different energy supply.

2. Methodology

The MCDA tool invented and presented herein was developed in MICROSOFT EXCEL. Its methodology is shown in Fig. 1 and described below:

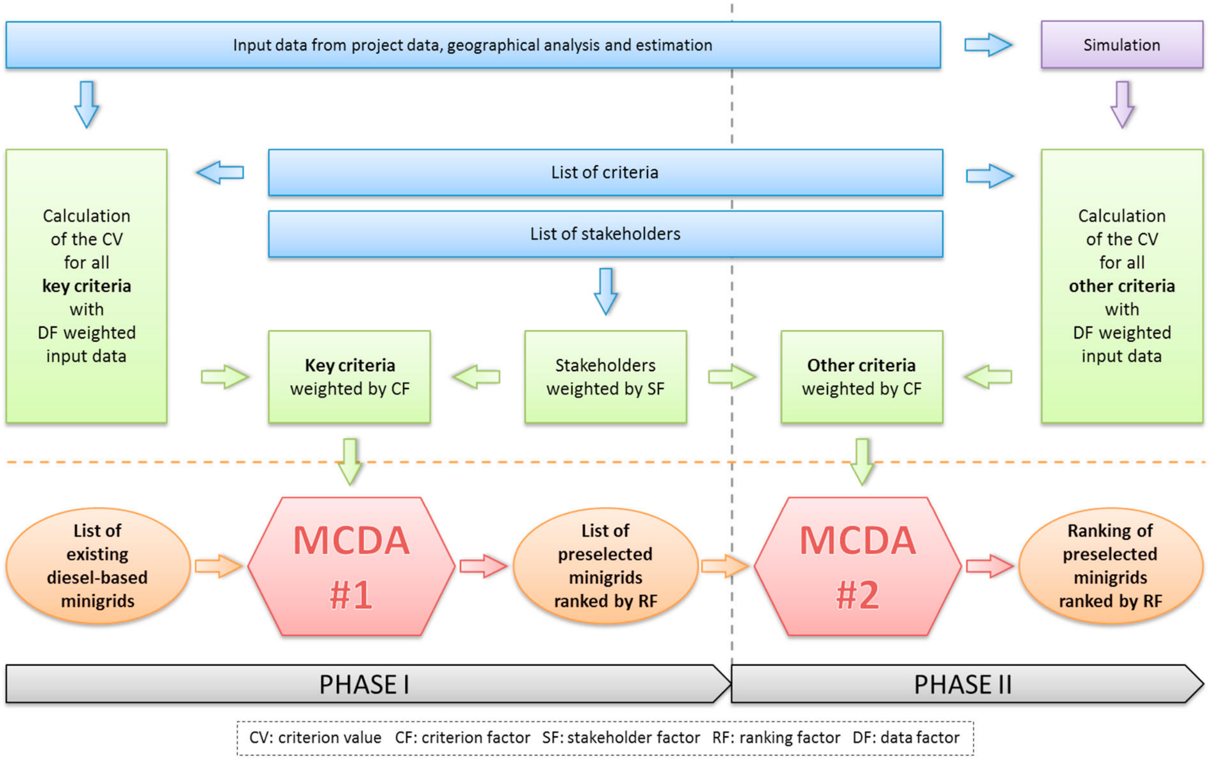

Fig. 1. Methodology for the MCDA

The first step is to gather all available data of the considered situation and to include it in the database of the tool. Relevant data are for example the population of the locality, the distance of the locality to the actual electricity network or the existence of large consumers.

2.1. Generation of the criteria

Based on the available data, an overall list of 26 criteria was established being separated into four categories: technical, financial, social and environmental criteria

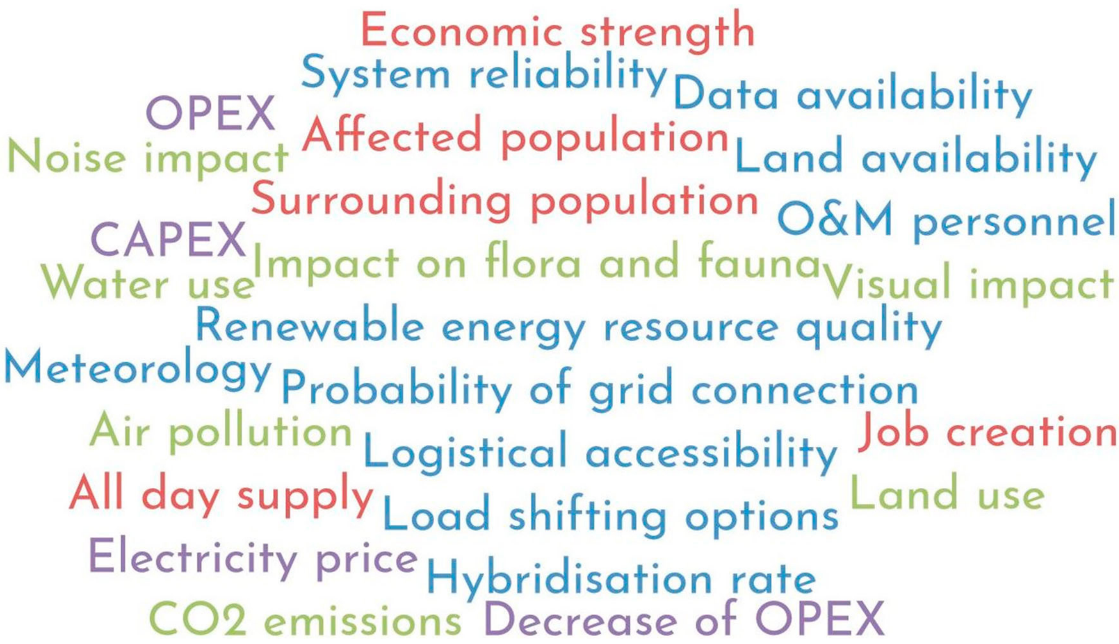

Fig. 2. List of criteria included in the MCDA tool

Each criterion is created by combining several weighted input data i to one dimensionless figure, called criterion value (CV). For criteria based on more than one input data, data factors (DF) have to be attributed to indicate their respective weightings. The data factors of each criterion sum up to "100", so that the range of each CV goes from "0" to "100". Moreover, the input data of each locality x is normalised – so reduced by the minimum value and then divided by the entire range of values. In that way, the entire range of values is considered, which enlarges the field of CVs for every criterion to its maximum.

$$CV_x = \sum_{i^+} DF_{i^+} \cdot \frac{{i^+}_{i,x} - {i^+}_{i,min}}{{i^+}_{i,max} - {i^+}_{i,min}} + \sum_{i^-} DF_{i^-} \cdot \left(1 - \frac{{i^-}_{i,x} - {i^-}_{i,min}}{{i^-}_{i,max} - {i^-}_{i,min}}\right) \quad (1)$$

Depending on the direction of the input data – indicating, if a lower or a higher value is favourable for a hybridisation – the CV is calculated in a way that positively oriented input data i^+ and negatively oriented input data i^- are summed up separately. Hence, in view of the hybridisation process, a CV of "100" is always the best possible value.

As an example for equation 1, the calculation of the CV for a sample criterion is shown. It shall represent the potential of reducing the CO_2 emissions with a proposed hybridisation using simulations. Since low CO_2 emission are good in view of the hybridisation process, they are negatively oriented, contrarily to the decrease of the CO_2 emissions, where a high percentage is wanted.

Table 1. Example values for creation of the "CO_2 emissions"-criterion.

Input data / Locality	CO_2 emissions i_1	Decrease of CO_2 emissions i_2
	$DF_{i_1} = 70$	$DF_{i_2} = 30$
Damagaram Takaya x_1	$i_{1,1} = 100\ t/a$	$i_{1,2} = 30\%$
Sassoumbroum x_2	$i_{2,1} = 400\ t/a$	$i_{2,2} = 50\%$

The CV for Damagaram Takaya is calculated as following:

$$CV_{1,1} = CV_{Damagaram\,Takaya} = DF_{i_1} \cdot \left(1 - \frac{i_{1,1} - i_{1,1}}{i_{2,1} - i_{1,1}}\right) + DF_{i_2} \cdot \frac{i_{1,2} - i_{2,2}}{i_{1,2} - i_{2,2}}$$
$$= 70 \cdot \left(1 - \frac{100-100}{400-100}\right) + 30 \cdot \frac{30\%-30\%}{50\%-30\%} = 70 \quad (2)$$

In the same way, the CV of Sassoumbroum is estimated:

$$CV_{1,2} = CV_{Sassoumbroum} = DF_{i_1} \cdot \left(1 - \frac{i_{2,1} - i_{1,1}}{i_{2,1} - i_{1,1}}\right) + DF_{i_2} \cdot \frac{i_{2,2} - i_{2,2}}{i_{1,2} - i_{2,2}}$$
$$= 70 \cdot \left(1 - \frac{400-100}{400-100}\right) + 30 \cdot \frac{50\%-30\%}{50\%-30\%} = 30 \quad (3)$$

Finally, if comparing both CVs, the city of Damagaram Takaya should be selected for a hybridisation in the case of this single criterion.

2.2. Stakeholders and their preferences

Separately, a list of stakeholders was established. The 8 stakeholders possibly involved in the decision-making process that are actually included in the MCDA tool are presented in Table 2.

Table 2: Stakeholders included in the MCDA tool

Financer	EPC Contractor	Utility	Local Beneficiaries
Consultant	Government	Operator	NGO's

Additionally, a factor – called stakeholder factor (SF) and going from "0" to "10" – is attributed to each stakeholder reflecting its importance and influence in the decision-making process. Moreover, the preferences of each stakeholder concerning the different criteria are represented by the criterion factor (CF) also varying between "0" and "10".

2.3. Calculation of the ranking

The final step is the calculation of the ranking factor (RF) for each locality. The higher it is, the more suitable the corresponding locality is for hybridisation. It is generated by the following equation composed of all normalised criterion values (CV), the corresponding criterion factors (CF) and the weighting of each stakeholder k using the stakeholder factor (SF). Finally, it is divided by the total amount of used criteria j to obtain a RF, whose maximum value is "10,000".

$$RF_x = \frac{1{,}000}{\sum SF_k \cdot \sum j} \cdot \sum_k \left(SF_k \cdot \sum_{j,k} CF_{j,k} \cdot \frac{CV_{j,x} - CV_{j,min}}{CV_{j,max} - CV_{j,min}}\right) \quad (4)$$

Aiming a quicker assessment method, the MCDA can be separated into two phases:

- Phase I of the MCDA allows a quick preliminary ranking that allows to eliminate the most unpromising localities and to significantly break down their amount (e.g. to 20 % of the initial list). Therefore, a handful of projects related key criteria must be selected. They will play a crucial role in the beginning of the assessment, since only these criteria are considered in Phase I. The advantage is to save time by generating data for all localities only for these key criteria, what is extremely useful if data availability is low or its gathering complicated.

- Phase II starts now with this list of all preselected localities, but includes now the entire range of criteria. The final output is a list of the highest-classed minigrids from Phase I sorted by their eligibility for hybridisation.

An example for the calculation of the RF of the two sample localities (Damagaram Takaya & Sassoumbroum) is shown below considering only two criteria (CO_2 emissions & Population – the last one compared to all other cities of the Niger project) and two stakeholders (Financer & Utility). [2]

Table 3. Example values for CV, SF and CF [2].

Criterion \ Stakeholder					Financer k_1 $SF_1 = 10$	Utility k_2 $SF_2 = 4$
CO2 emissions j_1	$CV_{1,min} = 30$	$CV_{1,1} = 70$	$CV_{1,2} = 30$	$CV_{1,max} = 70$	$CF_{1,1} = 5$	$CF_{1,2} = 3$
Population j_2	$CV_{2,min} = 2$	$CV_{2,1} = 23$	$CV_{2,2} = 54$	$CV_{2,max} = 100$	$CF_{2,1} = 2$	$CF_{2,2} = 10$

The ranking factor RF for Damagaram Takaya is then:

$$RF_1 = \frac{1{,}000}{14 \cdot 2} \cdot \left[10 \cdot \left(5 \cdot \frac{70-30}{70-30} + 2 \cdot \frac{23-2}{100-2}\right) + 4 \cdot \left(3 \cdot \frac{70-30}{70-30} + 10 \cdot \frac{23-2}{100-2}\right)\right] \approx 2{,}673 \quad (5)$$

In the same way, the ranking factor for Sassoumbroum can be calculated: $RF_2 = 1137$. Therefore, Damagaram Takaya should be selected for the hybridisation.

3. Case Study in Niger

To prove the effectiveness of the tool, it was tested within the Niger project of intec. Its goal was to select 20 out of the 115 diesel-based minigrids that seem to be the most promising for being hybridised with solar PV. [4] During the prefeasibility phase of the project, only a very rough but also quick estimation was done – so a single phase of the MCDA is sufficient. Moreover, only one single criterion (Probability of grid connection) was considered for the decision-making process. [5] The selection approach and its outcome were suggested by intec and no other stakeholder than the Consultant was involved at this stage. These frame conditions reduce the complexity of the tool to a minimum, what enables to check within these simplified conditions, if the simulated results from the tool match the selection made during the project.

After applying some strategical and political exclusion criteria [2], the output of the tool generated a very similar list of minigrids, what shows that the MCDA tool represents a professional way to obtain the desired output.

4. Conclusion and outlook

Finding the optimal solution is always tricky – even more, if several opinions are competing against each other trying to enforce their own position. In order to avoid a time-consuming discussion and to still find the best solution, an impartial and purely rational assessment approach is required. At this moment, the multi-criteria decision analysis tool described herein comes into play. The objective of the MCDA tool is to create a ranking of minigrids sorted by their eligibility for being hybridised. Being generated in a way that it is not susceptible to any personal opinions, this ranking is likely to be accepted by all stakeholders.

However, the potential of the tool exceeds this basic requirement and offers many more opportunities. First of all, the application of an MCDA tool saves time, so that discussions can focus on different topics. Another benefit of MCDA methods is that the stakeholders have a better understanding of the problem and the other stakeholders' points of view.

Applicability and adaptability to other cases is one of the most important features of tools. In this case, these are ensured by different levers:

- The list of localities, input data, criteria and stakeholders can be edited and extended.
- All input data and criteria are normalised.
- The tool works only with dimensionless factors that are entirely adjustable.

Due to these aspects, if any input data or factor is changed, the MCDA tool automatically generates new results. If for example a locality is added to the list, the tool immediately recalculates all criteria by considering the values of the new localities. In that way, a relative relationship between all localities is established. Due to this flexibility, the tool can be applied to a large range of situations.

Based on the tool developed herein, some modifications could be made in order to create a new tool that could provide an entire electrification strategy plan. This would allow determining a ranking of localities that should preferentially be electrified and furthermore, which electrification strategy should be adopted in every locality.

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