A Multi-Criteria Decision Analysis Tool to Support Electricity Planning

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Abstract: A Multi-Criteria Decision Analysis (MCDA) tool was designed to support the evaluation of different electricity production scenarios. The MCDA tool is implemented in Excel worksheet and uses information obtained from a mixed integer optimization model. Given the input, the MCDA allowed ranking different scenarios relying on their performance on 13 criteria covering economic, job market, quality of life of local populations, technical and environmental issues. The criteria were weighted using both direct weights and trade-off analysis. In this paper, scenarios for the case of the Portuguese electricity system are presented, as well as the results of the evaluation, using the MCDA tool, relying on the input from a group of academics with background in economics, engineering and environment.

Keywords: Energy decision making, electricity generation, MCDA, Sustainable Development.

1. Introduction

Over the last two decades, international treaties, such as Kyoto Protocol, have been signed, and strategies to mitigate CO_2 emissions have arisen in all the developed world nations. At the same time, Sustainable Development is becoming part of political discourse in the European Union. According to the European Union Sustainable Development Strategy (EUSDS), Sustainable Development envisages the "continuous improvement of the quality of life of citizens through sustainable communities that manage and use resources efficiently and tap the ecological and social innovation potential of the economy, so as to ensure prosperity, environmental protection and social cohesion" [1]. As a result, the electricity production planning gets more constrained than before, resulting in a multi-objective problem [2]. What traditionally was simply a cost minimizing problem should now be evaluated also under Sustainable Development criteria.

In this paper a Multi-Criteria Decision Analysis tool, designed for the evaluation of different electricity generation scenarios, is presented. When using multi-criteria decision methodologies, one has to have in mind that best solutions for some decision makers may not be universal best solutions, as results are made upon personal judgement of different criteria. In the present work, a panel of experts on energy systems was invited to map the diversity of opinions and preferences for the future of the Portuguese electricity system. The use of the MCDA tool was demonstrated for the evaluation of possible electricity scenarios drawn for Portugal in 2020.

The criteria used cover Sustainable Development (social, cost and environmental) issues among others like visual impacts and technical issues of power systems, as addressed in section 3.2. The criteria were drawn from both interviews conducted in previous work [3] and from the literature.

Figure 1 summarizes the methodological approach to the problem. The two main blocks of the methodology are Scenario Generation and Scenario Evaluation (MCDA Tool). Sections 2 and 3

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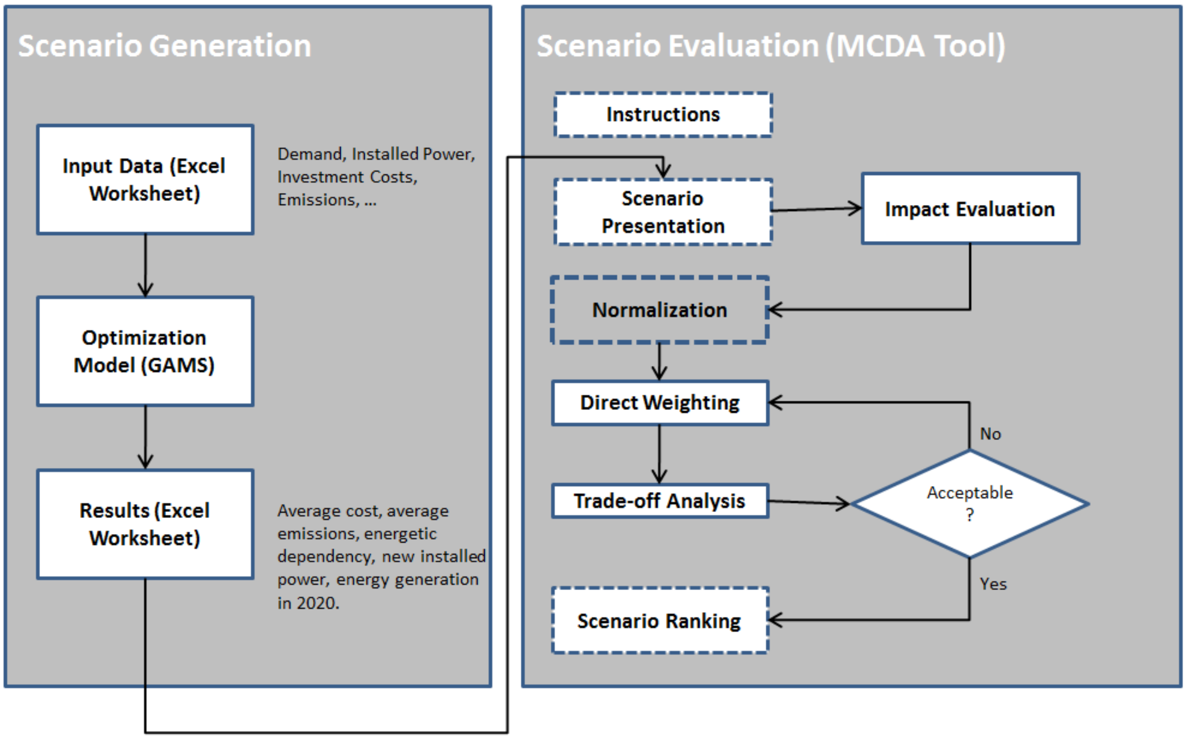

Figure 1: Evaluation of scenarios for electricity production, with MCDA evaluation

are dedicated to each one of these topics. As the Scenario Generation addesses the future of the Portuguese power generation system, the remainder of this section overviews this particular case.

1.1. Power Generation in Portugal

Electricity in Portugal is mainly generated from large hydro, thermal and wind power, as can be seen in Figure 2. Thermal power is mostly provided with coal and CCGT (combined cycle gas turbines) power plants. Special Regime Production include all the technologies benefiting from feed-in tariffs, which are in Figure 2 divided in Wind power and "Other SRP".

The Portuguese electricity system is strongly influenced by the rainfall characteristics. Although the large hydro power installed capacity remained almost unchanged between 2006 and 2010, in fact the hydro electricity production suffered strong variations.[1]

In 2007, the Portuguese state launched a new plan for installing more hydro power, known as PNBEPH (Plano Nacional de Barragens de Elevado Potencial Hidroeléctrico)[4]. It aimed to reduce the unused hydro power potential from 54% to 33% until 2020, installing new 2059 MW. This was expected to be achieved by two means: increasing installed power of already existing facilities (909 MW), and building ten new hydro power plants totaling 1150 MW of installed power. Among these projects, some include pumping capacity. The use of pumping was justified to the need to complement additional wind power to be installed: given that wind farms may produce more in off-peak hours when electricity prices are lower, this energy can be used to pump water back to dams, so that hydro power can be generated during the hours of higher consumption and higher electricity prices. In 2007 the PNBEPH forecasted that in 2010 there would be 5100 MW of installed wind power, which contrasted

[1] The yearly variation of hydro power production is reflected on the so-called "hydraulicity factor", which for an average year the equals 1.

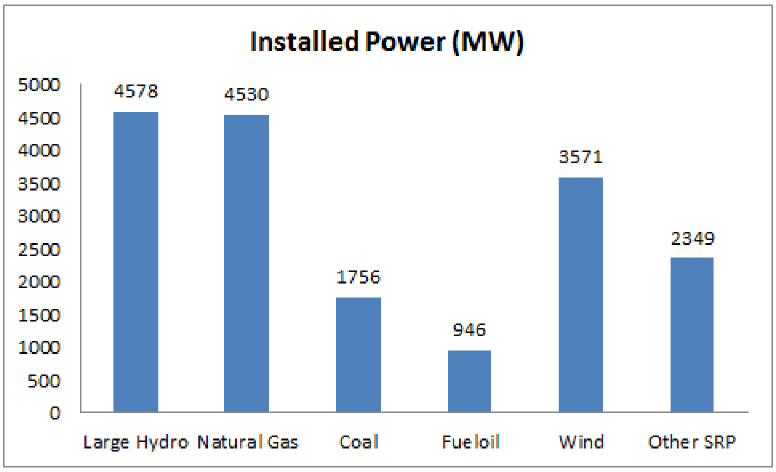

Figure 2: Installed power in Portugal, 2010. Own elaboration from www.ren.pt data. "Other SRP" include non-renewable and renewable cogeneration, biomass, small hydro, photovoltaics and wave power.

with the 3751 MW achieved in reality [5]. As a result, the completion of these plans is constrained by political and other factors (such as the fall of electricity consumption in 2010 and 2011). The future of the Portuguese power system remains uncertain, and in section 2.3 some possible scenarios for 2020 are explored.

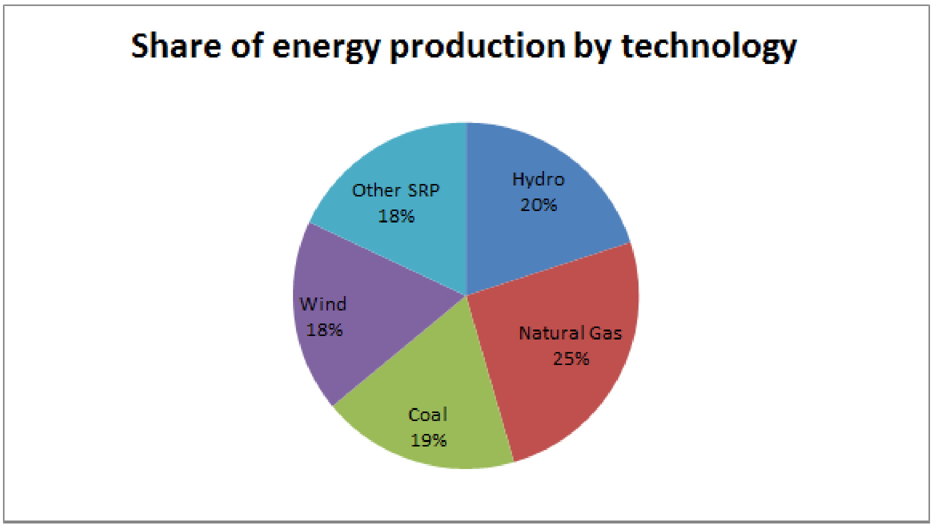

Figure 3: Electricity generation in Portugal, 2010. Own elaboration from www.ren.pt data. In order to present the numbers for a typical rainfall year, the numbers for hydro power were divided by the hidraulicity factor, which in 2010 was 1.31 [6]. The exceeding energy was assumed to be covered equally by coal and natural gas.

2. Scenario Generation

2.1. Model description

In this section the Scenario Generation phase of the methodology mentioned in Figure 1 is addressed. In short, a Mixed Integer Linear Programming (MILP) model, programmed in GAMS (General Algebraic Modeling System) was used. The input data is given in an Excel file, as well as the final results.

For the detailed description of the used model, see [7]. The source code was used to create scenarios with different characteristics, based on the cost optimization of the electricity system. These scenarios represent different possible futures for the Portuguese power generation system in a 10 year range, departing from the present characteristics of the system. A scenario is charaterized by a set of newly installed power plants of each technology, that, together with the already installed ones, will supply the electricity demand. The technologies considered as variables were hydro power, wind, natural gas and coal; on the other hand non-wind Special Regime Production was assumed to remain constant for every scenario. The remainder of this subsection contains complementary information of the given reference [7].

The demand and peak load data are presented in the Excel input file. The scenarios depend on the demand of electricity, $D_{t,m}$, which were computed according to recent forecasts, information available in the Portuguese National Renewable Energy Action Plans [8]. According to this data, demand, which was about 52 TWh in 2010, will increase 12 TWh in 10 years. The rate of the peak load growth was adjusted accordingly to the rate of consumption growth.

The present values of non-Wind Special Regime Production (SRP) installed power and generated energy, as well as expected growth are computed in the excel input worksheet, according to the information collected in the report available in the Portuguese Renewable Action Plan ([8], pages 117 and 118). Non-wind SRP includes the following technologies: non-renewable cogeneration, biomass, small hydro, photovoltaics and wave power. Therefore, a new parameter was added in the code, $srp\_renewable\_ratio_{t,m}$, to express the monthly percentage of renewable energy among the SRP. As addressed later in this section, this value is necessary to calculate the percentage of renewable energy generated in a given solution:

$$srp\_renewable\_ratio_{t,m,i} = 1 - \frac{PSRP_{t,m,i=non\_renewable\_cogeneration}}{PSRP_{t,m,i}} \qquad (1)$$

where $PSRP_{t,m,i}$ refers to the energy generated from SRP source i, in the month m of the year t.

In order to account for the CO_2 emissions of SRP, the monthly generation of non-renewable cogeneration was multiplied by the same CO_2 emissions factor that affects CCGT groups. The value of $srp\_average\_emissions$ was thus calculated in order to express the emissions from the SRP in the planning period (2011 to 2020).

For calculating the SRP costs, [9] values were used (exchange ratio of 1 USD = 0.7325 EURO). From these values, the overall SRP levelized costs, $srp\_levelized\_cost$ were obtained, for the whole planning period:

$$srp\_levelized\_cost = \sum_{t,m,i} c_i \frac{P_{t,m,i}}{PSRP_{t,m,i}} \qquad (2)$$

where c_i stands for the levelized cost for each SRP technology and $P_{t,m,i}$ is the monthly energy produced by SRP technology i in the month m of year t.

2.2. Scenarios

A variety of scenarios to use in the MCDA tool can be generated, and these are solutions for the model. In table 1, five possible scenarios of electricity generation in the year 2020 are presented, aiming to represent five different strategies, representative of different energy policy trends: investment in natural gas, investment in coal, investment in a mix of hydro and gas, investment in a mix of hydro and wind, and a moderated scenario following a business-as-usual approach. Obviously, none of these scenarios is likely to happen in this exact form due to the infinity of possible and distinct combinations. However, given the present state of the Portuguese electricity system, these are five possible strategies representative of different energy policy trends. The evaluation of more scenarios demands additional input information and higher response time on the MCDA tool. In order to ensure the effective participation of experts it was decided to keep the number of scenarios low.

As the objective function of the model is the minimization of the costs, different constraints used to diversify the scenarios were created. These constraints were of two types: allowing the program to install or not power plants of a specific technology, and, on the other hand, a renewable energy quota to be met in 2020. Not using these constraints would result in the model covering the growing demand by installing only new coal power plants, the least costly solution.

Table 1: Characterization of scenarios

	Constraints		**Results**			
Scenario	**Minimum Renewable Quota**	**New installed technologies**	**New installed power**	**Cost (euro per MWh)**	**Emissions (CO2 ton per GWh)**	**External energy Dependency**
Base	45%	All technologies allowed	700MW coal, 1000MW hydro, 4400MW wind, 1180MW other SRP (all SRP excluding wind power)	25.69	262	30%
Natural Gas	Turned off	Only CCGT allowed	2350MW natural gas, 1180MW other SRP	25.24	294	53%
Coal	Turned off	Turned off	2550MW coal, 1180MW other SRP	23.75	360	55%
Hydro-Gas	45%	Only CCGT and hydro power allowed	2050MW natural gas, 2000MW hydro, 1180MW other SRP	25.96	286	45%
Maximum Renewable	70%	No coal or CCGT allowed	2000MW hydro, 4400MW wind, 1180MW other SRP	26.37	250	28%

The "Coal" scenario is the least costly one, but also leads to the highest external energy dependency (that is, highest share of coal and natural gas) and presents the highest CO_2 emissions. The other extreme case, presenting lowest external energy dependency and less CO_2 emissions is the "Maximum Renewable" scenario, which costs are about 11% higher than for the "Coal" scenario.

3. Scenario Evaluation Using the Multi-Criteria Decision Analysis Tool

The MCDA tool[2] is presented on an Excel worksheet and aims to rank the suitability of electricity production scenarios according to 13 criteria. In the remainder of this section, firstly the methodology is exposed, then the MCDA tool is presented and finally applied to a case study, using the five scenarios presented in the previous section.

3.1. Methodology

A vast literature for MCDA applications to energy planning exists (see for example [10] and [11] for an overview). The proposed methodology could be summarized as direct weighting with an additive

[2]The tool is available for download in http://sepp.dps.uminho.pt/.

value function for amalgamation. As a result, it involves three phases, already mentioned in Figure 1: Impact Evaluation, Direct Weighting and Trade-off Analysis.

Impact Evaluation is the phase where a score, $score_{s,c}$ is assigned to each scenario s and criteria c. These values are then normalized, using a linear function $v_{s,c}$, so that the best values become 1 and the worst values become 0.

The user then assigns directly weights w_c to each criteria c. Finally, for every criteria c, trade-offs are presented in terms of costs, while the user is still able to change weights according to his perceptions.

The final value for the scenario s is calculated according to the Additive Value Function (AVF), as follows:

$$AVF_s = \sum w_{c_i} \times v_{s,c_i} \quad (3)$$

where the higher the value, the better the solution is.

A brief example is now presented to illustrate the calculation of a trade-off: consider, from the above scenarios, that the user is weighting only two criteria: costs and external dependency. Taking into account that "Coal" presents least cost and highest energy dependency, the opposite case of "Maximum Renewable", the normalization of these criteria would consist in $v_{coal,cost}$=1, $v_{max\_renew,cost}$=0, $v_{coal,dependency}$=0, $v_{max\_renew,dependency}$=1.

As can be seen in Table 2, if only two criteria are weighted and the user gives the same importance to the costs and the energy dependency, he assumes implicitly that for him it is indifferent to choose scenario "Coal" or "Maximum Renewable" scenarios. Here the notion of trade-off appears: for the user, the energy dependency of the "Maximum Renewable" scenario is worth 2,62 euro/MWh, which is the difference in cost between the scenario "Maximum Renewable" and "Coal" (26,37 minus 23,75). The calculation of the trade-off $T_{s,c}$ is performed according to the following equation:

$$T_{s,c} = \frac{w_c}{w_{cost}} \times score_{s,c} \times (26,37 - 23,75) \quad (4)$$

Since $T_{s,c}$ is already multiplied by the range of the price (the parcel on the right), its value is given in euro/MWh. The user is always given the % of the costs that this increment represents in relation of the coal solution cost: in the case of the example where costs and dependency have the same weight, T=2,62 euro/MWh and 2,62/23,75 equals 11,01%.

It is worthy observing that when the weight of the cost is equal to the weight of the external energy dependency, the scenario with best performance is the "Base", with AVF=94,79.

In case the user gives the costs a weight twice the energy dependency, he would value the energy dependency in 1,31 euro/MWh (or 5,5%) and in this case the "Coal" scenario performs better than any other.

Table 2: Calculation of additive value function (AVF) by weighting two criteria

	Scenario s				
Criteria c	**Base**	**Natural Gas**	**Coal**	**Hydro-Gas**	**Maximum Renewable**
$score_{s,cost}$	25,69	25,24	23,75	25,96	26,37
$v_{s,cost}$	0,26	0,43	1	0,15	0
$score_{s,dependency}$	30%	53%	55%	47%	28%
$v_{s,dependency}$	0,93	0,07	0	0,3	1
	$w_{cost}=w_{dependency}$**=80**				
AVF_s	94,79	40,47	**80**	36,09	**80**
	w_{cost}**=100,** $w_{dependency}$**=50**				
AVF_s	72,19	46,88	100	30,30	50
	w_{cost}**=40,** $w_{dependency}$**=80**				
AVF_s	84,43	23,20	40	29,90	80

3.2. The MCDA tool

The proposed MCDA tool is presented in an Excel Workbook with five Sheets, as follows:

1. **General Instructions** The purpose of the tool is presented, as well as a summary of each of the following pages.

2. **Scenarios** The scenarios are presented in the form of graphics of installed power and produced electricity. Energy dependency ratio, CO2 emissions and annualized costs are also displayed graphically.

3. **Instructions** Instructions for the following sheet are presented, along with an example.

4. **Impact Evaluation and Weighting** Here the user is presented with the 13 criteria, along with explanations of every one of them. The user then fills the required cells, according to what he percepts to be the impacts generated by each scenario. Trade-offs are presented.

5. **Results** Results are printed: both ranking of scenarios and contribution of each criterion is given.

In the remainder of this section the information on the sheet *Impact Evaluation and Weighting* is introduced.

The criteria, C_i, and their description, are given as follows in Table 3. Since not all the impacts can be easily agreed upon, it was decided that the user might play a role on valuing them, as detailed in Table 3, column "Scenario score $i_{s,c}$".

Information of investment, operation & maintenance of the whole group of power plants is included in a single cost criterion. Positive impacts in industry, job creation and dependency on foreign fossil fuels have been an international concern for sustainable energy decisions [11] [10] with implications at national level [8]. Diversification of the electricity mix is also seen as important for sustainability goals [12] contributing to the security of supply. Local income, visual and noise impacts, as well as land use and public health were identified as important issues for local populations' standards of living, by the authors [13]. It is sometimes argued that the intermittency of the renewables imply they are overrated in levelized costs [14]: therefore, a criteria which accounts for the dispatchable rate of power on each solution was included. According to [15], the transmission system expansion requirements may be larger when renewable energy shares are higher; as the scenarios vary respecting to that aspect, the criteria was proposed to be evaluated. Given the importance that CO_2 emissions play in the economy nowadays, this criterion was also included.

Table 3: Description of the criteria used in the MCDA

C_i	**Name**	**Description**	**Scenario score $i_{s,c}$**
C_1	Costs	Sum of fixed and variable costs, divided by the total electricity produced during the planning period. The fixed costs are related with the investment cost applied to the new power plants and also with all fixed O&M costs. The variable costs include fuel and variable O&M costs for new and previously installed power plants.	Values in €/MWh, obtained from the MILP model. *User can not change values*.
C_2	National Industry	Impact of the scenario on the dynamics of the national industry.	Score in ordinal scale, ranging from 1 (worst) to 5 (best). *Requires user to attribute values according to own perception*.
C_3	Energy Dependency	Rate of dependency on foreign sources in year 2020, calculated as the sum of energy produced in thermal power plants (coal, natural gas and non-renewable cogeneration) divided by the total energy amount produced.	Values in %, obtained from the MILP model. *User can not change values*.
C_4	Employment	Employment created by the construction, operation and maintenance of the power plants.	Values are number of jobs. Obtained from the MILP model, based on [16]. *Although values are given, the user may attribute different values according to own perception*.
C_5	Visual Impact	Impact caused by the construction of new power plants upon the sightseeing.	Score in ordinal scale, ranging from 1 (worst) to 5 (best). *Requires user to attribute values according to own perception*.
C_6	Noise	Noise impact caused in neighbor areas by the new infra-structures.	Score in ordinal scale, ranging from 1 (worst) to 5 (best), based on [17]. *Although values are given, user may attribute values different according to own perception*.

C_7	Local Income	Rents originated by land use, for both public and private sectors.	Score in ordinal scale, ranging from 1 (worst) to 5 (best). *Requires user to attribute values according to own perception.*
C_8	Diversity of Mix	Diversity of installed power, calculated according to the Shannon-Wiener Index.	Higher values are better. Obtained from the MILP model, based on [18]. *User can not change values.*
C_9	Rate of Dispatchable Power	Ratio between the sum of installed power of coal, CCGT, dam hydro power plants, and all the installed power.	Score is given in %. Obtained from the MILP model. *User does not change values.*
C_{10}	Investment in Transmission Network	Additional investments required by the scenario. It was assumed that wind power has the worst impact, followed by hydro power, and no additional investment is required by natural gas and coal power plants.	Score in ordinal scale, ranging from 1 (worst) to 5 (best). *Although the values are given, the user may attribute different values according to own perception.*
C_{11}	CO_2 Emissions	Ratio between CO_2 emissions and the total electricity generated in the overall planning period.	Values are given in tons of CO_2 per GWh of electricity produced in the planning period. Obtained from the MILP model. *User can not change values.*
C_{12}	Land Use	Amount of land which becomes unusable by the scenario.	Values are given in 1000 km2, based on [16]. Obtained from the MILP model. *User can not change values.*
C_{13}	Public Health	Contamination of air, water, and general impact on public health.	Score is based on [17]. Obtained from the MILP model. *User can not change values.*

Figure 4 presents an example of the user's views of the MCDA tool for the C_2 criterion (National Industry). The scale for this criterion ranges from 1 (Low dynamics in industry) to 5 (Leadership of industry, resulting in capacity for exporting), and the user has assigned the following impacts for $I_{s,c}$: $I_{base,national\_industry}$=4, $I_{natural\_gas,national\_industry}$=2, $I_{coal,national\_industry}$=2, $I_{hydro-gas,national\_industry}$=3, $I_{maximum\_renewable,national\_industry}$=5. The blue cell is the weight of the criterion, assigned as 20 in the example. The information displayed in the plot indicates that the user accepts to increase the costs in 2.20%, in order to increase the national industry dynamics from score 2 to score 5. In other words, the user wishes to increase dynamics national industry from "coal" or "national gas" levels, to the "maximum renewable" levels, and is willing to pay additional costs of 2.2% for that change. It is also implicit that the user is willing to pay more 1.47% to increase from score 2 to 4, and 0.73% to increase from 2 to 3.

Finally, the *Results* sheet contains two plots, as can be seen on Figure 5: the one on the left, showing the overall ranking for the scenarios, and the one on the right showing the contribution of each crite-

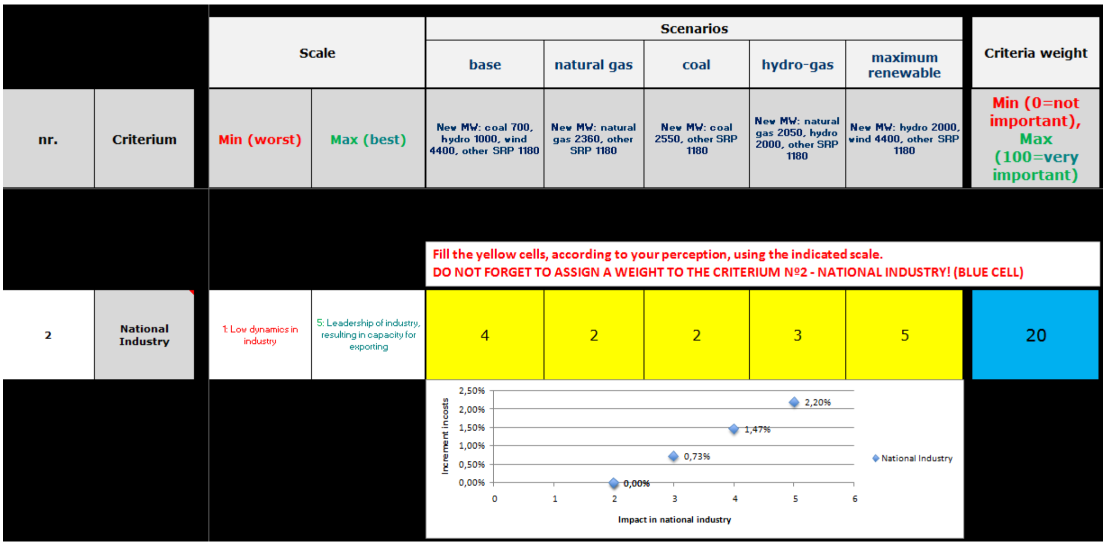

Figure 4: MCDA tool environment (Excel Sheet 4): Impacts and Criteria Weighting

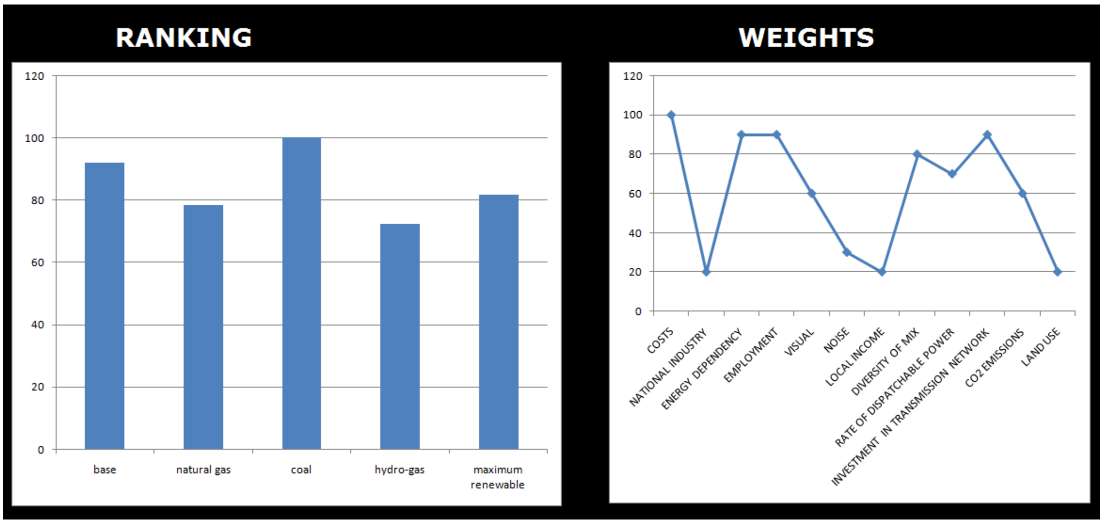

Figure 5: MCDA tool environment (Excel Sheet 5): Results. Here the user can validate his perceptions.

rion. The ranking is scaled so that the best scenario is scored by 100. On the given example, ”coal” scenario is the most rated, while the ”Cost” criterion is assigned as the most important.

4. Results

In this section the results are presented. The collaboration with academics took place in two phases. In the first place, the issues that should be included in power planning decision-making were collected with semi-structured interviews constructed over questions raised in the literature. The results of this exploratory research are described in section 2 of this report and published in [3]. In a second phase, the MCDA tool was sent by e-mail to approximately 60 academics, with background in energy, either from Economics or Engineering (Power Systems/Energy/Environment/Mechanical). The eleven experts that proceeded to the evaluation of the scenarios did it in a period of six weeks. Six of them

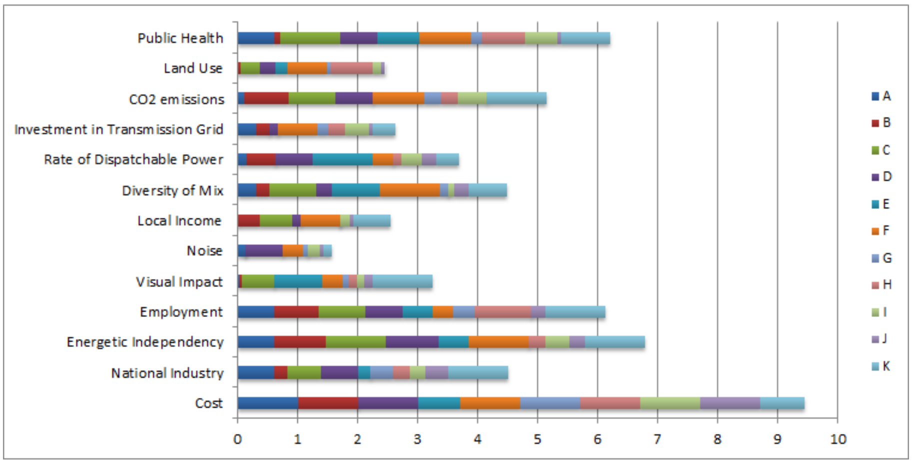

Figure 6: Aggregation of results

responded to the tool by themselves, while the other five respondents were aided in a personal interview, which they found helpful and less time-consuming. Table 4 presents the weights assigned by each respondent to each criterion.

Table 4: Criteria weights.

	Respondents										
Criterion	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Costs	50	80	25	80	70	100	100	80	80	80	80
National Industry	30	20	50	50	20	25	37	30	25	30	100
Energy Independency	30	70	70	70	50	100	0	30	35	20	100
Employment	30	60	60	50	50	50	37	75	35	20	100
Visual Impact	1	5	50	0	80	50	9	20	15	10	100
Noise	6	2	25	50	0	50	9	10	20	5	30
Local income	0	30	50	10	0	75	0	10	17	5	70
Diversity of Mix	15	20	60	20	80	100	15	10	12	20	70
Rate of Dispatchable Power	7	40	25	50	100	50	30	20	30	20	50
Investment in the Transmission Grid	15	20	25	10	0	75	18	30	35	5	50
CO_2 emissions	5	60	60	50	0	90	27	30	40	0	100
Land Use	0	5	40	20	20	75	5	60	15	5	20
Public Health	30	10	70	50	70	90	18	60	45	5	85

Figure 6 aggregates the results, that were normalized for each respondent, so that the highest weight equals 1 and the lowest equals 0. Costs prevailed as the most important criterion, followed by energy dependency, followed by two social concerns: public health and employment. Least important criteria were noise, visual impact, land use and local income.

The resulting rankings are presented in Table 5. There are no dominated solutions, which means that no scenario performs always worse than any other scenario.

Even in the case that cost is regarded as the most important criterion, the best solution can either be the cheapest or the most expensive: the proof is that ”Coal” and ”Maximum Renewable”, the cheapest and the most expensive scenarios respectively, were the ones that ranked first more times (4 times each).

The only scenario that never ranked first, for any respondent, was ”Hydro-Gas”. However, it is a balanced scenario, since it only ranks in the last place twice, while ”Maximum Renewable” and ”Natural Gas” rank in the last position for three respondents' profiles. On the other hand, ”Base” is the only scenario that never ranked last place, although only ranks first in two respondents.

Figure 7 presents the contrast between respondents favorable to ”Coal” and ”Maximum Renewable” scenarios, showing that while the former group clearly places costs high above any other criteria, the latter have five similarly valuated criteria: costs, public health, energy independency, national industry and employment.

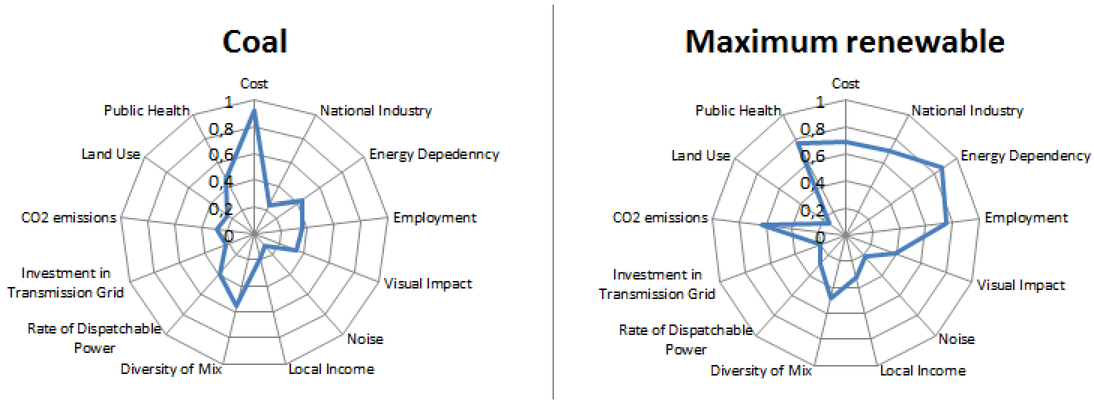

Figure 7: Average profile of respondents that chose either ”Coal” or ”Maximum Renewable” as preferred scenarios.

The obtained results confirm that costs are still the main obstacle for the incorporation of more renewable energy in electricity systems. Such as [19] case, our scenario ranking was also very sensitive to the input of costs weight.

What these results have shown is, in first place, that respondents felt it is important to trade-off costs with other criteria, hence the utility of multi-criteria methodologies. Only on rare occasions did a respondent assign zero to the weight of one criterion, but was free to do it in any criterion he wished to (if he assigned zero to all criteria besides costs, obviously the Coal scenario would be the first in the ranking, since it is the cheapest solution). Secondly, it is the magnitude of the trade-off that induces the divergence in the final rankings. For example, for the second most rated criterion, energy dependency, one respondent suggested that more information should be given when valuating this criterion (”in the worst case for fuel cost projections, how much would the price of the solution increase?”), otherwise it becomes difficult to state how much would value the criterion. However, using more information would significantly increase the response time.

5. Conclusions

In this paper, a tool to evaluate scenarios for electricity production was proposed. The tool uses multi-criteria decision analysis, and comprises a set of thirteen criteria, ranging from economic concerns,

Table 5: Scenario Ranking.

	Respondents										
Scenario	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Base	2	**1**	3	2	4	2	3	**1**	4	2	2
Natural Gas	5	5	4	5	3	4	2	4	**1**	4	5
Coal	3	3	5	4	**1**	**1**	**1**	3	2	**1**	4
Hydro-Gas	4	4	2	3	2	5	4	5	3	3	3
Maximum Renewable	**1**	2	**1**	**1**	5	3	5	2	5	5	**1**

to environmental and social as well as technical issues. The methodology combines an additive value function that aggregates results from direct weighting and trade-off analysis. The proposed tool was used on the particular case of Portugal, based on a set of scenarios for the electric system in 2020. A group of experts from academia, Engineers, Economists related to the energy sector, participated in the evaluation of these scenarios. From the results obtained, most respondents would be willing to increase the costs of power generation if other issues than the economical ones were to be taken into account. This fact alone proves the utility of MCDA. The evaluated scenarios were ranked differently by respondents with different perspectives, what is not unexpected when using multi-criteria methodologies. In fact, only one of the scenarios, "Hydro-Gas", was not chosen to be the preferred by any of the eleven respondents.

Aggregating the results, cost was considered the most important criterion, even for most respondents whose preferred scenario was "Maximum Renewable". Other also important criteria were the rate of dependency on fuel sources, the employment and the public health issues. Depending on the weight assigned to these criteria, the cost loses relative importance and most expensive solutions may rank first.

Future work envisages the collection of additional information, increasing the number of experts involved. Also, being the public acceptance of different technologies a fundamental aspect to ensure the success of strategic scenarios, the work is proceeding with the evaluation of public acceptance of different electricity generation technologies.

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