Knowledge Management in Electricity Generation Strategic Decisions: The Dawn of the Renewable Age

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Abstract— **The world has the challenge of expanding electricity production meeting demand and ensuring energy security for the support and development of society. Given data and information on energy sources are available on a large scale, there is an opportunity to develop a tool that enhances and contributes to decision making in the energy sector. With this in mind, this article brings together the use of technology, finance, information and intangibles with the objective of enhancing the decision-making process for the implementation and optimization of the fuel input mix for the power industry. The results presented in the article are obtained by means of technical, economic and information management analysis that constitute the theoretical basis of intangibles, all of them supported by information technology. This article presents both a new methodology and a new software to obtain optimum investment decisions in the power industry, focusing on power production. The development and validation of the methodology and software are described. The best energy investment to be made is based on the extraction and evaluation of the knowledge of the energy sector specialist in a logical and mathematical way. The results of the research present a decision-making process based on more formal and less personal criteria, guaranteeing greater neutrality and convergence in the decision-making process.**

Keywords— renewable energy; feasibility study; information management; decision-making; information system; design science, AHP-Analytical Hierarchy Process, fuel input mix.

I. INTRODUCTION (*HEADING 1*)

There is noticeable growth of electricity production using alternative renewable energy sources due to climate issues and the depletion of fossil resources. The recent reduction of costs [1]-[2] of these alternative sources has resulted in greater interest and investment activity. Because they are gentler to the environment [3]-[4], they have gained the attention of energy managers and concessionaires [5]-[12].

The identification of useful and strategic information to optimize the process of decision-making is performed in this work by a comparative study of the feasibility of energy sources. The incorporation of information management to identify intangible aspects of this process is a key objective of the work, beyond the recovery and use of strategic information. The result is the development of a prototype software tool that is able to enhance strategic decision making based on a mix of tangible and intangible criteria. [13]-[14].

The software combines information that has been collected from various sources and proposes an optimal solution to a given problem based on input by managers and experts.

A case study presents possible sources of renewable energy for a power plant in Minas Gerais, defined as a 20 MW rated power plant in the north of the state, and identifies how the tool affected the decision-making process in the selection of those sources. The alternatives initially considered were wind, solar, biomass and small hydroelectric plant. Although encompassing only renewables in the case study, the methodology is applicable to compare all sources of energy.

The focus in the case study is on alternative renewable energy sources. Global energy demand is increasing this growth will be strongly influenced by economic factors, population growth and energy availability worldwide. Production of oil and gas will depend on advancements in production technology and economic demand. Coal will also take a role in future energy supply, but its contribution will be limited because of its stronger environmental impact. Nuclear power will gain significance in meeting global demand when all the other options are un realistic and the necessity to abate carbon dioxide emission becomes urgent.

The two most preferred sources of energy to balance demand and supply are alternative renewable energy and energy-efficiency initiatives. The word 'alternative' implies the exclusion of large hydropower plants (due to their undesirable social and environmental impacts and the scarcity of places to construct reservoirs over the majority of the world's surface). Both are environmentally friendly. Energy-efficiency is also an attractive "source of power" and is expected to become increasingly significant. Alternative renewable energy (such as wind, solar, biomass, small hydropower, tides and waves and geothermal) will supply a large part of the world's energy in the foreseeable future, but its actual growth will be dependent on future technological development, governmental environmental policy and on energy prices for other sources.

Future technological development is the key to how much alternative renewable energy will be utilized. In order to make renewable energy competitive economically, decrease of capital costs to construct facilities such as solar panel and wind mill and decrease of operational cost for energy generation must be achieved. And these are partly dependent on how we estimate the development of alternative renewable energy technology in the future.

Future governmental policy will also influence the amount of alternative renewable energy that is generated. Generally, carbon tax on fossil fuel and financial subsidy to renewable energy facilities can narrow the overall cost gap between fossil fuel and renewable energy. If international frameworks designed to limit greenhouse gas emissions such as Kyoto Protocol and IPCC (Intergovernmental Panel on Climate Change) come into effect, governments will be forced to develop domestic policies to increase the contribution of alternative renewable energy. The next factor is the price of conventional fossil fuel. If its price is to increase due to the exhaustion of proven reserves or political constraints in fossil fuel exporting countries, the overall cost gap between fossil fuel and alternative renewable energy will narrow, resulting in more installation of alternative renewable energy. In addition, the environmental impact that large hydropower dams cause is a factor to preventing its adoption, as well as the ecological disturbance due to the construction of such dams. Meanwhile, energy output from alternative renewable sources is strongly dependent on natural condition such as wind strength for wind power and day's length for solar power. These disadvantages require renewable energy to be supported by conventional sources of energy in order to achieve stable energy supply.

If alternative renewable energy is not well developed and economically viable and strong energy-efficiency policy is not adopted, one should anticipate the possibility that a gap will exist between world energy demand and energy supply from oil, gas, coal, nuclear power, large hydropower plants and alternative renewable energy.

Conventional and unconventional reserves of oil and gas are not plentiful enough to meet the demand. And if a shortage of proven reserves takes place, prices of fossil fuel will increase. This increase of price will create new proven reserves by converting uneconomical resources to economical for exploration and make unconventional resources more economically viable. Furthermore, this increase of price will make renewable energy more economically competitive, resulting in greater worldwide adoption.

When such economical supply and demand is insufficient to fill the energy gap, introduction of global energy-efficiency policy is another possible option. It is possible to suppress the growth of world energy demand substantially by introducing measures to stabilize carbon dioxide emissions. Such measures include carbon/energy tax, reinforcement of thermal insulation regulation for houses and so forth. Nevertheless, these policies must be considered in conjunction with their negative impacts on world economic activities. In addition, it is important to know how to involve developing countries, which are expected to grow their energy demand dramatically, in world energy-efficiency policies.

More coal production should be recognized as an option should oil and gas production decline dramatically in the future. However, the extent of its expansion will be limited due to carbon dioxide abatement efforts.

Nuclear power could be a possible option to fill the gap. Places where nuclear power will achieve significance are thought to be limited partly due to environmental concerns such as radioactive waste disposal, safety problems of nuclear reactors and nuclear proliferation and partly due to economic concerns caused by huge capital cost. However, nuclear power, which emits less carbon dioxide, is attractive from the point of carbon dioxide abatement.

If a gap between world energy demand and world supply arises in the future, some options such as implementation of worldwide energy-efficiency policy, coal utilization and nuclear power can be recognized as tools to fill the gap other than the alternative renewable energy.

However, if increasingly strict environmental and safety policies are going to significantly increase and prevail, there is no better alternative for society other than to foster the alternative sources of renewable energy.

In this context, this research develops a methodology that includes intangible aspects in the evaluation of investments to increase the generation of electricity. It brings competitiveness to the decision-making process in the selection of alternative renewable energies. These aspects can ultimately be translated into error mitigation. Conventional sources of energy are linked to risks such as:

- Oil and gas: shortage of supply;
- Coal: prohibited carbon-dioxide emissions;
- Large hydropower dams: undesirable social and environmental impacts;
- Nuclear power: safety hazards.

II. Research Development

Firstly, the evaluation of the business environment that is part of the critical analysis of opportunities and competitive threats in the market was made. [15].

The work presents a model to improve the information management related to the decision-making process involved in the implementation of new energy sources of electricity, taking into consideration also intangible parameters.

A literature review, an economic-financial model, a decision-making model, a prototype and Proof of Concept was done.

The literature review on topics related to information management, decision making, concepts and techniques of organization, treatment, indexation and retrieval of information allowed the characterization of the current scenario of the energy sector (production) market.

Next, the technical feasibility and the economic-financial viability of each energy source are evaluated. Considering that the market in the energy sector is regulated and is based on population growth for industrial production, it is possible to recognize many alternatives for energy production in Brazil. Many studies demonstrate the abundance of these resources [17]. The construction of an economic-financial model constituted one of the methodological bases for the development of the research. The complete methodology can be found in references from [18] to [24].

The work considers the decision-making processes of complex organizations and, after studying the possible methods, adopts the Analytical Hierarchy Process (AHP). The AHP assists the organization of objectives, attributes, and allows stakeholders to view the problem hierarchically creating an overview of complex relationships and assists managers to assess the problem at different levels and points of view [16].

The development of the prototype was based on the result of the economic-financial model and on the method of decision-making including intangible parameters. The software architecture components consist of the core with the data model and the AHP algorithm.

The objective of software development is to use the software during a meeting of the energy managers for compared to the other alternatives. To achieve this objective, managers and experts convey their knowledge tacitly when making comparisons among the criteria and among the alternatives. The identification and validation of the presented criteria are the result of several personal interviews with specialists in the field of study. Seven criteria were selected between tangible and intangible to be presented to managers.

The prototype defines the calculation method to be used based on the selected criteria. During the meeting, each expert or manager makes their selection based on their knowledge, expertise and the available criteria.

For the validation of the proposal we made a Proof of Concept - POC presenting evaluations and results. The goal of the POC meeting with participation of experts and managers is to achieve an outcome which expresses the insight of the decision makers as a concise group. In this regard, the expected result is a team fully committed to successfully implementing the decision, with advanced neutrality and convergence...

The energy sector is always under regulation, and it is necessary to update seasonally. Information management is constantly checked and short-term follow-up between the assessment of the criteria and sources used is proposed. Information retrieval strategies and information organization, treatment, indexing and retrieval techniques are reviewed so the result of this work is maintained and kept relevant

A. Information Management

In order to define the sources of information used in the decision-making processes, information extraction techniques and knowledge representation concepts based on ontologies were considered. Information Extraction (IE) techniques have been developed, analyzed and categorized [25]. OBIE-like systems are "guided" by ontologies to extract information related to instances and property values of ontologies. The IE methods that have been used by OBIE systems are documented [26]. Different classification techniques, such as SVM (Support Vector Machines), maximum entropy models and decision trees have also been used. Tagging techniques such as Hidden Markov Models (HMM) and Conditional Random Fields (CRF) are also studied. Some OBIE systems construct semantically annotated trees to analyze the text as a part of the process. Trees constructed are not intended to represent the semantic content of the text globally [27].

B. Sustainable Design, Technical and Economic-Financial Viability and Case Study Method

All these subjects can be seen and analyzed in [28].

C. Decision Supoort Model

The multicriteria method and its mathematics constitutes the theory of the decision-making process of the methodology and the software [28].

“Modeling complex problems in a hierarchical structure involves the evaluation of relationships between goals, criteria that express goals, and alternatives. The hierarchical structure matches the goal or objective to the criteria and alternatives at successive levels [16].

The method used has three principles for its application:
- Construction of hierarchies: the problem is structured at hierarchical levels and is a fundamental step.
- Definition of priorities: it is based on the capacity to perceive the correlation between objects and diverse situations. The comparison between pairs of criteria is used.
- Logical consistency: The Analytic Hierarchy Process (AHP) allows evaluation of the prioritization model by making use of mathematical concepts, including properties of matrices.

The pairwise comparison between the criteria and alternatives always generates square matrices, where the number in row i and column j gives the importance of the criterion **C*i*** in relation to the **C*j***, as seen in the matrix form indicated below.

Then, the subsequent steps include:
- Peer judgments: pairwise relative grading between the elements of a hierarchy level with the use of specific scale. By means of this comparison, the relative amounts (weights) of each criterion are determined;
- Normalization of the matrices of judgment: normalized matrices are obtained by adding up the elements of each column of the matrices of judgment and subsequently dividing each element of these matrices by such sum. In other words, the calculation shall comprise the sum of the elements of each column and the division of each element of the column by this sum of the elements of its corresponding column. The resulting matrix is called the normalized matrix;

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} & \dots & a_{1j} \\ 1/a_{12} & 1 & a_{23} & \dots & a_{2j} \\ 1/a_{13} & 1/a_{23} & 1 & \dots & a_{2j} \\ \dots & \dots & \dots & 1 & \dots \\ 1/a_{1j} & 1/a_{2j} & 1/a_{3j} & \dots & 1 \end{pmatrix}$$

- Vector of priorities or priority vector (eigenvector) calculation: each priority vector (PV) element is the average of the corresponding line of the normalized matrix. It is calculated by the sum of the line divided by the order of the matrix. This PV, as well as the judgment matrix, changes according to the criterion to be analyzed. Hence, there is a specific vector associated with each criterion and each specific vector comprise all alternatives. The set of priority vectors form the local priority vectors (LPVs);
- There is an unique priority vector when the criteria are weighted in relation to each other. In this last case, the priority vector is the so-called global priority vector (GPV). In this last step, the global priority vector is identified which stores the priority associated with each criterion in relation to the main objective is obtained.

Table I represents a hypothetical judgment matrix to illustrate part of the development. The elements which form the matrix columns are the inverse of those which form the corresponding matrix rows, thus resulting in a reciprocal matrix.

TABLE I: Matrix of Judgment

	AA	BA	CA
AA	1	1	2
AB	1	1	1
AC	1/2	1	1

TABLE II: Normalization of the Matrix of Judgment - step 1

	AA	BA	CA
AA	1	1	2
AB	1	1	1
AC	1/2	1	1
SUM	**2 1/2**	**3**	**4**

The sum of each column is then performed and the division of each element by corresponding sum is shown in Tables II and III.

TABLE III: Normalization of the Matrix of Judgment - step 2

	AA	BA	CA
AA	2/5	1/3	1/2
AB	2/5	1/3	1/4
AC	1/5	1/3	1/4

For the proposed example, after the normalization of the judgment matrix, the resulting priority vector is:

Priority Vector
0,41
0,33
0,26

Since this is a value judgment to a certain extent, inconsistent assessments can occur in some situations. In anticipation of this, procedures are proposed to evaluate the consistency of the judgments. For this, the Consistency Index (CI) evaluates the degree of inconsistency of the, and it is obtained by the following equation:

$$IC = \frac{|\lambda_{\max} - N|}{N-1}$$

Where, N is the order of the matrix and λ_{max} is the largest eigenvalue of the pairwise judgment matrix.

The AHP proposes to calculate the Consistency Ratio of the judgments, denoted by RC = IC / IR, where IR is the Random Consistency Index obtained for a reciprocal matrix of order N, with non-negative elements randomly generated. The consistency condition determines, from the judgments, whether the comparisons were made properly, and considers the set of all the answers obtained. The judgment matrix is consistent when RC ≤ 0.10 is found. If, by the calculations of the judgment matrices, the CR is > 0.10, a new comparison is necessary between the pairs, thus re-evaluating the matrices of judgment."

D. Expected Benefits

It is expected that the results of this research contribute to broadening the discussion about the use of alternative renewable sources of energy, as well as guiding and subsidizing the decision-making process. Taking into account the use of information management, in addition to the technical and economic assumptions that result in the viability of the investment, the amount of information available grows and, as a consequence, the decision-making capacity and the risk management improves. Especially, considering the inclusion of intangible parameters to optimize the decision making.

The appeal of the work is attributed to the insertion of intangible parameters in the methodology and in the software. This is achieved by means of a sophisticated recursive weighting process

III. INFORMATION´S SCENARIO

The initial step is the elaboration of a questionnaire, which should be answered by decision-makers and other professionals who deal with the theme of implementation of energy sources. The results obtained are reported in [29].

Tab. IV shows the parameters initially considered for the decision process.

TABLE IV: Preliminary Parameters [28]

Parameters in the Decision Process
Availability of Energy Resource
Vocation of the Company for production with the specified source
Profitability (Sources of Financing and Benefits of the Sector)
Source Type (Renewable / Traditional or Alternative)
Environmental impact
Technology Domain
Regulatory Alignment
Company Visibility

The questionnaire was applied in two phases. After the first round of answers, a new round of reviewed questions was reviewed and applied, and important aspects were captured for the elaboration of the prototype.

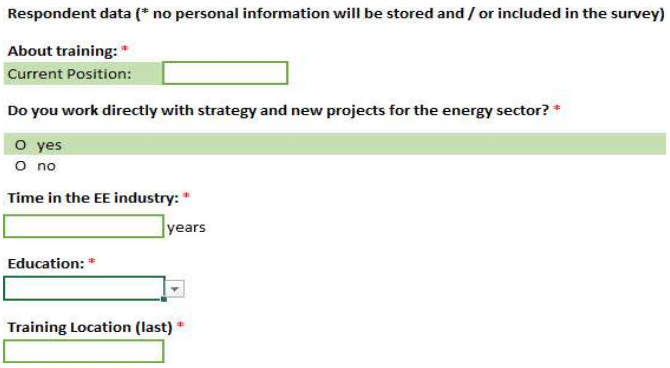
Fig. 1 represents the survey that collected data, taking into account the experience time of the respondents in the energy sector.

Fig. 2 represents the manager's view in relation to the sector indicators considered. Therefore, a new questionnaire was applied, from which they were refined until reaching the criteria considered.

After the application of a second questionnaire, an interview script was designed, with questions, and answers, (structured). A large part of the time for the interview was left unstructured seeking to leave the interviewee free to express opinions about the energy sector, always directing the interviewee to power production and the raw sources used.

These interviews, which occurred in a period between 2015 and 2017, produced the survey from suggestions, clarifications and observations of the elements mentioned. These were considered for the determination of the criteria to be implemented in the prototype.

The development and computational techniques applied to the prototype is the subject of another work. Thus, the more general features for understanding the resulting software artifact are briefly presented in the next section.


Respondent data (* no personal information will be stored and / or included in the survey)

About training: *

Current Position:

Do you work directly with strategy and new projects for the energy sector? *

O yes

O no

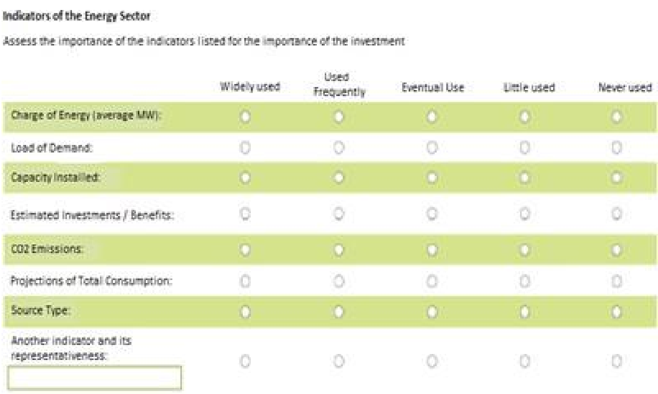
Time in the EE industry: *

years

Education: *

Training Location (last) *

Fig. 1: Characterization of respondents [28]


Indicators of the Energy Sector

Assess the importance of the indicators listed for the importance of the investment

	Widely used	Used Frequently	Eventual Use	Little used	Never used
Charge of Energy (average MW):	O	O	O	O	O
Load of Demand:	O	O	O	O	O
Capacity Installed:	O	O	O	O	O
Estimated Investments / Benefits:	O	O	O	O	O
CO2 Emissions:	O	O	O	O	O
Projections of Total Consumption:	O	O	O	O	O
Source Type:	O	O	O	O	O
Another indicator and its representativeness:	O	O	O	O	O

Fig. 2: Sector indicators [28]

IV. THE PROTOTYPE AND CASE STUDY

A. *Development of prototype*

The Model-View-Controller (MVC) Software Architecture standard was chosen to develop this prototype. The Model is made up of entities that represent the application data. The purpose of View is to present these data and manage the events through the interfaces. The Controller makes the connection between the other two levels, performing the event handling, acting on the Model and changing View elements to represent the new shape of the data. Fig. 3 shows this interaction between the layers.

The MVC standard suggests a software architecture divided into components, allowing the organization to develop the code efficiently and reliably. Component independence is achieved through layers ensuring scalability, efficiency, and reuse.

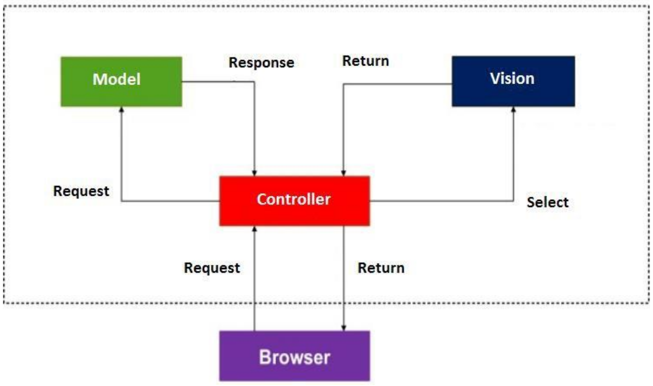


Fig. 3: Interaction between layers [28]

The core of the prototype consists of the data models (storage) and the AHP algorithm. The AHP method supports decision making by first framing the problem in hierarchical levels. It is necessary that both the criteria and the alternatives involved in the problem to be solved can be structured in a hierarchical way. The first level of the hierarchy corresponds to the general purpose of the problem, the second to the criteria and the third the alternatives to be considered.

The final seven criteria of the case study are the following:

1- Energy Resource Availability;
2- Impact on Environment;
3- Technology Mastering;
4- Regulatory Compliance;
5- Consumption Demand;
6- Net Present Value (NPV);
7- Payback.

B. *Implementation of the AHP Algorithm*

The AHP algorithm follows some steps, as shown.

By deploying the AHP, a comparison of the degree of importance that a user gives to one criterion in relation to the other is performed

From the judgments made, the matrices of judgment are formed. They´re always quadratic with order equal to the number of criteria considered.

After the determination of these matrices, their normalization makes the calculation of Local Priority Vectors (LPVs) possible. It is carried out by the user by weighting in relation to one another for each pair of criteria (two criteria each time), The Global Priority Vector (GPV) is generated through the AHP when votes are counted.

With the GPV and LPVs defined, the final calculation is performed, which shows the result in percentage. Each energy source weight fits with the participants' experience and knowledge.

Since this is a value judgment, inconsistent assessments can be expected in some situations. In anticipation of this eventuality, procedures are implemented to allow to assess the consistency of the judgments. For this, the Consistency Index (CI) evaluates the degree of inconsistency of the matrix of judgments, and is represented by the following equation:

$$IC = \frac{|\lambda_{\max} - N|}{N-1}$$

Where, N is the order of the matrix and λ_{max} is the largest eigenvalue of the pairwise judgment matrix.

The AHP proposes to calculate the Consistency Ratio of the judgments, denoted by RC = IC / IR, where IR is the Random Consistency Index obtained for a reciprocal matrix of order N, with non-negative elements and randomly generated. The consistency condition determines, from the judgments, whether the comparisons were made properly, and considers the set of all the answers obtained. The judgment matrix is consistent where RC ≤ 0.10 is found. If, by the calculations of the judgment matrices, the CR is > 0.10, a new round of comparison is necessary among the pairs, thus re-evaluating the matrices of judgment.

More details about the method and how the author´s used the algorithm in the implementation of the prototype, can be seen on [28].

C. Case study

Reference [28] case study is utilized here.

The AHP algorithm can be divided into 3 steps:
1- Construction of the LPV (Local Priority Vectors);
2- Construction of the GPV (Global Priority Vector);
3- Allocation of alternatives;
4- Validation test.

Each step is explained and described in detail in the following paragraphs.

1 - Construction of the LPV (Local Priority Vectors):

The Local Priority Vector is used to determine the relative importance between the alternatives in relation to each specific criterion and, later, the values obtained for the measurement in relation to the overall objective is used.

For the first criterion, defined "availability of energy resource", the matrix of judgment of the alternatives defined in the case study was constructed. The judgment matrix defined is represented in Table V:

Table V: The Matrix of Criterion 1 (C1) of the Case Study

C1	Wind	PV Solar	SHP	BIO
Wind	1	3	3	5
PV Solar	1/3	1	2	3
SHP	1/3	1/2	1	3
BIO	1/5	1/3	1/3	1

The criterion considered "Availability of Energy Resource" is represented by C1 in the upper left corner and each alternative is represented by the acronym EOL (Wind Power Plant) / FOTO (Photovoltaic Plant) / PCH (Small Hydropower Plant) / BIO (Biomass Plant), respectively.

The normalization process is used to define the priority eigenvector in the light of each of the criteria. For each judgment node of the hierarchy the normalized matrix is calculated. The calculation shall comprise the sum of the elements of each column and the division of each element of the column by such sum.

Table VI: C1 Normalized Matrix of Criterion 1 (C1) of the Case Study

C1	Wind	PV Solar	SHP	BIO
Wind	0,54	0,62	0,47	0,42
PV Solar	0,18	0,21	0,32	0,25
SHP	0,18	0,10	0,16	0,25
BIO	0,11	0,07	0,05	0,08

Following, the local priority vector (LPV) is calculated, which is the average of the normalized matrix lines, called relative weight of the criterion.

Table VII: Local Priority Vector (LPV) of Criterion 1 (C1) of the Case Study

					LPV C1
C1	Wind	PV Solar	SHP	BIO	
Wind	0,54	0,62	0,47	0,42	0,512
PV Solar	0,18	0,21	0,32	0,25	0,238
SHP	0,18	0,10	0,16	0,25	0,172
BIO	0,11	0,07	0,05	0,08	0,078

The LPV allows an evaluation of all alternatives in relation to each criterion, one by one. It is not possible, however, to make a global judgment from the perspective of one criterion only. The same process then follows for all the identified criteria. This whole process is carried out by the prototype.

It is necessary to obtain all matrices of judgment and the respective calculation of all LPVs. After calculating all such values, the calculation of all alternatives in relation to the overall objective is performed in steps.

2 - Construction of the GPV (Global Priority Vector):

The Global Priority Vector (GPV) is defined by comparing the importance (weight) of each criterion from the perspective of the overall goal and it is an intermediate step necessary to execute the final ranking of the alternatives. The elements of the GPV thus represent the performance of the alternatives from the perspective of the overall objective.

As for the case study example, the judgment matrix of the criteria was defined in relation to the overall objective:

Table VIII: Matrix of Criteria Weighting under the Global Objective

Global	C1	C2	C3	C4	C5
C1	1	2	5	7	3
C2	1/2	1	2	5	3
C3	1/5	1/2	1	5	1/2
C4	1/7	1/5	1/5	1	1/3
C5	1/3	1/3	2	3	1

The process of calculating the GPV is the same applied beforehand and results in the following global priority vector:

Table IX: Normalized Matrix and Global Priority (GPV) of the Case Study

Global	C1	C2	C3	C4	C5	VPG
C1	0,46	0,50	0,49	0,33	0,38	**0,43**
C2	0,23	0,25	0,20	0,24	0,38	**0,26**
C3	0,09	0,12	0,10	0,24	0,06	**0,12**
C4	0,07	0,05	0,02	0,05	0,04	**0,05**
C5	0,15	0,08	0,20	0,14	0,13	**0,14**

3 - Allocation of alternatives:

The next calculation represents the priority vector (PV) or global priorities (PG) for all alternatives. The sum of the multiplication of the priorities of the criteria in relation to the overall objective is achieved by the representativeness of the alternatives under the focus of each of the criteria. In this way the weights found representing the global priority are:

PG_{A1} = (0,43x0,51 + 0,26x0,52 + 0,12x0,10 + 0,05x0,40 + 0,14x0,51) = **0,46**

PG_{A2} = (0,43x0,24 + 0,26x0,07 + 0,12x0,06 + 0,05x0,47 + 0,14x0,26) = **0,19**

PG_{A3} = (0,43x0,17 + 0,26x0,29 + 0,12x0,55 + 0,05x0,05 + 0,14x0,09) = **0,23**

PG_{A4} = (0,43x0,08 + 0,26x0,12 + 0,12x0,29 + 0,05x0,08 + 0,14x0,14) = **0,12**

Therefore, the vector of the global priorities of the alternatives is:

	A1	A2	A3	A4
PG	0.46	0.19	0.23	0.12

These figures represent the Global Priority for the proposed example (case study). It is important to note that this result refers to an isolated experiment whose objective was to study and analyze the viability of the method to the specified requirements.

4 - Validation test:

Using the same criterion as in the previous examples, the calculation of consistency of the judgment matrix of the alternatives with respect to C1 is performed, a general example, as follows:

- Divide the element of the judgment matrix by the sum of its column, as in the normalization process. Referring to the matrix under the judgment of C1, as an example, the result is presented in Matrix A ':

$$A' = \left\{ \begin{matrix} 0,54 & 0,62 & 0,47 & 0,42 \\ 0,18 & 0,21 & 0,32 & 0,25 \\ 0,18 & 0,10 & 0,16 & 0,25 \\ 0,11 & 0,07 & 0,05 & 0,08 \end{matrix} \right\}$$

Then follows the calculation of the largest eigenvalue relative to this judgment matrix. The sum of the rows of the matrix divided by the order of the matrix generates a new vector C.

C
0,512
0,238
0,172
0,078

The sum of the multiplication of the above vector by the sums of the columns of the judgment matrix (Table 3) determines the eigenvalue (**λmax**), as follows:

λmax = [(0.512 * 1.87) + (0.238 * 4.83) + (0.172 * 6.33) + (0.078 * 12)] = **4.133**

By the formula of the Consistency Index, one obtains:

IC = (**λmax** - N) / (N - 1)
or
IC = (4.133 – 4) / (4 – 1) = **0.044**

The calculation of the consistency ratio for each of the judgment matrices is represented by RC = IC / IR, where the ratio to be found (RC) is the result of the division of the obtained consistency index (IC) by the random index corresponding to the order of the matrix (IR), in the case 0.9. Where IR is obtained to a reciprocal random matrix, with no negative element, according to Saaty approximation [15], as depicted in Table X.

Table X: Random Consistency Index

Matrix Order (n)	1	2	3	4	5	6	7	8	9	10	11
IR Values	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The following result is then obtained by these calculations:

$RC = 0.044 / 0.9 = 0.049$

By the method´s definition, in order to consider the appropriate judgments, without the need to define again the matrices, an RC ≤ 0.10 must be found. If the RC is greater than such value, it is necessary to repeat the construction of the corresponding matrix of judgment.

The validation test is bundled in two stages.

In stage 1, by deploying the AHP, a comparison of the degree of importance that a user gives to one criterion in relation to the other ones is compared. The final seven criteria of the case study are the following:

1- Energy Resource Availability;
2- Impact on Environment;
3- Technology Mastering;
4- Regulatory Compliance;
5- Consumption Demand;
6- Net Present Value (NPV);
7- Payback.

The GPV (Global Priority Vector) is generated through the AHP when votes are counted.

In stage 2, the alternative sources are weighted in relation to one another for each of the 7 criteria (one criterion each time), by the user. The results from the 7 LPVs.

With the VPG and LPVs defined, the final calculation is performed, which shows the result in percentage. Each energy source weight fits with the participants` experience and knowledge.

D. Proof of Concept

Proof of Concept (POC) consists of a practical model of documented experimental approval of a product or service. The objective is to provide stakeholders with one way to evaluate the proposal, requirements, architecture and design of the system. In this research, three POCs were performed, as follows:

i) Initial step - in a conceptual way, with the team of researchers and developers, during a face-to-face meeting, the navigation options and interface screens were presented, and the requirements were discussed. Recommendations were made for finalizing the prototype;

ii) Intermediate step – in a conceptual and practical way, with the team of researchers and developers, during a face-to-face meeting, the participants conducted the voting for simulation and prototype testing without the ambition of obtaining real results because of the lack of experts (from utilities) at this step;

iii) Final step - in a practical way, with the participation of team researchers and developers and invited utility experts.

The methodology proved to be of great importance as a construction, consolidation and validation tool. A real situation was presented, and the expert participants led the simulation. And researchers and developers watched the simulation.

During the last meeting, the experts had enough time to review the criteria and proceed with the vote. Some recommendations and questions were raised, discussed and analyzed by the specialists. In the end, the best option was calculated and presented.

E. Application in the northern region of Minas Gerais State in Brazil

The example performed illustrate the application of the methodology, as described above.

The northern region of the State of Minas Gerais in Brazil has good potential for generation of 20 MW of electricity through the 4 sources in question, namely: biomass, wind, SHP and solar photovoltaic.

Photovoltaic energy proves to be technically viable, but with prohibitive costs; being therefore discarded.

The choice between the construction of a small hydropower - SHP or a wind power plant proved to be a difficult choice. The fact of having a lower payback gave the advantage to the wind power source. The complex licensing environment of a SHP reinforces the choice of wind source.

The energy from the biomass obtained through the pigs are technically feasible and its costs are practically identical to those of wind power generation. Due to this fact, it was not possible to choose one of these sources as more competitive than the other. The decision was referred to subjective criteria established by the entrepreneur.

Reinforcing the statement of the previous paragraph through a final comparison by means of the use of the LCOE of each of the two sources (wind and biomass) had, practically the same attractiveness for the region under study.

The solution developed includes intangibles in the decision-making process, combining information from various external and internal sources to the organization.

The next step consists of the computational simulation based on tangible and intangible criteria. The criteria are processed in a logical and mathematical way to achieve the final result, the best investment option for the energy portfolio. These foundations of the software include technical, economic and financial factors. The methodology with intangible elements proposes to extract the knowledge of the experts with the analysis of previously defined criteria. The simulation is performed by pairwise comparison of parameters by systemic analysis. The result presents the best option to neutralize individual bias. In this way, the process becomes more consistent in terms of decision making.

Electrical engineers and domain experts performed the POCs, validating the effectiveness and breadth of the developed model. The proposal includes an important property of counteracting individual process-based decision making. From the moment that the comparison of the criteria is extracted, the feeling of each specialist is felt individually, and the final decision is formally based on the comparison of all the criteria by all specialists.

The model presents an extended form of applications in different contexts from the definition of another set of criteria applied to other domains or fields of study.

In relation to the case study, the investment qualified at the end was a wind farm.

V. Conclusion

The goal of this work is to improve the decision-making process and outcomes with respect to investments in electricity generation. The expected result of the work is a team fully committed to successfully implementing the decision, with neutrality and improved agreement within a group of decision makers., According to the hypothesis, if a gap between world energy demand and world supply arises, alternatives such as the implementation of worldwide energy-efficiency policy, coal utilization and nuclear power can be utilized to fill the gap in place of alternative renewable energy sources.

Assuming increasingly strict environmental and safety policies are going to significantly increase and prevail, there is no better alternative for society other than to foster the alternative sources of renewable energy. The research presents a way to increase the competitiveness of alternative renewable energy sources. This work presents a methodology which includes tangible and intangible parameters when evaluating investments for incremental electricity generation. These parameters can be used ultimately in risk mitigation. The risks are attached to the conventional sources of energy oil and gas, shortage of supply; coal, prohibited carbon-dioxide emissions; large hydropower dams, undesirable social and environmental impacts; nuclear power, safety hazards; alternative sources of energy such as solar photovoltaic, wind farm, biomass, small power plant, among others.

The results show that information management can improvement the decision-making process with human knowledge extraction techniques, together with traditional investment and risk analysis.

This project was developed with a team of professors and students from the Federal University of Minas Gerias - UFMG, Federal University of Ouro Preto - UFOP, Pontifical Federal University of Minas Gerais - PUCMinas and engineers of the Energy Company of the State of Minas Gerais - CEMIG and other professionals. The work showcases in an interdisciplinary way, the development of a solution merging academics and proven application problem solving techniques in an energy company.

The applied research presents, among other things, a methodology for the decision-making process for alternative sources of renewable energy.

Acknowledgment

The authors gratefully acknowledge the financial support of FAPEMIG – Minas Gerais Foundation to Support Researches and CEMIG – Minas Gerais Electricity Utility.

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