Investments in Renewables
Decision Making Based on Tangible and Intangible Criteria

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ABSTRACT

The article presents an important stage of the Research and Technological Development Project "Information management for the sustainability of the portfolio of electric energy generation with alternative renewable sources" in the CEMIG (Minas Gerais Energy Company) P&D (Research and Development) Program executed by UFMG. The objective is to apply information management and knowledge assumptions to improve the decision-making process in a Brazilian energy company. The research presented leverages a previous models and methodology to produce a prototype application that will be used to determine optimum investment decisions for the electric power sector. This article presents the development methodology and validation of the system with a group of experts that correspond to the end users. For the validation, planning meetings were analyzed with the participation of seven specialists, CEMIG's electrical engineers and Professors. The prototype developed was used during the meetings. Two meetings were held as a proof of concept with a third meeting expected at the end of the project. The research project presents a partial result of the simulation of a real encounter with the use of the prototype to assist the managers in the decision-making process. The output of the model is a projection of the best investment to be made based on the extraction and evaluation of the knowledge of the specialists 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 in the decision-making process.

Keywords: Decision Making. Information Management. Information System. AHP - Analytical Hierarchy Process. Energy. Design Science.

1. INTRODUCTION

Identifying trend indicators, assessing the business environment and sectoral developments are part of the critical analysis of opportunities and competitive threats in the market [1].

For Saaty (1990) the decision-making processes of organizations making strategic decisions is complex with many elements and dimensions. This author defined the AHP (Analytical Hierarchy Process) as the preferred method for creating a hierarchical classification of these elements. For the author: "[...] organizing the objectives, attributes, issues and stakeholders in a hierarchy serves two purposes. Provide an overview of the complex relationships inherent to the situation and assist the decision maker to assess whether the issues at each level are of the same order of magnitude so that they can accurately compare these homogeneous elements "[2].

The electric power sector is an expanding market. However, the market is constrained by governmental regulations based on either demographic growth or industrial production.

The use of several energy sources for the production of electric energy has been the focus of several works and studies. Energy sources are classified into non-renewable and renewable, and renewable energy can be traditional or alternative. Brazil is in a promising position with many alternatives for energy production and abundant resources

[3]. The analysis of each energy source passes through technical feasibility and economic-financial viability evaluations.

This work presents the fourth stage of the R & D - Research and Development project - conducted by the authors of this research, researchers from the Federal University of Minas Gerais (UFMG), together with representatives at CEMIG (Companhia Energética de Minas Gerais). The research project is funded by FAPEMIG (Minas Gerais Research Support Foundation) and by CEMIG. The objective of the Project is to generate a global model to improve the information management related to the decision-making process involved with the implementation of renewable energy sources.

The first stage of the Project was a literature review on topics related to information management, decision making, concepts and techniques of organization, treatment, indexation and retrieval of information, ontologies, knowledge representation, alternative and renewable sources of energy, technical feasibility and economic-financial.

The second stage characterized the competitive landscape of CEMIG and the electricity market. The third stage delivered an economic-financial model and the methodology for the development of the project according to the characteristics of CEMIG. All these steps well documented in [4] to [10]. The fourth step, to be presented in this paper is the development of the prototype with the application of the AHP - Analytical Hierarchy Process methodology. The process is automated based on the result of the economic-financial model and the method of decision-making.

The objective of this article is to present the methodology for the development of the prototype, including the architecture, the components, the core with the data model and the AHP algorithm. Another objective is to present in a descriptive way the POC - Proof of Concept applied for the validation of the prototype, as well as the current results and the final considerations.

The prototype consists of the development of an artifact to support the decision-making process. During a management meeting to decide in which renewable source of electricity the investment will be made, managers can compare the criteria two-to-two. The criteria were defined previously from interviews with experts Seven criteria were selected between tangible and intangible to be presented to managers. The process begins with the presentation of investment possibilities and the simulation of options. Then each manager takes the vote by comparing the criteria two to two.
The internal processing of 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.

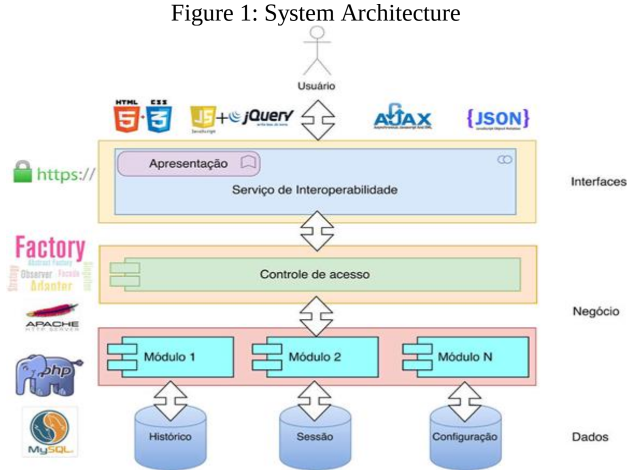
This model provides for the extraction of managers and experts' knowledge throughout the voting process.

The primary objective 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 implement the decision.

2. SOFTWARE ARCHITECTURE

In this context, Software Architecture consists of a high level model (Fig. 1) that allows for the understanding and implementation of the prototype to be developed. An important application of the software architecture is the possibility of using it as a tool to communicate the projected solution to the various stakeholders that participate in the software development process [11]. Fig. 1 presents the architecture diagram.

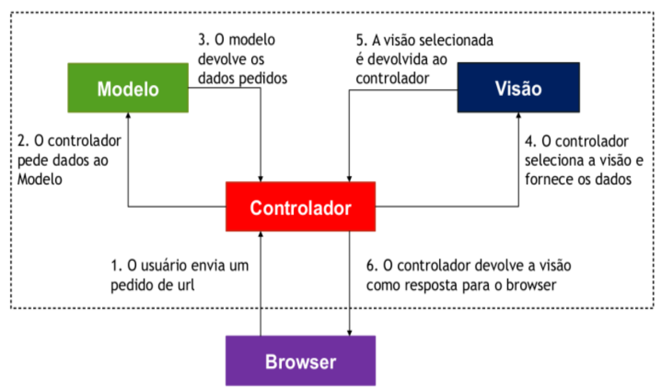
Figure 1: System Architecture



Source: Created by the authors.

The MVC (Model-View-Controller) Software Architecture standard was used because it is very widespread in the development of software applications in general. 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. Figure 2 shows this interaction between the layers.

Figure 2: Interaction between the layers



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The Browser makes the requests that are received by the Controller. It queries the models about the requested data and returns them to the Controller, selecting a view that will be sent in response to the requester (user or Browser).

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

3. PROTOTYPE

The core of the prototype consists of the data models (storage) and the algorithm AHP. 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.

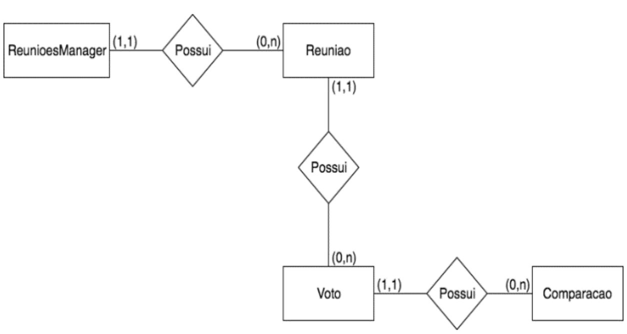
Technology

The prototype was developed using the web framework Django, the programming language Python and a relational database. The architecture is based on the MVC standard (previous section), layering the model (application data, business rules, logic and functions), view (data representation) and controller (input).

Data Model

The storage layer of the prototype is composed of four models/classes: *ReunioesManager (MeetingManager), Reuniao (Meeting), Voto (Vote) e Comparacao (Comparison).* The MER - Entity-Relationship Model shows the relationships, Figure 3.

Figure 3: MER - Entity-Relationship Model



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Implementation of the AHP algorithm

The AHP algorithm can be divided into 3 steps:
1- Construction of the GPV (Global Priority Vector);
2- Construction of LPV (Local Priority Vectors);
3- Allocation of alternatives.
The following describes the implementation of each of these steps.

Step 1: Global Priority Vector (GPV).

This stage is responsible for the construction of the GPV, which indicates the weight (or importance) of each criterion in the decision to be made. For this, the prototype, according to the definition of the algorithm, performs four steps: matrices representing each vote; calculation of the weighted average matrix; calculation of simple average of the votes; normalization of the matrix of averages; priority vector calculation.

i) Construction of the matrices representing each vote. To perform the mathematical calculations of the AHP algorithm, it is necessary to represent each vote using the matrix data structure. Figure 4 contains the code fragment responsible for loading comparisons data from the database to matrices in RAM.

Figure 4: Judgment Matrices Function

```python
def _build_votes_matrices(self, comparison_type, matrix_len, criterion=None):
    """
    Votes are represented as individual comparisions in the database.
    This method fetch the comparisons from DB and build a matrix representing
    all the comparisons for a given vote (participant).
    """
    votes_matrices = {}

    for vote in self.voto_set.filter(finished=True):  # only completed votes

        votes_matrices[vote.id] = []  # initialize the vote matrix

        # get comparisions between criteria (1st step)
        comparisons = vote.comparacao_set.filter(
            comparison_type=comparison_type,
            criterion=criterion,
        )

        self._fill_vote_matrix_with_comparisons(
            votes_matrices[vote.id],
            comparisons,
            matrix_len,
            criterion,
        )

    return(votes_matrices)
```

Source: Created by the authors.

ii) Calculation of the matrix of averages. The matrix of averages is obtained by calculating the average of the weight of the comparison between two alternatives/criteria. It can also be understood as the weighted average vote of the participants. Figure 5 represents the code snippet that computes the weighted average of the participant's votes.

Figure 5: Calculation of average of the votes

```python
def _build_average_votes_matrix(self, votes_matrices, matrix_len):
    """
    Return a matrix storing the average of the votes for each comparison
    between criteria.
    """
    average_matrix = []
    for i in range(matrix_len):
        average_matrix.append([0 for x in range(matrix_len)])

    for i in range(matrix_len):
        for j in range(matrix_len):
            values = []
            for vote_id in votes_matrices:
                values.append(votes_matrices[vote_id][i][j])
            average_matrix[i][j] = float(sum(values)) / max(len(values), 1)

    return(average_matrix)
```

Source: Created by the authors.

iii) Normalization of the matrix of averages. The normalization of the matrix of averages is an intermediate stage that prepares the matrix for the calculation of the priority vector. During normalization the value of each cell is adjusted in relation to the sum of its column (Figure 6), representing a weight relative to the rest of the column.

Figure 6: Normalization of the matrix of averages

```
def _normalize_average_votes_matrix(self, average_matrix, matrix_len):
    """
    The normalization calculates the weight of each individual cell
    regarding the other cells on the same column of the
    average matrix.
    """
    normalized_matrix = []
    for i in range(matrix_len):
        normalized_matrix.append([0 for x in range(matrix_len)])

    for j in range(matrix_len):

        # calculate the sum of the column j
        column_sum = 0
        for i in range(matrix_len):
            column_sum += average_matrix[i][j]

        # calculate the normalized value for each cel of the column j
        for i in range(matrix_len):
            normalized_matrix[i][j] = average_matrix[i][j] / column_sum

    return(normalized_matrix)
```

Source: Created by the authors.

iv) Priority Vector Calculation. The priority vector indicates the weight of each criterion in decision making. The result will be a percentage for each criterion indicating its importance in relation to the others. The sum of the importance of all criteria is 100%. The code in Figure 7 refers to the execution routine of step 1, where the voting matrices are constructed, matrix of average is calculated, normalized, and the priority vector returned.

Figure 7: Execution Routine - Step 1

```
def step1_build_priorities_vector(self, substep=None, formatted=False):
    """
    The priorities vector indicate the importance of each cretirion regarding
    the objective.
    The output is a vector (line) with a priority (percentage) for each
    criterion.
    substep = votes_matrices | average_matrix | normalized_matrix
    """

    votes_matrices = self._build_votes_matrices(
        COMPARISON_TYPES['CRITERIA'],
        len(CRITERIA)
    )
    average_matrix = self._build_average_votes_matrix(
        votes_matrices,
        len(CRITERIA)
    )
    normalized_matrix = self._normalize_average_votes_matrix(
        average_matrix,
        len(CRITERIA)
    )

    # substep is used to implement the AHP step-by-step visualization.
    if substep:
        if substep == 'votes_matrices':
            return(votes_matrices)
        elif substep == 'average_matrix':
            return(average_matrix)
        elif substep == 'normalized_matrix':
            return(normalized_matrix)

    priorities_vector = []

    for i in range(len(CRITERIA)):
        line_average = float(sum(normalized_matrix[i])) / max(len(normalized_matrix[i]), 1)
        if formatted:
            line_average = "%.2f%%" % (line_average*100)  # 0.2 = 20%
        priorities_vector.append(line_average)

    return(priorities_vector)
```

Source: Created by the authors.

Step 2: Local Priority Vectors (LPV). In step 2, the algorithm calculates the LPV (Figure 8). The vectors represent the importance of each alternative in relation to the criteria of decision making. The steps are the same as those of the GPV, the difference consisting of the evaluation of the five dimensions (an evaluation for each intangible criterion): are five matrices of averages (one for each criterion), five normalized matrices and five vectors of priorities. Each local priority vector indicates the importance of the alternatives in relation to a criterion. The tangible criteria are evaluated in a direct mathematical way and not by weighting, so they have a simpler vector of priorities. The calculation is done with the relative weight of each value in relation to the whole.

Figure 8: LPV calculation

```
def step2_build_local_priorities_vectors(self, substep=None, formatted=False):

    num_alternatives = len(self.energy_sources)

    votes_matrices = {}

    for crit in CRITERIA:

        # initialize the vote matrix
        votes_matrices[crit['code']] = self._build_votes_matrices(
            COMPARISON_TYPES['ENERGY_SOURCES'],
            # we build the matrix with 4, but then we remove the energy sources
            # that need to be removed
            4,
            crit['code'],
        )

    # build average matrices and normalize them
    averages_matrices = {}
    normalized_matrices = {}
    local_priorities_vectors = {}
    for crit in CRITERIA:
        averages_matrices[crit['code']] = self._build_average_votes_matrix(
            votes_matrices[crit['code']],
            num_alternatives,
        )
        normalized_matrices[crit['code']] = self._normalize_average_votes_matrix(
            averages_matrices[crit['code']],
            num_alternatives,
        )

        # calculate the local priorities vectors (those vectors tell the
        # importance of each energy source relativily to the criteria)
        local_priorities_vectors[crit['code']] = []
        n_matrix = normalized_matrices[crit['code']]
        for i in range(num_alternatives):
            line_average = float(sum(n_matrix[i])) / max(len(n_matrix[i]), 1)
            if formatted:
                line_average = "%.2f%%" % (line_average*100)  # 0.2 = 20%
            local_priorities_vectors[crit['code']].append(line_average)

    # calculate the local priorities for tangible criteria and save it back
    # into the local_priority_vectors dictionary
    self._tangible_criteria_lpv(local_priorities_vectors, formatted)

    # substep is used to implement the AHP step-by-step visualization.
    if substep:
        if substep == 'votes_matrices':
            return(votes_matrices)
        elif substep == 'average_matrix':
            return(averages_matrices)
        elif substep == 'normalized_matrix':
            return(normalized_matrices)

    return(local_priorities_vectors)
```

Source: Created by the authors.

Step 3: Alternatives ranking. Realizado o cálculo do VPG (que indica a importância de cada critério em relação à decisão a ser tomada) e do VPL (que indica a importância de cada alternativa em relação a cada critério) é possível realizar o ranqueamento final das alternativas multiplicando as prioridades presentes nos dois vetores (Figura 9). The VPG captures the importance of each criterion in relation to one another. The VPL, in turn, conveys the idea of how each technology (type of source) fits more or less each criterion. The product of both, VPG and VPL, provides the relative weight of each alternative renewable source.

Figure 9: Final ranking of alternatives.

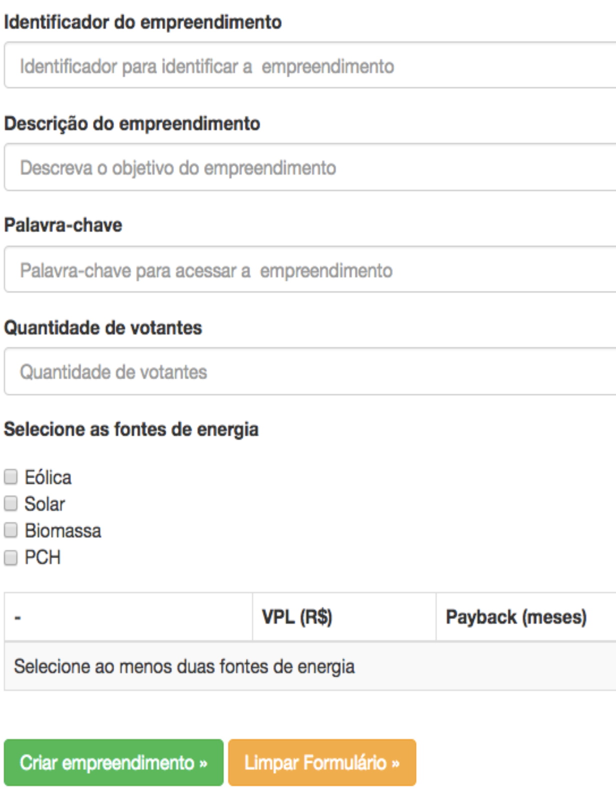
```
def step3_build_final_rank(self, formatted=False):

    num_alternatives = len(self.energy_sources)

    gpv = self.step1_build_priorities_vector()  # global priorities vector
    lpv = self.step2_build_local_priorities_vectors()  # local priorities vectors

    rank_matrix = {}
    for crit in CRITERIA:
        rank_matrix[crit['code']] = []
        for i in range(num_alternatives):
            result = gpv[crit['code']-1] * lpv[crit['code']][i]
            rank_matrix[crit['code']].append(result)

    final_rank = []
    for i in range(num_alternatives):
        importance = 0
        for crit in rank_matrix:
            importance += rank_matrix[crit][i]
        if formatted:
            importance = "%.2f%%" % (importance*100)  # 0.2 = 20%
        final_rank.append(importance)

    return(rank_matrix, final_rank)
```

Source: Created by the authors.

Validation Test

The algorithm that simulates the AHP technique was tested according to the user validation methodology, simulating a session with two participants and three energy sources: wind, solar and biomass. Votes were counted, and the tangible factors were defined. The result was calculated with AHP algorithm, both manually and by the program, obtaining consistent and satisfactory results.
Figure 10 shows the creation screen for a new project. When selecting energy sources, the user is asked for the tangible criterion for each of the energy sources - their NPV and Payback. Figures 10, 11, 12, 13 and 14 present the interface for managers vote.

Figure 10: Interface for new project



Source: Created by the authors.

Stage 1. Stage 1 (*Etapa 1*) AHP compares the degree of importance that a user gives to one criterion in relation to the other six, for a total of seven criteria:

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.

Fig. 11 presents the voting process of Step 1.

Figura 11: Voting Screen (Step 1)

Source: Created by the authors.

Etapa 2. In step 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 form a LPV. Fig. 12 illustrates the voting procedure in process in step 2, associated with one criterion.

Figura 12:- Step 2 votes

Source: Created by the authors.

Result
With the VPG and LPVs defined, the final calculation is performed, which shows the result in percentage.How much each energy source fits with the participants''experience and knowledge.

4. 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 POC's were performed:

i) first - in a conceptual way, with the internal team of researchers and developers; during a face-to-face meeting of the project developers, including the UFMG teachers and students team, PUC-MG and the responsible manager of CEMIG, the navigation options and interface screens were presented and the requirements were discussed; recommendations were made for finalizing the prototype;

ii) intermediate - conceptual and practical with the internal team of researchers and developers; during a face-to-face meeting of the project developers, including the UFMG teachers and students team, PUC-MG and the responsible manager of CEMIG, a staff member and specialist, electrical engineer, presented the conditions of a new project; the participants conducted the voting for simulation and prototype testing without the intention of obtaining real results because the were not experts;

iii) finally - in a practical way, with the participation of the Project team, the CEMIG team and invited experts. Among the participants were CEMIG specialists and Professors.

The methodology proved to be of great importance as a construction, consolidation and validation tool; during a face-to-face meeting with developers and participants. A real situation was presented, the expert participants did the simulation. And developers watched the simulation.

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

5. CONCLUSION

The step presented in this paper consist of the computational simulation of a decision-making process based on tangible and intangible criteria. The criteria are processed in a logical and mathematical way to achieve the final result of the best investment in the renewable energy portfolio. This process was based on technical, economic and financial factors and proposed a methodology to extract the knowledge of the experts with the analysis of previously defined criteria. The simulation was done by pairwise comparison of parameters by systemic analysis. The result presents the best option to neutralize the individual choice. In this way the process makes it more consistent for the decision making about which energy project to invest.

The proof of concept carried out with electrical engineers, domain experts, validated 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 developed model was applied, tested and analyzed within the specific domain proposed by the project, that is, in the area of electrical engineering for decision making processes of investment in renewable energy sources. The model presents an extended form of applications in different contexts from the definition of another set of criteria and applied to other domains.

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