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Fuzzy Logic for Evaluation of Renewable Energy Projects

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ABSTRACT:-*The disproportionate use of fossil fuels generated by the different human activities continues to produce increasingly drastic effects by the emissions of pollutants, which are reflected in the negative effects of climate change. Most of the renewable energy projects are developed taking into account economic, social and environmental criteria and most of them are of subjective nature. This work presents a Fuzzy Logic system that allows establishing the viability of carrying out a renewable energy project considering a number of different objective factors. The system was implemented using the MATLAB Fuzzy Logic Toolbox for its evaluation. The advantage of our methodology is in that it will allow analyzing the feasibility of new projects.*

Keywords:-*Fuzzy, Renewable, Projects, Investment.*

I. INTRODUCTION

There are many factors that contribute to the continuous change of the mosaic of primary energy production in the world. Among the most important are: environmental degradation due to climate change, nuclear accidents, shortage of traditional energy sources and the scientific development reached by all countries. With the influence of this environment, it is expected that by the year 2050, 20% of the primary energy would come from photovoltaic energy and that by 2100, 70% would be reached, obviously combined with other traditional and renewable sources[1].In 2015, these numbers are completely reversed; the main primary energy sources are coal, gas and oil.

For this reason, it is expected that for the next few years, there is an increase in renewable energy projects whose objective would be to offer the possibility of generating electricity and heat basically without emissions, with low operating costs and in a sustainable manner. These projects are characterized for being different form each other.

Currently, a canned food plant can be cloned from one country to another with minor changes. Would it be the same to install 1 MW of power in Germany than in the northwest of Mexico, or, would it be the same to install a wind farm in Patagonia in Argentina than to install a solar park in the Atacama Desert? The conditions change completely; they are two completely different projects. What source of renewable energy should be used in a certain place in the planet? Once this problem is solved, the greatest problem of all must be faced: the search for risk capital to invest in photovoltaic projects. Most countries are not prepared with financial instruments to face this type of investment, for this reason, a new question arises, which capital structure would be favorable for a photovoltaic business?

Soft Computing techniques have been applied successfully on multiple current applications; one of the most successful is Fuzzy Logic. This research work presents the application of fuzzy logic for the evaluation of renewable energy projects and, above all, the advantage that it presents with respect to other tools for the analysis of solutions for project and investment proposals [2]. Fuzzy Logic is proposed as an alternative approximation to the probability theory to quantify decisions and take risks unlike existing tools that are characterized by uncertainty, vagueness and approximation.

Why use Fuzzy Logic? The use of Fuzzy Logic (FL) is advisable when you have highly complex systems or when the mathematical models that describe them are unknown and at the same time you have the experience of an expert that manages to successfully control the system, that is, introduces vagueness and the inherent subjectivity of human activity in an automated procedure. Thus, fuzzy logic emulates one of the intelligent features of humans, reasoning under uncertainty. Additionally, it is advisable to use this tool when certain parts of the system to be controlled are unknown and cannot be reliably measured (with possible errors) and when the adjustment of a variable could produce disadjustment of other variables.

The purpose of this article is to present a system using Fuzzy Logic that allows making decisions on whether or not it is convenient to carry out a renewable energy project. The system will be implemented using MATLAB´s Fuzzy Logic Toolbox for its evaluation.

The algorithm, once it is refined, could be extended with ease, increasing the number of input variables, as well as the rules that represent the knowledge of the expert. This process of extension will be, without a doubt, easier than it is in any other mathematical model.

II. FUZZY LOGIC AND FUZZY SETS

Fuzzy Logic is mostly known today thanks to the work of Lotfi A. Zadeh from Berkeley University during the sixties [3]where the concepts of fuzzy logic were formalized. During that decade, a great part of the logical and mathematical structures in terms of fuzzy logic are widespread: relations, functions, sets, operations, operators, algorithms, etc. In the seventies, different Japanese groups make major contributions to the development of theory, as well as the study of its applications[4],[5]. Mamdani develops the first fuzzy controller for a steam engine in 1974 [6]. During the eighties, the first practical implementation of a fuzzy logic occurs in the FL Smidth& Co. cement plant in Denmark [7]. In 1983, Fuji Electric Co. in Japan [8] applies fuzzy logic to chemical injection control in a wastewater treatment plant for the first time. In 1987, Hitachi [8] starts up a fuzzy controller to control the fast train in Sendai. Omron [8]develops the first commercial controllers.

The boom of Fuzzy Logic applications occurs during the 90s when consumer products marked as fuzzy began to appear. Although the application to the fuzzy control was not the first application of the fuzzy set theory, it did draw attention to this theory. The most interesting part of Fuzzy Logic is that it accepts uncertainty in its inputs, which is inherent to them and deals with them in a way that the results are not affected by these uncertainties, thus the result is precise.

As it has been explained, fuzzy logic is nowadays known for all of its contributions and basically the contributions of L. Zadeh, however, its origins date back to 2500 years ago when Greek philosophers mentioned varying degrees of veracity and falsehood.

2.1 Fuzzy Sets

A fuzzy set is defined as one in which its elements belong to it with a certain degree of membership μ. A fuzzy set A is defined with a *Membership Function* $\mu_A(x)$ which maps the elements of a domainor*Universe of Discourse* X with elements of the interval $[0,1]$ [9], [10] $A: x \to [0,1]$

The closer the $A(x)$ element is to the value1, the greater the membership of the object "x"to set A. The values of membership vary between 0 (does not belong at all) and 1 (total belonging).Then A is defined as:

$$A = \{(x, \mu_A(x)); x \in X\}$$

The fuzzy set A is defined as a set of ordered pairs $(x, \mu_A(x))$ where x belongs to X with its membership degree, that is, the Universe of Discourse with its membership degree. It can also be represented as a *sum of pairs.*

$A = \sum A(x_i)/x_i$ (The pairs in which $A(x_i) = 0$, are not included)

If the Universe of Discourse is continuous, then

$$A = \int_x A(x)/x$$

The *summations* and *integrals* should not be considered algebraic operations**.**

The concept of membership does not represent a statistical probability, but the degree in which an element of a set displays a property that characterizes the fuzzy set. This is different from the probability of rolling any of the sides when a die is tossed. [11].Next, some important definitions are presented [12]

Linguistic Variable: it is the notion or concept that we are going to evaluate in a fuzzy manner: height, age, error, etc.

Universe of Discourse: the range of values that can be taken by the elements that have an expressed property by the linguistic variable.
Linguistic Value: the different classifications done on the linguistic variable: Low, Medium, High, Very High, etc.
Membership Function: it is the application that relates every element of a fuzzy set to the degree it belongs in the associated linguistic value.
A fuzzy set can also be represented *graphically* as a function, especially when the universe of discourse *X* (or underlying domain) is continuous (not discrete), as it can be observed in Fig 1.

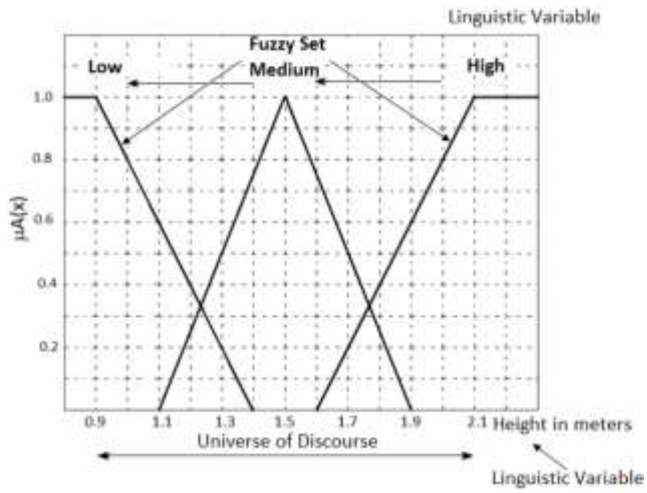

Figure 1: Fuzzy Set.Membership Function. (Abscissa (X-axis): Universe of Discourse X; Ordered (Y-axis): Membership Degrees in the interval [0,1])

In fuzzy logic, many types of membership functions can be defined according to the problem, expert experience and suitability. Some of the most commonly used are presented next (see Fig 2).

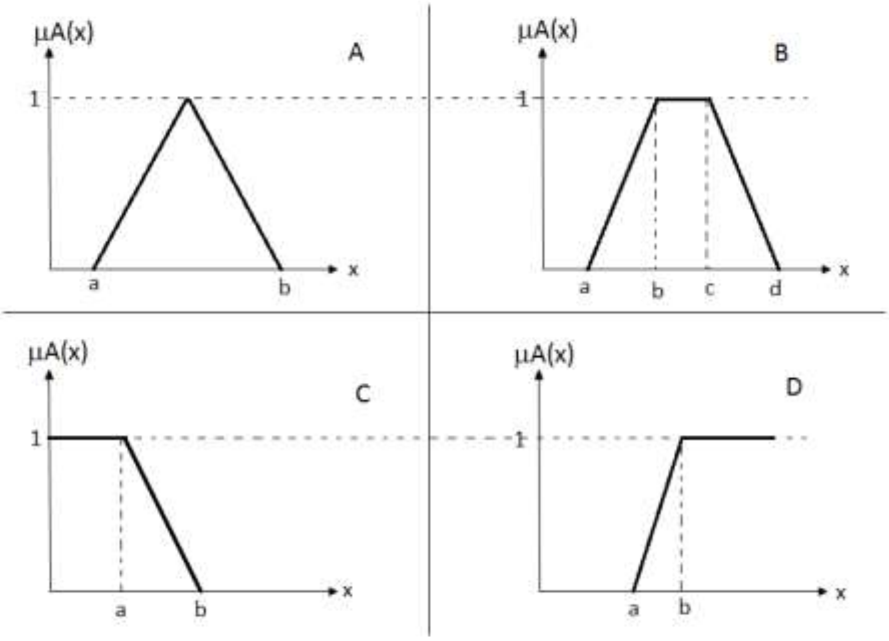

Figure 2: The most used Membership Functions. (a) Triangular. (b) Trapezoidal. (c) L Type (d) Gamma

2.2 Fuzzy Inference System (FIS)

The Fuzzy Inference System (FIS) is a rule based system. They are a set of rules that express the foundation of the fuzzy set theory and fuzzy logic. The FIS maps the input space to the output space.
The FIS allows constructing structures that are used to generate responses (outputs) by certain inputs. The rule base expresses the relation between inputs of a system and expected outputs.

The FIS responses are based on stored knowledge (the relation between response and stimulus). The knowledge is stored in the form of a rule base; the knowledge of an experienced expert. These systems are sometimes known as expert systems. The Fuzzy Inference System is also known as fuzzy knowledge-based system.

2.3 Fuzzy Decision Making System (FDMS).

A fuzzy decision making system is integrated by four components [13]

- Fuzzification Interface.
- Knowledge Base.
- Decision-making Logic.
- Defuzzification Interface.

Fuzzification Interface: Input variable values are applied to their membership function to determine the degree of truth of each premise.

Knowledge Base: The expert´s experience is reflected here; the set of rules that relate the inputs with the outputs. The membership functions of inputs and outputs are designed by the expert according to his experience and the system.

*Decision-making Logic:*The basic process of decision-making consists of evaluating a set of alternatives in the presence of relevant objectives and restrictions. If these objectives and restrictions are presented in a linguistic form, they can be represented in terms of fuzzy sets. The decision will be determined by means of their joint or aggregate consideration, and it is similar to human decision-making. They are inferred from the fuzzy control actions based on the rules in fuzzy inference. The evaluation of a rule is based on the calculation of the degree of truth in its premise and applying it to its final part. As a result, there is a mapping of a fuzzy subset for each output variable of the rule.

*DefuzzificationInterface:*A fuzzy control action is converted to a non-fuzzy control action. The most common defuzzification method is the center of area method.

2.4 Construction of the Model.

The Systems based on Fuzzy Rules have been used in many areas of research and in applications to model systems. Due to its various uses, these fuzzy systems have divided the literature into three main categories: the Mamdani, Takagi-Sugeno (T-S) [14],[15] and Tsukamoto systems. Their fundamental difference is in the form in which they implement the structures to the fuzzy rules.

Besides this classification, depending on the fuzzy application that is going to be done, there is another important division of two main approaches. The first is the fuzzy linguistic modeling in which a good human interpretation of the problem emphasizes the fuzzy model; under this condition, the Mamdani structures are used. The second is known as the precise fuzzy modeling where T-S and Tsukamoto fuzzy rules structures are generally used. Usually, Mamdani fuzzy rules structures are easier to interpret for a human being and it can explain a systems behavior better than the T-S.

The development of the model is done according to the aspects that most researchers agree in relation to the topic and based on our own experiences. This means that it is possible that another researcher may have different experiences and thus, some formulations might differ. This will be reflected on the selection and amount of linguistic variables, as well as the linguistic values in the form of membership functions and base rules. Our model is constructed on the MATLAB based algorithms in the Fuzzy Logic Toolbox.

III. DEFINITION OF LINGUISTIC VARIABLES.

Linguistic variables are the indicators that will be used to characterize or evaluate the system in a fuzzy form.

Since our model is constructed on the MATLAB based algorithms in the Fuzzy Logic Toolbox and based on what was stated before, the meaning of each of the linguistic variables used will be explained.

Now, the indicators that an expert would use when evaluating the implementation of a photovoltaic project need to be determined. When an evaluation program is developed, many indicators will be considered based on their importance, and it will always be in the same manner. An advantage of project evaluation with intelligence programming is that it will not rely on the evaluator´s conditions, not even if there are different evaluators. Next, the most important indicators are presented:

1. Socio-economic.
a) Gross Domestic Product (GDP).
b) Recent laws that regulate investment on Renewable Energy.
2. Natural-environmental.
a) Available areas for the installation of energy plants.
b) Recent energy disasters.

c) Raw material.
i. Daily insolation.
ii. Fossil fuels existence.
iii. Wind.
iv. Geothermic.
v. Other
3. Raw material costs.
a) Volatility of raw material.
4. Type and cost of technology.
5. Energy contribution from raw materials.
6. Political will.

It is certain that more indicators can be determined; however, the main problem is that these indicators need to be measurable in order to be fuzzified and integrated into the system. For simplicity purposes and because it does not affect the presentation of the problem, only 3 of them will be used.

- Cost of raw material.
- Cost of technology.
- Internal energy.

The selection of the number of linguistic variables, as well as their linguistic values affects the computational task since:

Number of rules to evaluate = (# Linguistic variables) $^{\text{\# of linguistic values.}}$

If we take 3 linguistic variables, like in our example, and their values are divided in 3 ranges, we will only have 27 rules, which is a convenient number to manage in an example such as this. However, if we only take *10* linguistic variables y divide their values in 5 ranges, we will have 100000 rules to evaluate. These numbers are not excessive in a real problem. This is the rational for taking just 3 linguistic variables and dividing their values into 3 ranges.

3.1 Cost of raw material. Fuel to produce energy [16].

Oil, Coal, Natural Gas, Solar Energy, Wind Power, Urban Waste, and Agricultural Waste will be taken into account. The unit of measurement would be *USD/kg.*

For the Renewable Energies such as Solar and Wind, this unit of measurement does not apply; however, since its cost is 0, it does not affect the problem. Therefore, the lower limit for the Universe of Discourse of the linguistic variable Cost of Raw Material is zero.

The traditional fuels to produce electricity are oil, coal and natural gas. Their costs are calculated based on extraction, transportation, gains and insurance. Another important aspect to consider is the worldwide reserves; for coal, it is calculated to lasts for 200 years, while oil is calculated to last for only 45 years. Besides these objective factors, there are the subjective elements such as regional confrontations, regional agreements or groups of producers' agreements, and stock market speculation. This causes volatility in prices and therefore, only one upper limit will be established. The price of oil at 110 USD/barrel is between 0.73 and 0.92 USD/kg. The Linguistic variable Fuel Price (FP) will have a universe of discourse range between ***0***to 1USD/kg.

3.2 Membership Function.

The easiest membership functions have been taken: triangular, L type and Gamma.They are graphically represented in Figure 3.

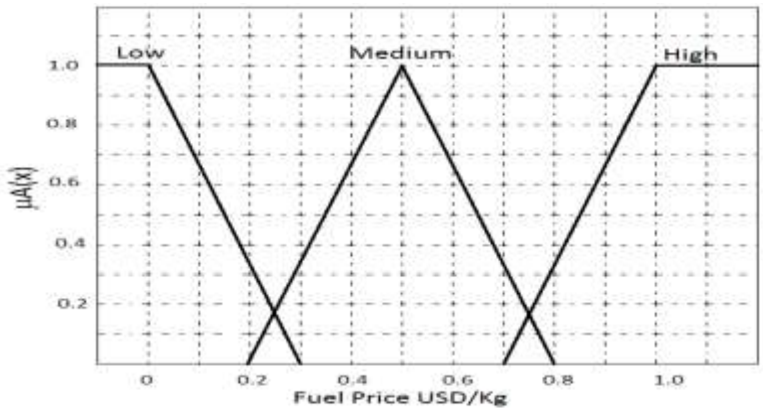

Figure 3: Transference functions for the linguistic variable Fuel Price with the linguistic values Low, Medium and High.

3.3 Cost of Technology. [17], [18]

The cost of technology is one of the most difficult variables to reduce to a range since it depends not only on the type of technology, but also on the size of the installation. Since the intention in this research work is to define the Universe of Discourse of the linguistic variable Cost of Technology, only 2 extreme values are taken. In the Table 1, it can be seen that:

Table I:

Cost of Generating Installations		
Type of Technology	Price of USD/kW	Size of Installation
Hydroelectric Power Plant	*400-3000*	*500 MW*
Coal	*877*	*150 MW*
Gas	*326*	*300 MW*
Diesel	*267*	
Biomass	*1500*	*30 MW*
Combined Cycle	*424*	*200*
Solar Photovoltaic	*6500*	*1 kW*

The cost of installation will be established between 0.1 and 10 USD/W with linguistic values divided in three membership functions.

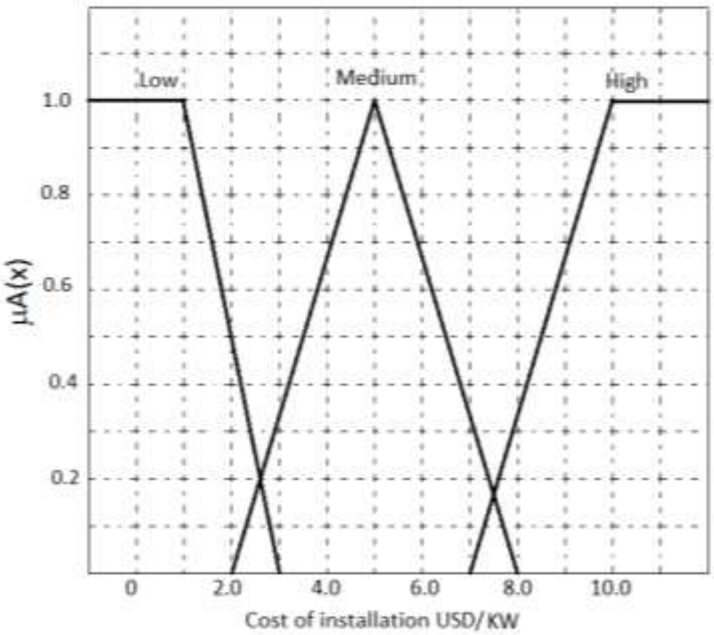

Figure 4: Membership Function for the cost of installation.

3.4 Internal Energy. [19]**,** [20]**,**[21]

This linguistic variable brings us back **t**o the genesis of all production; how much would the maximum of energy obtained from a dollar invested in fuel be? This maximum is given by the internal energy from the raw material. How much energy is obtained by breaking the bonds of coal to release it? How much does this process cost?

The Kep (kilogram equivalent petroleum) approximately equals to 10 000 Kcal, according to the oil that is taken as reference. We know that on average, an oil barrel can weight around 135 Kg of oil. The price of an oil barrel has been, for many years, near 100USD. As it can be seen, we are dealing with a vague linguistic variable, with a great deal of uncertainty which is something characteristic of a variable that is going to be used for a fuzzy problem. Taking into account all of these factors, it can be said that **1 Kep** is equal to 23.24 KWh/USD.

In a similar reasoning, 1 Kec (coal) is equal to 81.4 KWh/USD. For the energy from the Sun it is slightly different since it cannot be weighed or taken as volume units. Its measurement is done by square meters, thus the cost of the raw material will be taken by square meters. In this way, the Meter Equivalent to Solar Energy is defined as MES, which is equal 12 KWh/USD. From this reasoning, the linguistic values and membership function shown in Figure 5 are defined.

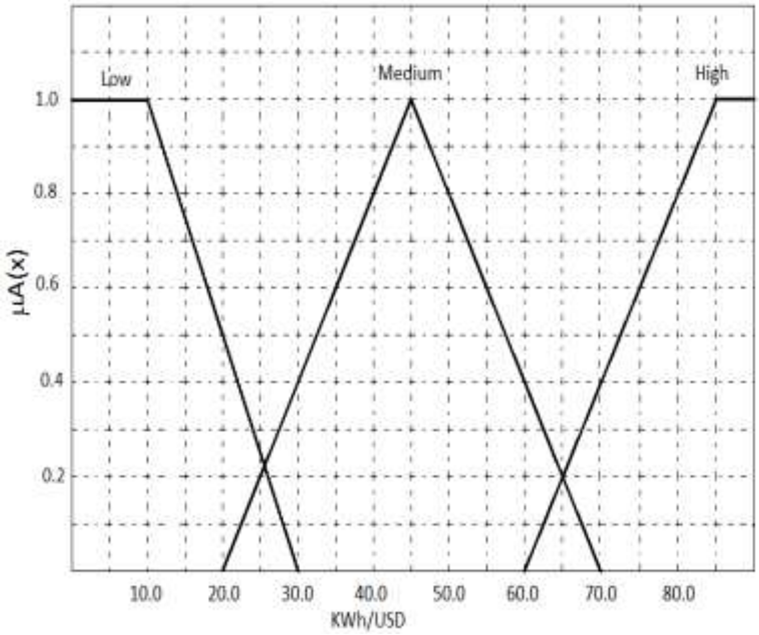

Figure 5: Membership Function of the Internal Energy Variable

IV. SETTING

For the evaluation of a project, crisp values must be taken in the place where the project is intended to be carried out and at the time it will be done; then, fuzzify them according to the defined membership functions and apply them to the rules that were created. After obtaining the fuzzy values of the output variables, defuzzify them to obtain a value that makes sense to a human being. This process was carried out using MATLAB Fuzzy Logic Toolbox. Figure 6 shows a representation of the membership function, as well as the linguistic values of the input variable "Costo MP" (Cost of Raw Material).

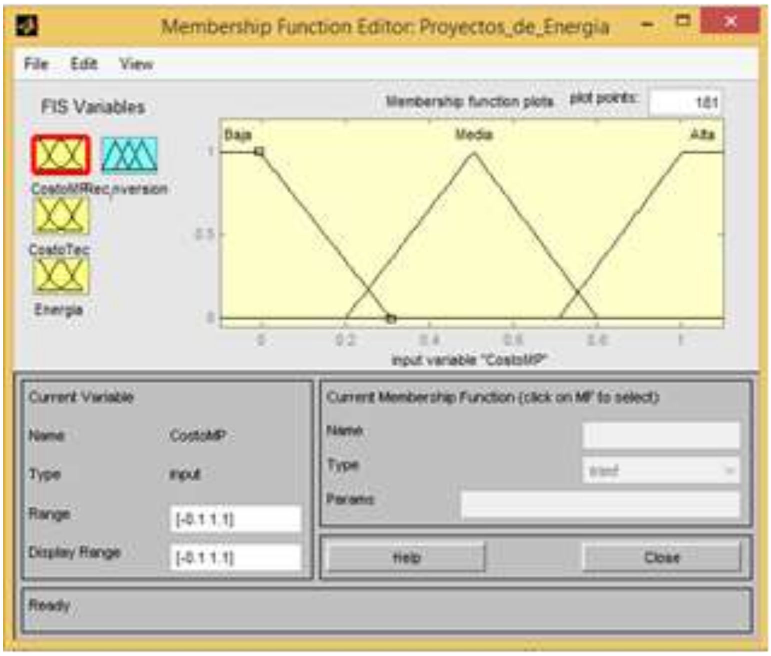

Figure 6: Membership Function and linguistic values of the variable 'Cost of Raw Material'.

Figure 7 shows MATLAB´s rule editor and some of the 27 rules used in the problem.

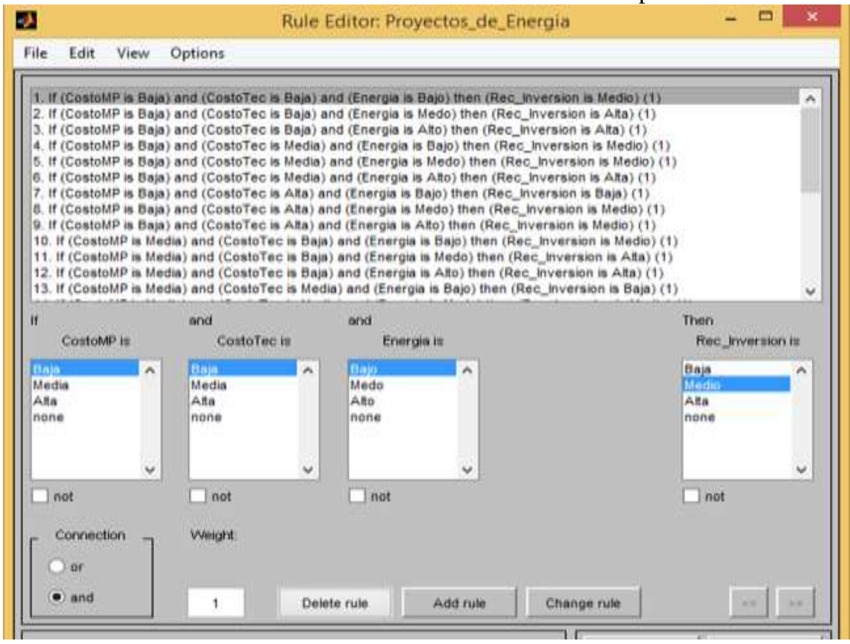

Figure 7: MATLAB´s Rule Editor and some of the 27 rules.

Figure 8 shows the evaluation of the 27 rules, as well as the values of output variables.

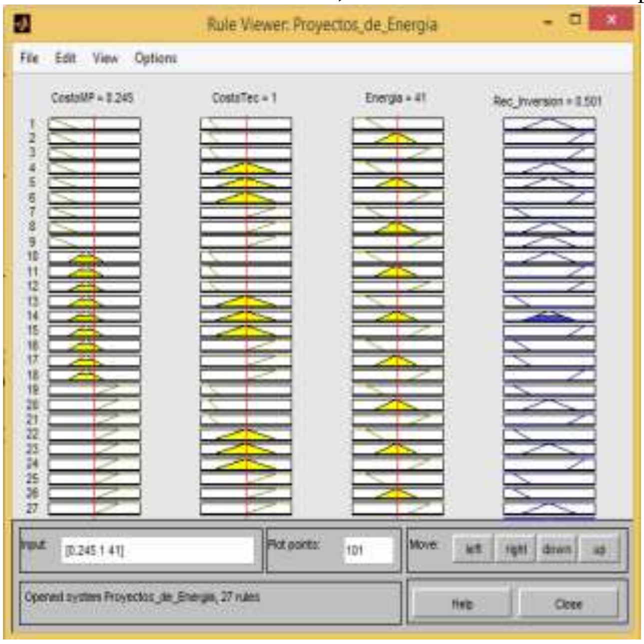

Figure 8.Application of rules.

V. RESULTS

With the linguistic variables defined, the development of a solar project receives an evaluation of only 0.5 points. In this case, it is limited by the cost of internal energy per square meter. If the price of the land is reduced in a manner that this variable approximates to 59 KWh/USD, then the 0.5 value increases to *0.84*, which means that the project´s development could be very interesting for an investor if the cost of technology remains lower than 0.84 USD/KWh.

A thermoelectric plant with fossil fuels could reach similar levels of acceptance if the cost of raw material is 0.26 USD/Kg and if the cost of technology is 0.2 USD/KW. The limitation here is in the cost of raw material.

VI. CONCLUSIONS AND RECOMMENDATIONS.

In the results, it can be observed that the development of some objective conditions can be established from the evaluation of real situations in order to determine the best project. Thus, a program such as this, allows evaluating possible investments, but above all, it allows the planning in which these objective conditions need to be directed for a project to be viable.

In this brief description, it has become evident that the variables to take into account are vague; no mathematical relation of any type has been taken into account, therefore, this problem needs to be evaluated in a fuzzy manner.

For its real application it is clear that the following must be done: an increase of linguistic variables, reformulation of the rules, optimization of the membership functions, etc. All these modifications must be done by an expert in investment opportunity and by a Fuzzy Logic specialist.

When a program of such magnitude is carried out, it can easily be used by any person who does not have a high level of expertise. This will allow evaluating projects in different regions and by different people, but with the same approach. A tool such as this could be useful for administrative, financial and political organizations.

Through an extensive literature review, it has been demonstrated that the application of fuzzy logic in decision-making regarding the application of photovoltaic projects has not been reported [22].

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REFERENCES

[1]. "WBGU'S World Energy Vision," 2003. [Online]. Available: http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/hauptgutachten/jg2003/wbgu_jg2003_engl.pdf.. [Accessed 28 12 2015].

[2]. K. N. Vinay and S. K. Yadav, " Proyect Management Efficiency - A Fuzzy Logic Approach.," *International Journal of Engineering and Advanced Technology (IJEAT),* vol. 1, no. 3, pp. 34-38, February 2012.

[3]. L. Zadeh, " Fuzzy Sets," *Information and Control 8,* pp. 338-353 , 1965.

[4]. M. Sugeno, "Fuzzy measures and fuzzy integrals—a survey.," *Fuzzy Automata and Decision Processes.,* p. 89–102, 1977.

[5]. M. Kumano, " The clinical significance of differential diagnosis of the hepatic scintiphotograph in diffuse liver diseases.," *Journal of Japan Radiological Society 36.,* pp. 491-519 , 1976.

[6]. E. Manndami, "Application of fuzzy algorithms for the control of a dynamic plant.," *Proc. IEE 121.,* pp. 1585-1588., Dec 1974.

[7]. H. L.P. and J. Ostergard, "Control of cement kiln by fuzzy logic. (1982).," *Fuzzy information processes,* pp. 389-399.

[8]. M. Norton Wise, Growing Explanations Historical perspectives on Recent Science, Duham and London: Duke University Press, 2004, p. 162.

[9]. J. Jantzen, " Tech. report noTech. report no 98-E 868," DK - 2800 Lyngby, DENMARK, 19 Aug 1998..

[10]. M. Mendel Jerry, " Fuzzy Logic Systems for engineering: A Tutorial.," *Proceedings of the IEEE,* vol. 83, no. 3, March 1995.

[11]. K. Bart., "Fuzziness vs Probability.," *Int. J. General Systems.,* vol. 17, pp. 211-240, March 1990.

[12]. D. Kaehler Steven, "www.ing.unibs.it," [Online]. Available: http://www.ing.unibs.it/~cassinis/Dida/2003/robb/Documentazione/Tutorial%20fuzzy%20logic.pdf.. [Accessed 28 12 2015].

[13]. D. F., "Fuzzy development of crisp activity relationship charts for facilities layout.," *Computer and Industrial Engineering 36. ,* pp. 1-16, 1999.

[14]. M. Sugeno and Y. Takahiro, "A Fuzzy – Logic – Based Approach to qualitative Modeling," *IEEE Transaction on Fuzzy Systems,* vol. 1, no. 1, Feb 1993.

[15]. M. Sugeno, "An introductory survey of fuzzy control," *Information Sciences.,* Vols. 36,, no. 1-2, p. 59–83., July–August 1985..

[16]. BPStats, "www.bp.com," [Online]. Available: http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2015/bp-statistical-review-of-world-energy-2015-full-report.pdf. [Accessed 28 12 2015].

[17]. P. R. Díaz Herrera, "www.academia.edu," [Online]. Available: https://www.academia.edu/6079727/An%C3%A1lisis_comparativo_de_la_configuraci%C3%B3n_de_las_tecnolog%C3%ADas_de_generaci%C3%B3n_el%C3%A9ctrica_con_captura_y_almacenamiento_de_CO2_en_M%C3%A9xico. . [Accessed 28 12 2015].

[18]. "es.scribd.com," [Online]. Available: http://es.scribd.com/doc/61153946/COSTOS-DE-CENTRALES-ELECTRICAS#scribd.. [Accessed 28 12 2015].

[19]. "Biblioteca Central - OCID," [Online]. Available: http://biblioteca.uns.edu.pe/saladocentes/archivoz/curzoz/tablas_tema_3.pdf.. [Accessed 28 12 2015].

[20]. "www.siel.gov.co," [Online]. Available: http://www.siel.gov.co/Siel/Documentos/documentacion/Generacion/Costos_Indicativos_Generacion_EE.pdf.. [Accessed 28 12 2015].

[21]. [Online]. Available: http://www.redproteger.com.ar/conversiones_energeticas.html . [Accessed 28 12 2015].

[22]. A. A. S. Suganthi L. S. Iniyan, "Applications of fuzzy logic in renewable energy systems–A review.," *Renewable and Sustainable Energy Reviews 48,* p. 585–607., 2015.