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A FUZZY EXPERT SYSTEM FOR THE ASSESSMENT OF THE SUSTAINABILITY OF ENERGY TECHNOLOGIES

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SOMMARIO

The power plants provided the energy required for the economic and technological development in last decade. At the same time the environmental effects of electricity generation are significant because modern economy uses large amounts of electrical power. So power plants activity can produce positive and negative effects on the population which must be taken into account. In many cases some kinds of power generation systems - due by release of air pollutants, radioactivity, water and soil contaminations (oil spill)- can have a significant adverse impact on the environment increasing health risks and reducing standard of living of local communities. In this paper a methodology based on fuzzy-sets is proposed to assess the impact on local scale of the sustainability of the most important electricity power production technologies.

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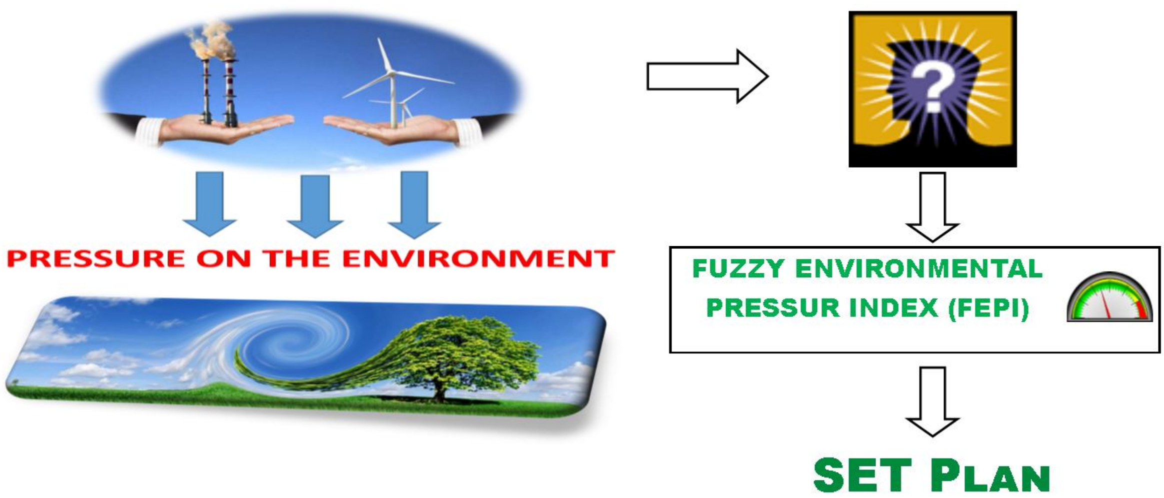
1. Introduction

Power plants activity can produce positive and negative effects on the population which must be taken into account. In many cases some kinds of power generation systems - due by release of air pollutants, radioactivity, water and soil contaminations (oil spill) - can have a significant adverse impact on the environment increasing health risks and reducing standard of living of local communities. For this reasons we cannot absolutely to ignore the environmental effects of electricity production processes. In literature interesting papers have gaven to the light the important relationship between electricity production processes and ecological and human health modifications (Santoyo-Castelazo, Azapagic 2014; Evans, Strezov, Evans 2009; Prakash, Bhat 2009; Maxim A, 2014; Cavallaro, Ciraolo 2013). Unfortunately in many cases the amount of information used in the assessment models is affected by uncertainty. A first source of uncertainty comes from the variability of the data, due to the non-deterministic nature of social and natural facts. Another type of uncertainty is imprecision that appears when observing or measuring the values of a variable, because of both the measuring instrument and the observer that undertakes the task (Cavallaro 2010). Fuzzy-set based methods have proved to be able to deal with uncertainty in environmental topics.

In this paper a methodology based on fuzzy-sets is proposed to assess the pressure on the environment of the most important electricity power production technologies. This paper is organized as follows: the section 2 describes the fuzzy inference approach, section 3 contains the application of the model, finally in the section 4 is reported the conclusion.

Figure 1 The proposed model

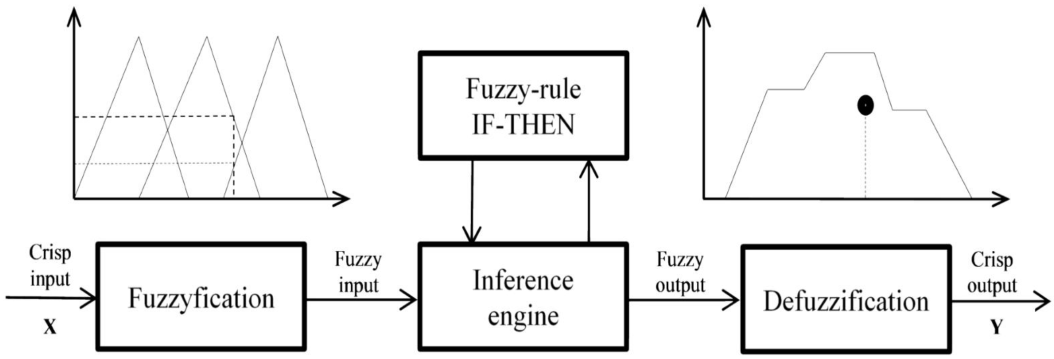


2. Fuzzy inference system

In a fuzzy inference model (approximate reasoning) the reasoning process is based on a series of *if-then* rules as a kind of expert knowledge (Cornelissen et al 2001; Öztaysi et al. 2013). The conditional statement (or proposition) contains a *premise*, the *if-part*, and a *conclusion*, the *then-part*. The knowledge incorporated in a fuzzy control system is made up of a collection of several parallel rules in the form '*if X is A then Y is B*', or more generally '*if X_1 is A_1 and ...and X_n is A_n then Y is B*', where *A, A_n, B* are fuzzy sets (Dubois et al. 2007). The *knowledge base*, which contains the general knowledge concerning a problem domain, and which connects antecedents with consequences, premises with conclusions, or conditions with actions. A fuzzy inference system (FIS) is composed of three blocks (Saberi Nasr et al. 2012). The first one, *fuzzification*, converts the crisp value input to a linguistic variable using the membership functions stored in the fuzzy knowledge base. To the second block, the *inference engine*, is assigned the task of evaluating the input's

degree of membership to the fuzzy output sets using the fuzzy rules. Finally, the defuzzifier block transforms the fuzzy output into a crisp value (Fig. 2).

Fig. 2 Fuzzy Inference System (FIS)



The inference stage utilizes the fuzzy input values to activate the inference rules and generate the fuzzy output value. There are two main approaches to fuzzy inference, which are usually denoted as the Mamdani type and the Takagi-Sugeno-Kang type (or simply the Sugeno type) FIS (Klir, Yuan 1995). A graphic illustration of Mandami FIS is also shown in Figure 3 .

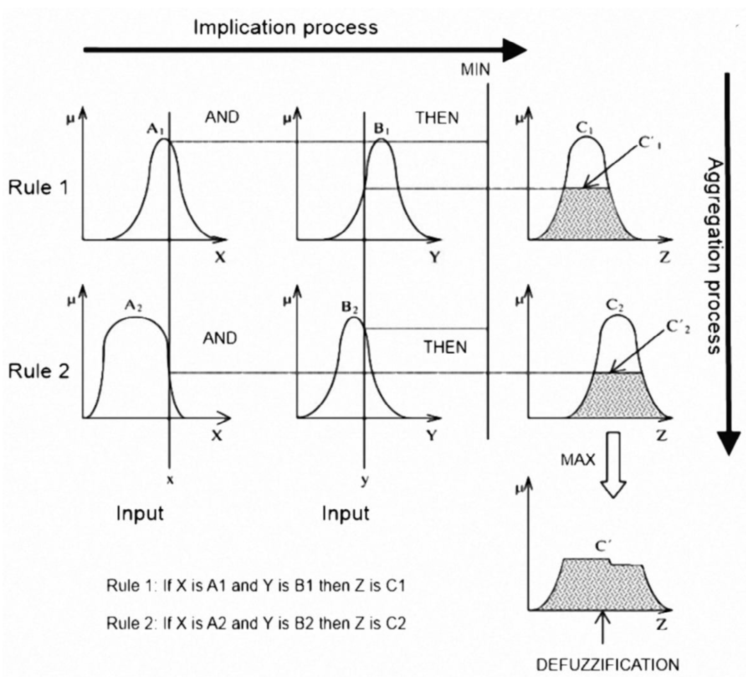
Although many methods for the composition of fuzzy relations (e.g., min-max, max-max, min-min, max-min, etc.) are available in the literature, the max-min is the most frequently used technique. For example, a two-rule max-min composition Mamdani FIS model is the following (Saberi Nasr et al. 2012):

$$\mu_{Ck}(Z) = max\left[min[\mu_{Ak}(input\ (x)), \mu_{Bk}(input(y)]\right]$$

$K=1,2,\ldots r$

Where μ_{ck}, μ_{Ak} and μ_{Bk} are the membership functions of output *Z* for rule *k* input *A* and input *B*. Even so, other minor fuzzy inference methods have been proposed.

Fig. 3 Mamdani (FIS)



3. A FIS model to assess the environmental pressure of electricity production

To design the framework of fuzzy model some experts have defined the parameters and ranges of the membership functions. Five input parameters were selected and an overall environmental pressure index, represented by a score on a scale of zero to 100, was obtained. The membership functions (MF) are reported in Figure 4,5 and 6.

·The first input parameter used in the model is the life-cycle "***CO_2 emissions per kWh"*** of electricity produced by electric power sources.

·The second indicator employed is "***land use***" (LU). This is very important because it represents the area destined for power generation.

·The third indicator is "***water consumption***" (WC). This refers to the portion of extracted water not returned to the "immediate water environment".

·The four indicators correspond to the "***pressure on ecosystems***" (PC), and because ecosystems are closely connected to their environment, every environmental change has ecological consequences.

·Finally, the last indicator defines the "***external cost"*** to the environment" (EC). Cost can be defined as "external" when it is produced by the activity of one subject but is incurred by another subject. (For a synthesis of the input parameter data, see Table 1 and Table 2).

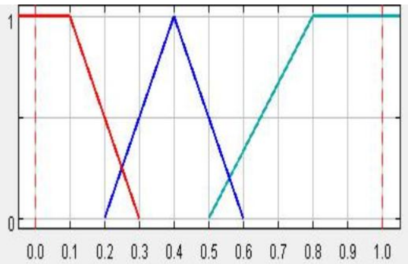


Fig. 4 MF "Pressure on ecosytem"

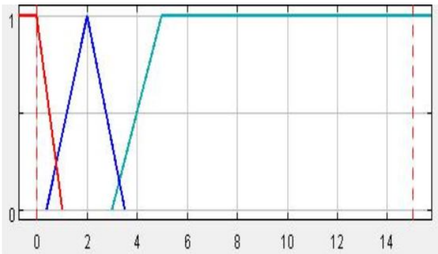


Fig. 5 MF "Land Use"

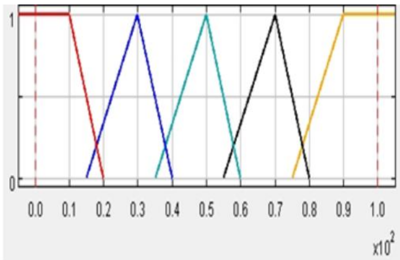


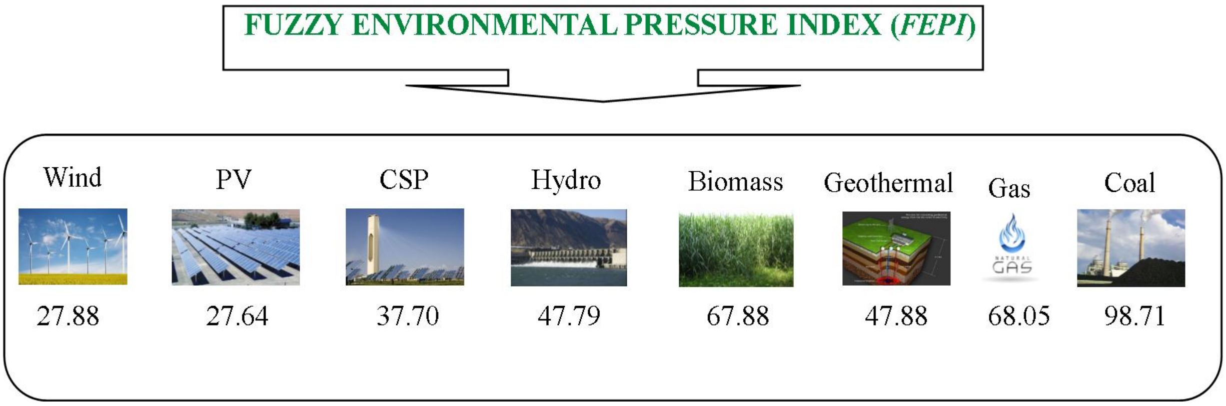
Fig. 6 MF "Fuzzy Environmental Pressure"

Table 2. Input data and the EPI for some selected technologies

Input variables	Linguistic values	Base variable	Range
Carbon dioxide	(optimal, acceptable, not- acceptable)	gCO_{2eq}/kWh	[0-1000]
Land use	"	Km^2/TWh	[0-15]
Water cons.	"	Kg/kWh	[0-250]
Pressure on Ecosystem	"	Score	[0-10]
External cost	"	€c/kWh	[0-10]

Finally we obtain the value, after defuzzification, on a scale of zero to 100 of the "**Fuzzy Environmental Pressure Index" (FEPI)**. This measures the impact of energy technologies on the environment. In order to classify both the input and output parameters, three membership functions are used such as *optimal, acceptable, not-acceptable*. The output membership functions of the FEPI in the form of linguistic ratings are described as *very low*, *low*, *middle*, *middle high*, *high*, and *very high* (see Fig. 6). After testing the model we obtained the following results for the FEPI (fig. 7): Wind (27.88) and PV (27.64), CSP (37.70), hydro (47.79), biomass (67.88), geothermal (47.88) and finally gas (68.05) and coal (98.71).

Figure 7. FEPI results



4. Conclusion

In this paper, we proposed a fuzzy expert system to assess the sustainability of energy production. An FIS contains information and experience of an expert in the design of a system that controls a process whose input–output relations are defined by a set of fuzzy control rules. A fuzzy index (EPI) has been developed to measure the pressure from energy technologies on the environment. After testing the model we obtained the following results for the EPI: wind (27.88), PV (27.64), CSP (37.70), geothermal (47.88), hydro (47.79), biomass (67.88) and finally gas (68.05) and coal (98.71). Future research will deal with the improvement of the model using others parameters and more accurate data.

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