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Giant Reed for Electricity Generation: A Fuzzy Inference System

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Abstract In this paper the annual electricity's generation at a electricity's generation plant in relation to the cultivating area with giant reed and to the land's yield was estimated by the building a Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab (Intelligent system). Data for this study were collected by research papers. This industrial unit will contribute to the local development as it can provide jobs for a great part of the rural population for the cultivation of giant reed. The cultivation of giant reed is one of the new promising energy crops for electricity's generation and it constitutes a way out from the problems that the agricultural sector faces nowadays. In this paper an ideal solution was estimated which is formulated as follows "the electricity generation plant absorbing the giant reed's production of a cultivating area of 8,080 acres and having a mean land's yield in the order of 8.79 tons dm/acre/year would produce 15,000 KW of electricity annually". 71,010 tons dm of giant reed annually should be consumed (burnt) for the operation of an electricity generation plant of 15 MW_{el} (15,000 KW) which would serve the electrification of 15,000 residences. 8,069 acres cultivated with giant reed are required for the production of this amount of dry biomass. Such an area of land would offer a complementary occupation to a significant number of young farmers for the cultivation of giant reed which will probably be well subsidized, will provide economic motives to the planters, support the agricultural economy and sustain the population in the countryside.

Keywords giant reed, electricity generation plant, fuzzy logic, Mamdani-type FIS

Introduction

The authors believe that the establishment of a electricity generation industrial unit which will use giant reed as a plant raw material will comprise respiration on local level because apart from the electricity's generation, the cultivation of giant reed which will probably be well subsidized, will provide economic motives to the planters, support the agricultural economy and sustain the population in the countryside. In this paper the annual electricity's generation at a electricity generation plant in relation to the cultivating area with giant reed and to the land's yield was estimated by the building a Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab (Intelligent system).

Giant Reed (*Arundo donax)*

Giant reed is a C3 perennial rhizomatous grass, which is native of Mediterranean area through to India. It is naturalised in parts of China and the southern states of USA where it is often regarded as a pest [1]. In the wild it grows along riverbanks and wetter areas, however due to its extensive root system it can utilise deep sub-soil water tables up to 1 m deep [2]. It can grow on almost any soil type and the resulting growth is up to 6 m height and to 10 m in ideal conditions [1]. Good preparation of the ground with ploughing and harrowing is beneficial for successful establishment and no herbicides are required as sections of rhizomes or stem cuttings are used [1]. The use of these means that there is a rapid development of a dominant canopy which smothers potential competitors. However planting at present is a manual activity as the rhizomes are large (10-18 cm length, diameter 1-10 cm) and no planting machinery is available. The use of rhizomes means that there are high establishment costs which can be as much as 20% of total cost of production, representing the highest cost element for the biomass production of this crop [3].

It has a 15-year productive life span, and full productivity begins four years after establishment [3]. Giant reed can be harvested one to three times annually depending on climate. Autumn is the best time as this to avoid wind damage and the loss of biomass in winter [4]. Cutting in autumn also allows new buds to develop ready for spring growth. However a harvest period from January to April has been suggested as a suitable period for southern European conditions [5].

Yields of 20.0 to 27.0 t dm/ha have been achieved in Greece, Italy and Spain [6]. Irrigation does improve yields and in southern Europe Dalianis et al. [4] has reported yields of 30.2 t dm/ha/y. The giant reed's yield for the infertile rainfed lands ranges from 8-9.2 tons dm/acre/year, while for the fertile irrigated lands from 10.4-12 tons dm/acre/year [2-7]. Fertilisation with N has no effect on yields in the initial growth period but it is required when the grass is irrigated [5]. An annual gross energy yield of 18.6 Mj/kg of dry matter has been calculated [7].

This grass has been identified as potentially the champion of biomass crops in Europe due to its aggressive growing potential, its high yields, its low agronomic input requirements, and its pest and disease resistance. Cultivation and harvesting can all be achieved with conventional methods however little selection work has been done yet to maximise yields. Other uses for this plant include paper production for which it is ideal as it is pithless, thatching and in bio-filtration systems for the removal of organic pollutants.

Electricity Generation

There can be many advantages to using biomass instead of fossil fuels for power generation, including lower greenhouse gas (GHG) emissions, energy cost savings, improved security of supply, waste management/reduction opportunities and local economic development opportunities [8]. Bioenergy can be converted into power through thermal-chemical processes (i.e. combustion, gasification and pyrolysis) or bio-chemical processes like anaerobic digestion [9]. Direct combustion of biomass for power generation is a mature, commercially available technology that can be applied on a wide range of scales from a few MW to 100 MW or more and it is the most common form of biomass power generation. Around the globe, over 90% of the biomass that is used for energy purposes goes through the combustion route. There are two main components of a combustion– based biomass plant: 1) the biomass-fired boiler that produces steam; and 2) the steam turbine, which is then used to generate electricity. The two most common forms of boilers are stoker and fluidised bed. These can be fuelled entirely by biomass or can be co-fired with a combination of biomass and coal or other solid fuels. The steam produced in the boilers is injected into steam turbines. These convert the heat contained in the steam into mechanical power, which drives the generation of electricity [10].

In a plant dedicated to electricity production alone, only a portion of the primary energy of fuel is actually converted into electrical power, ranging typically from 35% to 40%. The remaining part is lost in the form of heat dissipated to the environment. The traditional power stations do not use the heat by-product and there are other losses due to transmission of electricity to homes over long distances [11].

Working with the Fuzzy Logic Toolbox

The Fuzzy Logic Toolbox provides apps to let you perform classical fuzzy system development and pattern recognition. In general, using the Fuzzy Logic Toolbox, you can [12-13]:

- Develop and analyze fuzzy inference systems
- Develop adaptive neurofuzzy inference systems
- Perform fuzzy clustering.

What Are Fuzzy Inference Systems?

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made or patterns discerned. The process of fuzzy inference involves: Membership Functions, Logical Operations and If-Then Rules. Two types of fuzzy inference systems can be implemented in the Fuzzy Logic Toolbox: Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined [14-16].

Mamdani-type inference is a type of fuzzy inference in which the fuzzy sets from the consequent of each rule are combined through the aggregation operator and the resulting fuzzy set is defuzzified to yield the output of the system.

Sugeno-type inference is a type of fuzzy inference in which the consequent of each rule is a linear combination of the inputs. The output is a weighted linear combination of the consequents.

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani [14] as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes [17].

Mamdani-type inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This type of output is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, the weighted average of a few data points is used. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant [18-19].

Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems and computer vision. Because of their multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and simply (and ambiguously) fuzzy systems [20-21].

Methodology

Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools to build a Mamdani-type fuzzy inference system

The Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools were used in this paper to build a Mamdani-type fuzzy inference system (FIS). The following GUI tools were used to build, edit and view the fuzzy inference system:

Fuzzy Inference System (FIS) Editor to handle the high-level issues for the system—How many input and output variables? What are their names? Fuzzy Logic Toolbox software does not limit the number of inputs. However, the number of inputs may be limited by the available memory of the machine. If the number of inputs is too large or the number of membership functions is too big, then it may also be difficult to analyze the FIS using the other tools.

Membership Function Editor to define the shapes of all the membership functions associated with the input and output variables of the FIS.

Rule Editor to edit the list of rules that defines the behavior of the system using full English-like syntax.

Rule Viewer to view the fuzzy inference diagram. Rule Viewer is used as a diagnostic to see, for example, which rules are active or how individual membership function shapes influence the results. Rule Viewer lets you view the detailed behavior of a FIS to help diagnose the behavior of specific rules or study the effect of changing input variables.

Surface Viewer to view the dependency of one of the outputs on any one or two of the inputs. It generates and plots an output surface map for the system. Surface Viewer generates a 3-D surface from two input variables and the output variable of a FIS.

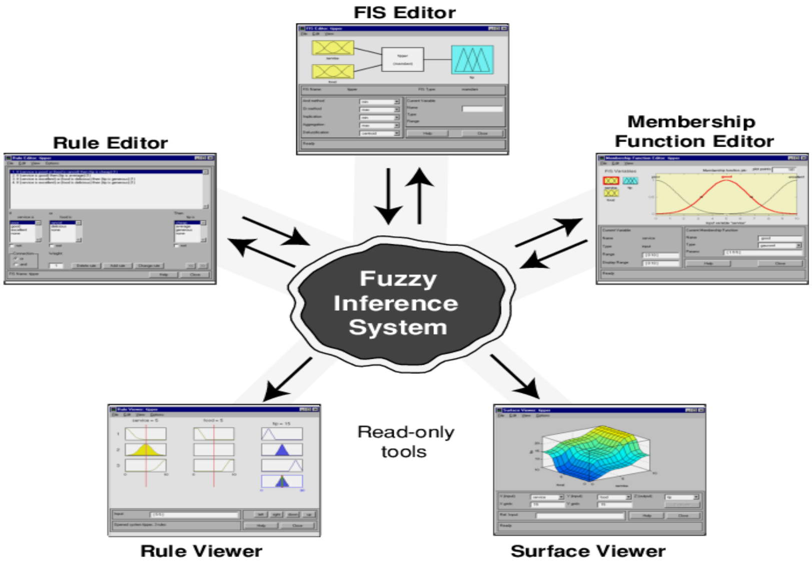


Figure 1: A Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools. The Membership Function Editor (top right), FIS Editor (center), Rule Editor (top left), Rule Viewer (bottom left) and Surface Viewer (bottom right).

The Problem

Given two sets of numbers, the first one between 0 and 10,000 acres and the second one between 0 and 12 tons dm/acre/year that respectively represent the cultivating area with giant reed and the land's yield. What should the annual electricity's generation be? In this paper the annual electricity's generation at a electricity generation plant in relation to the cultivating area with giant reed and to the land's yield was estimated by the building a Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab (Intelligent system). Data for this study were collected by research papers concerning the range of giant reed yield for various land categories (infertile rainfed land, fertile irrigated land).

Results-Discussion

Building of a Mamdani-type Fuzzy Inference System

Fuzzy Approach

The following 3 rules were set:

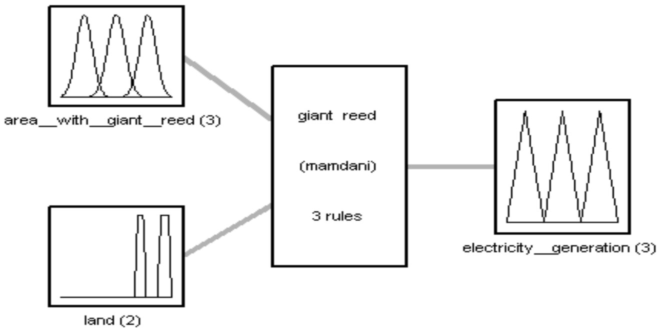
- If cultivating area with giant reed is small and land is infertile rainfed, then the annual electricity's generation is low;
- If cultivating area with giant reed is satisfactory, then the annual electricity's generation is satisfactory;
- If cultivating area with giant reed is large or land is fertile irrigated, then the annual electricity's generation is high.

The four basic steps for building and simulating of a fuzzy logic system are the following [13, 19, 22]:

- Defining inputs and outputs;
- Creating membership functions;
- Creating rules;
- Simulating the results of a fuzzy logic system.

1st Step-defining Inputs and Outputs

The Mamdani-type fuzzy inference system was selected in the FIS Editor. This problem has 2 input variables and 1 output variable. The input 1 variable is the "cultivating area with giant reed". The input 2 variable is the "land's yield". The output variable is the "annual electricity's generation" (Fig. 2).



System giant reed 2 inputs, 1 outputs, rules

Figure 2: Defining inputs and outputs

2nd Step-creating Membership Functions

The membership functions for the 3 variables were defined, namely for the variables: "cultivating area with giant reed", "land's yield", "annual electricity's generation". The gaussmf was selected as a type of membership function for the input 1 variable "cultivating area with giant reed". The number of membership functions is 3 (small, satisfactory, large). The range of "cultivating area with giant reed" is between 0 and 10,000 acres (Fig. 3).

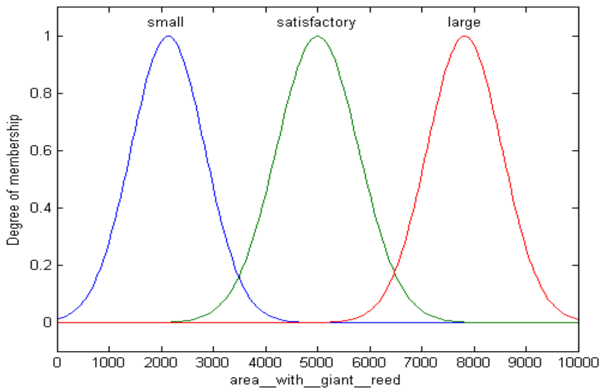


Figure 3: The three membership functions (small, satisfactory, large) for the input 1 variable "cultivating area with giant reed"

The trapmf (trapezoid membership function) was selected as a type of membership function for the input 2 variable "land's yield". The number of membership functions is 2 (infertile rainfed, fertile irrigated). The range of "land's yield" is between 0 and 12 tons dm/acre/year (Fig. 4).

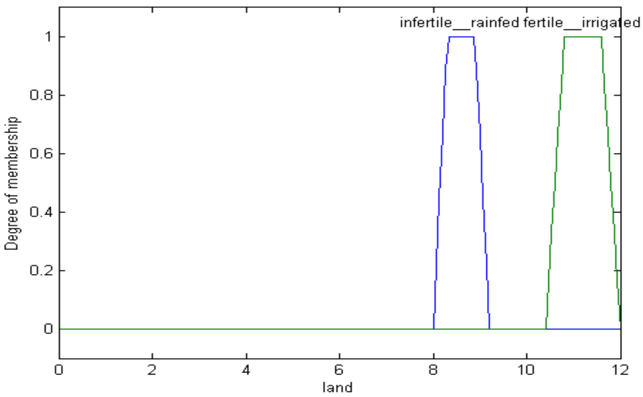


Figure 4: The two membership functions (infertile rainfed, fertile irrigated) for the input 2 variable "land's yield"

The trimf (triangular membership function) was selected as a type of membership function for the output variable "annual electricity's generation". The number of membership functions is 3 (low, satisfactory, high). The range of "annual electricity generation" is between 0 and 18,000 KW of electricity (Fig. 5).

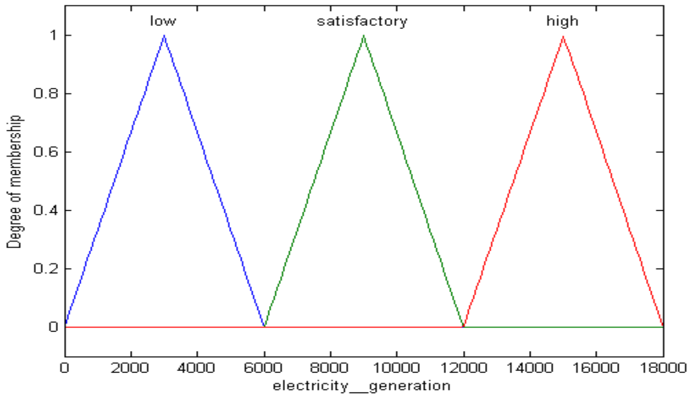


Figure 5: The three membership functions (low, satisfactory, high) for the output variable "annual electricity's generation"

3rd Step-creating Rules

Rule statements are constructed automatically in the Rule Editor. The 3 rules of fuzzy approach were added in the Rule Editor (Fig. 6).

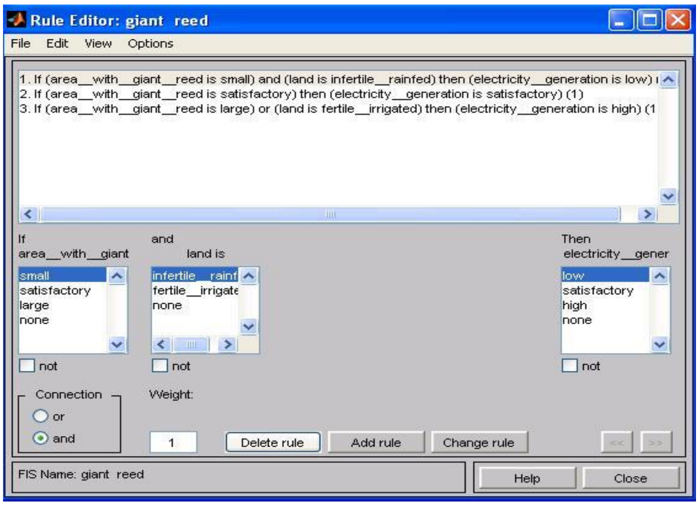


Figure 6: The rule editor: the three rules are appeared in the up part of this window

4th Step-simulating the Results of a Fuzzy Logic System

The results of Rule Viewer (Fig. 7) and Surface Viewer (Fig. 8) of a Mamdani-type fuzzy inference system are simulated and analyzed.

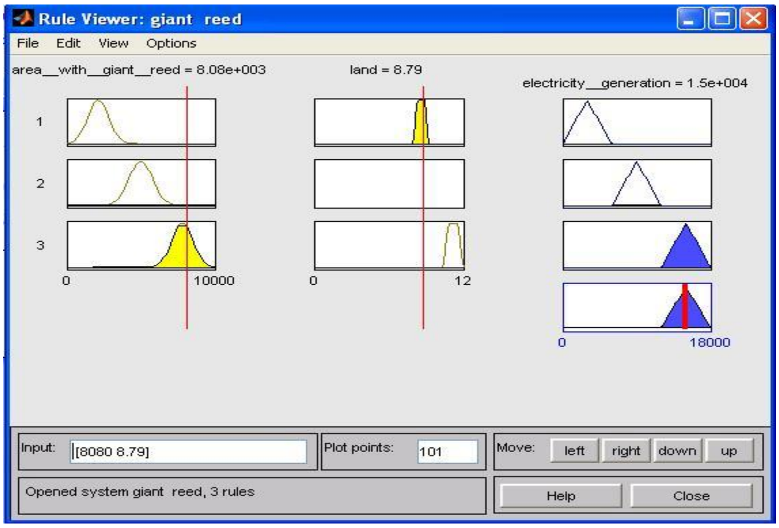


Figure 7: The rule viewer

In the Rule Viewer (Fig. 7), each column shows a set of membership functions for a particular variable. 3 membership functions for “cultivating area with giant reed” input 1 variable, 2 membership functions for “land’s yield” input 2 variable and 3 membership functions for “annual electricity’s generation” output variable are presented in Fig. 7.

Each membership function in this set is associated with a particular rule and maps input variable values “cultivating area with giant reed” and “land’s yield” to rule input values. In other words, the number of rows here is the number of rules that the authors have. The first row corresponds to the first rule, the second row corresponds to the second rule and the third row corresponds to the third rule. The plots in the output column show how the rules are applied to the output variable. The bottom right plot shows how the output of each rule is combined to make an aggregated output and a defuzzified value. The red line provides the defuzzified value for the annual electricity’s generation. The input value for “cultivating area with giant reed” is 8,080 acres and the input value for “land’s yield” is 8.79 tons dm/acre/year and they correspond to an output value for “annual electricity’s generation” equal to 15,000 KW of electricity.

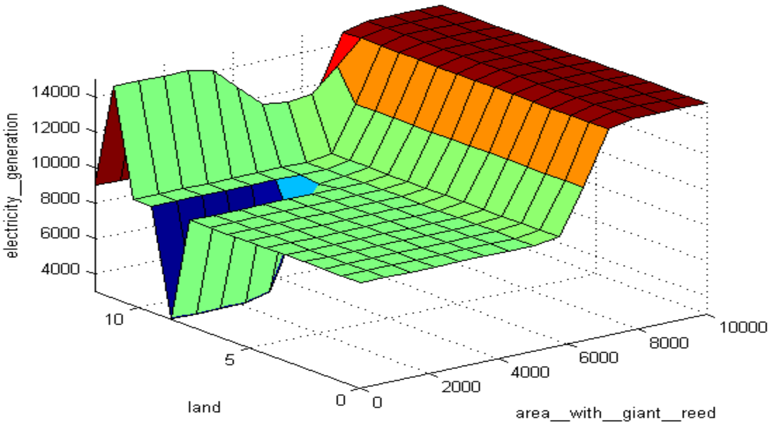


Figure 8: The surface viewer: annual electricity’s generation as it is affected by the cultivating area with giant reed and land’s yield

The Surface Viewer (Fig. 8) displays a surface that represents a mapping from the “cultivating area with giant reed” and the “land’s yield” to the “annual electricity’s generation”. This shows a high value of annual electricity generation for large cultivating area with giant reed and fertile irrigated lands, a low value of annual electricity generation for a small cultivating area with giant reed and infertile rainfed lands as well as a large flat area in the middle corresponding to a satisfactory (medium) annual electricity’s generation for satisfactory (medium) cultivating area with giant reed.

Electricity generation plant 15 MW_{el} fuelled with giant reed for the electrification of 15,000 residences

71,010 tons dm of giant reed annually should be consumed (burnt) for the operation of an electricity generation plant of 15 MW_{el} (15,000 KW) which would serve the electrification of 15,000 residences. 8,080 acres cultivated with giant reed are required for the production of this amount of dry biomass. 8.79 tons dm / acre / year were taken as a mean yield of giant reed.

8,107 Kg / hr (consumption, combustion of giant reed dry matter) x 4,420 Kcal / Kg (calorific value of giant reed) = 35,832,940 Kcal or 41,673,709 Wh

41,673,709 Wh corresponding to 100%

X =? electricity corresponding to 36% (efficiency)

The generated electricity is X = 15,002,535 Wh of electricity or 15.002 MW or 15,002 KW.

Conclusion

Fuzzy inference is a method that interprets the values in the input vector and based on user-defined rules, assigns values to the output vector. Using the editors and viewers in the Fuzzy Logic Toolbox, the rules set were built, the membership functions were defined and the behavior of the fuzzy inference system (FIS) was analyzed. In this paper the annual electricity's generation at a electricity's generation plant in relation to the cultivating area with giant reed and to the land's yield was estimated by the building a Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab (Intelligent system). Data for this study were collected by research papers concerning the range of giant reed yield for various land categories (infertile rainfed land, fertile irrigated land). This industrial unit will contribute to the local development as it can provide jobs for a great part of the rural population for the cultivation of giant reed. The cultivation of giant reed is one of the new promising energy crops for electricity's generation and it constitutes a way out from the problems that the agricultural sector faces nowadays.

The authors built a Mamdani-type fuzzy inference system, namely defined inputs and outputs, created membership functions, created rules and the authors simulated the results of Rule Viewer and Surface Viewer of the fuzzy inference system. The Surface Viewer shows a high value of annual electricity generation for large cultivating area with giant reed and fertile irrigated lands and a satisfactory (medium) annual electricity's generation for satisfactory (medium) cultivating area with giant reed. By the Rule Viewer is shown that the input value for "cultivating area with giant reed" is 8,080 acres and the input value for "land's yield" is 8.79 tons dm/acre/year and they correspond to an output value for "annual electricity's generation" equal to 15,000 KW of electricity. This constitutes the ideal solution in the problem, which was found by using of the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools of Matlab. In other words, the electricity generation plant absorbing the giant reed's production of a cultivating area of 8,080 acres and having a mean land's yield in the order of 8.79 tons dm/acre/year would produce 15,000 KW of electricity annually. 71,010 tons dm of giant reed annually should be consumed (burnt) for the operation of an electricity generation plant of 15 MW_{el} (15,000 KW) which would serve the electrification of 15,000 residences. 8,069 acres cultivated with giant reed are required for the production of this amount of dry biomass. Such an area of land would offer a collateral occupation to a significant number of young farmers for the cultivation of giant reed which will probably be well subsidized, will provide economic motives to the planters, support the agricultural economy and sustain the population in the countryside.

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