



Willow for electricity generation: A Mamdani-type fuzzy inference system

Michael Tsatiris, Kiriaki Kitikidou

Department of Forestry and Management of the Environment and Natural Resources, Democritus University of Thrace, Orestiada 68200, Greece

Abstract In this paper the annual electricity generation at a electricity generation plant in relation to the cultivating area with willow 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 willow. The cultivation of willow is one of the new promising energy crops for electricity 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 willow's production of a cultivating area of 9,300 acres and having a mean land's yield in the order of 10 tons dm/acre/year would produce 20,000 KW of electricity annually". 92,997 tons dm of willow annually should be consumed (burnt) for the operation of an electricity generation plant of 20 MW_{el} (20,000 KW) which would serve the electrification of 20,000 residences. Such a vast area of land would offer a complementary occupation to a significant number of young farmers for the cultivation of willow 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 willow, electricity generation plant, fuzzy logic, Mamdani-type FIS

Introduction

The authors believe that the establishment of a electricity generation industrial unit which will use willow as a plant raw material will comprise respiration on local level because apart from the electricity generation, the cultivation of willow 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 generation at a electricity generation plant in relation to the cultivating area with willow 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).

Willow (*Salix spp.*)

To mitigate climatic change caused by greenhouse gas emissions, the developed world is working to substitute fossil fuels with renewable energy sources. Short rotation forestry (SRF), i.e. fast-growing tree crops grown in carefully tended plantations for rotations shorter than 15 years have an important role to play, because of their numerous ecological benefits. This special type of forestry is concerned with maximization of wood biomass output per hectare for energy production. Highly productive pioneer species are willow, poplar and eucalypt species as a short rotation coppice (SRC) system. It is assumed that for the SRC system the first harvest takes place after 5 years and subsequently every three years up to an age of 20-25 years (willows) and for poplars



and eucalypts 7-10 years rotations are applied. Fertilization, annual weeding and mechanical harvesting are assumed. The density of SRC systems is assumed 9000-10000 stools per hectare [1-3].

The biomass produced from short rotation coppice (SRC) systems, such as willow, poplar and eucalypt may have a number of uses: as a fuel for electricity generation, district heating, cogeneration; for the production of charcoal; as a soil amendment for clay caps; or simply as a carbon sink for atmospheric CO₂ [4]. The willow's yield for the infertile rainfed lands ranges from 8-10.4 tons dm/acre/year, while for the fertile irrigated lands from 12-14.4 tons dm/acre/year [1-5]. Willows have several characteristics that make them ideal for SRC systems, including high yields that can be obtained in a few years; ease of vegetative propagation; a broad genetic base; a short breeding cycle and ability to resprout after multiple harvests [5].

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 [6]. Bioenergy can be converted into power through thermal-chemical processes (i.e. combustion, gasification and pyrolysis) or biochemical processes like anaerobic digestion [7]. 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 [8].

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 [9].

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:

- 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 [10-12].

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 [10] 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 [13].

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 [14-15].

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 [16-17].

Methodology

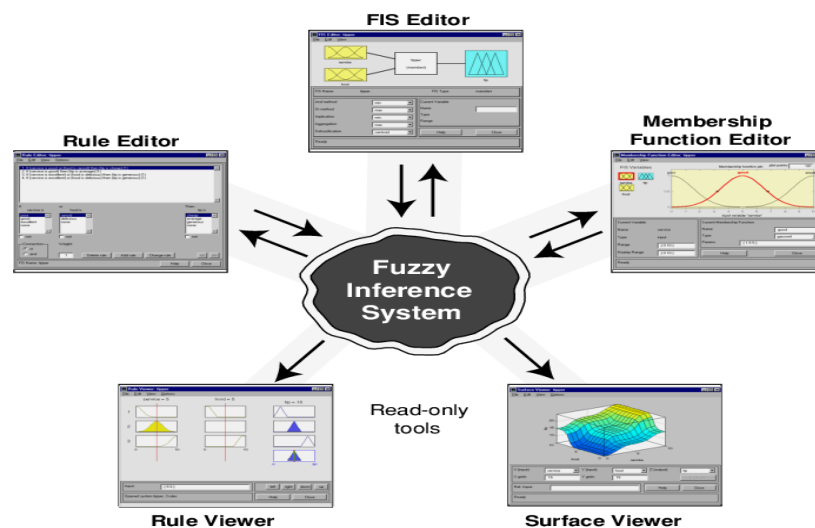


Figure 1: A Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools. The Membership Function Editor (top right), FIS Editor (center), Rule Editor (top left), Rule Viewer (bottom left) and Surface Viewer (bottom right).

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.

The Problem

Given two sets of numbers, the first one between 0 and 12,000 acres and the second one between 0 and 14.4 tons dm/acre/year that respectively represent the cultivating area with willow 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 willow 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 willow 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 willow is small and land is infertile rainfed, then the annual electricity's generation is low;
- If cultivating area with willow is satisfactory, then the annual electricity's generation is satisfactory;
- If cultivating area with willow 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 [15, 18-19]:

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

3.1.2 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 willow". The input 2 variable is the "land's yield". The output variable is the "annual electricity's generation" (Fig. 2).

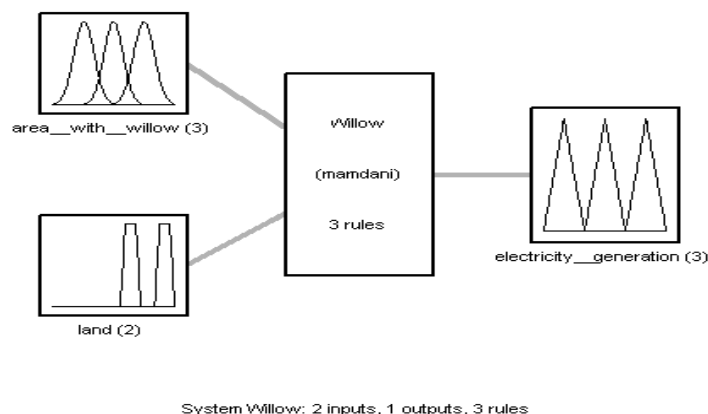


Figure 2: Defining inputs and outputs



2nd Step-creating Membership Functions

The membership functions for the 3 variables were defined, namely for the variables: “cultivating area with willow”, “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 willow”. The number of membership functions is 3 (small, satisfactory, large). The range of “cultivating area with willow” is between 0 and 12,000 acres (Fig. 3).

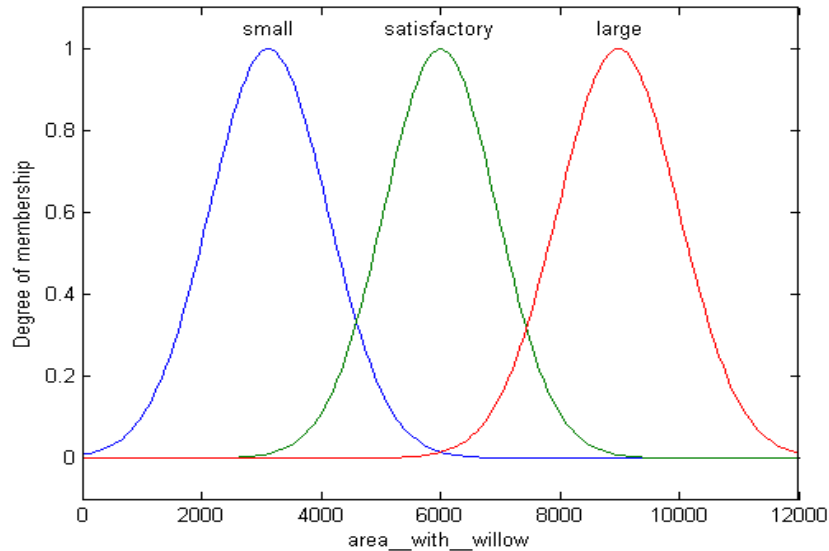


Figure 3: The three membership functions (small, satisfactory, large) for the input 1 variable “cultivating area with willow”

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 14.4 tons dm/acre/year (Fig. 4).

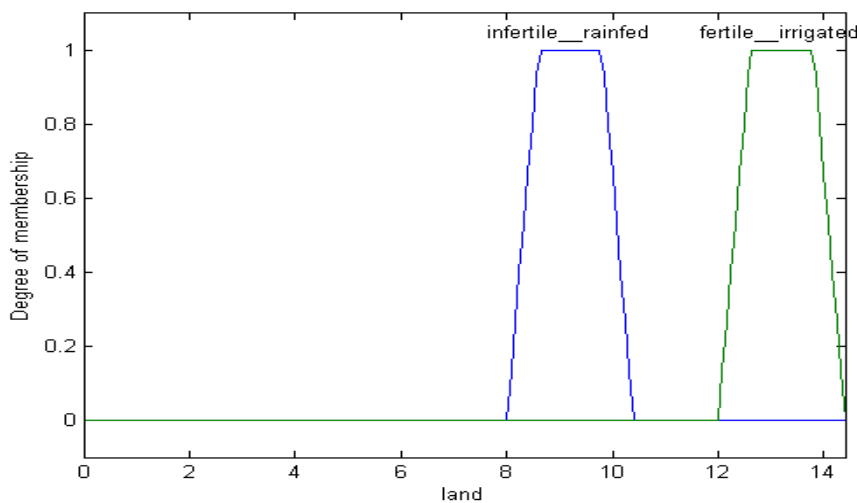


Figure 4: The two membership functions (infertile rainfed, fertile irrigated) for the input 2 variable “land’s yield”

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 24,000 KW (Fig. 5).

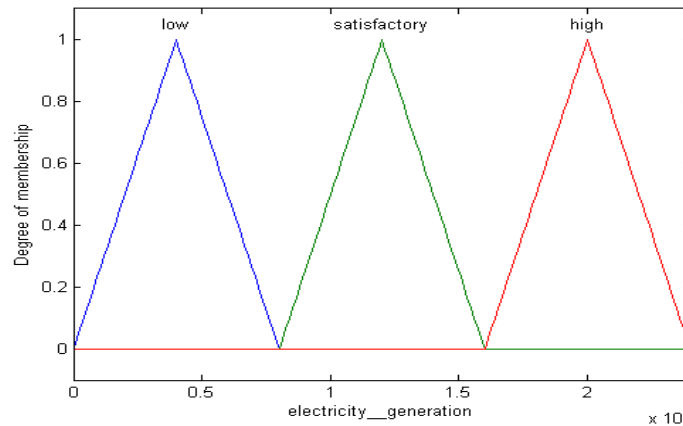


Figure 5: The three membership functions (low, satisfactory, high) for the output variable “annual electricity’s generation”

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).

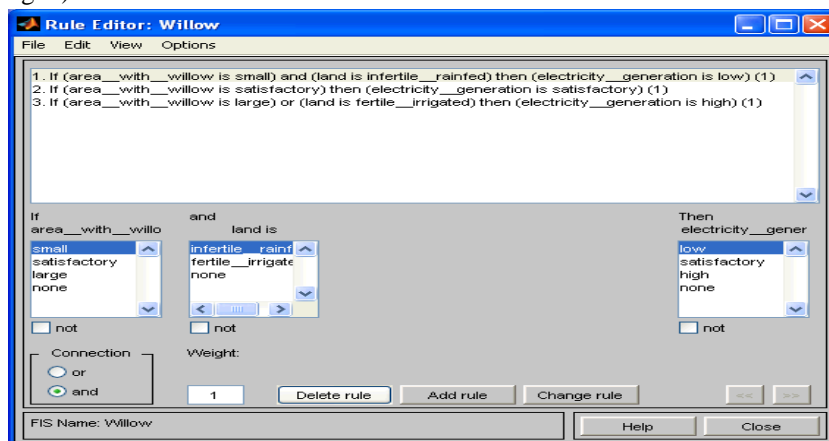


Figure 6: The rule editor: the three rules are appeared in the up part of this window

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.

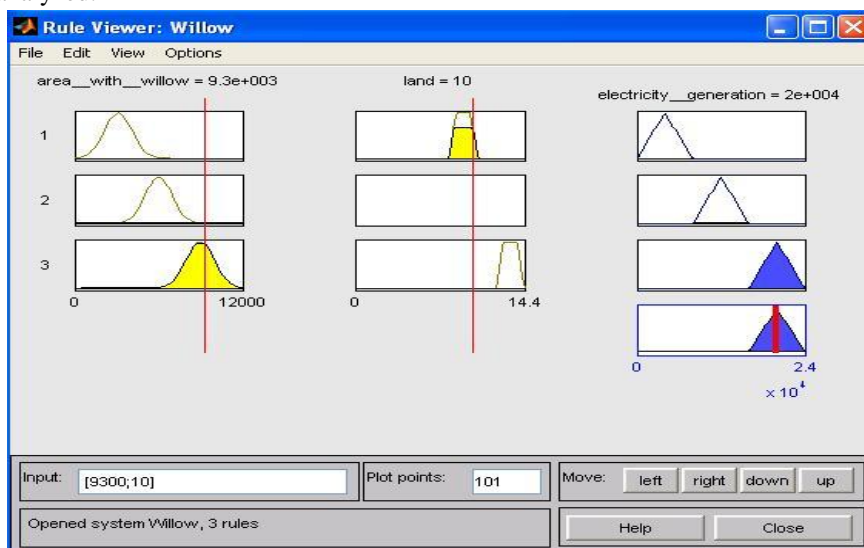


Figure 7: The rule viewer

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 willow” 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 willow” 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 willow” is 9,300 acres and the input value for “land’s yield” is 10 tons dm/acre/year and they correspond to an output value for “annual electricity’s generation” equal to 20,000 KW.

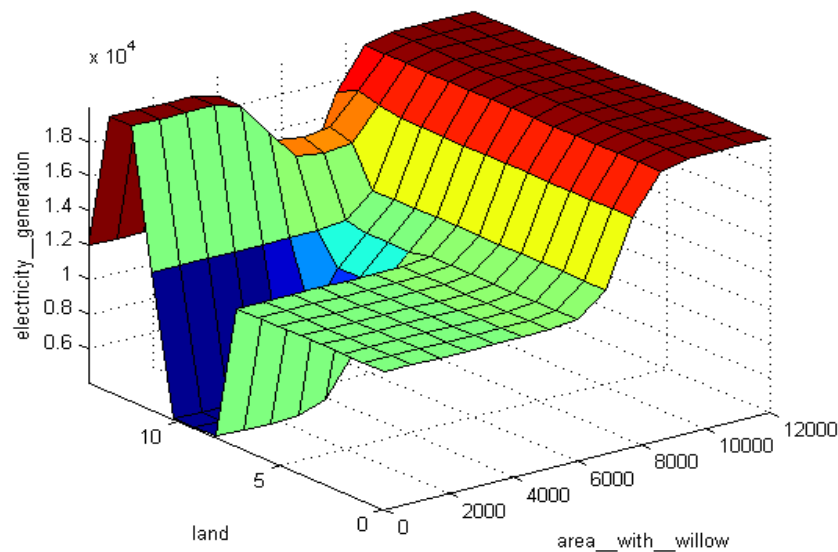


Figure 8: The surface viewer: annual electricity’s generation as it is affected by the cultivating area with willow and land’s yield

The Surface Viewer (Fig. 8) displays a surface that represents a mapping from the “cultivating area with willow” 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 willow and fertile irrigated lands, a low value of annual electricity generation for a small cultivating area with willow 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 willow.

Electricity generation plant 20 MW_{el} fuelled with willow for the electrification of 20,000 residences

92,997 tons dm of willow annually should be consumed (burnt) for the operation of an electricity generation plant of 20 MW_{el} (20,000 KW) which would serve the electrification of 20,000 residences. 9,299.75 acres cultivated with willow are required for the production of this amount of dry biomass. 10 tons dm / acre / year were taken as a mean yield of willow.

$10,616 \text{ Kg / hr (consumption, combustion of willow dry matter)} \times 4,500 \text{ Kcal / Kg (calorific value of willow)} = 47,769,180 \text{ Kcal or } 55,555,556 \text{ Wh}$

55,555,556 Wh corresponding to 100%

X = ? electricity corresponding to 36% (efficiency)

The generated electricity is X = 20,000,000 Wh of electricity or 20 MW or 20,000 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 generation plant in relation to the cultivating area with willow 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 willow 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 willow. The cultivation of willow 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 willow and fertile irrigated lands and a satisfactory (medium) annual electricity's generation for satisfactory (medium) cultivating area with willow. By the Rule Viewer is shown that the input value for "cultivating area with willow" is 9,300 acres and the input value for "land's yield" is 10 tons dm/acre/year and they correspond to an output value for "annual electricity's generation" equal to 20,000 KW. 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 willow's production of a cultivating area of 9,300 acres and having a mean land's yield in the order of 10 tons dm/acre/year would produce 20,000 KW of electricity annually. 92,997 tons dm of willow annually should be consumed (burnt) for the operation of an electricity generation plant of 20 MW_{el} (20,000 KW) which would serve the electrification of 20,000 residences. Such a vast area of land would offer a collateral occupation to a significant number of young farmers for the cultivation of willow which will probably be well subsidized, will provide economic motives to the planters, support the agricultural economy and sustain the population in the countryside.

References

- [1]. Gullberg, U. 1993. Towards making willows pilot species for coppicing production. *Forestry Chronicle*, 69: 721–726.
- [2]. Ceulemans, R., McDonald, A. J. S., and Pereira, J. S. 1996. A comparison among eucalypt, poplar, and willow characteristics with particular reference to a coppice, growth-modeling approach. *Biomass and Bioenergy*, 11: 215–231.
- [3]. Abrahamson, L. P., Volk, T. A., Kopp, R. F., White, E. H., and Ballard, J. L. 2002. Willow Biomass Producer's Handbook. Short Rotation Woody Crops Program, SUNY-ESF, Syracuse, NY.
- [4]. Heller, M. C., Keoleian, G. A., and Volk, T. A. 2003. Life cycle assessment of a willow biomass cropping system. *Biomass and Bioenergy*, 25(2): 147–165.
- [5]. Tharakan, P. J., T. A. Volk, L. P. Abrahamson, E. H. White, 2003. Energy feedstock characteristics of willow and hybrid poplar clones at harvest age. *Biomass and Bioenergy* Vol. 25, 6: 571–580.
- [6]. Fischer, J. 2003. Technologies for small scale Biomass CHP-plants – an actual survey. Riso International Energy Conference, Riso, Denmark, May 2003
- [7]. Kellett, P. 1999. Combined Heat and Power for the Irish Wood Processing Industry - Report on Wood Biomass, Irish Energy Center - Renewable Energy Informatin Office, Bandon, Ireland.
- [8]. Neave, E. 2013. Biomass heating and electricity production. Canadian Model Forest Network. Ontario, Canada.



- [9]. EPA 2007. Biomass Combined Heat and Power catalog of Technologies. US Environmental Protection Agency. New York.
- [10]. Mamdani, E. and S. Assilian. 1975. An experiment in linguistic synthesis with a fuzzy logic controller. *International Journal of Man-Machine Studies*, Vol. 7, No. 1, pp. 1-13.
- [11]. Sugeno, M. 1985. Industrial applications of fuzzy control. Elsevier Science Pub. Co.
- [12]. Jang, J. and T. Sun. 1997. Neuro-Fuzzy and Soft Computing: A Computational Approach to Learning and Machine Intelligence, Prentice Hall.
- [13]. Zadeh, L. 1973. Outline of a new approach to the analysis of complex systems and decision processes. *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 3, No. 1, pp. 28-44.
- [14]. Nguyen, H. and Walker, E. 2006. A First Course in Fuzzy Logic. CRC Press Taylor and Francis Group, Boca Raton.
- [15]. Sivanandam, S., Sumathi, T. and Deepa, L. 2007. Introduction to Fuzzy Logic Using Matlab. Springer, Berlin Heidelberg.
- [16]. Dubois, D. and H. Prade. 1980. Fuzzy Sets and Systems: Theory and Applications, Academic Press, New York.
- [17]. Ross, T. 2010. Fuzzy Logic with Engineering Applications. Third Edition, Wiley, Chichester, UK.
- [18]. Berkan, R. and Trubatch, S. 1997. Fuzzy system design principles. Wiley-IEEE Press, New York.
- [19]. Negnevitsky, M. 2005. Artificial Intelligence. A Guide to Intelligent Systems. Second Edition. Addison-wesley, Pearson Education Limited, Essex, England.

