



Rapeseed for Biodiesel Production: 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 biodiesel production at a biodiesel plant in relation to the cultivating area with rapeseed 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 rapeseed. The cultivation of rapeseed is one of the new promising energy crops for biodiesel production 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 biodiesel plant absorbing the rapeseed's production of a cultivating area of 144,000 acres and having a mean land's yield in the order of 277 liters biodiesel/acre/year would produce 40,000 tons of biodiesel annually". Such a vast area of land would offer a complementary occupation to a significant number of young farmers for the cultivation of rapeseed 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 rapeseed, biodiesel plant, fuzzy logic, Mamdani-type FIS

Introduction

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

Rapeseed (*Brassica napus*)

Rapeseed is the main oil crop grown in Europe accounting for more than half of the biofuel production. In 2008 in Europe, rapeseed accounted for 79 % of all feedstock crops used for biodiesel production. It is cultivated in almost all European countries [1]. The most important raw material for biodiesel production in EU is rapeseed (82.82%) as well as sunflower (12.50%) [2].

Most of the countries within the European Union as well as majority of the transition countries initiated biodiesel production in the previous decade. This tendency will be continued in the future, which is proved by the European Commission's proposal 2003/30/EC [3] concerning alternative fuels in road transportation as well as measures for promotion of biofuels.

Rapeseed can be grown either as a winter or a spring crop and potentially could be cropped anywhere that spring and winter wheat is grown. Rapeseed cannot tolerate extreme cold, and the winter varieties have a



restricted planting period. The seedlings must be 2 to 3 inches high before the first frost if they are to survive. Rapeseed does not tolerate poorly drained soils [4]. The rapeseed's yield for the infertile rainfed lands ranges from 172-220 liters biodiesel/acre, while for the fertile irrigated lands from 308-360 liters biodiesel/acre [1-2, 4].

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 [5-7].

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 [7] 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 [8].

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 [9-10].

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 [11-12].

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.

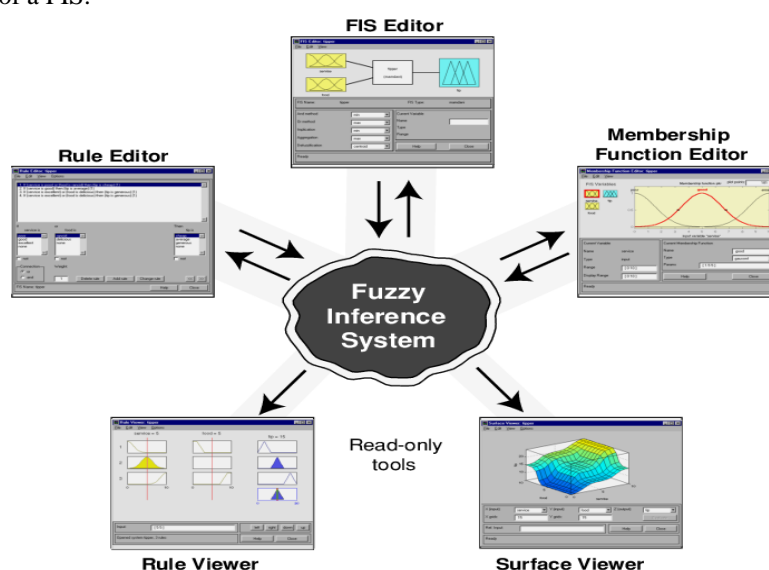


Figure 1: A Mamdani-type fuzzy inference system using the Fuzzy Logic Toolbox Graphical User Interface (GUI) Tools. The Membership Function Editor (top right), FIS Editor (center), Rule Editor (top left), Rule Viewer (bottom left) and Surface Viewer (bottom right).

The Problem

Given two sets of numbers, the first one between 0 and 170,000 acres and the second one between 0 and 360 liters biodiesel/acre/year that respectively represent the cultivating area with rapeseed and the land's yield. What should the annual production of biodiesel be? In this paper the annual biodiesel's production at a biodiesel plant in relation to the cultivating area with rapeseed 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 rapeseed yield for various land's 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 rapeseed is small and land is infertile rainfed, then the annual production of biodiesel is low;
- If cultivating area with rapeseed is satisfactory, then the annual production of biodiesel is satisfactory;



- If cultivating area with rapeseed is large or land is fertile irrigated, then the annual production of biodiesel is high.

The four basic steps for building and simulating of a fuzzy logic system are the following [10, 13-14]:

- 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 rapeseed”. The input 2 variable is the “land’s yield”. The output variable is the “annual production of biodiesel” (Fig. 2).

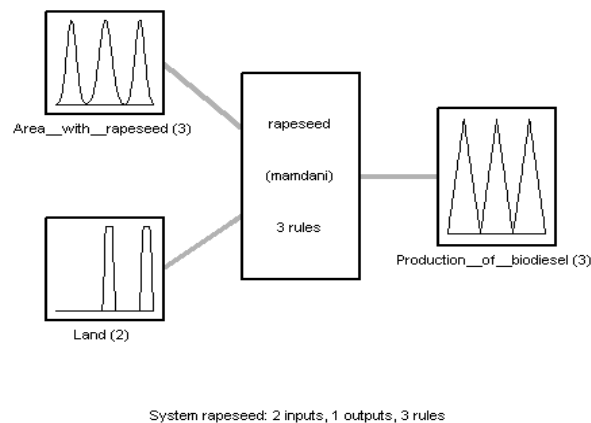


Figure 2: Defining inputs and outputs

2nd Step-creating Membership Functions

The membership functions for the 3 variables were defined, namely for the variables: “cultivating area with rapeseed”, “land’s yield”, “annual production of biodiesel”. The gaussmf was selected as a type of membership function for the input 1 variable “cultivating area with rapeseed”. The number of membership functions is 3 (small, satisfactory, large). The range of “cultivating area with rapeseed” is between 0 and 170,000 acres (Fig. 3).

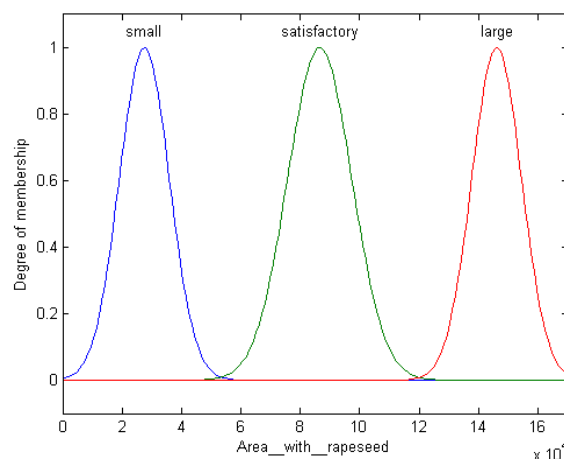


Figure 3: The three membership functions (small, satisfactory, large) for the input 1 variable “cultivating area with rapeseed”

The trapezmf (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 360 liters biodiesel/acre/year (Fig. 4).



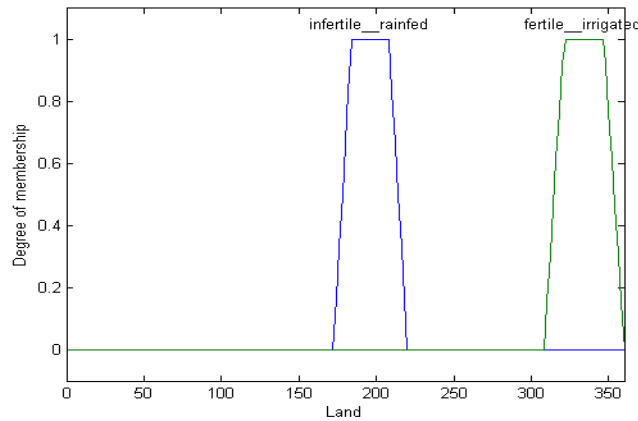


Figure 4: The two membership functions (infertile rainfed, fertile irrigated) for the input 2 variable “land’s yield”

The trimf (triangular membership function) was selected as a type of membership function for the output variable “annual production of biodiesel”. The number of membership functions is 3 (low, satisfactory, high). The range of “annual production of biodiesel” is between 0 and 48,000 tons of biodiesel/year (Fig. 5).

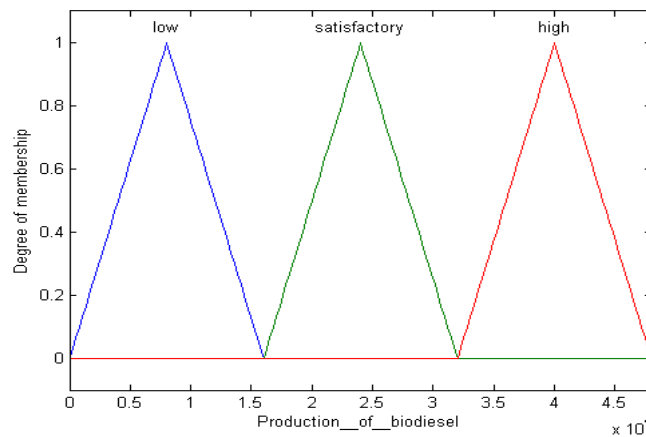


Figure 5: The three membership functions (low, satisfactory, high) for the output variable “annual production of biodiesel”

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).

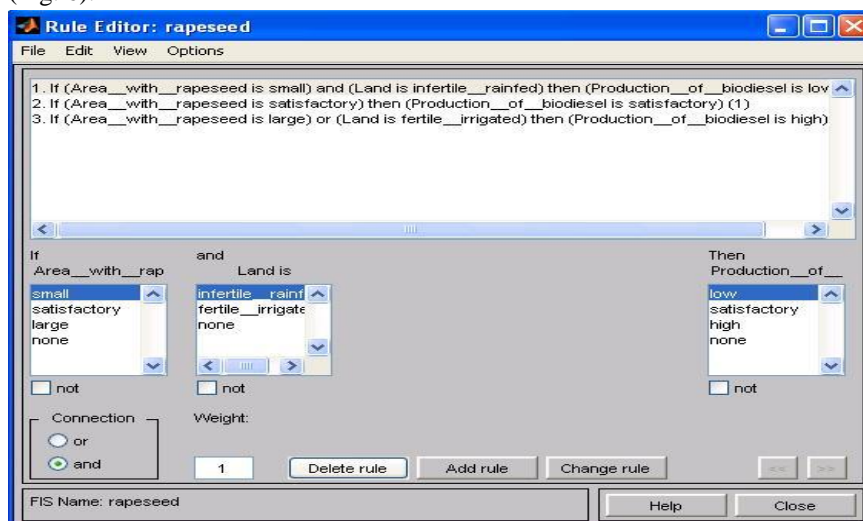


Figure 6: The rule editor: the three rules are appeared in the up part of this window

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.

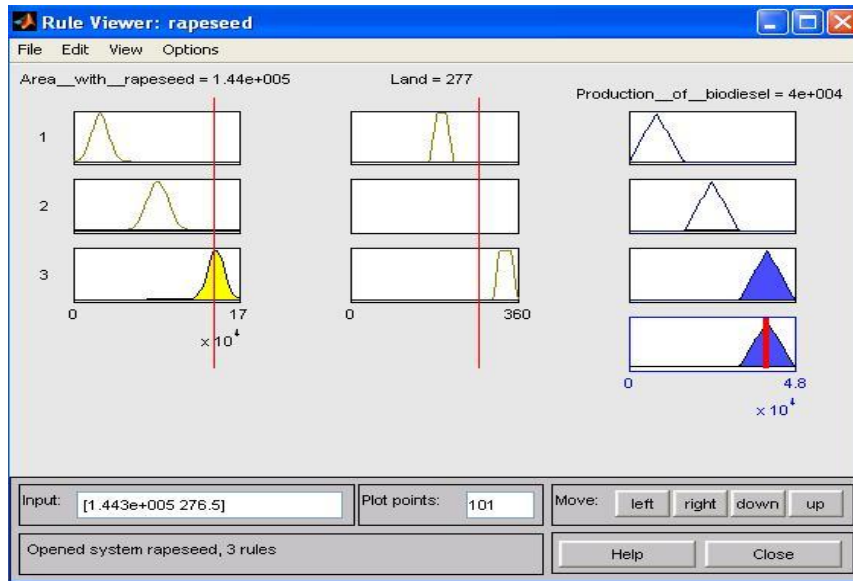


Figure 7: The rule viewer

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 rapeseed” input 1 variable, 2 membership functions for “land’s yield” input 2 variable and 3 membership functions for “annual production of biodiesel” 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 rapeseed” 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 production of biodiesel. The input value for “cultivating area with rapeseed” is 144,000 acres and the input value for “land’s yield” is 277 liters biodiesel/acre/year and they correspond to an output value for “annual production of biodiesel” equal to 40,000 tons of biodiesel.

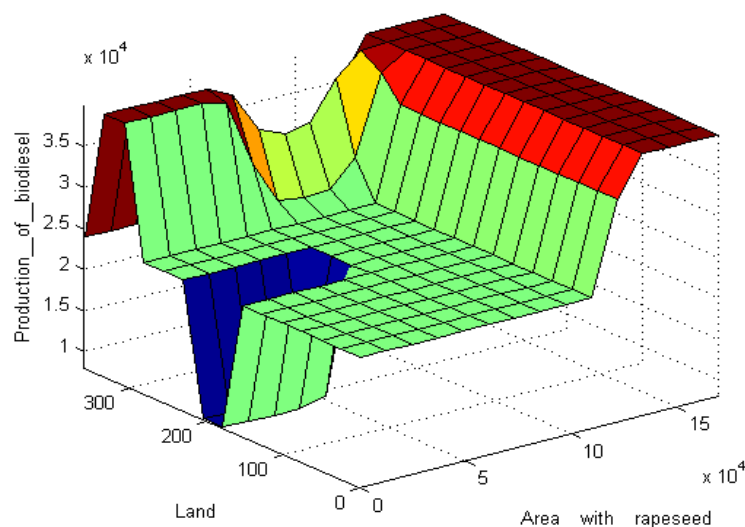


Figure 8: The surface viewer: annual production of biodiesel as it is affected by the cultivating area with rapeseed and land’s yield



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

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 biodiesel production at a biodiesel plant in relation to the cultivating area with rapeseed 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 rapeseed 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 rapeseed. The cultivation of rapeseed is one of the new promising energy crops for biodiesel production 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 production of biodiesel for large cultivating area with rapeseed and fertile irrigated lands and a satisfactory (medium) annual production of biodiesel for satisfactory (medium) cultivating area with rapeseed. By the Rule Viewer is shown that the input value for “cultivating area with rapeseed” is 144,000 acres and the input value for “land’s yield” is 277 liters biodiesel/acre/year and they correspond to an output value for “annual production of biodiesel” equal to 40,000 tons of biodiesel/year. 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 biodiesel plant absorbing the rapeseed production of a cultivating area of 144,000 acres and having a mean land’s yield in the order of 277 liters biodiesel/acre/year would produce 40,000 tons of biodiesel annually. Such a vast area of land would offer a collateral occupation to a significant number of young farmers for the cultivation of rapeseed 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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