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Comparative Study on Experimental 2 To 9 Triangular Fuzzy Membership Function Partitioned Type 1 Mamdani's FIS for G 2 EDPS

Burak Omer Saracoglu

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Abstract

There are some theories on how the World will end (e.g. super volcano eruption, massive star explosion, death of the Sun, asteroid impact, pandemic, nuclear war, climate change). Some of them can be prevented, because the cause is human by itself. For instance, spread of deadly diseases can be prevented by some quarantine zones and periods, nuclear wars by disarmament of weapon of mass destruction (zero weapons) and climate change by new life styles and acts (zero emissions: carbon dioxide CO2, methane CH4, nitrous oxide N2O, fluorinated gases). Electricity generation plays a key role in zero emissions life styles and acts. A Global Grid can be designed, invested and operated by 100

Index terms— global grid, electricity demand, fuzzy inference system, mamdani, prediction.

1 Introduction

cientists have some ideas on how the World will end. Most of these ideas are shared on public websites and TV programs. Some of these ideas are super volcano eruption, massive star explosion, death of the Sun, asteroid impact, pandemic, nuclear war and climate change (visit [1,2,3]). These events can be grouped under two main sets. One of them is nonhuman caused events, the other one is human caused events. Super volcano eruption is an extreme natural event **??**4]. Massive star explosion, death of the Sun, asteroid impact are rare cosmic events [5]. Catastrophic effects of these events can't be prevented by humankind's present technological and technical capabilities. Pandemic is an indirectly human caused event. Nuclear war and climate change are two directly human caused events. Prevention of pandemic is possible today [6]. Prevention of a nuclear war is the simplest one. All weapons must be destroyed by a worldwide disarmament program (simplest thing on Earth according to author's point of view) [7,8]. Solution of the climate change (global warming) problem is more complicated and difficult than the other ones. New technologies, techniques and approaches have to be developed and adopted in the short to mid period. Lifestyles and human habits have to be changed and accepted in the daily life (e.g. "infrastructure upgrade", "move closer to work", "consume less", "be efficient", "one child" [9]). Electricity generation can play a key role in this zero emissions life style. Electricity can possibly be generated from only renewable energy sources by today's technologies (no non-renewable power plants). This approach is nowadays technically possible by current technologies. Hydropower, geothermal, wind, solar, and ocean resources are sufficiently enough. Hence, scientific development studies of 100% renewable power grids have to be finalized and presented in short to mid terms. This research study contributes in this respect. There are already some futuristic conceptual recommended electricity grids. The European Supergrid [10], and the Global Grid Concepts [11] are two of them (see also [12,13]). This research focuses on the Global Grid Concept that is described as "a grid spanning the whole planet and connecting most of the large power plants in the world" [11]. One of the important modeling steps of the Global Grid is the electricity demand prediction. Electricity grid demand forecasting time horizons are ranged from very shortrange to long-range forecasting in the literature (see [14,15]).

This research study aims to focus on forecasts or forecasting in the period of 100 years ahead by Mamdani's fuzzy inference system (FIS) (fuzzy control system: FCS, fuzzy rule base system: FRBS, fuzzy expert system: FES, fuzzy logic controller: FLC, etc.), that can be used for strategic planning (e.g. grid design, interconnection, and expansion plans) of the Global Grid. It is believed that achievements on this respect can be gained by help of research findings on the historical data. Hence, this research study first contributes in this approach to the scientific studies.

Section 2 presents the literature review. Section 3 has the concise presentation of the preliminaries and the details of this comparative research study. Section 4 presents the concluding remarks and further research.

2 II.

3 Literature Review

The literature review period was 20 days in almost 10 working hours conditions (from 11/06 to 01/07 2015). Some academic online database and journals were reviewed by some queries. The search queries were organized in a narrowing content. These queries were searched on 15 academic publication websites ("Fig. 1"). Only 40 papers amongst 38727 search results were long term electricity load and demand forecasting studies (eliminated duplications, triplications etc.). A few papers from this literature review are as following. Al-Ghandoor and Samhouri worked on five models by multivariate linear regression and adaptive neuro-fuzzy inference system in the industrial sector of Jordan from 1985 to 2004 (19 years) [31]. The square root of average squared error (RASE) for each model and average RASE of the linear regression and the neuro-fuzzy techniques were compared (unit: terajoule TJ). The linear regression RASEs were respectively presented as 132,15, 176,54, 168,19, 121,00, and 143,80 and the neuro-fuzzy RASEs were respectively presented as 94,75, 126,75, 175,00, 133,00, and 69,75. The average of the linear regression and the neuro-fuzzy techniques were given as 148, 34 and 119,85 [31]. Tasaodian et.al. worked with the adaptive-networkbased fuzzy inference system (ANFIS) [32]. They investigated the long term electricity consumption of the Group of Eight (G8) Industrialized Nations (U.S.A, Canada, Germany, United Kingdom, Japan, France, Italy). They constructed a different model per country, so that they had several models. Their models had 0,005696, 0,011739, 0,013136, 0,00446, 0,007985, 0,012971 and 0,014929 MAPE (%) values respectively for the U.S.A, Canada, Germany, the United Kingdom, Japan, France, Italy. There were also some other interesting studies, which could be presented in a review study.

This literature review showed that some researchers worked in the electricity consumption prediction subject. However, none of them studied the Global Grid Concept until 01/07/2015. Moreover, none of them presented a comparative study of a type 1 Mamdani FIS with several triangular fuzzy membership functions. Hence, this study would most probably contribute to the scientific research studies in this field much.

4 III.

5 Concise Preliminaries of Fuzzy

Inference Systems [33,34,35,36,37,38])

This new representation of overall structure of a generalized fuzzy inference system (FIS) (Type 1 or Type 2 fuzzy) (Mamdani, or Takagi-Sugeno-Kang or others) is generalized and presented by this study based on FIS representations in the literature [see 33 **??**38]. FISs are powerful to deal with ambiguity, imprecision, and unsharpness of data, information, and also reasoning, because mainly FISs are all based on fuzzy mathematics' principles. Henceforth, many real world problems can be modeled and solved by FISs. Critical issue and point with FISs is same critical issue and point with all fuzzy methods and approaches. As Liu and Lin underlines very clearly "fuzzy mathematics mainly deals with problems of the phenomenon with cognitive uncertainty by experience with the help of affiliation functions." [39]. As a result, natural situations and events can possibly be modeled precisely by fuzzy theory based models by experienced people. Here, experience is not only the experience about fuzzy modeling, but also about the natural phenomenon by itself (for instance: design of control systems of an autonomous unmanned aerial vehicle needs sufficient knowledge on aviation and flight principles). Thus, design process of fuzzy models needs timely efforts to get precise results. Fuzzy logic was proposed by Lotfi A. Zadeh (alive by 11/11/2015) (one of genius humans in his generation) in 1965 [40,41]. Ebrahim H. (Abe) Mamdani (another genius scientist passed away on 22/02/2010) came up with a very clever idea, Mamdani fuzzy inference, in 1974 to use Zadeh's fuzzy logic principles for control systems [42,43]. Afterwards, Kang, Larsen, Sugeno, Takagi, Tsukamoto and others followed Mamdani's research studies and proposals. They recommended some new fuzzy logic controller models (e.g. Sugeno, Takagi-Sugeno-Kang) [44,45,46]. Many studies underline that the most important design issue in FISs is its approximation capability [47,48]. These studies also indicate very clearly that several membership function types satisfy FISs that can approximate any continuous function with an arbitrary accuracy [47,48,49]. Tatjewski (2007) warns about the most important points in FIS modeling as "defining the number of fuzzy sets and assigning a shape and values of parameter to the membership function of each set" and "defining the structure and parameters of functional consequents of individual rules" [49]. Main guidance in this respect is also given as "Too small a number of these sets and wrong positioning in relation to each other leads to unsatisfactory design of the fuzzy model, which does not satisfy the quality requirements and is too imprecise. Assuming too large a number of fuzzy sets leads to an oversized model with too many parameters; the design is then more difficult and the model is slower in operation" [49]. More importantly and mainly defining the aim and foundation of this research study, it is presented that "in practice it is still most efficient to take a human-made decision about the number of sets and their initial positioning, in an interactive mode, if necessary" [49]. The readers should mainly follow these three publications to understand the research aim of the current study. Several inference systems such as Larsen, and Sugeno can be preferred in FISs design. Mamdani's inference system or decision making unit is preferred in this experimental research study, because all previous studies in the literature mention that Mamdani's FIS is more suitable for human judgments and perceptions than other ones [50,51].

Accordingly, this research study contributes in FISs applications for electricity demand prediction and shall hopefully be a start for a global research, development, demonstration, & deployment (RD 3) efforts of a Global Grid electricity demand prediction system (G2EDPS). This research study may be described with the quote: "Knowing is not enough; we must apply. Willing is not enough; we must do." Goethe IV.

6 Comparison of Experimental FISs

This research study is one of the preliminary conceptual design studies of the G2EDPS ("Fig. 3" Climate System Scenario Tables, Table **??**II.7.5, RCP2.6 (95%), RCP4.5 (95%), RCP6.0 (95%), RCP8.5 (95%), and SRES A1B (95%) predictions (see [54]) ("Fig. 4 Data Series Historical: -0,22, -0,14, -0,17, -0,20, -0,28, -0,26, -0,25, -0,31, -0,20, -0,11, -0,34, -0,27, -0,31, -0,36, -0,32, -0,25, -0,17, -0,18, -0,30, -0,19, -0,13, -0,19, -0,29, -0,36, -0,43, -0,29, -0,26, -0,41, -0,42, -0,47, -0,45, -0,44, -0,40, -0,38, -0,22, -0,16, -0,36, -0,44, -0,31, -0,29, -0,27, -0,21, -0,29, -0,25, -0,24, -0,21, -0,08, -0,18, -0,16, -0,31, -0,11, -0,08, -0,11, -0,25, -0,09, -0,15, -0,10, 0,03, 0,05, 0,01, 0,06, 0,07, 0,05, 0,05, 0,13, 0,00, -0,08, -0,05, -0,11, -0,12, -0,19, -0,07, 0,01, 0,08, -0,12, -0,13, -0,18, 0,03, 0,05, 0,03, -0,04, 0,06, 0,04, 0,08, -0,19, -0,10, -0,04, -0,01, -0,05, 0,06, 0,04, -0,07, 0,02, 0,16, -0,07, -0,01, -0,12, 0,15, 0,06, 0,12, 0,23, 0,28, 0,09, 0,27, 0,12, 0,08, 0,15, 0,29, 0,36, 0,24, 0,39, 0,38, 0,19, 0,21, 0,29, 0,43, 0,33, 0,46, 0,62, 0,41, 0,41, 0,53, 0,62, 0,60, 0,52, 0,66, 0,60, 0,63, 0,49, 0,60, 0,67, 0,55, 0,58, 0,60, 0,68 The detailed investigations of this modeling section will be studied in the future research studies. Experimental Mamdani's type FIS rules are defined by human judgments (in other words expert judgments). This Mamdani's type FIS capability is the modeling power and flexibility in this research field. Some rules are the same for all MFs. Total number of MFs, total rules and total effective rules are presented in the EMS and "Fig. 6". When rule structure can be differentiated by inputs and output values, this rule is defined as effective rule. When two or more rules can be defined as only one rule by easily combining these two or more rules, then these rules are defined as only rule. For instance Rule n: IF input1 is MF1 AND input2 is MF1 THEN output is MF1 Rule n+x: IF input1 is MF1 AND input2 is MF2 THEN output is MF1 These rules can be modelled as only one effective rule as Rule n: IF input1 is MF1 AND input2 is less than or equal to MF1 THEN output is MF1 Detailed investigations of this modeling section will be studied in future research studies. Scilab 5.5.2 SciFLT Model rules and scripts are also presented as in the "Tab. 1" and "Tab. 2". Readers can copy and paste to their Scilab 5.5.2 Console and run the models. APE of 2 MFs model ranges between 0,25 and 0,66, so that MAP of this model is found as 0,66. MAPE of this model is calculated as 0,49. APE of 3 MFs model ranges between 0,32 and 0,65, so that MAP of this model is found as 0,65. MAPE of this model is calculated as 0,53. APE of 4 MFs model ranges between 0,17 and 0,52, so that MAP of this model is found as 0,52. MAPE of this model is calculated as 0,37. APE of 5 MFs model ranges between 0,18 and 0,42, so that MAP of this model is found as 0,42. MAPE of this model is calculated as 0,30. APE of 6 MFs model ranges between 0,19 and 0,35, so that MAP of this model is found as 0,35. MAPE of this model is calculated as 0,28. APE of 7 MFs model ranges between 0,17 and 0,32, so that MAP of this model is found as 0,32. MAPE of this model is calculated as 0,27. APE of 8 MFs model ranges between 0,19 and 0,33, so that MAP of this model is found as 0,33. MAPE of this model is calculated as 0,26. APE of 9 MFs model ranges between 0,18 and 0,32, so that MAP of this model is found as 0,32. MAPE of this model is calculated as 0,26 (see ESM). MAP and MAPE values are also given by "Fig. 8" in this main text.

7 Conclusions and Future Work

It is believed and hoped that this research paper focuses and defines one of the important real world problems well. One of the major contributions of this research study is the kick-off for a worldwide (RD3) study of a Global Grid electricity demand prediction system (G2EDPS) under a Global Grid Prediction Systems (G2PSs) (see **??**59]). Main design philosophy behind the eyes of G2EDPS is its modularity. G2EDPS modules will be consist of country (per country), multinational (several nations or countries), continental (per continent) and finally worldwide (world or globe) based approaches. Several prediction models and approaches for countries, multi-nations, continents and globe will be designed and integrated into this system. One of these modules is tried to be developed based on the type 1 Mamdani's fuzzy inference system principles. This research paper investigates a comparative study on experimental 2 to 9 triangular fuzzy membership function partitioned type 1 Mamdani Global Grid electricity demand forecasting fuzzy inference systems. The whole world (Global Grid electricity demand) is in focus of this approach. Fuzzy membership functions are developed in an almost automatic manner. Mamdani FIS is preferred to use its human judgment presentation capability. This expert decision and information transformation ability is observed very well during FIS rules definition. Three prediction performance measures as APE, MAP, and MAPE are checked in this study for comparison of these experimental 2 to 9 triangular fuzzy membership function partitioned type 1 Mamdani's FIS. According to MAP and MAPE values 7 membership functions are suggested to RD3 engineers. It is believed that several hundreds of these kinds of research studies should be finalized and presented for investigating the fuzzy inference systems different modules of the G2EDPS in the future research studies.

VI. [1 2 3]

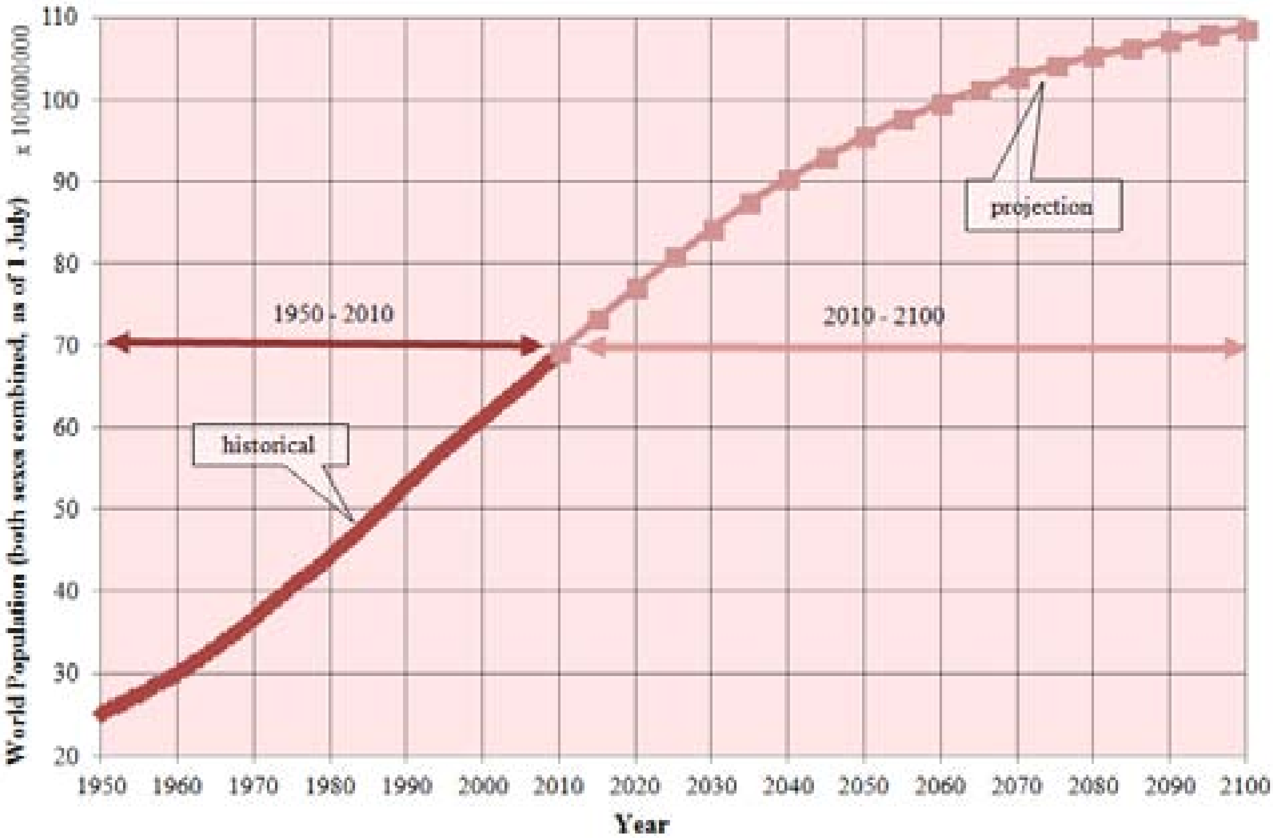
No	Phrase 1	Operator	Phrase 2	Operator	Phrase 3	Operator	Phrase 4
1	FLIS[1]	and	Electricity				
2	FLIS[1]	and	Forecast				
3	FLIS[1]	and	Demand				
4	FLIS[1]	and	Electricity	and	Forecast		
5	FLIS[1]	and	Electricity	and	Demand		
6	FLIS[1]	and	Electricity	and	Forecast	and	Demand
7	FIS[2]	and	Electricity				
8	FIS[2]	and	Forecast				
9	FIS[2]	and	Demand				
10	FIS[2]	and	Electricity	and	Forecast		
11	FIS[2]	and	Electricity	and	Demand		
12	FIS[2]	and	Electricity	and	Forecast	and	Demand
13	FCS[3]	and	Electricity				
14	FCS[3]	and	Forecast				
15	FCS[3]	and	Demand				
16	FCS[3]	and	Electricity	and	Forecast		
17	FCS[3]	and	Electricity	and	Demand		
18	FCS[3]	and	Electricity	and	Forecast	and	Demand
19	FRS[4]	and	Electricity				
20	FRS[4]	and	Forecast				
21	FRS[4]	and	Demand				
22	FRS[4]	and	Electricity	and	Forecast		
23	FRS[4]	and	Electricity	and	Demand		
24	FRS[4]	and	Electricity	and	Forecast	and	Demand

1

Figure 1: Figure 1 :

[2]Comparative Study on Experimental 2 To 9 Triangular Fuzzy Membership Function Partitioned Type 1 Mamdani's FIS for G 2 EDPS

[3]Year 2017 J Comparative Study on Experimental 2 To 9 Triangular Fuzzy Membership Function Partitioned Type 1 Mamdani's FIS for G 2 EDPS



2

Figure 2: Figure 2 :

3

Figure 3: Figure 3 :

Figure 4:

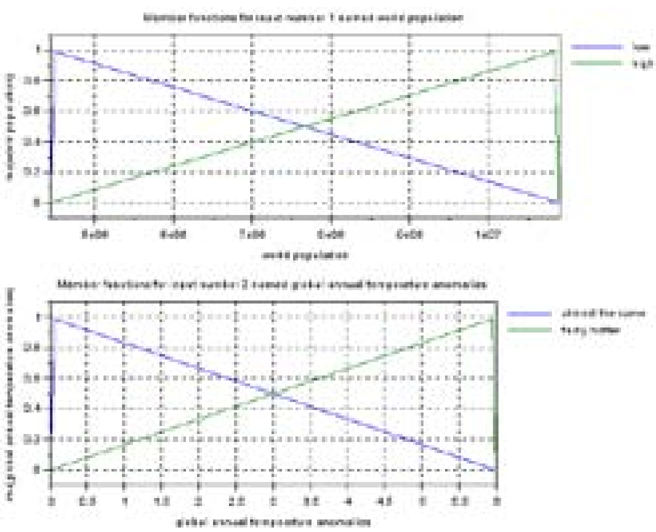


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Figure 5: Figure 4 :

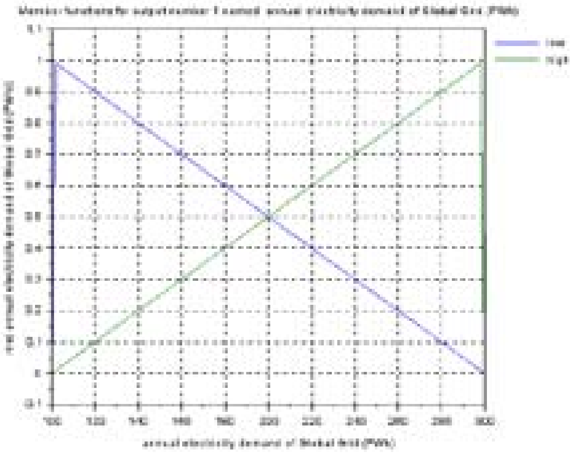

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Figure 6: Figure 5 :

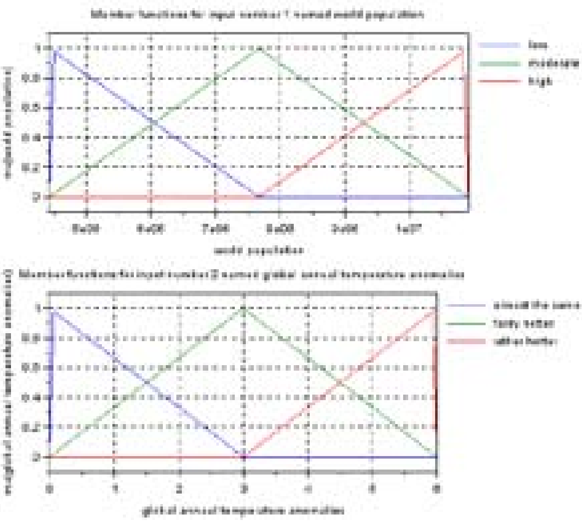

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Figure 7: Figure 6 :

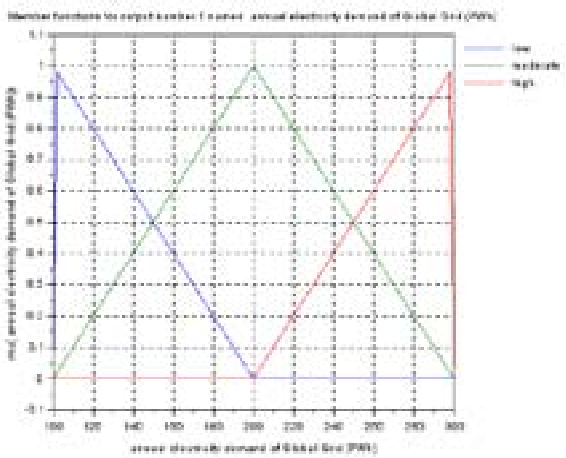

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Figure 8: Figure 7 :

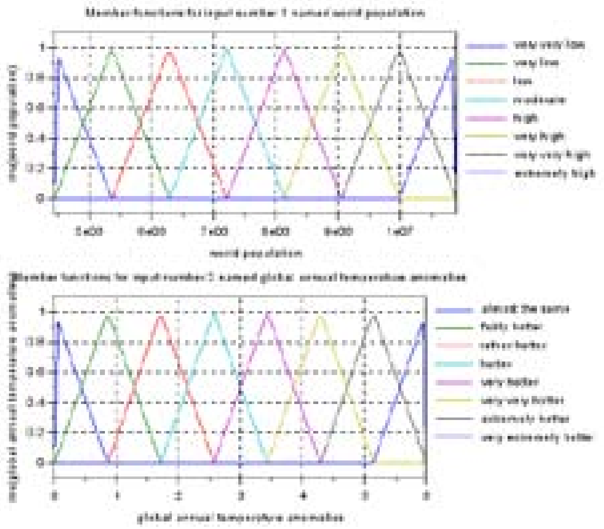

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Figure 9: Figure 8 :

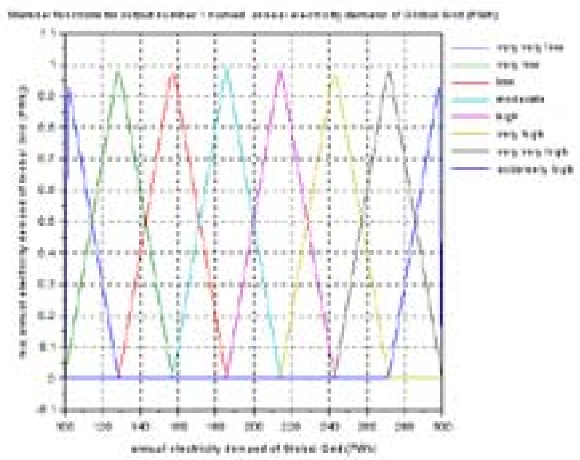

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Figure 10: Figure 9 :

		Knowledge Base		
Input (Crisp or Fuzzy) (Singleton or Non-Singleton)	Data Base (All Data & Membership Functions)		Rule Base (All Rules)	Output (Crisp)
	Fuzzification Interface or Fuzzifier	Inference System or Decision Making Unit	Defuzzification Interface or Defuzzifier	

Figure 11:

Experimental Inputs global population	Experimental Fuzzifiers	algebraic sum of S-Norm class type	Experimental De-fuzzifier	Experimental Output
	2, 3, 4, 5, 6, 7, 8, 9	algebraic product of T-Norm class type	centroide	annual electricity demand of
global annual temperature anomalies	Triangular Type 1 Membership Functions	classical complement of Complement class type		Global Grid
		product implication method		
		maximum aggregation method		
crisp world		fuzzy world		crisp world

Figure 12: On Scilab 5.5.2 Fuzzy Toolbox 0.4.6 also a simple presentation of the foundation of one of the G 2 EDPS modules Experimental Mamdani's Inference System

1

Figure 13: Table 1 :

[Note: (maximum error rate of historical prediction) of experimental 7 triangular type 1 membership function partitioned Mamdani type fuzzy inference system (MAP:Data Series RCP4.5 95%: 0,83, 1,22, 1,57, 1,97, 2,19, 2,32, 2,54, 2,59, 2,64 Data Series RCP6.0 95%: 0,90, 1,17, 1,41, 1,81, 2,18, 2,52, 2,88, 3,24, 3,60 Data Series RCP8.5 95%: 0,99, 1,39, 1,77, 2,37, 2,99, 3,61, 4,22, 4,81, 5,40 Data Series SRES A1B 95%: 0,91, 1,38, 1,79, 2,14, 2,67, 3,12, 3,47, 3,84, 4,21]

Figure 14: J

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