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An Experimental Private Small Hydropower Plant Investments Selection Classification System

Burak Omer Saracoglu[1,*]

[1] *Independent Scholar, Türkiye*

Abstract: Investment selection problems and models are crucial for humans, communities, and states. Private small hydroelectric power/hydropower plant investments (PSHPPIs) selection problem is a unique one in those problems and models. Many available scientific methods can be implemented on this research topic. One methods group is type-2 Mamdani's type fuzzy inference systems (FISs). This study presents an experimental one-node general type-2 4-zslices Mamdani's type FIS model for PSHPPIs selection. There are 3 input variables (total estimated electricity generation: M1, total estimated cost: M2, change in the average runoff: M3), 1 output variable (O1: selected/unselected, selection classification of PSHPPIs), and 49 rules. M1 is designed in 5 triangular and trapezoidal general type-2 4-zslices fuzzy membership functions (MFs), M2 in 5 triangular and trapezoidal general type-2 4-zslices fuzzy MFs, M3 in 5 Gaussian type-2 4-zslices fuzzy MFs, and O1 in 2 Gaussian type-2 4-zslices fuzzy MFs. All modeling details are finalized by a human-expert decision process. JuzzyOnline V2.0, a browser-based platform of Juzzy (a Java-based library: Juzzy toolkit), is used for all FIS modeling and calculation activities. Five PSHPPI options assumed to be in their very early investment stages in Turkiye are evaluated in an experimental application. It is clear that an improved, tuned, and fine-tuned version of this model will help private investors to take more convenient/satisfying actions/decisions in a very short evaluation period in their PSHPPIs decision processes. An automatic investment selection classification system can be built in an appropriate development period after experiencing many methods and models. This study is one of the open-science humanoid robot, robot and platform development activities entitled Global Power Robots and Platforms: GPRP/GPRAP (Global Power Plants Developers: GP2D/G2PD/GPPD, Global Power Plants Engineers: GP2E/G2PE/GPPE, Global Power Plants Owners: GP2O/G2PO/GPOO, Global Power Prediction Systems: GP2S/G2PS/GPPS), Global Profile Analyses Systems, and Global Social Network Analyses Systems.

Keywords: type-2 fuzzy logic, small hydropower, private investment, fuzzy rule base, fuzzy logic inference system

1. Introduction

When real-sector private investors are studied in detail, characteristic differences such as "criminal investor," "manipulative investor," "risk-averse investor," "risk-seeking investor," "risk-neutral investor," "atheist investor," "Muslim investor," or "Muslim investor working with Islamic banks" are easily and clearly understood (Adkins, 2021; Beattie, 2021; Chen, 2021; Chen, 2022; Chen, 2023; Gafoor, 1999; Halton, 2022; Hayes, 2022a; Hayes, 2022b; Kartskhiya et al., 2020; McGavin, 2010; Scott, 2022). All private investors consider (would/should consider) their ability, belief, capability, capacity, competence, expertise, experience, religion, talent, and know-how during their investment evaluations with respect to investment sizes. Therefore, research subjects related to investments, investors, investment models, investment selection models, and similar are important. Hence, the first motivation of this research is to focus on the investment selection models.

The real-sector private investors have had the chance to search, find, decide, and invest in power plants and become the shareholders of private power plants after the privatization, and restructuring acts in the electricity/power sector legalized by some laws and regulations in Turkiye (Karahan & Toptas, 2013). There are many power plant types (e.g., coal, natural gas, solar, wind) in Turkiye, which can take the attention and interest of all private investors. Hydropower technology is one of the most attractive technologies among all power plant technologies in Turkiye (hydropower plants) (Bobat, 2023; Urasoglu & Ilbas, 2020). Therefore, research subjects related to power plants, power technologies, renewable power technologies, hydropower technology, and similar are important. Hence, the second motivation of this research is to study the investment selection models of private hydropower plant investments.

There are several hydroelectric power plant (HPP) classification studies. The general consensus is the classification by the installed capacity/power (P) (e.g., large, medium, small, mini, micro, pico) (Bajaj et al., 2007; Berakovic et al., 2009; Burrett et al., 2009; Dragu et al., 2010; Johansson & Burnham, 1993; Kurien & Sinha, 2006; Saxena, 2007). HPP project developers can present billions and billions of HPP project and investment alternatives in different types and sizes like the small hydropower plant (SHPP)

*Corresponding author: Burak Omer Saracoglu, Independent Scholar, Türkiye. Email: burakomersaracoglu@hotmail.com

projects (1 MW < P ≤ 10 MW according to some classification approaches) for domestic and foreign private investors (MW: megawatt, HPP examples in Figure 1 (monovolume architecture +design, 2008; monovolume architecture+design, 2012; monovolume architecture+design, 2013)). SHPPs do not have the advantage of medium and large HPPs with reservoirs (photo: Punibach and Winnebach hydropower plants (monovolume architecture+design, 2008; monovolume architecture+design, 2012; monovolume architecture+design, 2013)). They do not have any chance to store water for their operation/operational schedule in many cases. They cannot operate to maximize their performance and profits like the medium and large HPPs with reservoirs. As a result, they have more challenging conditions than the other power plant investment options, not only during their design phase but also in their operation/operational phase. Hence, the third motivation of this research is to focus on the investment selection models of private small hydropower plant investments (PSHPPIs).

In some European countries, these SHPPs operation/operational challenges have taken into account during the sales price policy decisions by some governments (government budgeted political and economic incentive policies or incentives in governments' budgets like budgeting local/regional/central/general elections, local/regional/central politicians, local/regional/central bureaucrats, universities/academics, schools/teachers, hospitals/doctors/nurses, public investments, public private partnership investments, or investment guarantees; please note that all voters (some people including evangelists, zionists, hypocrites and infidels; friend, foe or neutral (FFN)) select local/regional/central politicians and governments in the democracies; not robots select, some humans select)), so that some governments identify and define the electricity sales prices (feed-in-tariffs: FiTs) based on the installed power of HPPs as security bonuses (e.g., FiTs for large HPPs are very much less than FiTs for SHPPs: FiTlarge HPPs <<< FiTsmall HPPs or FiTlarge HPPs: no/none, FiTsmall HPPs: yes/something appropriate) (Couto & Olden, 2018; European Small Hydropower Association, 2004; Gagliano et al., 2014; International Energy Agency, 2021). This case is not the same budgeting case in Turkiye (at least exactly not in Turkiye and some other states/countries), instead it is very different, which is not a well-organized approach for job creation, capacity design/usage, investment attractiveness, financial/monetary resource allocation, environmental friendless, and war against climate change (bearing in mind evangelists, zionists, hypocrites and infidels, FFN) (Mevzuat, 2005; The London School of Economics and Political Science, 2005). Accordingly, the design and operation of SHPPs in Turkiye are more challenging and critical. Hence, the fourth motivation of this research is to study the investment selection models of PSHPPIs in very early investment stages in Turkiye.

Many scientific methods can be used/implemented in the investment selection research topic (Li & Saracoglu, 2021; Saracoglu, 2022a). Type-2 Mamdani's type fuzzy inference systems (FISs) or fuzzy rule base systems (FRBSs) can effectively be used in several models for many problems and adopted in all automatized systems. For this reason, a one-node type-2 Mamdani's type FIS/FRBS evaluation approach is experimentally designed and run in the current study. Moreover, a virtual private investor (VPI) is proposed as a fictional investor to investigate some available PSHPPIs in Turkiye as some fictional investment alternatives. Hence, the final motivation of this research is to show how a Mamdani's type FIS/FRBS evaluation approach in the scope of artificial intelligence (AI) can be used in the selection classification of PSHPPIs in very early investment stages in Turkiye.

It must definitely be underlined that this study does not present any real-life PSHPPIs investment plan. It is just an academic study so nothing is commercial in this publication like the author's previous publications. In addition, this study is only a small part of a huge research, development, demonstration, deployment, and diffusion (RD3&D) activity to present some open-science robots and platforms called Global Power Robots and Platforms: GPRP/GPRAP (Global Power Plants Developers: GP2D/G2PD/GPPD, Global Power Plants Engineers: GP2E/G2PE/GPPE, Global Power Plants Owners: GP2O/G2PO/GPOO, Global Power Prediction Systems: GP2S/G2PS/GPPS), Global Profile Analyses Systems (GPAS) and Global Social Network Analyses Systems (GSNAS)) (Li & Saracoglu, 2021; Saracoglu, 2022a; Saracoglu, 2022b). Thus, it must be understood very well that nothing can be accepted as a final model/product/software. There are many activities/tasks that need to be accomplished in a long RD3&D period.

In this paper, the next section presents the literature review. The third section presents the experimentally proposed PSHPPIs investment selection model and case study (fictional investment alternatives). The concluding remarks and further RD3&D activities are presented in the fourth section.

2. Literature Review

A well-organized literature review was conducted on some well-known scientific online databases and journal websites in two separate periods (before manuscript submission until 04th October 2014, during journal review until 29th October 2023). The key phrases in the current study were queried by 2 chunks/wording groups (1st-chunk and 2nd-chunk) on Directory of Open Access Journals, Google Scholar (without including patents and citations, in other words excluding patents and citations), Science Direct, and Springer (in the 2nd review period, Springer noted "*We only show the first 1000 results for any query. Please refine the search criteria by amending your query.*") without any query limitation (e.g., books, journal articles, conference presentations) (Tables 1, 2 and 3). All documents were reviewed in their titles (1st), abstracts (2nd), and main texts (3rd).

There were 2170 results/documents in the 1st literature review period (before submission until 04th October 2014). However, none of them was relevant to the scope of this study. It was realized that most researchers had focused on the control systems of HPPs/SHPPs. Also, a few researchers studied the electricity/power grid modeling. In summary, this 1st literature review showed that researchers had not studied this subject yet or their publications on this subject had not been available on the scientific online database and journal websites until 04th October 2014.

There were 27820 results/documents in the 2nd literature review period (during journal review until 29th October 2023). Only 231 of them could be accepted as somehow-somewhat relevant (e.g., environmental impact statements, evaluating power generation, planning hydropower production) according to the subjective evaluation, or the author's point of view (e.g., Kishore et al., 2021; Laks et al., 2023). Among them, only 26 of them were more relevant (e.g., site selection, performance evaluation) to the current scope (author's point of view) (Roy et al., 2014; Wang et al. 2009). Only three most relevant publications, excluding the author's own works, were summarized in this section considering the scope of this study and journal page limits.

Table 1
Literature review summary by key terms for searching with AND operator

No	1st-chunk	2nd-chunk
1	Small hydroelectric power plant investment	Type-2 fuzzy
2	Small hydroelectric power plant investment	Fuzzy
3	Small hydroelectric power plant investment	Mamdani
4	Small hydroelectric power plant investment	Fuzzy inference
5	Small hydroelectric power plant investment	Fuzzy rule base
6	Small hydroelectric power plant investment	Juzzy
7	Small hydroelectric power plant	Type-2 fuzzy
8	Small hydroelectric power plant	Fuzzy
9	Small hydroelectric power plant	Mamdani
10	Small hydroelectric power plant	Fuzzy inference
11	Small hydroelectric power plant	Fuzzy rule base
12	Small hydroelectric power plant	Juzzy
13	Small hydro	Type-2 fuzzy
14	Small hydro	Fuzzy
15	Small hydro	Mamdani
16	Small hydro	Fuzzy inference
17	Small hydro	Fuzzy rule base
18	Small hydro	Juzzy

Figure 1
HPP examples

Table 2
Literature review summary by numbers

No	04th October 2014		29th October 2023			
1	0		405	(0)		
2	0		1165	(5)	(1)	(1)
3	0		132	(1)	(1)	(0)
4	0		698	(0)		
5	0		1044	(0)		
6	0		0	(0)		
7	0		463	(15)	(0)	
8	17	(0)	1721	(30)	(6)	(0)
9	0		156	(0)		
10	2	(0)	865	(0)		
11	0		1341	(0)		
12	0		0			
13	10	(0)	1363	(12)	(3)	(0)
14	1967	(0)	10558	(95)	(13)	(2)
15	41	(0)	590	(17)	(1)	(0)
16	116	(0)	3096	(31)	(1)	(0)
17	17	(0)	4220	(25)	(0)	
18	0		3	(0)		
Total	2170	(0)	27820	(231)	(26)	(3)

XXXXX(XX)(XX)(X): total search hit (somehow-somewhat relevant documents in the current subject) (directly related to this study) (summarized documents in this publication)

Khandekar et al. (2015) proposed a fuzzy axiomatic design (FAD) model for SHPP project selection and presented an illustrative example with 4 project alternatives, 7 main criteria (i.e., "C_1: technical feasibility," "C_2: approachability," "C_3: constructability," "C_4: legal and environmental impact assessment," "C_5: risk/return ratio," "C_6: socio-economic climate," "C_7: purchasing and feed-in tariffs"), and 2 sub-criteria of "technical feasibility" criterion (i.e., "C_{11}: water head availability," "C_{12}: availability of technical manpower"). They used nine verbal scales for evaluations assigned with trapezoidal fuzzy numbers. They used triangular fuzzy numbers (TFNs) for design range values of beneficial and cost criteria. Their FAD model is a promising model, but it needs many research activities such as setting investment stages (e.g., initial idea, project pre-development, project development), factors definitions and decisions (e.g., how many factors, definition of factors), exploring and modeling of fuzzy membership function (MF) types (e.g., Gaussian, trapezoidal), and all necessary verification and validation activities. Hopefully, this paper will give an idea to those authors to continue their research activities and publish them in an academic manner.

Suryadimal et al. (2020) studied feasibility assessment selection criteria of mini hydro power plants using analytic hierarchy process. They defined eight criteria "head," "watershed," "water discharge," "accessibility to location," "location distance from the nearest power grid," "climate and rainfall," "whether the location status (principle permit) is already owned," and "as the river been utilized for other activities." There are some incomprehensible issues in their paper (e.g., "maps, Economic," "levels, Analysis," "impacts, Hydrological" typing error or something else, "Heat" or "Head" as criterion typing error or something else, "fluid duration current (FDC)" missing definition or something else, "PLN network" missing abbreviation or something else). Their study is in a very early stage, so it needs further research activities such as performing literature review in detail, and factors definitions in detail and their decisions (e.g., how many factors, definition of factors). Hopefully, this paper will inspire to those authors in their research activities and publish them in an appropriate manner.

Ghumman et al. (2020) proposed a framework from site selection to optimal design of small-sized hydropower plants (SHPs) in three successive decision-making (DM) levels and eight main activities as such "development of screening factors and sustainability evaluation criteria" (selected criteria: C_1: "safety concerns" (i.e., "safety of plant's machinery and equipment," "workers' health and safety on the plant site during construction," "workers' health and safety during plant operations"), C_2: "social aspects" (i.e., "local population include job opportunities," "improvement in public health security," "community service,"

Table 3
Literature review summary by short details

No.	Publication	Aim	Methods	Factors
1	Khandekar et al. (2015)	SHPP project selection	Fuzzy axiomatic design	(1) Technical feasibility (2) Approachability (3) Constructability (4) Legal and environmental impact assessment (5) Risk/return ratio (6) Socio-economic climate (7) Purchasing and feed-in tariffs
2	Suryadimal et al. (2020)	Feasibility assessment selection criteria of mini hydro power plants	Analytic hierarchy process	(1) Head (2) Watershed (3) Water discharge (4) Accessibility to location (5) Location distance from the nearest power grid (6) Climate and rainfall (7) Whether the location status (principle permit) is already owned (8) As the river been utilized for other activities
3	Ghumman et al. (2020)	Decision-making of SHPs site selection to SHPs optimal design	Level 1 DM: fuzzy-based multicriteria decision-making Level 2 DM: fuzzy quality function deployment	Level 1 DM: (1) Safety concerns (2) Social aspects (3) Hydrological factors (4) Economic viability (5) Technical feasibility (6) Environmental impacts (7) Climate change impact Level 2 DM: (1) Customer requirements/design objectives (i.e., minimum hydrological variations, optimal plant sizing, electricity generation efficiency, low energy prices, minimal greenhouse gas emissions) (2) Design requirements/sustainability objectives (i.e., technical feasibility, hydrological reliability, environmental sustainability, economic viability, social acceptability) Level 3 DM: (1) Predictions using global circulation model and hydrologic modeling (2) Hydropower modeling to determine optimal sizing of a SHP under climate change impact

"other indirect benefits"), C_3: "hydrological factors" (i.e., "rainfall intensity," "river flows," "available head"), C_4: "economic viability" (i.e., "initial project cost," "maintenance cost," "levelized cost of electricity," "payback period," "investment returns"), C_5: "technical feasibility" (e.g., "topography of the area," "tunnel alignment," "geology," "expected efficiency"), C_6: "environmental impacts," C_7: "climate change impact" (i.e., "hydrological conditions," "extreme flow variations," "flood frequency," "changes in precipitation")), "development of potential SHP sites' alternatives," "evaluation and ranking of SHP sites using fuzzy-based multicriteria decision-making" (level 1 DM), "development of customer requirements/design objectives (i.e., "minimum hydrological variations," "optimal plant sizing," "electricity generation efficiency," "low energy prices," "minimal greenhouse gas emissions") and design requirements/sustainability objectives (i.e., "technical feasibility," "hydrological reliability," "environmental sustainability," "economic viability," "social acceptability")", "evaluation and ranking of SHP sites using fuzzy quality function deployment" (level 2 DM), "detailed data collection, development of digital elevation model and hydrological inputs," "predictions using global circulation model and hydrologic modeling," "hydropower modeling to determine optimal sizing of a SHP under climate change impact" (level 3 DM). They preferred TFNs and group DM with 4 decision-makers for criteria evaluation. They performed hydropower modeling and determined their SHP size by the RETScreen 4.1 software using its hydropower model. Their framework is data and information rich, but it needs many research activities such as structuring all stages, steps, activities, levels very well, factors definitions and decisions (e.g., how many factors, definition of factors), exploring and modeling of fuzzy MF types (e.g., Gaussian, trapezoidal), and all necessary verification and validation activities. Hopefully, this paper will give feedback to those authors to continue their research activities and publish them in an academic and more careful manner (e.g., "firs challenge").

It was seen that although there were some publications somehow-somewhat relevant to the current topic, there were no more than a handful of studies directly related to PSHPPIs selection problem. Accordingly, a definite research gap was clearly observed in this review activity. Therefore, this journal paper could be the first one on the modeling of PSHPPIs selection classification in very early investment stages by a one-node type-2 Mamdani's type FIS/FRBS evaluation approach in the literature.

3. Experimental Proposed Model and Its Application

3.1. Experimental proposed model

The current experimental proposed PSHPPIs selection model has two stages. The 1st stage (stage-1) is an experimental FIS/FRBS model and the 2nd stage (stage-2) is an experimental threshold evaluation (Figure 2).

The current experimental FIS/FRBS model (Cordon, 2011; Garg et al., 2013; Kumar et al., 2010) (stage-1) is designed according to the general principles and structure of one-node general type-2 4-zslices Mamdani's type FISs/FRBSs (Figure 3). It consists of three experimental input variables (attributes, criteria, factors, measures, parameters, etc.) (Measure-1: M1, Measure-2: M2, Measure-3: M3), which are crucial for SHPPs/PSHPPIs, some experimental linguistic rules, an experimental fuzzifier based on type-2 fuzzy MFs, Mamdani's inference engine, an experimental defuzzifier-based on the centroid type reduction/defuzzification, and one experimental output variable (Output-1: O1, selected/unselected, selection classification of PSHPPIs).

Three experimental input measures are used because of their high relevancy with the investment selection preferences of PSHPPIs as the total estimated electricity generation (annual) (Measure-1: M1), the total estimated cost (the whole economic life/period, the whole facility) (Measure-2: M2), and the change in the average runoff (period) (Measure-3: M3).

The first experimental input measure is the total annual estimated electricity generation (Measure-1: M1), which is calculated based on the annual (yearly) data, in kWh unit (kWh: kilowatt-hour). The annual electricity generation of an SHPP is very rarely the same for two or more than 2 years or consecutive years, because of nature itself (the law of nature, precipitation, rainfall, snowfall). The average design flow (m^3/s) and the net head (m) are the main variables of this measure (terms: U.S. Department of Energy Office of Energy Efficiency & Renewable Energy, 2023). Henceforth, either any change in the average flow (m^3/s) or any change in the net head (m) causes/makes some changes directly in the generated electricity (kWh) of an SHPP. In addition to this basic information, engineering calculation methods and their approximations should also be kept in mind. Although this criterion is important for the other power plant types, ambiguity, imprecision, incompleteness, unsharpness, uncertainty, and unpredictability of any engineering approximations, methods, data, information, and reasoning of this measure in SHPPs/PSHPPIs are more decisive, forceful, or important than the others. Thus, this input variable should be preferred for PSHPPIs selection models in these kinds of analyses.

Figure 2
The experimental proposed PSHPPIs selection model

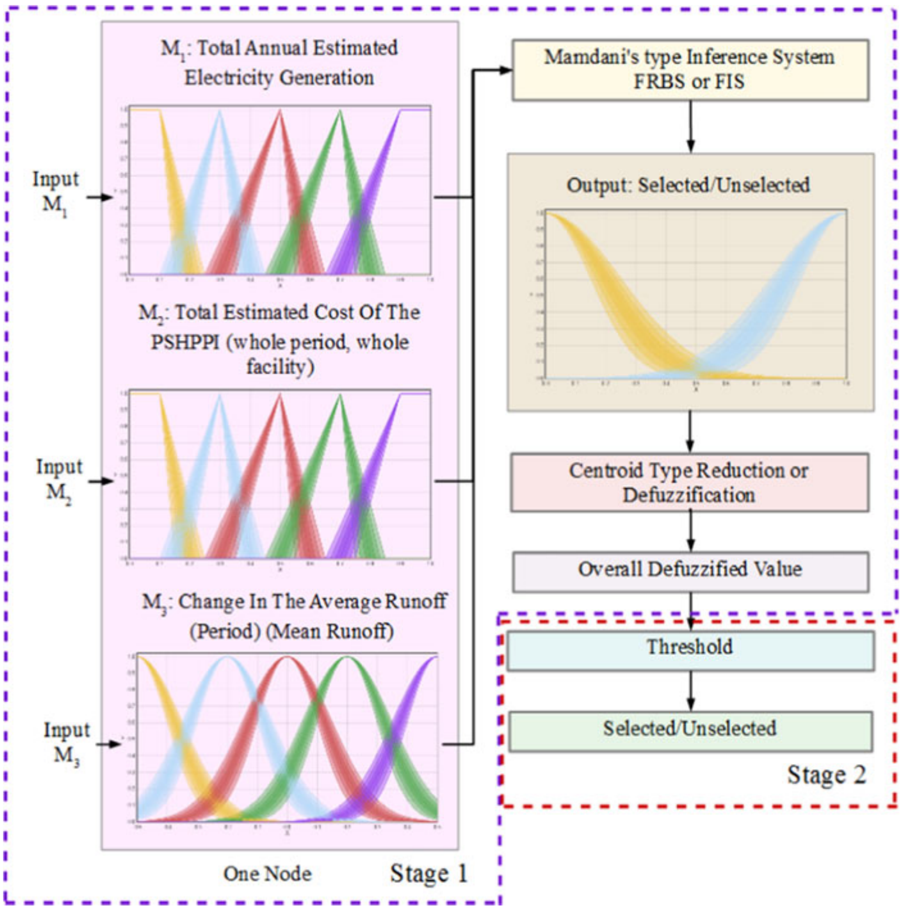
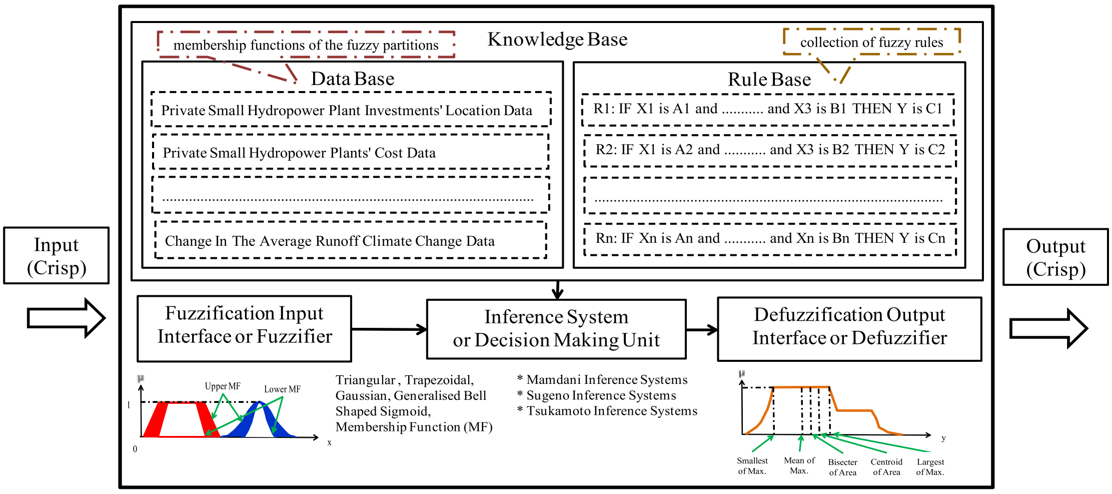


Figure 3
The current experimental one-node type-2 Mamdani's type FIS/FRBS structure



The second experimental input measure is the total estimated cost (the whole economic life/period, the whole facility) (Measure 2: M2). This factor is also important for the other power plants; however, when power/electricity generation, earnings/incomes/revenues, and their high variability during the whole economic life of SHPPs/PSHPPIs are taken into account, the importance and seriousness of this criterion for SHPPs/PSHPPIs can easily be realized, especially where a FiT scheme is like in Turkiye. The capital, which is required for the investment period and some part of the operation/operational period, is estimated by this factor. Thus, this input variable should be preferred for PSHPPIs selection models in these kinds of analyses.

The third experimental input measure, which is the most interesting one for the author, is the change in the average runoff (period) (mean runoff) (Measure 3: M3). Nowadays, almost all researchers agree that many effects of climate change are observed very clearly in lots of events like droughts, floods, and coastal storms all over the world, so it is very meaningful and necessary to use this factor in the current PSHPPIs model. The basic data and information can be taken from the Intergovernmental Panel on Climate Change (IPCC) documents (IPCC annual mean runoff change projection for 2081–2100 based on 1986–2005 data: Collins et al., 2013; Stocker et al., 2014).

The main pillars of the current experimental investment selection model are "fuzzy set theory," "fuzzy logic," "type-2 fuzzy logic," and "Mamdani's type FIS/FRBS." Lotfi A. Zadeh (Lotfali Askar Zadeh/Lotfi Aliaskerzadeh) (1921–2017) introduced the fuzzy set theory to deal with the fuzziness of human judgments in 1965 (Zadeh, 1965). Ebrahim H. (Abe) Mamdani (1942–2010) presented the Mamdani fuzzy inference in 1974 based on Zadeh's fuzzy theory (Mamdani, 1974). The type-2 fuzzy sets were defined by Zadeh in 1975 (Zadeh, 1975). In addition to these main pillars, the main thoughts and explanations of researchers in this field such as Jin's are as follows:

- "the most important thing is that the designed fuzzy system is theoretically able to realize the desired functional mapping. Therefore, the approximation capability of the fuzzy systems is of great concern",
- "Furthermore, it has also been shown that various types of commonly used MFs satisfy the conditions for the fuzzy systems to be universal approximators. By universal approximators, we mean that a fuzzy system can approximate any continuous functions on a compact set to an arbitrary degree of accuracy" (Jin, 2003), the research studies and findings of Rensis Likert (1903–1981) (Likert, 1932), George Armitage Miller (1920–2012) (Miller, 1956), Richard M. Shiffrin (1968–alive), and Robert M. Nosofsky (alive) (Shiffrin & Nosofsky, 1994), and finally Bernd Rohrmann (alive) (Rohrmann, 2007) are used and adopted in this study.

The type-2 fuzzy logic is specifically preferred in the current model for handling and minimizing the effects of uncertainties in the type-1 fuzzy sets and systems (Gera & Dombi, 2008; Mendel, 2007). Furthermore, Mamdani's FIS/FRBS is specifically used in this model for handling human judgments better (Alcalá et al., 2000; Cordon, 2011; Garg et al., 2013; Kumar et al., 2010). The current experimental PSHPPIs selection model's knowledge is acquired according to the direct knowledge acquisition method (terms: indirect, direct, and automatic knowledge acquisition Likert, 1932) (Appendix Code/script/link.1).

Only one expert (the author) is in the process to formalize the experimental fuzzification of the measures. The experimental fuzzification of M1 is based on the expert judgment according to the expert's knowledge of the measure. The meaningful similarity of MFs for M1 to represent the expert judgment on the expert's knowledge on M1 is defined by the expert opinion on the degree of MFs for each linguistic variable (5 triangular and trapezoidal general type-2 4-zslices fuzzy MFs). The experimental fuzzification of M2 and M3 is performed as the same as the experimental fuzzification of M1 in this study (M2: 5 triangular and trapezoidal general type-2 4-zslices fuzzy MFs, M3: 5 Gaussian type-2 4-zslices fuzzy MFs). Likewise, O1 is modeled in 2 Gaussian type-2 4-zslices fuzzy MFs (Appendix Code/script/link.1).

The current experimental one-node general type-2 4-zslices Mamdani's type FISs/FRBSs model is presented using the JuzzyOnline V2.0 (website by Christian Wagner, Mathieu Pierfitte, and Amandine Pailloux, design by freecsstemplates.org), that is, a Java-based online/browser-based FIS/FRBS platform developed by Christian Wagner (Wagner, 2013; Wagner et al., 2014) (Appendix Code/script/link.1).

There are 49 experimental rules in the current experimental FIS/FRBS model (Appendix Code/script/link.1). A simplistic rule base is defined as:

- When the total annual estimated electricity generation (Measure 1: M1) is very low, PSHPPI is not preferable. The total estimated cost (Measure 2: M2) and the change in the average runoff (Measure 3: M3) are not important in this rule. The electricity generation risk is eliminated by this rule.
- When M2 is very high with any defined M1 and M3 conditions, PSHPPI is also not preferable. M1 and M3 are not important in this rule. The total cost risk is eliminated by this rule.
- When M3 is much worse or somewhat worse with any defined M1 and M2, PSHPPI is also not preferable. M1 and M2 are not important in this rule. The climate change risk is eliminated by this rule.
- All other rules are defined in a similar manner and presented on the rule editor.

The experimental reduction/defuzzification of the current experimental FIS/FRBS model is decided according to its popularity in the literature. The centroid type reduction/defuzzification is mentioned as the most popular defuzzification method in the literature. Hence, it is used in the current model. It is mathematically given as in Equation 1.

$$centroid\ defuzzification = \frac{\int_a^b \mu_A(x)xdx}{\int_a^b \mu_A(x)dx} \quad (1)$$

where a is the minimum value of the measure (normalized values in this study), b is the maximum value of the measure (normalized values in this study), x is the measure, and $\mu_A(x)$ is the degree of membership ($\int$: Integral terminology).

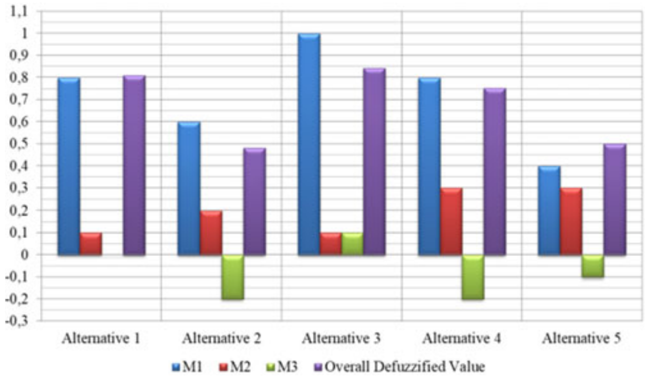
3.2. Experimental application

The experimental application is performed for only 5 PSHPPI alternatives/options amongst available 354 HPPs until 2014 in Turkiye (fictional investment alternatives). The summary of all inputs and results, and the evaluations of alternatives are presented in Figure 4.

The inputs are specifically given as in the real values (not in fuzzy numbers), because of gathering the data in their original forms. This approach is the most simplistic one in the current RD3&D stage. The data and information gathering of M1 and M2 are not so difficult as the data and information gathering of M3 in this application, because all values of M1 and M2 are taken from the official HPP records. The data and information of M3 in this experimental application are tried to be gathered by the natural eye reading (not any computerized tools, such as the ones based on the AI applications for audio, image, and video) on the annual mean runoff change projection map(s).

The values of M1, M2, and M3 input measures are respectively (Alternative 1: 0.8; 0.1; 0.0), (Alternative 2: 0.6; 0.2; −0.2), (Alternative 3: 1.0; 0.1; 0.1), (Alternative 4: 0.8; 0.3; −0.2), and (Alternative 5: 0.4; 0.3; −0.1). The smallest values of M1, M2, and M3 are respectively 0.4 (Alternative 5), 0.1 (Alternative 1, Alternative 3), and −0.2 (Alternative 2, Alternative 4). The largest values of M1, M2, and M3 are respectively 1.0 (Alternative 3), 0.3 (Alternative 4, Alternative 5), and 0.1 (Alternative 3). All other values of M1, M2, and M3 are in between these smallest and largest values.

Figure 4
The summary of inputs and results



Alternatives/ Options	M1	M2	M3	Overall Defuzzified Value
Alternative 1	0.8	0.1	0.0	0.8103445867860549
Alternative 2	0.6	0.2	-0.2	0.4818359483036966
Alternative 3	1.0	0.1	0.1	0.8432086512474439
Alternative 4	0.8	0.3	-0.2	0.752758146607152
Alternative 5	0.4	0.3	-0.1	0.5

The stage-2 is an experimental threshold evaluation. The threshold value is run in the overall defuzzified value set (Alternative 1: 0.8103445867860549; Alternative 2: 0.4818359483036966; Alternative 3: 0.8432086512474439; Alternative 4: 0.752758146607152; Alternative 5: 0.5). If and when the threshold value is assumed/selected as 0.50 (≥ 0.50), then all alternatives are selected as the preferred PSHPPIs (Alternative 1; Alternative 2; Alternative 3; Alternative 4; Alternative 5). If and when the threshold value is assumed/selected as 0.60 (≥ 0.60), then 3 alternatives are selected as the preferred PSHPPIs (Alternative 1; Alternative 3; Alternative 4). If and when the threshold value is assumed/selected as 0.80 (≥ 0.80), then 2 alternatives are selected as the preferred PSHPPIs (Alternative 1; Alternative 3). If and when the threshold value is assumed/selected as 0.82 (≥ 0.82), then 1 alternative is selected as the preferred PSHPPIs (Alternative 3). If and when the threshold value is assumed/selected as 0.85 (≥ 0.85), then none of them is selected as the preferred PSHPPIs.

In the current experimental application, the experimental threshold is selected as 0.60 (≥ 0.60), so that Alternative 1, Alternative 3, and Alternative 4 can be analyzed better with many additional activities and studies; in contrast, Alternative 2 and Alternative 5 do not have sufficient overall defuzzified values to be studied in detail based on their current conditions and experimental model. As a result, VPI should focus on only three options (Alternative 1/3/4) based on the current model, data, and information (Appendix Code/script/link.1, Figure 4).

4. Conclusions and Future Work

Investment selection models, private hydropower plant investments, PSHPPIs, investment selection models of PSHPPIs in very early investment stages in Turkiye, type-2 fuzzy models, and Mamdani's type FIS/FRBSs are studied in the current RD3&D activity. An experimental model in two stages is proposed for PSHPPIs selection. An experimental one-node general type-2 4-zslices Mamdani's type FIS/FRBS model is designed in the 1st stage and an experimental threshold evaluation approach is designed in the 2nd stage. An experimental application is executed for 5 PSHPPI alternatives that are assumed to be in their very early investment stages in Turkiye. The current investment selection model shows the possibility of using Mamdani's type FIS/FRBS in this crucial subject. Moreover, it presents the power of type-2 FIS models in handling the fuzziness of real-world problems.

The main differences between this study and previous ones in the literature are (1) this study directly contributes to open science, others not; (2) this study directly focuses PSHPPIs selection, others not; (3) this study starts modeling with an experimental approach, others not; (4) this study tries to use the least number of factors, others not; (5) this study presents a FIS/FRBSs model, others not; (6) this study presents a Mamdani's type FIS/FRBSs model, others not; (7) this study presents a general type-2 4-zslices Mamdani's type FIS/FRBSs model, others not; and (8) this study presents an experimental application for some PSHPPI alternatives/options in Turkiye as fictional investment alternatives by using real-world PSHPPIs data and information, others not.

Additionally, this article enriches the study of this stream by (1st) cost and inflation reduction act by a new investment/economic policy; (2nd) suggesting the investment/economic doctrine of Islam, the investment/economic jihad (as a whole approach); (3rd) recommending a very well organized RD3&D program; (4th) presenting open-science robots and platforms entitled as Global Power Robots and Platforms: GPRP/GPRAP (Global Power Plants Developers: GP2D/G2PD/GPPD, Global Power Plants Engineers: GP2E/G2PE/GPPE, Global Power Plants Owners: GP2O/G2PO/GPOO, Global Power Prediction Systems: GP2S/G2PS/GPPS), GPAS and GSNAS); (5th) developing those Islamic-jihadist robots and platforms; (6th) aiming to collect and implement all available methods and their related supportive things; and (7th) modeling investment DM with one-node general type-2 4-zslices Mamdani's type FIS/FRBS model.

In future studies, investment selection models (private, public, public–private partnerships, power plants, renewable power plants, HPPs, SHPPs) and many other investment selection models with their variables will be studied in detail. Afterward, all fuzzification processes and fuzzy MFs (e.g., generalized bell-shaped, Gaussian, piecewise-quadratic, trapezoidal, triangular) of all variables will be investigated in detail. Besides, the degree of the MFs for each linguistic variable will be studied better and improved according to the new findings. Then, Mamdani-type FIS/FRBS rules and their definitions shall be studied very well. For instance, some rules of the current FIS/FRBS model can easily be eliminated and the number of rules in the rule base may be reduced to only a few rules. Meanwhile, the consistency of rules will be checked with serious verification, validation, and accreditation (VV&A) efforts. At the same time, the current model shall be tuned and fine-tuned for gathering better and better results with the help of VV&A efforts. Furthermore, some sophisticated one/multi-mode type-2 Mamdani FIS/FRBSs will be built, tested, and presented for real-world applications. Moreover, many other methods like type-1 Mamdani FIS/FRBSs, type-1 Sugeno FIS/FRBSs, neural networks, artificial neural networks, and deep neural networks in the literature will be studied and used to present billions and billions of different models. After an appropriate development period with experiencing many methods and models, an automatic investment selection classification system can be deployed and diffused in the robots and platforms (GPRP/GPRAP, GP2D/G2PD/GPPD, GP2E/G2PE/GPPE, GP2O/G2PO/GPOO, GP2S/G2PS/GPPS). All of these robots and platforms are open-science so some specific studies are also necessary to find out the best way to present them as re-runnable, repeatable, reproducible, reusable, and replicable, simple, traceable, transparent, and trustworthy manner. They will evolve into open-science humanoid robots after their very long-term RD3&D periods (Li & Saracoglu, 2021; Saracoglu, 2022a; Saracoglu, 2022b).

Nomenclature and Abbreviations

$\int$:	Integral
$\mu_A(x)$:	degree of membership
m:	metre (meter) (head, net head)
m^3/s:	cubic meter per second (flow)
AD:	axiomatic design
AHP:	analytic hierarchy process
AI:	artificial intelligence
ANN:	artificial neural networks
approx.:	approximately
DNN:	deep neural networks
DM:	decision-making
e.g.,:	exempli gratia (for example)
FAD:	fuzzy axiomatic design
FIS(s):	fuzzy inference system(s)
FiT(s):	feed-in-tariff(s)
FFN:	friend, foe, or neutral
FRBS(s):	fuzzy rule base system(s)
GP2D/G2PD/GPPD:	global power plants developers
GP2E/G2PE/GPPE:	global power plants engineers
GP2O/G2PO/GPOO:	global power plants owners
GP2S/G2PS/GPPS:	global power prediction systems
GPAS:	Global Profile Analyses Systems
GSNAS:	Global Social Network Analyses Systems
HPP(s):	hydroelectric power plant(s)
i.e.:	id est (that is)
IPCC:	Intergovernmental Panel on Climate Change
kWh:	kilowatt-hour
M(s):	measure(s)
MF(s):	membership function(s)
MW(s):	megawatt(s)
NN:	neural network
O:	output
P:	installed capacity/power
PSHPPI(s):	private small hydroelectric power/hydropower plant investment(s)

RD3&D:	Research, Development, Demonstration, Deployment, and Diffusion
SHP(s):	small-sized hydropower plant(s)
SHPP(s):	small hydropower plant(s)
TFN(s):	triangular fuzzy number(s)
Türkiye (in Turkish characters):	Turkiye (Turkey)
U.S.:	United States
VPI(s):	virtual private investor(s)
VV&A:	verification, validation, and accreditation

Availability of Code and Data

Global Power Robots and Platforms (Global Power Plants Developers: GP2D/G2PD/GPPD, Global Power Plants Engineers: GP2E/G2PE/GPPE, Global Power Plants Owners: GP2O/G2PO/GPOO, Global Power Prediction Systems: GP2S/G2PS/GPPS), Global Profile Analyses Systems (GPAS), and Global Social Network Analyses Systems (GSNAS) robots and platforms are in their research, development, demonstration, deployment, and diffusion stages, and their details can be found at the https://github.com/burakomersaracoglu?tab=projects, https://www.researchgate.net/profile/Burak_Saracoglu

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

Data Availability Statement

The data that support the findings of this study are openly available in [Github] at https://github.com/burakomersaracoglu?tab=projects and in [researchgate] at https://www.researchgate.net/profile/Burak_Saracoglu

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Appendix

http://ritweb.cloudapp.net:8080/JuzzyOnline2/gensys?type=g2&name=Selection%20Classification%20Of%20The%20Private%20Small%20Hydropower%20Plant%20Investments&z=4&input=total%20estimated%20electricity%20generation&lb=0.0&ub=1.0&mfnb=5&mf=Very%20Low&fun=trapezoidal&p=0.0_0.0_0.1_0.25_0.0_0.0_0.1_0.15&p=0.0_0.0_0.1_0.23333333333333334_0.0_0.0_0.1_0.16666666666666666&p=0.0_0.0_0.1_0.21666666666666667_0.0_0.0_0.1_0.18333333333333332&p=0.0_0.0_0.1_0.2_0.0_0.0_0.1_0.19999999999999998&mf=Low&fun=triangular&p=0.1_0.3_0.45_0.2_0.3_0.35&p=0.11666666666666667_0.3_0.43333333333333335_0.18333333333333335_0.3_0.36666666666666664&p=0.13333333333333333_0.3_0.41666666666666667_0.16666666666666669_0.3_0.3833333333333333&p=0.15000000000000002_0.3_0.39999999999999997_0.15000000000000002_0.3_0.39999999999999997&mf=Moderate&fun=triangular&p=0.25_0.5_0.65_0.35_0.5_0.55&p=0.26666666666666666_0.5_0.6333333333333333_0.3333333333333333_0.5_0.5666666666666667&p=0.2833333333333333_0.5_0.6166666666666667_0.31666666666666665_0.5_0.5833333333333333&p=0.3_0.5_0.5999999999999999_0.3_0.5_0.5999999999999999&mf=High&fun=triangular&p=0.45_0.7_0.85_0.55_0.7_0.75&p=0.34666666666666667_0.7_0.8333333333333333_0.5333333333333333_0.7_0.7666666666666666&p=0.48333333333333334_0.7_0.8166666666666667_0.5166666666666666_0.7_0.7833333333333332&p=0.49999999999999994_0.7_0.7999999999999998_0.49999999999999994_0.7_0.7999999999999998&mf=Very%20High&fun=trapezoidal&p=0.65_0.9_1.0_1.0_0.75_0.9_1.0_1.0&p=0.6666666666666667_0.9_1.0_1.0_0.7333333333333334_0.9_1.0_1.0&p=0.6833333333333333_0.9_1.0_1.0_0.7166666666666668_0.9_1.0_1.0&p=0.7_0.9_1.0_1.0_0.7000000000000002_0.9_1.0_1.0&input=total%20estimated%20cost&lb=0.0&ub=1.0&mfnb=5&mf=Very%20Low&fun=trapezoidal&p=0.0_0.0_0.1_0.25_0.0_0.0_0.1_0.15&p=0.0_0.0_0.1_0.23333333333333334_0.0_0.0_0.1_0.16666666666666666&p=0.0_0.0_0.1_0.21666666666666667_0.0_0.0_0.1_0.18333333333333332&p=0.0_0.0_0.1_0.2_0.0_0.0_0.1_0.19999999999999998&mf=Low&fun=triangular&p=0.1_0.3_0.45_0.2_0.3_0.35&p=0.11666666666666667_0.3_0.43333333333333335_0.18333333333333335_0.3_0.36666666666666664&p=0.13333333333333333_0.3_0.41666666666666667_0.16666666666666669_0.3_0.38333333333333333&p=0.15000000000000002_0.3_0.39999999999999997_0.15000000000000002_0.3_0.39999999999999997&mf=Moderate&fun=triangular&p=0.25_0.5_0.65_0.35_0.5_0.55&p=0.26666666666666666_0.5_0.6333333333333333_0.3333333333333333_0.5_0.5666666666666667&p=0.2833333333333333_0.5_0.6166666666666667_0.31666666666666665_0.5_0.5833333333333333&p=0.3_0.5_0.5999999999999999_0.3_0.5_0.5999999999999999&mf=High&fun=triangular&p=0.45_0.7_0.85_0.55_0.7_0.75&p=0.46666666666666667_0.7_0.8333333333333333_0.5333333333333333_0.7_0.7666666666666666&p=0.48333333333333334_0.7_0.8166666666666667_0.5166666666666666_0.7_0.7833333333333332&p=0.49999999999999994_0.7_0.7999999999999998_0.49999999999999994_0.7_0.7999999999999998&mf=Very%20High&fun=trapezoidal&p=0.65_0.9_1.0_1.0_0.75_0.9_1.0_1.0&p=0.6666666666666667_0.9_1.0_1.0_0.7333333333333334_0.9_1.0_1.0&p=0.6833333333333333_0.9_1.0_1.0_0.7166666666666668_0.9_1.0_1.0&p=0.7_0.9_1.0_1.0_0.7000000000000002_0.9_1.0_1.0&input=change%20in%20the%20average%20runoff%20&lb=-0.5&ub=0.5&mfnb=5&mf=Much%20Worse&fun=gaussian&p=-0.5_0.15_-0.5_0.1&p=-0.5_0.14166666666666666_-0.5_0.10833333333333334&p=-0.5_0.13333333333333333_-0.5_0.11666666666666667&p=-0.5_0.125_-0.5_0.125&mf=Somewhat%20Worse&fun=gaussian&p=-0.2_0.15_-0.2_0.1&p=-0.2_0.14166666666666666_-0.2_0.10833333333333334&p=-0.2_0.13333333333333333_-0.2_0.11666666666666667&p=-0.2_0.125_-0.2_0.125&mf=About%20The%20Same&fun=gaussian&p=0.0_0.15_0.0_0.1&p=0.0_0.14166666666666666_0.0_0.10833333333333334&p=0.0_0.13333333333333333_0.0_0.11666666666666667&p=0.0_0.125_0.0_0.125&mf=Somewhat%20Better&fun=gaussian&p=0.2_0.15_0.2_0.1&p=0.2_0.14166666666666666_0.2_0.10833333333333334&p=0.2_0.13333333333333333_0.2_0.11666666666666667&p=0.2_0.125_0.2_0.125&mf=Much%20Better&fun=gaussian&p=0.5_0.15_0.5_0.1&p=0.5_0.14166666666666666_0.5_0.10833333333333334&p=0.5_0.13333333333333333_0.5_0.11666666666666667&p=0.5_0.125_0.5_0.125&output=Selection%20Classification&lb=0.0&ub=1.0&mfnb=2&mf=Unselected&fun=gaussian&p=0.0_0.25_0.0_0.15&p=0.0_0.23333333333333334_0.0_0.16666666666666666&p=0.0_0.21666666666666667_0.0_0.18333333333333332&p=0.0_0.2_0.0_0.19999999999999998&mf=Selected&fun=gaussian&p=1.0_0.25_1.0_0.15&p=1.0_0.23333333333333334_1.0_0.16666666666666666&p=1.0_0.21666666666666667_1.0_0.18333333333333332&p=1.0_0.2_1.0_0.19999999999999998&if=0_0&then=0_0&if=0_1_1_4&then=0_0&if=0_1_1_3&then=0_0&if=0_1_1_2&then=0_0&if=0_1_1_1&then=0_0&if=0_1_1_0_2_0&then=0_0&if=0_1_1_0_2_1&then=0_0&if=0_1_1_0_2_2&then=0_1&if=0_1_1_0_2_3&then=0_1&if=0_1_1_0_2_4&then=0_1&if=0_2_1_4&then=0_0&if=0_2_1_3&then=0_0&if=0_2_1_2_2_0&then=0_0&if=0_2_1_2_2_1&then=0_0&if=0_2_1_2_2_2&then=0_1&if=0_2_1_2_2_3&then=0_1&if=0_2_1_2_2_4&then=0_1&if=0_2_1_1_2_0&then=0_0&if=0_2_1_1_2_1&then=0_0&if=0_2_1_1_2_2&then=0_1&if=0_2_1_1_2_3&then=0_1&if=0_2_1_1_2_4&then=0_1&if=0_2_1_0_2_0&then=0_0&if=0_2_1_0_2_1&then=0_0&if=0_2_1_0_2_2&then=0_1&if=0_2_1_0_2_3&then=0_1&if=0_2_1_0_2_4&then=0_1&if=0_3_1_4&then=0_0&if=0_3_1_3_2_0&then=0_0&if=0_3_1_3_2_1&then=0_0&if=0_3_1_3_2_2&then=0_1&if=0_3_1_3_2_3&then=0_1&if=0_3_1_3_2_4&then=0_1&if=0_3_1_2_2_0&then=0_0&if=0_3_1_2_2_1&then=0_0&if=0_3_1_2_2_2&then=0_1&if=0_3_1_2_2_3&then=0_1&if=0_3_1_2_2_4&then=0_1&if=0_3_1_1_2_0&then=0_0&if=0_3_1_1_2_1&then=0_0&if=0_3_1_1_2_2&then=0_1&if=0_3_1_1_2_3&then=0_1&if=0_3_1_1_2_4&then=0_1&if=0_3_1_0&then=0_1&if=0_4_1_4&then=0_0&if=0_4_1_3&then=0_1&if=0_4_1_2&then=0_1&if=0_4_1_1&then=0_1&if=0_4_1_0&then=0_1

Code/script/link 1. The link of the whole experimental one-node type-2 Mamdani's type FIS/FRBS model (directly copy and paste the link) (visualization and computation by using JuzzyOnline V2.0; Wagner, 2013; Wagner et al., 2014; http://juzzy.wagnerweb.net, http://ritweb.cloudapp.net:8080/JuzzyOnline2)