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RESEARCH PAPER

Designing a Fuzzy Inference System for Measuring Sustainability Levels in Livestock Centers with a Real Case Study

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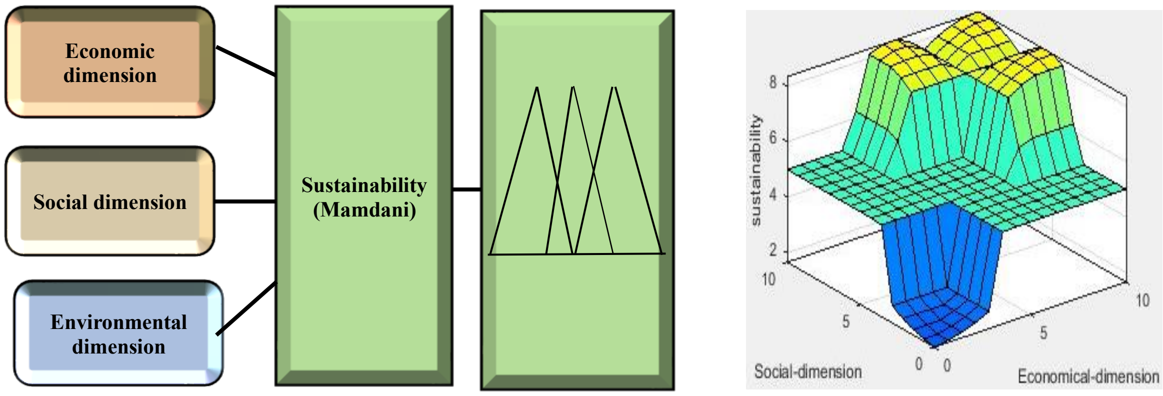
ABSTRACT
One of the most important issues regarding community health is animal health, followed by the health of animal products. Providing a sustainable environment for production facilities like livestock centers is essential. In this study, we have proposed designing four fuzzy inference systems for managing the sustainability of livestock centers. The first, second, and third systems are applied for the economic, social, and environmental dimensions. The fourth is for a system whose output is the sustainability level while its inputs are the three addressed sustainability dimensions. The data source was experts' judgment, and the major limitation of this research was access to a limited number of experts in making system rules. The validation is made by cross-checking with other experts. Considering a maximum of 10 points for each sustainability dimension and supposing that the economic dimension is 5.05, the social dimension is 7.77 and the environmental dimension is 8.12, the sustainability level turns out to be 7.92.

KEYWORDS: *Sustainability measurement; Fuzzy inference system; Environmental dimension; Social dimension.*

GRAPHICAL ABSTRACT



1. Introduction

Developing a sustainable system encompassing its different dimensions has been one of the major concerns for academics and practitioners. Economic, environmental and social dimensions should be considered in designing a sustainable system. Such systems consider the social dimension by which the needs of all involved people are met while simultaneously trying to protect the environment and carefully use organizational resources. As a sustainability concept, the needs of the existing people should be satisfied with minimal damage to the capabilities of the next generations in meeting needs. Sustainability in livestock centers may mean growing poultry like turkeys instead of cows since they require less land, feed and water. Sometimes, it means pasture management, zero-grazing, crop-livestock integration, grassland restoration and management, and manure management (e.g., recycling).

In designing sustainable operational systems, whether producing goods or services may be one of the managers' concerns. The system in question in this research is a livestock center that produces raw milk to send to dairy companies. There are a

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number of factors that affect the sustainability of livestock. The selection of optimal values for the addressed factors can have a considerable effect on the performance of the livestock center in terms of economic, social, and environmental criteria. In this study, a fuzzy inference system (FIS) is given to evaluate and increase the sustainability of a livestock center. Mirzaei et al. [1] did a comprehensive review on designing sustainable indices for food SC under climate change.

One of the roles of fuzzy logic is to formulate the uncertainties of operational systems. FIS is a well-known tool for receiving fuzzy inputs and making crisp or fuzzy outputs through a number of given rules [2]. In this method, we utilize the knowledge and experiences of experts to design the addressed system. FISs have the ability to make decisions and control a system using expert knowledge. In fact, without knowing the internal interactions among the components of a complex system as a black box, we can predict the system behavior, i.e., output parameters, by changing the values of the input parameters. This can be considered a decision support system for managers. FIS generally has one or more fuzzy inputs and is knowledge-based, including several designed rules and a database that provides the logical basis for the reasoning process. FIS is responsible for applying the designed rules (generally, in the form of if-then) for reasoning and giving the results of some outputs. Finally, the output values may be generated by the defuzzification process. Azar and Faraji [3] briefly provided the steps of an FIS, including fuzzification of input parameters, designing a knowledge base, fuzzy inference, and defuzzification.

As is clear from Figure 1, the first step is the fuzzification of the crisp input parameters. In this stage, crisp parameters are converted to fuzzy numbers by defining qualitative specifications. For example, the qualitative specifications may be less, average, and high. In the second step, the knowledge base is designed so that some "if $\Longrightarrow$ then" rules are made utilizing some experts' knowledge and experiences. In the third step, fuzzy inferences are made considering the rules and input parameters of the fuzzy type. In the final step, the fuzzy outputs are converted into corresponding crisp values, i.e., defuzzification.

The major motivation factors of the current research are as follows:

- Minding sustainability factors in operational decisions of a livestock center
- Requiring a rule-based system to control the sustainability level of operational decisions
- Comparing the impact of each sustainability factor in the total sustainability level of the operational system

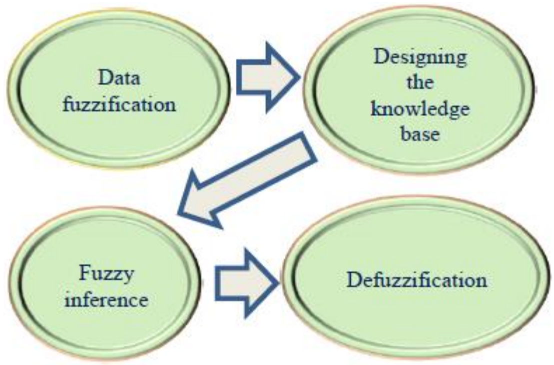

Fig.1. A schematic of steps of a FIS

In the present research, the sustainability of the livestock center is formulated using an FIS. Economic, social, and environmental dimensions are considered as the system's inputs, while sustainability is the output. Similarly, each sustainability dimension can be considered as the output of three systems with several other inputs. Seven factors for each sustainability dimension, i.e., economic, social, and environmental, are considered [4]; in total, there are 21 factors, as shown in Figure 2. From among these factors, transportation cost, the safety of workers, the welfare of workers, employment, production of high-quality milk, fertilizing method, wastewater treatment plant, and controlled use of chemicals are extracted from Allaoui et al. [5] and were confirmed by the experts for this study in the livestock center. Other factors are extracted from the experts' ideas and judgments. The number of factors could be five or ten, but we have reached seven factors for each sustainability dimension based on the expert's opinion. The equity of the number of factors is not necessary for the system. Still, we followed this policy to balance the effects of the economic, social and environmental factors.

The economic dimension includes seven of the most important cost factors in the livestock industry. The first economic factor is the cost of animal feed supply, which accounts for about 77 to 78 percent of the costs [6]. The second factor is labor and overhead costs, including wages and salaries paid to workers, insurance costs, and renting niches. The third factor is the transportation cost of raw milk dairy plants. The fourth factor is energy cost, which includes the cost of utilizing water, electricity and gas in the livestock center. The fifth factor is treatment and vaccination costs for maintaining livestock health. Since a clean environment is needed to produce quality milk with low microbial load, we need to spend on buying disinfectants as the sixth cost factor. Finally, livestock requires investment in its facilities to maintain them operable and promote their operations. Banks are known sources of financing for livestock centers.

The social dimension includes seven factors. The first social factor is the safety of workers in the livestock center. A livestock center may have different hazards, such as electrocution and injuries caused by contact with livestock. The second factor is the welfare of workers. The welfare policies should be in such a way as to encourage them to devote themselves to the work and have a good feeling in the work areas. The third factor is the employment dimension of the social factor in a livestock center. Job creation is essential, particularly in areas with high unemployment rates.

The fourth factor is equipment maintenance for livestock. This item directly affects the reduction of milk loss, which is important from the social point of view due to the paid governmental subsidy to livestock centers. In fact, waste of the mentioned subsidy is not desirable from the social dimension. The fifth dimension is livestock health monitoring, which reduces the loss of livestock. The sixth factor is the production of organic milk, which increases the health of society by providing products without additives or preservatives. The seventh factor is the production of high-quality milk, which results in the ultimate customer satisfaction in the milk supply chain (SC).

The environmental dimension also includes seven factors that cause the least environmental damage, such as water, soil, and air. The first social factor is the fertilizing method. Since fertilizers have high nitrate content, additional nitrate can enter the soil and eventually absorb the roots of plants and cause serious damage to the environment due to not using modern fertilizing methods. The second factor is investment in the establishment of wastewater treatment plants. There is much ammonia in the wastewater of livestock centers, so if the wastewater is not treated, the ammonia can enter the groundwater and bring environmental damage to the water resources.

The third factor is livestock feed rationing. Each livestock needs a certain amount of food and protein per day; these foods often have a lot of phosphorus; if the food given to the livestock is higher than needed, the additional amount enters the soil through livestock feces; this can threaten the environment's health. The fourth factor is the dosage of medicine. If the dosage of the drugs injected into the livestock exceeds the permissible limits, it can cause the growth of antibiotic-resistant bacteria in the intestines of livestock; the bacteria can enter the soil and water resources through manure. The fifth factor is the distance traveled to transport the milk by vehicle. This can reduce carbon emissions and directly affect air pollution. The sixth factor is the optimal usage of water.

Nowadays, due to climate change and shortages of water resources in dry countries, livestock centers should invest in intelligent water-use methods. For example, making circulation systems can prevent water waste in livestock. The seventh factor is the controlled use of chemicals according to the specified standards.

Figure 2 shows the inputs of different sustainability dimensions in an integrated picture. In this research, four FISs are studied: the economic dimension, the social dimension, the environmental dimension, and the system itself, whose inputs are the three addressed dimensions with sustainability as the output. The FIS is developed according to the steps given in Figure 1.

Considering the literature, we have developed a fuzzy rule-based system for sustainability level measurement for the first time in this work; we have implemented this system for a livestock center by collecting the required factors for different sustainability dimensions using the literature and experts' judgments. We have used different types of FNs, such as triangular, trapezoidal, and Gaussian, for making variety in quantifying experts' judgments, as well; however, employing each type of FN should have its justifications. For example, trapezoidal FN is usually employed when the membership values of a range of numbers are recognized as one. Research objectives are:

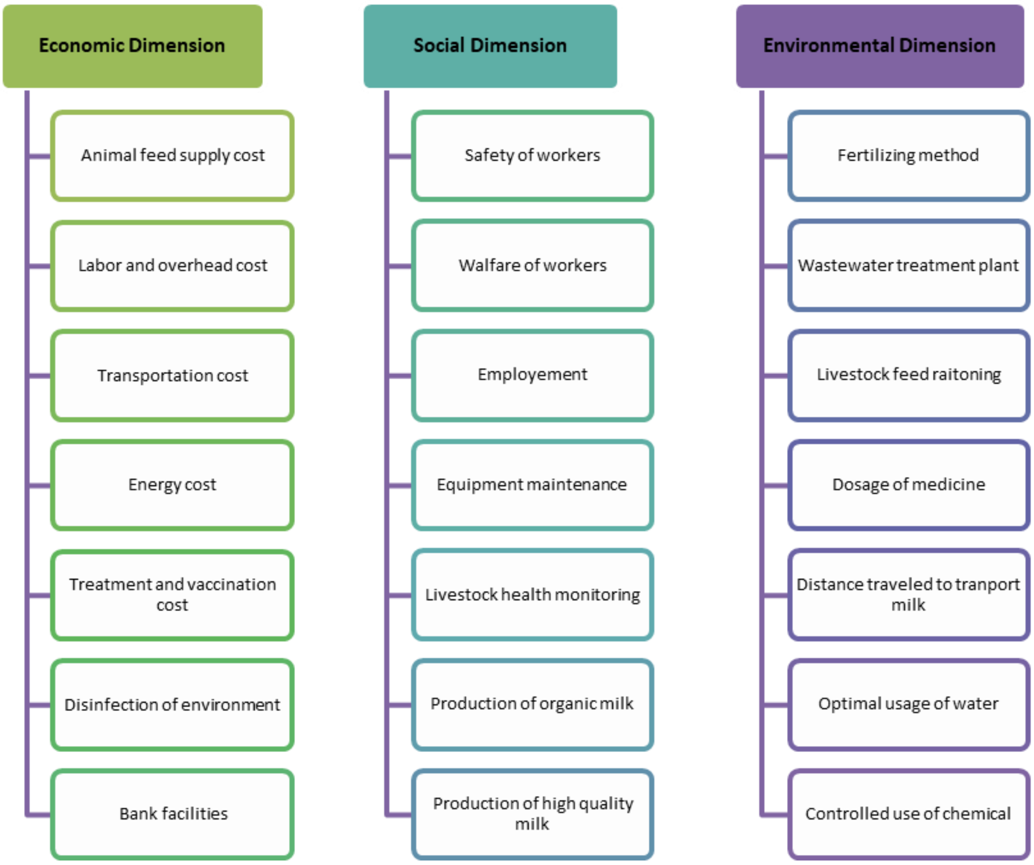

Fig.2. A schematic of the sustainability dimensions and their related inputs

1- Finding suitable criteria for measuring each sustainability dimension
2- Measuring each sustainability dimension utilizing a rule-based system
3- Managing the sustainability level of the livestock center by making trade-offs among influential factors

The research questions are:

1- What are the suitable criteria for measuring each sustainability dimension?
2- What are the efficient rules for making inferences when designing fuzzy inference systems?
3- How many fuzzy inference systems are required to measure and manage the sustainability of livestock centers?
4- How can we manage and measure the sustainability level of the given livestock centers?

The selected method is a fuzzy inference system. Since the input factors of the system are of linguistic terms, we have used the Mamdani fuzzy inference system for this purpose. Its initial output is also linguistic but converted to a crisp number using the center of gravity method (COGM). We have used different types of fuzzy numbers to make a sensitivity analysis and have not restricted the results to a special type of fuzzy number in the numerical results section.

The paper is structured as follows: in Section 2, we give a literature review. Sections 3, 4, and 5 deal with the economic, social, and environmental dimensions of the FISs. Section 6 is on designing the sustainability-based FIS; in the end, in Section 7, conclusions are given.

2. Literature Review

Since the problem is about sustainability measurement and improvement by using FISs in livestock centers, we have categorized the existing research into three categories, including FIS design, sustainability measurement, and applications of FISs and sustainability in the food industry.

2.1. FIS design

Akilli et al. [7] designed an FIS to classify Holstein dairy cows according to five inputs. They found that using the FIS to investigate uncertainties in livestock farming is very efficient. There are some inputs in the designed FIS, such as calving interval, 305-day milk yield and artificial insemination. This research has no special discussion on environmental or social aspects. Caglayan et al. [8] gave an FIS to investigate and control destructive greenhouse gases affecting livestock health in livestock centers. They determine the appropriate temperature and humidity for the herds and air conditioning fans' speed to provide a suitable air quality space. Rango et al. [2] used FIS to classify users of machine-to-machine platforms to design an eco-friendly driving style. Due to the expansion of the use of the Internet of Things, they analyzed the speed, acceleration and fuel of cars to reduce CO_2 Emissions. Urbina et al. [9] designed an FIS in the chemical industry to reduce the emission of greenhouse gases in producing methanol. They utilized data-driven tools for analyzing greenhouse gas emissions. The reason for developing an FIS is the uncertainty of data in chemical production processes. As is evident from the abovementioned research, there have been some applications of FISs in some SCs or industries that consider environmental factors. Still, no known research is considering the application of FIS for sustainability measurement. Goodarzian et al. [10] developed an FIS for forecasting the COVID-19 medical waste amount. Then, a new fuzzy sustainable location-allocation model, which categorizes patients, was developed to design the pertinent SC. Yang et al. [11] developed a hybrid decision-making structure for evaluating urban energy internet, which is important for constructing low-carbon cities from the sustainability viewpoint. They used fuzzy and multi-criteria decision-making techniques for this purpose.

2.2. Sustainability and its measurement

Uysal [12] developed an integrated model using the laboratory evaluation test method, graph theory and matrix approach to measure SC sustainability performance by examining three companies. Cango et al. [13] developed a framework to evaluate sustainability performance for industries with economic, social and environmental dimensions. They proposed a few systems for sustainability performance measurement. Tiwari and Shadab Khan [14] analyzed the one-way variance and regression analysis to measure sustainability in three seafood production plants in India. They found that the lack of safety standards, green SC standards and prevention of environmental risks increased the time and cost of operations in the addressed plants. Segerkvist et al. [15] measured sustainability concerning economic, social and environmental dimensions for livestock farming with broiler cows. The data for this study was collected from January 2000 to March 2020 in New Zealand. The environmental dimension includes life cycle analysis, the economic dimension includes costs associated with production, and the social dimension includes labor rights, community resilience, community development, health, and social equity.

Hosseini-Motlagh et al. [16] incorporated resilience and sustainability in a wheat SC network design problem with multiple objectives and uncertainty. Hosseini-Motlagh et al. [17] incorporated resilience and sustainability in an electricity SC network design problem with dispersed generators and uncertainty. Sharifi et al. [18] developed a multi-objective, multi-period, multi-product, uncertain integrated sustainable-resilient model for designing a second-generation biofuel SC under uncertainty. The uncertainty was tackled by applying a hybrid stochastic fuzzy-robust approach.

Samani and Hosseini-Motlagh [19] developed a sustainable-efficient multi-period, multi-product bioenergy SC network design under uncertainty. A mathematical model was proposed to minimize inefficiency, environmental impacts, and SC costs. Zhang et al. [20] measured the sustainability performance of some firms in different provinces of China using Er-Xiang's dual processing theory. They presented four strategies for the sustainable development of the addressed firms. This paper's main innovation is introducing and measuring the process, state, and coordination indexes. Di Vaio et al. [21] measured tourists' sustainable behaviors and satisfaction levels in a port in Italy by using ordinal logit models and filling out some questionnaires. The tourists were classified into three clusters. Ruojue et al. [22] measured sustainability efficiency in energy storage technologies via the three economic, social and environmental dimensions. They used some measurement tools, such as the data envelopment analysis method. Efficiency of sustainability was measured under uncertainty. Barry and Hoyne [23] presented strategies and suggestions, such as increasing the country's budget in the field of meteorology to measure sustainability due to the sudden climate change in European countries. They also used the three economic, social and environmental dimensions for this study. The impacts of climate change in environmental dimensions are greenhouse gas emissions, temperature change, precipitation, and sea-level rise. The impacts of climate change on economic dimensions are research funding, eco-innovation, and enterprise development. The impacts of climate change on social dimensions are environmental justice, education, and risk perception. Dehshiri et al. [24] evaluated renewable energy projects considering sustainability goals and a fuzzy-based approach.

As is evident from the abovementioned research, sustainability measurement has been studied in several researches using different mathematical tools. Still, we could not find any research that discusses the application of FIS for sustainability measurement in the literature.

2.3. Application of FIS or fuzzy logic and sustainability in the food industry

As for applying FIS or generally the fuzzy logic in designing a sustainable food SC, we can mention Allaoui et al. [5], in which a sustainable food SC network that includes all three economic, environmental, and social perspectives is designed. The economic dimension includes cost reduction, the environmental dimension reduces greenhouse gas emissions, and the social dimension includes employee satisfaction. Since sustainability management is vital in food transportation, in the research of Djekic et al. [25], an analysis of the performance of transportation stability using fuzzy logic has been presented. The model describes the direct relationship between the number of trips and transportation routes with carbon dioxide emissions. De and Singh [26] studied sustainability issues using fuzzy logic in the agricultural SC. They concluded using fuzzy applications with big data in the addressed SC can make reliable models. Lal et al. [27] analyzed the quality of raw milk produced in cattle farms by applying the Internet of Things and FIS tools and monitoring temperature, electrical conductivity, the amount of solutes in raw milk, and the amount of acid. Zheng et al. [28] developed a multi-objective model for online food delivery by using fuzzy logic and considering the uncertainty of data. Several strategies were given by dynamically tuning the objective weights. As the literature shows, there is no specific research in which the design and application of an FIS are discussed for sustainability measurement in food SC. In this research, we have precisely designed and applied a FIS for sustainability measurement in a dairy SC.

We have developed a fuzzy rule-based system for sustainability level measurement for the first time in this work; we have implemented this system for a livestock center by collecting the required factors for different sustainability dimensions using the literature and experts' judgments. We have used different types of FNs, such as triangular, trapezoidal, and Gaussian, to make variety in quantifying experts' judgments.

2.4. Other sustainability assessment techniques

D'Amico et al. [29] proposed the structure of an artificial neural network for assessing and forecasting energy and environmental performance of a case study in Italy. They showed the high reliability of the proposed network for this purpose. El Amrani et al. [30] proposed a novel index for assessing the overall sustainability of a biomass SC network. A Bayesian network approach was applied to consider the causal relationship among different sustainability factors. Anbarkhan [31] proposed a novel approach for assessing sustainability in software engineering within Industry 5.0 using the fuzzy technique for order of preference by similarity to ideal solution (fuzzy TOPSIS) methodology.

3. Designing the FIS: Economic Dimension

As stated earlier, the three steps of this dimension are given as follows. It should be noted that the philosophy of considering different types of fuzzy numbers (i.e., triangular, trapezoidal, and Gaussian) for input and output factors is to remove the skewness and make the results more valid.

3.1. First step: fuzzification of economic factors

Figure 3 depicts a schematic of the FIS, including the inputs and outputs for the economic dimension.

As shown in Figure 3, this system includes seven inputs and one output, which is the economic dimension of the FIS. For the economic dimension, seven input factors exist, including the cost of animal feed supply, labor and overhead costs, transportation cost of raw milk dairy plants, energy cost, treatment and vaccination cost, disinfectant of environment and bank facilities. The factors were described earlier. Three linguistic variables, i.e., low, medium and high, represent each economic factor's level as the input of the economic FIS. The values are assumed to be generated from 0 to 10.

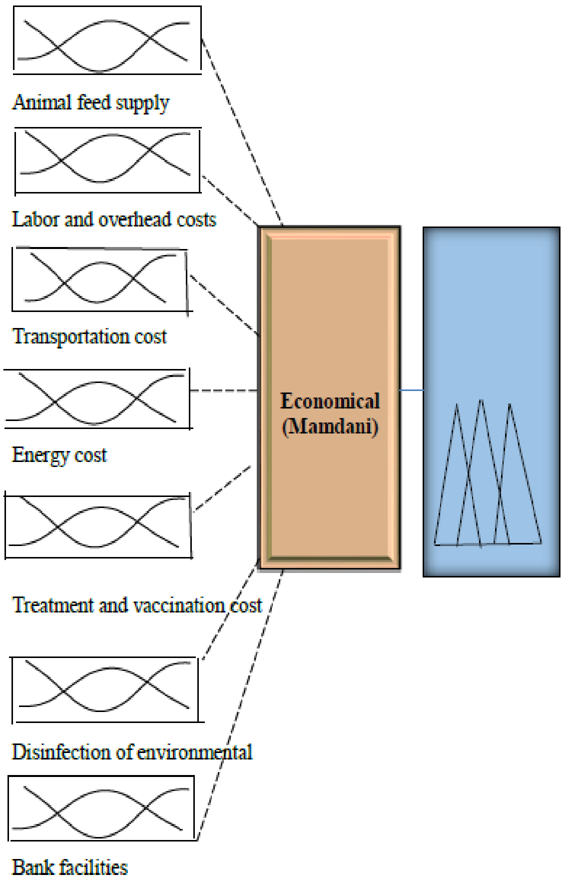

Fig.3. A schematic of the FIS of the economic dimension

Table 1 illustrates the fuzzy linguistic variables and the related trapezoidal FNs.

Tab.1. Trapezoidal FNs for economic factors

Linguistic variable	Trapezoidal FN
Low	[0,0,1,4]
Medium	[3,5,6,7]
High	[5.5,7.5,9,10]

Furthermore, Table 2 shows the fuzzy linguistic variables of the system's output, i.e., the economic dimension. Triangular FNs in the range of 0 to 10 are considered to represent the corresponding linguistic variables.

Tab.2. Triangular FNs for the economic dimension

Linguistic variable	Triangular FN
Low cost	[0,2.5, 5]
Medium cost	[3,6, 7]
High cost	[6.5,8,10]

Figure 4 shows the trapezoidal FNs given in Table 1, while Figure 5 depicts the triangular FNs of Table 2 graphically.

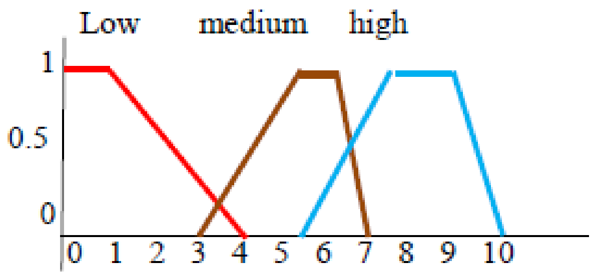

Fig.4. The graphical representation of trapezoidal FNs of the input factors of the economic dimension

As shown in Figure 4, the input members of the economic dimension are demonstrated by three linguistic variables: low, medium, and high in the specified intervals. Furthermore, as shown in Figure 5, the output economic dimension is also demonstrated by three linguistic variables: low, medium, and high.

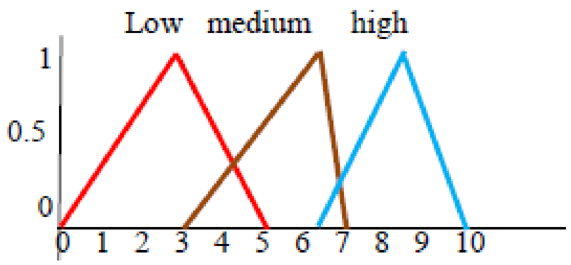

Fig.5. The graphical representation of triangular FNs of the output economic dimension

3.2. Second step: collection and evaluation of economic rules

In this step, we have collected the rules of the addressed FIS rules based on the experts' judgments. The validation is made by cross-checking with other experts. Table 3 gives the rules of the economic FIS. For example, as per Rule 1, if the first and second factors are low, the third, fourth, fifth, and seventh factors are medium, and the sixth factor is high, then the economic dimension of sustainability is low.

Tab.3. Rules to be integrated in the Economic FIS

	Input and output							
Rule	**Animal feed supply cost**	**Labor and overhead costs**	**Transportation cost**	**Energy cost**	**Treatment and vaccination cost**	**Disinfection of environment**	**Bank facilities**	**Economic dimension**
1	low	low	medium	medium	medium	high	medium	low cost
2	low	high	-	-	-	-	-	medium cost
3	medium	medium	-	-	-	-	-	medium cost
4	high	high	-	-	-	-	-	high cost
5	high	-	-	-	-	-	high	high cost
6	medium	high	low	low	low	low	high	high cost
7	medium	high	high	medium	low	low	low	high cost
8	low	medium	medium	high	high	medium	high	medium cost
9	high	medium	low	low	High	high	medium	high cost
10	low	medium	-	-	-	-	low	low cost

3.3. Third step: inference and defuzzification of economic dimension

Considering the rules in Table 3, we use the COGM to defuzzify the output value. For example, if the animal feed supply is 2.22, the labor and overhead costs are 3.35, and so on, then the economic dimension value turns out to be 2.5, as in Figure 6a. As is apparent from Figures 6b and 6c, when the input economic factors are increased, the output value increases correspondingly.

4. Designing the FIS: Social Dimension

As stated earlier, the three steps of this dimension are given as follows:

4.1. First step: fuzzification of social factors

Figure 7 depicts a schematic of the FIS, including the inputs and outputs for the social dimension.
As shown in Figure 7, this system includes seven inputs and one output, which is the social dimension of the FIS. For the social dimension, there exist seven input factors, including the safety of workers, the welfare of workers, employment, equipment maintenance, livestock health monitoring, production of organic milk and production of high-quality milk. The factors were described earlier.
Three linguistic variables, i.e., low, medium, and high, are included to represent each social factor's level as the input of the social FIS. The values are assumed to be generated from 0 to 10.
Table 4 illustrates the fuzzy linguistic variables and the related Gaussian FNs. Gaussian FNs have been used to represent the values of the input factor of the social dimension. In Gaussian graphs, the parameters include two values representing the standard deviation and the center of the Gaussian curve, respectively, from left to right.

Tab.4. Gaussian FNs for the social dimension factors

Linguistic variable	Parameter
low	{2.123,0}
medium	{2.123,5}
high	{2.123 ,10}

Furthermore, Table 5 gives the fuzzy linguistic variables of the system's output, i.e., social dimension.
Trapezoidal FNs in the range of 0 to 10 are considered to represent the corresponding linguistic variables.

Tab.5. Trapezoidal FNs for the social dimension

Linguistic variable	Parameter
Low	[0,0,1,3]
Medium	[2,4,5, 6]
high	[5.5,7, 9,10]

Figure 8 shows Gaussian FNs of Table 4 while Figure 9 shows the trapezoidal FNs of Table 5 graphically.
As shown in Figure 8, the input factors of the social dimension are shown by three linguistic variables low, medium, and high in the specified intervals. Furthermore, as shown in Figure 9, the output social dimension is also demonstrated by three linguistic variables: low, medium and high.

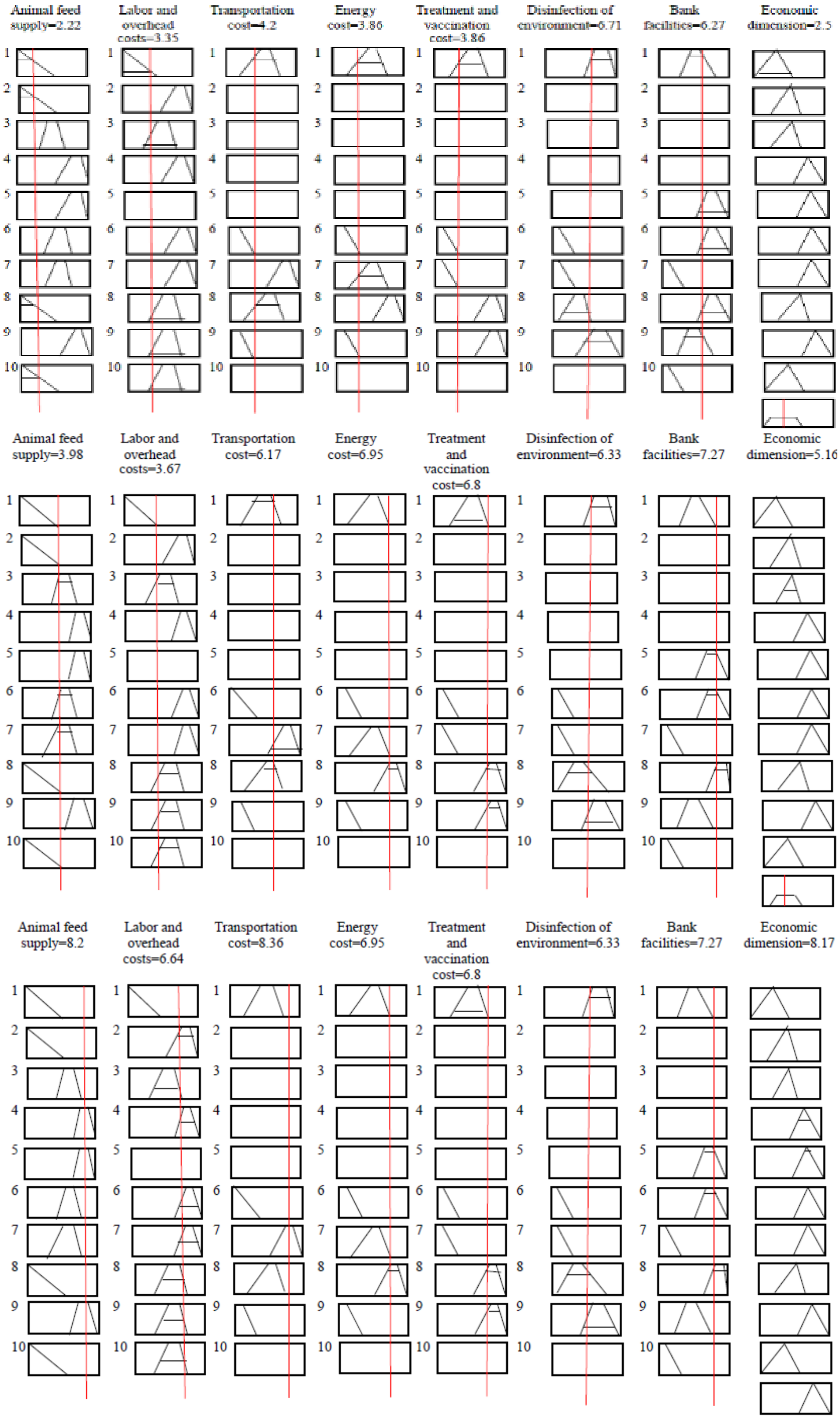

Fig.6. a) A schematic representation of the values for the input economic factors and the corresponding output value of the economic dimension equal to 2. b) A schematic representation of the values for the input economic factors and the corresponding output value of the economic dimension equal to 5.16. c) A schematic representation of the values for the input economic factors and the corresponding output value of the economic dimension equal to 8.17

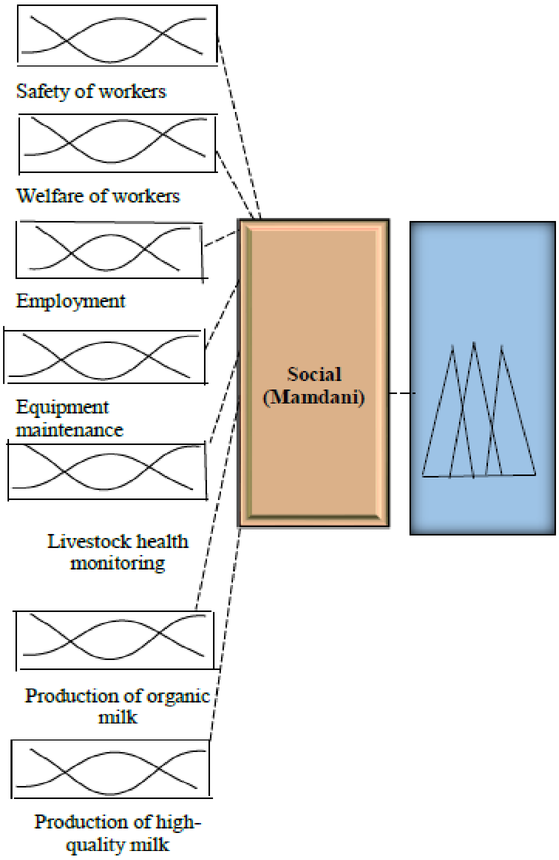

Fig.7. A schematic of the FIS of the social dimension

4.2. Second step: collection and evaluation of social rules

In this step, we have collected the rules of the addressed FIS based on the expert's judgments.

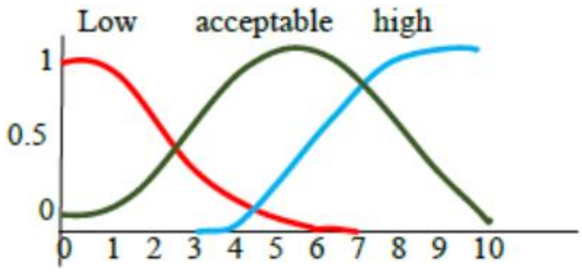

Fig.8. The graphical representation of Gaussian FNs of the input factors of the social dimension

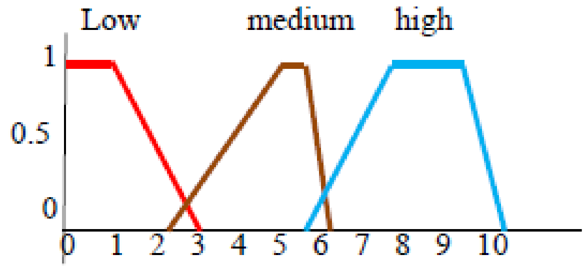

Fig.9. The graphical representation of trapezoidal FNs of the output social dimension

Table 6 illustrates the rules of the social FIS. For example, as Rule 1, if the first, second, fourth and sixth factors have any arbitrary value, while the third, fifth, and seventh factors are high, then the social dimension of sustainability is high.

Tab.6. Rules to be integrated into the Social FIS

	Inputs and output							
Rules	**Safety of workers**	**Welfare of workers**	**Employment**	**Equipment maintenance**	**Livestock health monitoring**	**Production of organic milk**	**Production of high-quality milk**	**Social dimension (output)**
1	-	-	high	-	high	-	high	high
2	-	-	medium	-	medium	-	medium	medium
3	-	-	low	-	low	-	low	low
4	high	medium	high	low	medium	medium	high	high
5	medium	medium	medium	medium	low	low	medium	medium
6	medium	medium	medium	low	medium	high	high	high
7	medium	low	high	low	medium	low	low	low
8	medium	medium	high	high	low	medium	low	low
9	high	medium	low	high	medium	low	low	low
10	high	high	low	medium	low	low	medium	low
11	low	low	low	low	high	medium	high	medium
12	low	low	low	low	medium	low	medium	low
13	high	medium	low	low	medium	high	high	medium
14	high	high	high	low	medium	low	medium	medium
15	medium	medium	high	high	low	medium	medium	medium
16	low	medium	high	high	low	medium	low	low

4.3. Third step: inference and defuzzification of social dimension

Considering the rules in Table 6, we use the COGM to de-fuzzify the output value. For example, if the safety of workers is 7.73, the welfare of workers is 5, and so on, then the social dimension value turns out to be 7.11, as in Figure 10.

5. Designing the FIS: Environmental Dimension

As stated earlier, the three steps of this dimension are given as follows:

5.1. First step: fuzzification of environmental factors

Figure 11 depicts a schematic of the FIS, including the inputs and outputs for the environmental dimension.

As shown in Figure 11, this system includes seven inputs and one output, which is the environmental dimension of the FIS. For the environmental dimension, seven input factors, including fertilizing method, wastewater treatment plant, livestock feed rationing, medicine dosage, distances traveled to transport milk, optimal usage of water and controlled use of chemicals, are considered. Three linguistic variables, i.e., low attention, acceptable attention, and high attention, are considered for showing the level of each environmental factor as the input of the environmental FIS. The values are assumed to be generated from 0 to 10.

Table 7 gives the fuzzy linguistic variables and related Gaussian and trapezoidal FNs. Gaussian FNs have been used to represent the value of the acceptable attention variable.

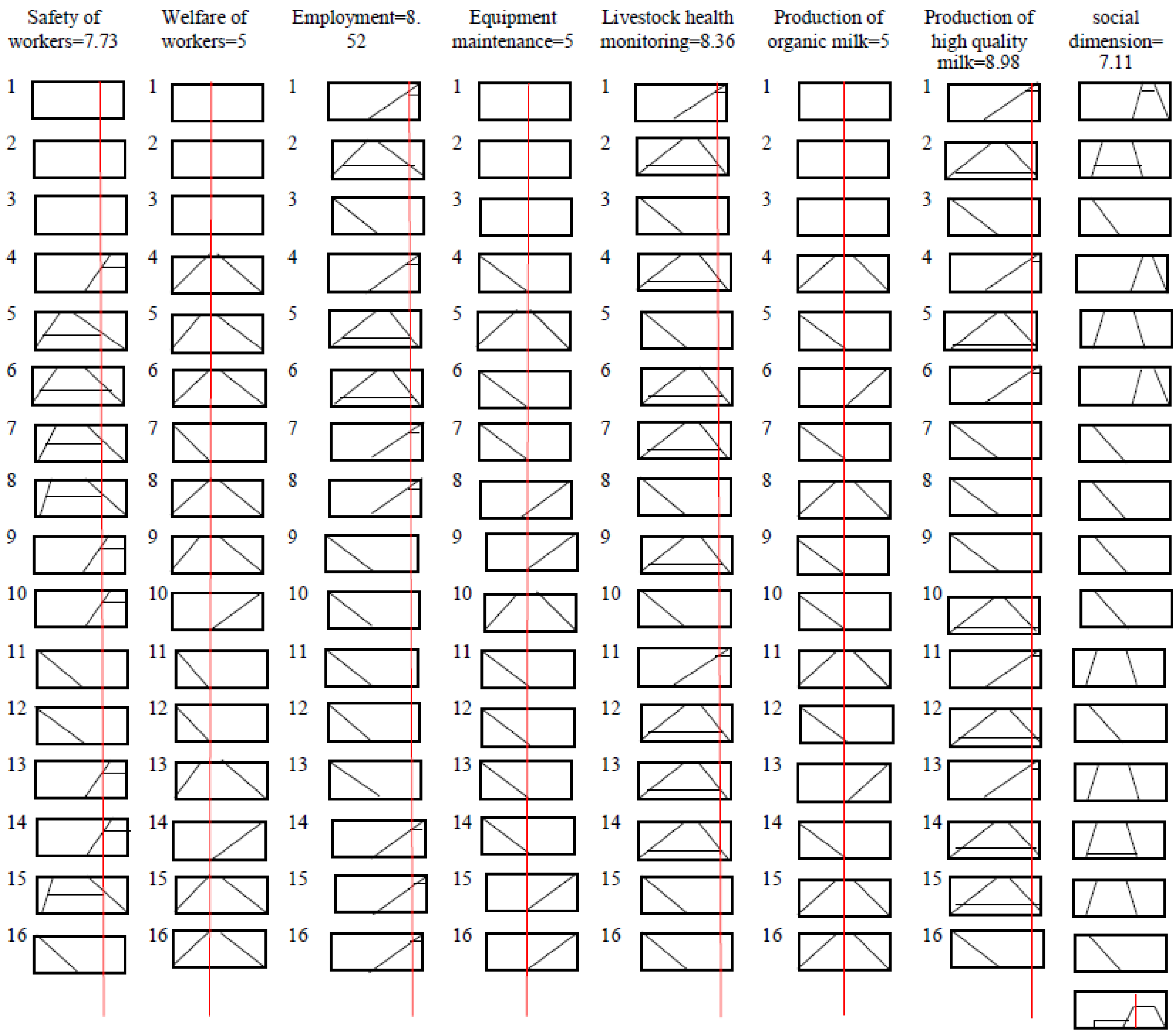

Fig.10. A schematic representation of the values for the input social factors and the corresponding output value of the social dimension equal to 7.11

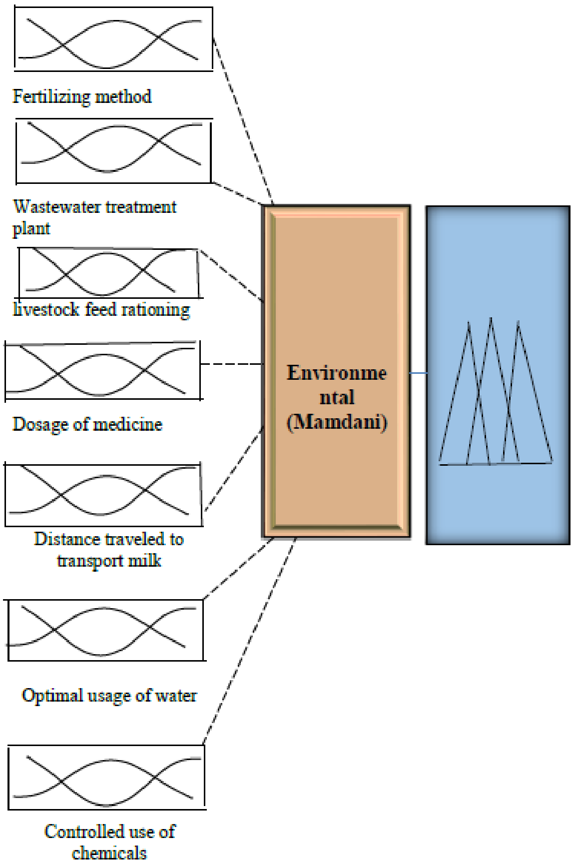

Fig.11. A schematic of the FIS of the environmental dimension

Tab.7. Gaussian and trapezoidal FNs for the environmental dimension factors

Linguistic variable	Parameter
Low attention	[0, 0,1,3]
Acceptable attention	{2.123, 5}
High attention	[6,7, 9,10]

Furthermore, Table 8 shows the fuzzy linguistic variables of the system's output, i.e., the environmental dimension. Gaussian FNs in the range of 0 to 10 are considered to represent the corresponding linguistic variables.

Tab.8. Gaussian FNs for the environmental dimension

Linguistic variable	Parameter
Low attention	{2.123,0}
Acceptable attention	{2.123,5}
High attention	{2.123,10}

Figure 12 shows the trapezoidal and Gaussian FNs in Table 7, while Figure 13 shows the Gaussian FNs in Table 8 graphically.
The input factors of the environmental dimension are shown in Figure 12 by three linguistic variables: low attention, acceptable attention, and high attention in the specified intervals. Furthermore, as shown in Figure 13, the output environmental dimension is represented by three linguistic variables: low attention, acceptable attention, and high attention.

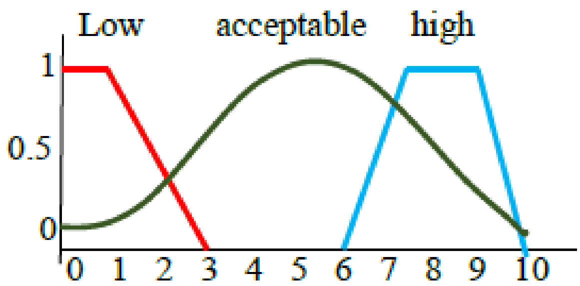

Fig.12. The graphical representation of the trapezoidal and Gaussian FNs of the input factors of the environmental dimension

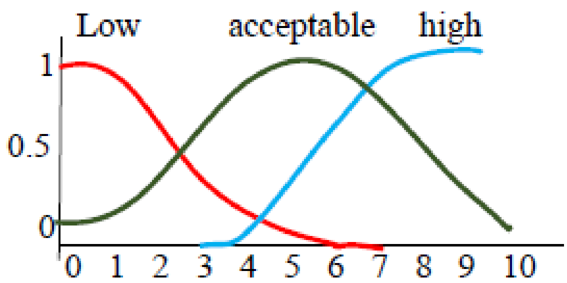

Fig.13. The graphical representation of the Gaussian FNs of the output environmental dimension

5.2. Second step: collection and evaluation of environmental rules

In this step, we have collected the rules of the addressed FIS based on the experts' judgments. Table 9 illustrates the rules of the environmental FIS. For example, as Rule 1, if the first, third, fourth, sixth and seventh factors have any arbitrary value, while the second and fifth are high, then the environmental dimension of sustainability is high.

5.3. Third step: inference and defuzzification of environmental dimension

Having the rules given in Table 9, we use the center of gravity method (COGM) for de-fuzzification of the output value. For example, if the fertilizing method is 7.62, the wastewater treatment plant is 8.11, and so on, then the environmental dimension value turns out to be 7.03, as in Figure 14.

Tab.9. Rules to be integrated in the Environmental FIS

Inputs and output								
Rule	**Fertilizing method**	**Wastewater treatment plant**	**Livestock feed rationing**	**Dosage of medicine**	**Distance traveled to transport milk**	**Optimal usage of water**	**Use of chemicals**	**Environmental dimension (output)**
1	-	high	-	-	high	-	-	high
2	-	low	-	-	low	-	-	Low
3	-	acceptable	-	-	acceptable	-	-	acceptable
4	acceptable	high	high	acceptable	low	high	high	high
5	acceptable	high	low	low	acceptable	high	high	high
6	low	acceptable	acceptable	high	low	low	acceptable	Low
7	high	acceptable	low	high	high	low	low	acceptable
8	high	low	high	acceptable	acceptable	high	low	Acceptable
9	low	low	high	high	high	low	high	acceptable
10	low	low	low	acceptable	acceptable	low	low	Low
11	acceptable	acceptable	acceptable	low	low	acceptable	low	acceptable
12	high	high	high	high	low	acceptable	low	high
13	low	low	acceptable	high	acceptable	low	acceptable	Low

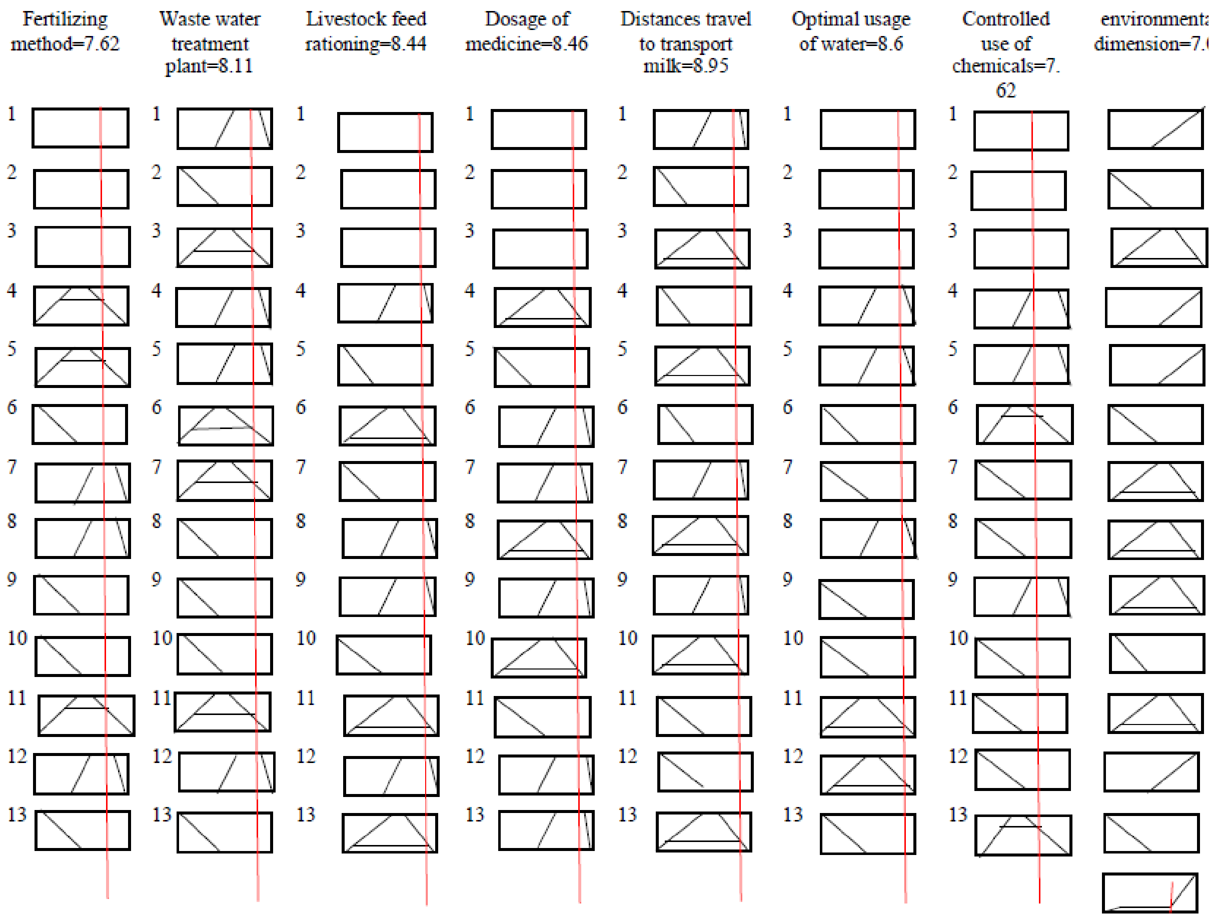

Fig.14. A schematic representation of the values for the input environmental factors and the corresponding output value of the environmental dimension equal to 7.03

6. Designing the Sustainability-Based

As stated earlier, the three steps of this dimension are given as follows:

6.1. First step: fuzzification of three sustainability dimensions

Figure 15 depicts a schematic of the FIS, including the inputs and outputs for the environmental dimension.

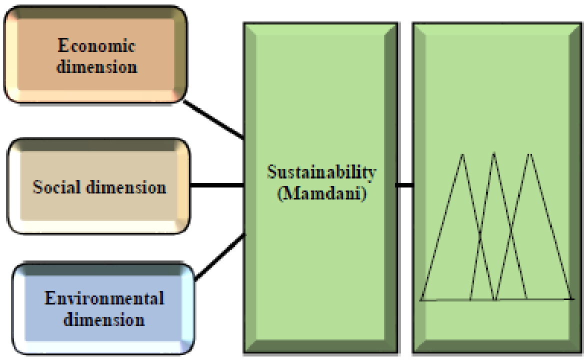

Fig.15. A schematic of the FIS of the sustainability level

Figure 15 shows the system with three inputs and one output. Economic, social, and environmental dimensions are used as input, and sustainability level is used as output. Three linguistic variables, i.e., low, medium and high, are included to represent the level of each sustainability factor as the input of the sustainability FIS. The values are assumed to be generated from 0 to 10. Table 10 illustrates the fuzzy linguistic variables and related Gaussian and trapezoidal FNs. Gaussian FNs have been used to represent the value of the high variable.

Tab.10. Gaussian and trapezoidal FNs for the sustainability level factors

Linguistic variable	parameter
low	[−4,0,4]
medium	[3,5, 6,7]
high	{1.699,10}

Furthermore, Table 11 shows the fuzzy linguistic variables of the system's output, i.e., sustainability level. Gaussian FNs in the range of 0 to 10 are considered to represent the corresponding linguistic variables.

Tab.11. Gaussian FNs for the sustainability level

Linguistic variable	parameter
low	{2.123,0}
medium	{2.123,5}
high	{2.123,10}

Figure 16 shows the trapezoidal and Gaussian FNs in Table 10, while Figure 17 shows the Gaussian FNs in Table 11 graphically.
Figure 16 shows the trapezoidal and Gaussian FNs of the sustainability level factors, and Figure 17 presents the graphical representation of the Gaussian FNs of the sustainability level.

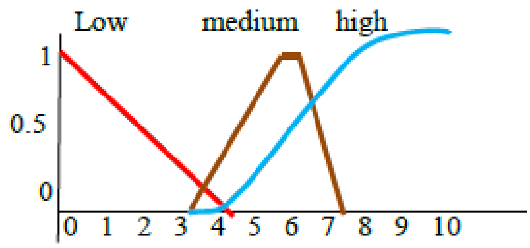

Fig.16. The graphical representation of the trapezoidal and Gaussian FNs of the sustainability level factors

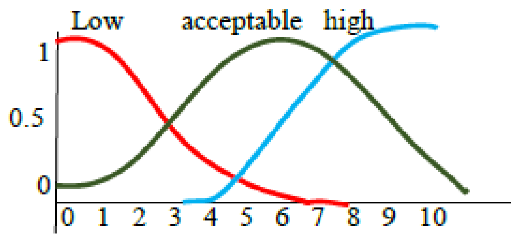

Fig.17. The graphical representation of the Gaussian FNs of the sustainability level

6.2. Second step: collection and evaluation of sustainability rules

In this step, we have collected the rules of the addressed FIS based on the experts' judgments. The rules are presented in Table 12. For example, as Rule 1, if the first, second and third factors are low, then the sustainability level is also low.

6.3. Third step: inference and defuzzification of sustainability level

Following the rules given in Table 12, we use COGM to de-fuzzify the output value. For example, if the economic dimension is 5.05, the social dimension is 7.77 and the environmental dimension is 8.12, then the sustainability level becomes 7.92. Another example is that if the economic dimension decreases to 1.9, the social dimension decreases to 2.66, and the environmental dimension stays fixed (i.e., 8.12), then the sustainability level becomes 2.2. This example shows that by decreasing the economic dimension by 62%, decreasing the social dimension by 65%, and keeping the environmental dimension constant, the sustainability level decreases by 72 %. As shown in Figure 18, the sustainability level increases by increasing the social and economic factors.

Tab.12. Rules to be integrated in the Sustainability level FIS

	Input and output			
Rule	**Economic dimension**	**Social dimension**	**Environmental dimension**	**stainability level (output)**
1	low	low	low	low
2	high	low	low	low
3	high	high	high	high
4	low	medium	medium	medium
5	medium	high	high	high
6	high	low	high	medium
7	high	high	low	medium
8	low	high	high	medium
9	high	medium	high	high
10	high	high	medium	high
11	low	high	low	low
12	low	low	high	low
13	low	high	medium	medium
14	medium	medium	medium	medium
15	medium	high	low	medium
16	medium	high	medium	high
17	medium	medium	low	medium
18	medium	medium	high	high
19	medium	low	low	low
20	medium	low	medium	medium
21	low	medium	high	medium
22	medium	low	high	medium
23	low	low	medium	low
24	high	low	medium	medium
25	high	medium	medium	high
26	high	medium	low	medium
27	low	medium	low	low

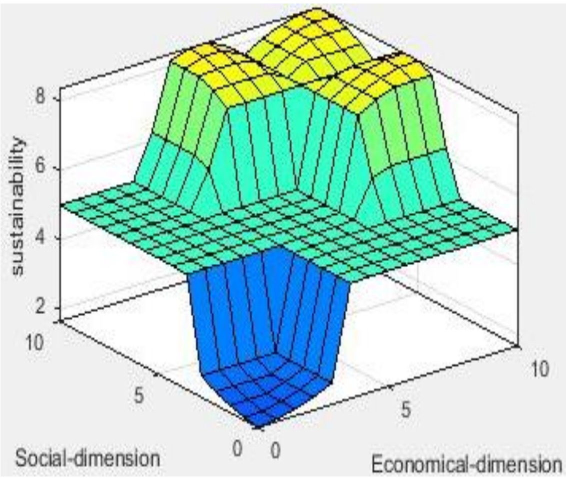

Fig.18. The increasing trend of sustainability level by increasing economic and social dimensions

7. Conclusions and Future Research Suggestions

In the last few decades, most emphasis has been placed on environmental and economic factors, while the social dimension has been neglected. One of the important components of sustainable architecture is social sustainability. This research tried to study designing an FIS for managing the sustainability level in a livestock center. Each dimension of sustainability includes some factors as input of FISs. Ultimately, we developed a FIS in which the three addressed dimensions of sustainability are inputs while the sustainability level is the system's output. The results showed that the FISs can work well and be used in management decision-making as an efficient tool if the required rules are well-defined.

The idea is to develop a decision support system to implement this logic practically and professionally. The system's component will be an interface for user interactions, a knowledge base for storing and managing the collected rules, and a database for managing other required data like fuzzy numbers. However, a model-based component can be added if it is supposed to use the output of such a system for optimization purposes and utilize meta-heuristic algorithms like genetic algorithms. The limitation of this research is the impact of a constraint on the research design. They are the flaws or weaknesses in the study, which may influence the outcome of the research. We can mention the two following limitations:

1. Access to more experts to increase the rules' accuracy.
2. The suitable selection of the appropriate type of fuzzy numbers for different inputs.

As a future direction, the addressed systems can be developed for other industries, including service or goods-producing companies. The factors considered for each dimension can be of importance and attraction. We can use other sustainability measurement tools mentioned in the literature review, such as artificial neural networks, Bayesian networks and different multi-criteria decision-making techniques.

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