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An Intelligent System for the Evaluation of Climate Change Effects on the Environment

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A large amount of processes, which are physical, chemical and biological, are related to the global climate, which is the main component of climate change. These processes transform the global environment into a complicated situation. Climate change is the most large-scale and well-known vexed question. This paper presents a Fuzzy Inference System (FIS) to predict the relationship between the causes and effects of climate change. Here, CO2 (Carbon Dioxide), Global Temperature Changes, Snow Cover, Percentage of Forestlands, Natural Forces, and Net Radiation are considered as important factors and FIS inputs while the considered FIS outputs are: Ozone Layer Changes, Arctic Ice Sheet Level, Permafrost Level, and Sea Level. The proposed FIS is tested on realistic scenarios and the results are in agreement with results from other authors' approaches. However, the use of a FIS allows to include elements of uncertainty and vagueness in the input variables considered.

Keywords: Climate change, global warming, greenhouse effect, fuzzy logic, fuzzy set theory, fuzzy inference system, MIMO.

1 INTRODUCTION

Climate change is number one of the buzz topics in the world. In 2019, climate change has earnt leaders' attention at the United Nations Submit by one of the young Swedish activists. The perspective is to warn people about the importance of climate change and its consequences. It is a critical time

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for the world to act on climate change. According to NASA (the National Aeronautics and Space Administration) for 2018, the global temperature has increased in one year by an average of 0.82 Celsius. The recent sign of climate change is the fire in Amazon Rainforest in 2019. After the Amazon Rainforest fire, some ice holes have been observed in Antarctica, and the scientists explain that these holes were the result due to the ashes of the Amazon Rainforest fire.

The climate in the Earth is naturally variable on all time scales. However, the equilibrium between incoming and outgoing energy regulation depends on its long-term state and average temperature, which defines the Earth's energy balance. Climate change determines the changes in climate across the entire planet, which includes precipitation patterns, droughts, desertification, sand storms, extreme weather events, reducing glacier areas or increasing sea level. Every natural and anthropogenic activity has effects on climate change. In the early era of Earth, the natural greenhouse effects existed, and these natural effects were negligible. After the Industrial Revolution, the natural greenhouse gas effects have broken, and the anthropogenic greenhouse gas effects were born. The human-caused greenhouse gas effect determines the blocking of reflection of the Sun's heated infrared radiation to the Earth's atmosphere. Due to more technological developments in the 20th century, greenhouse gas production is rising.

The primary cause of greenhouse gas emissions and the main contributor to climate change is anthropogenic factors. Some reflections of climate change for environment and ecosystem are a measured rise in global temperature, changing weather patterns (increased frequency and intensity of heatwaves and drought, flash floods and seasonal flooding), melting glaciers, melting the Earth's permafrost reserves, reduced snow cover, increasing desertification, rising sea levels, coastal flooding, increased erosion, biodiversity loss, species extinction, insect-borne disease and transmission to new areas. Some natural factors are affected by the Earth's climate, and these factors are significant volcanic eruptions, plate tectonics displacements, solar variability, the Earth's tilt, the Earth's orbit around the sun, and changing ocean currents.

The United States Environmental Protection Agency projections considers CO2 (carbon dioxide), CH4 (methane), N2O (nitrous oxide), CFCs (chlorofluorocarbons), HFCs (hydrofluorocarbons), HCFCs (hydrochlorofluorocarbons), PFCs (perfluorocarbons), and SF6 (sulfur hexafluoride) as the primary greenhouse gasses. The greenhouse gases can be divided into two main groups, which are long-lived greenhouse gases and short-lived greenhouse gases, according to their spending time in the atmosphere. Some examples of long-lived and short-lived gases and particles are illustrated in Table 1 with their approximate spending time in the Earth's Atmosphere.

Gases And Particles	Average Lifetime	Effect On Climate
Long-Lived Gases		
CO2 (Carbon Dioxide)	More than 100 years	Warming
NH4 (Methane)	10 years	Warming
N2O (Nitrous Oxide)	120 years	Warming
Short-Lived Gases and Particles		
Tropospheric Ozone	Days to Weeks	Warming
Black Carbon	1 week	Warming
Organic Carbon	1 week	Cooling
Dust	Days	Cooling
Nitrate	1 week	Cooling
Sulphate	1 week	Cooling

TABLE 1
Long-lived and Short-lived Gases and Particles with Atmosphere Lifetime [2]

The leading anthropogenic cause of climate change is greenhouse gases and mainly the CO2. However, the effects of natural causes also are undeniable. The scientific discussion has not been conclusive on several issues, including the relative size of specific causes of climate change such as sulphate aerosols, the El Niño-Southern Oscillation, black carbon, the existence of climate feedbacks in the global carbon cycle, and whether increases in carbon dioxide precede or follow global warming [3].

The scientific evidence explains that CO2 (carbon dioxide) has the direct cause of climate change. However, the effects of indirect objects cannot be denied. Generally, the scientists observe, measure, and calculate clearly for understanding the relationship between causes and results. These traditional methodologies have drawbacks for dealing with vagueness, imprecision and uncertainty, and the uncertainty of climate change comes from anthropogenic factors.

The Fuzzy Inference System (FIS), proposed in this article, is one of the best methodologies to deal with uncertainty and vagueness. [20-30]

A Fuzzy Inference System rule-based program has been devised here to model some climate change factors and evaluate the impact of some factors as inputs on the resultant factors as outputs. The results show that CO2 Level has enormous effects on outputs like the other researchers' publications.

This article is organized into five sections: some literature examples are showing in Section 2; Section 3 provides the proposed methodology, which is the Multiple-Input-Multiple-Output Mamdani Fuzzy Inference System. The results of the Multiple-Input-Multiple-Output Mamdani Fuzzy Inference

System are illustrated in Section 4. Finally, some conclusions and future work of the study are presented in Section 5.

2 LITERATURE REVIEW

Previous studies on climate change using Fuzzy Logic have considered carbon emissions and global temperature.

There are numerous studies on meteorology with a Fuzzy system. Paulo Vitor de Campos Souza et al. [4] has presented a hybrid model consisting of Artificial Neural Network techniques and a Fuzzy system to predict the rainfall and temperate in the capital of Minas Gerais, Brazil. This study [4], has used an intelligent hybrid model capable of extracting fuzzy rules from a historical series of temperatures and Rainfall and found out that in the intelligent hybrid model can act with efficiency in the generation of predictions about the temperatures and average rainfall.

Fernando Ferrari Putti et al. [5], have developed a fuzzy mathematical model that estimates the influence of global warming on the vitality Laelia purpurata growing in different Brazilian environmental conditions. Temperature, humidity and shade condition are considered as inputs and vitality of plant is considered as output. The Fuzzy Rules have been elaborated through the interview with an orchid farmer specialist and literature review, which leads the simulation to a high precision level. The trapezoidal membership function is used for each parameter, and the gravity method is applied as a defuzzification process. The paper [5], successfully detected that a higher temperature has a negative effect on the vitality of plants.

Climate change is a topical matter in the research field. Climatologists are trying to understand the effect of climate change. Various numerical and statistical methods have been used to predict the different aspects of climate change. The Fuzzy Inference System (FIS) can be useful in predicting climate change effects. The difference between other statistical methods with the Fuzzy Inference System (FIS) is that the FIS can include the uncertainty of the nature of climate change. The rise of global temperature and CO2 concentration for the projected level of CO2 emission by 2100 has been predicated utilizing a Fuzzy Logic Model, [6]. In [6], it is predicted that the future range of global temperature would be 2 to 4.5 C.; and the CO2 concentration in the atmosphere will vary from 500 to 960 ppm. The results are comparable to a report by IPCC.

Thomas J Crowley has analyzed the cause of climate change over the past 1000 years [7]. Though Greenhouse Gasses are responsible for climate change, other factors such as solar irradiance reduction also have an impact. Energy Balance Model was used to calculate the mean annual temperature response to estimated forcing changes. In [7], the greenhouse gases (GHG), volcanic forcing, solar forcing, and anthropogenic forcing

are considered the system inputs. According to this analysis, GHG and tropospheric aerosol changes are similar to IPCC before 1850. Though the volcanic contribution increases 41 to 49% from 1400 to 1500, the average was 22 to 23% of the decadal-scale variance over the entire pre-anthropogenic interval. The solar index varies from as low as 9% to as high as 45% for the range 1000-1850.

Carlos G. Gay et al. also work on the Global temperature Fuzzy model as a function of Carbon Emission [8]. Here the relationship between temperature and CO Emission is evaluated by relative equations. The fuzzy model runs for 50 years and the obtained results compared with the historical data. The fuzzy model created a positive causality over time, but it has a nonlinear behaviour. The dynamic relationship may depend on the combination of Atmospheric CO2 and Carbon Emission [8].

Lazim Abdullah et al. also forecasted the CO2 Emission with type 2 TSK fuzzy logic and type 2 Mamdani fuzzy logic. Six variables were used as inputs [9]. The type 2 TSK FLS performs better than other models, as its error percentage is smaller than the others. The values of RMSE, MAE, and MAPE are 0.5338, 0.5112 and 7.2597, respectively. It is worth to mention that one hundred forty governments came to the conclusion that the surface temperature of our planet needed to be reduced by 2 C in 2009. The target was to reduce the emission 25%-40% below 1990 level by 2020 and 50%- 80% below 1990 by 2050.

Benjamín Martínez-López et al., derived a fuzzy model of CO2 emission [10]. The result of their work was to show that the simple fuzzy model was comparable to those reported by IPCC. This model was able to illustrate the dynamic behaviours of CO2 emission paths. Thought the fuzzy model is simple, fuzzier rules and variables will able to make this fuzzy controller more realistic and sophisticated.

Bastien-Olvera Bernardo et al. developed a fuzzy model of CO2 Emission to represent the concentration pathway emission described by IPCC to stabilize the surface temperature [11]. The climate model, where the change in atmospheric Carbon Concentration depends on the emission and in the Carbon Concentration of the system, developed by Tahvonen et al. was used [11]. In the system developed in [11], seven membership functions were used for inputs, such as far low, middle-low, close low, desired, close high, middle high and far high to show closeness to the desired temperature. The output domains of the temperature defined increasing, decreasing and stable.

3 METHODOLOGY

In our study, the MATLAB® [12] software is used to develop, a Fuzzy Inference System (FIS) for climate change evaluation. First, it had to be decided what kind of developments could be done. Our new FIS development options

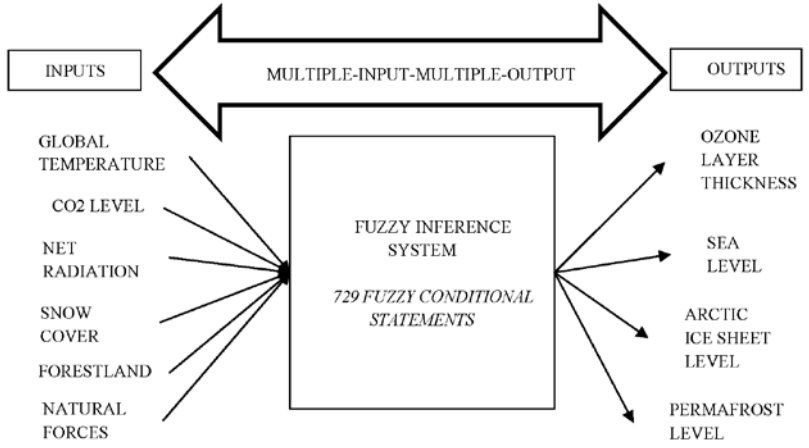

FIGURE 1
Illustration of Developed Climate Change MIMO Fuzzy Inference System

when compared to our previous model [1], it was realized that considering more inputs helps to reach better results for outputs. The Mamdani Fuzzy Inference System approach used here, has been selected as in the previous system [1]; because when there is a nonlinear relationship between inputs and outputs and linguistic inputs, the Mamdani Fuzzy Inference System can give an accurate result.

The previous Fuzzy Inference System [1] considers five inputs and three outputs. These inputs are CO2 Level, Global Temperature Changes, Net Radiation, Snow Cover and Forestland; while Ozone Layer Thickness, Arctic Ice Sheet Level and Sea Level are the outputs of the system. The differences between the new FIS proposed here and our previous model in [1], is the number of inputs and outputs, fuzzy conditional statements, and the number of outputs membership functions. There are six inputs and four outputs in the proposed new Fuzzy Inference System. The new input and new outputs based are illustrated in Figure 1, respectively. Also, a Multiple-Input-Multiple-Output (MIMO) model based on a Mamdani Fuzzy Inference System, similar as in [1], is considered. This model is illustrated in Figure 2.

3.1 Mamdani Fuzzy Inference System

Two types of fuzzy inference systems widely used are the Mamdani Fuzzy Inference System and the Sugeno Fuzzy Inference System. There are nonlinear equations or constant relation between inputs and outputs in the Sugeno Fuzzy Inference System; while Mamdani Fuzzy Inference System can also consider the linguistic variables as inputs. The Mamdani Fuzzy Inference System has been used in this article; because this system can deal with linguistic variables and their relationships.

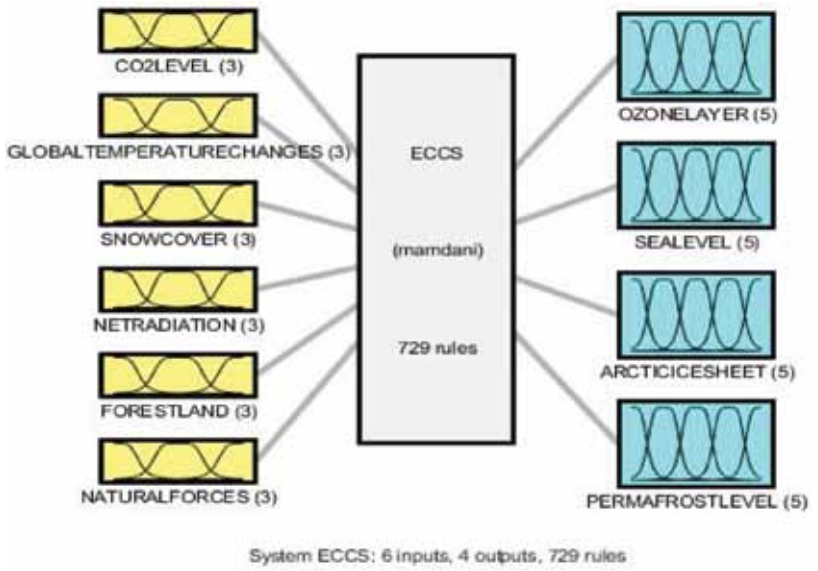

FIGURE 2
Fuzzy Inference System in MATLAB®

In the Mamdani Fuzzy Inference System, when fuzzy output sets are desired to be crisp output sets, defuzzification methods such as Centroid of Area, Bisector of Area, Mean of Maximum, Smallest of Maximum and Largest of Maximum, are needed to be used. In the proposed Multiple-Input-Multiple-Output Mamdani Fuzzy Inference System, the Centroid of Area defuzzification method is used. The advantage of the Centroid of Area defuzzification method is that all activated membership function of the conclusion takes part in the defuzzification process [17].

The inputs to the FIS are CO2 Level, Global Temperature Changes, Net Radiation, Snow Cover, Percentage of Forestlands, and Natural Forces, while, according to these inputs, the outputs are Ozone Layer Changes, Arctic Ice Sheet Level, Permafrost Level, and Sea Level.

3.2 System Inputs

In the proposed system, each input considers three different ranges: low level, medium level, and high level. Furthermore, the generalized bell function has been chosen as the membership function for each range.

The previous studies in literature and observations from agencies, such as NASA, show that many causes affect climate change. However, the observation data considers the main differences and contributions of each cause. All causes do not have similar effects on climate change. The chosen inputs here have a more significant effect on climate change. Also, the correlation

between climate change causes has helped to eliminate some of the parameters, such as greenhouse gases, rainfall, droughts. For example, the greenhouse gases (CH4 and others) has been eliminated because these gases have a relationship with CO2 Level and Net Radiation. Rainfall and droughts are not considered either due to their effect oon Global Temperature, Forestland and Snow Cover.

CO2 Level

Human beings have helped to increase the surplus of CO2 (carbon dioxide) by approximately 50%, starting with the Industrial Revolution. The primary input of the system is CO2 (carbon dioxide) level. It has been proven that the core reason of climate change is the greenhouse gases, and these gases are CO2 (carbon dioxide), CH4 (methane), N2O (nitrous oxide), CFCs (chlorofluorocarbons), HFCs (hydrofluorocarbons), HCFCs (hydrochlorofluorocarbons), PFCs (perfluorocarbons), and SF6 (sulphur hexafluoride). These gases affect the natural greenhouse effect on the atmosphere and the reflection of unwanted Sun's energy. Also, CO2 (carbon dioxide) is one of the long-lived gases in the Earth's atmosphere. The lifetime of CO2 (carbon dioxide) is more than 100 years. CO2 has a direct effect on the system's outputs and also inputs.

According to NASA's (the National Aeronautics and Space Administration) publishment in October 2019, the CO2 Concentration Level has increased by approximately 3 ppm in the last one year and reached 412 ppm [12].

In the proposed system, the lowest value of CO2 (carbon dioxide) is 200 ppm (parts per million), while 750 ppm is the highest value of CO2.

Global Temperature

The Global temperature has indirect effects on climate change, but due to the increase of global temperature in both ocean and land surfaces, the outputs have been affected. The variations on global temperature depend on greenhouse effects on the atmosphere. Even though greenhouse effects will decrease, the increase in heat will not dissolve.

After the greenhouse effect, the global temperature has increased by nearly 1 Celsius, and it is continuing to increase slightly but in a stable manner. The range of global temperature changes is between -0.2 Celsius and 5.8 Celsius. Scientists are trying to develop a new system for keeping global temperature level stable.

Net Radiation

Climate change is also related to the Earth's energy balance, which comprises of incoming energy and outgoing energy. The significant incoming energy is from the Sun, and the Sun's energy heats the Earth. This heating happens with radiation.

According to The Natural Aerospace and Space Administration's scale, net irradiation or net radiation should be between -180 and 180 .

Snow Cover

One of the climate change effects is to change weather conditions and extreme weather events. When climate change is recognized, and the impact of climate change is observed, one of the weather events is the snowing situation in some countries. Generally, increasing global temperature affects existing snow cover and snowy weather. Snow cover is one of the critical inputs because it affects more than one output. These outputs are influencing countries' destiny.

Forestland

Forests are one of the precautions for reducing greenhouse gases emission, especially CO2, because the forests have the mechanism to produce more O2 (oxygens). Nowadays, the forest area percentage of the Earth is 32%. However, day by day, this percentage reduces slightly. There are many critical reasons for this reducing. One of the primary reasons is that after industrialization, forest areas converted to agriculture areas. This conversion is affecting the Earth's lungs. Another reason is that of forest fires. After the fires, renewing the forest areas need more time.

In the previous system [1], the range for forestland was between 25% and 32%. However, in the new system proposed here, the forestland change can be in the range between 0% and 32%.

Natural Forces

The Earth's climate is influenced by many natural factors, such as continental drift, volcanic activities, ocean currents, the Earth's tilt, comets, meteorites and the Earth's orbit around the Sun [19]. These natural factors do not have huge impacts on climate change like greenhouse gas emissions, but their effects cannot be discarded.

In our previous system [1], natural forces were not considered as a cause of climate change. However, here, the effects of natural forces are considered as significant as the other factors.

3.3 System Outputs

In the proposed system, each output considers five different ranges: very low, low level, medium level, high level, and very high level. Furthermore, the generalized bell function has been chosen as the membership function for each range.

The observations related to climate change effects on the environment show that the most influenced factors are Ozone Layer Thickness, Arctic Ice Sheet Loss Level, Sea Level, Permafrost Level, Agricultural Production, Natural Sources, and The Number of Disasters. Although there are some statistics about Agricultural Production, Natural Sources and the Number of Disasters, the results are based on each geographical area. However, all factors except Agri-

cultural Production, Natural Sources and the Number of Disasters could comprise all over the world, and those factors have chosen for the proposed model.

Ozone Layer Thickness

The Earth's atmosphere has four different layers: troposphere, stratosphere, mesosphere, thermosphere and exosphere. One of the reasons for the sustainability of the Earth is its atmosphere, and the Earth's atmosphere is like the protector of human beings from the sky, and its protection is life-sustaining air quality, harmful ultraviolet solar radiation and crush of some space items such as meteorites. This protection is to help human beings to live peacefully and comfortably. However, after the climate change effects, the Earth's atmosphere has some problems like other environmental events, such as natural weather changes and disasters.

NASA has monitored the yearly change of Arctic total ozone with the series of whole ozone maps, which are illustrated in Figure 4. NASA explains that "Each map is an average during March, the month when some ozone depletion usually observes in the Arctic. In the 1970s, the Arctic region had typical ozone values in March, with values of 450 DU and above (red colours). Ozone depletion on the scale of the Antarctic ozone hole does not occur in the Arctic. Instead, late winter/early spring ozone depletion has eroded the normal high values of total ozone. On the maps from the late 2000s and early 2010s, the extent of values of 450 DU and above greatly reduced in comparison with the 1970s maps. The significant regions of low total ozone in 1997 and 2011 (blue colours) are unusual in the Arctic record, but not unexpected [20]."

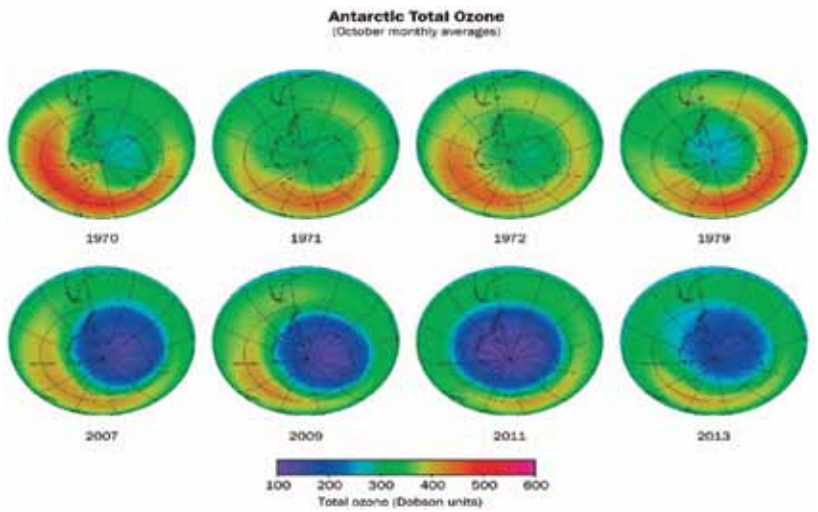

FIGURE 3
Total Ozone Maps [14]

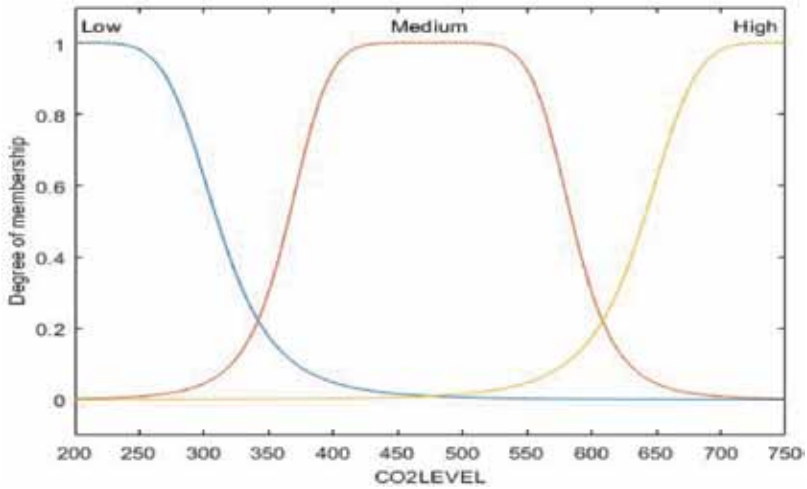

FIGURE 4
The plot of one input's membership functions

In the system, the lowest value of the Ozone Thickness Layer is defined at 100 DU (Dobson Unit), and 600 DU is the highest value of the Ozone Thickness Layer. There are five different membership functions, which are very low Level, low Level, medium level, high level and very high level, and the generalized bell function has chosen for membership functions.

Arctic Ice Sheet Loss Level

The northern part of the Earth is one of the most affected parts by climate change. Massive amounts of ice have started to melt, and the ecosystem in Antarctica and Greenland is damaged because of this melting. Some reasons for this melting are due to an increasing global temperature, the amount of greenhouse gas emissions, the reduction in the amount of snow cover and snow activities, and deforestation. In 2017, the total loss of arctic ice was nearly 1870 gigatons. When these losses rates considered, the range of Arctic Ice Sheet Loss Level is between 0 gigatons and 3000 gigatons.

Sea Level

It is a scientific fact that the melting ice transforms into water. After starting losing arctic ice and ice sheets, the melting ice and ice sheets turn to sea level in general. The two primary reasons for rising sea levels are the melting ice sheets and the glaciers water addition and seawater expansion due to the effects of global warming. The sea's height has increased by 94.6 mm since 1993. According to new scientific projections by 2050, sea level ris-

ing will erase some cities, i.e, Southern Vietnamese cities, Bangkok, Shanghai, some parts of East Chinese cities, Mumbai, Alexandria, Basra, and some others.

Permafrost Level

Permafrost is the frozen layer of the Earth, and it can be found in Arctic regions such as Greenland, the USA state of Alaska, Russia, China and Eastern Europe. The permafrost should remain below 0 Celsius for at least the following two years. The changes in the permafrost show the Earth's climate changes. During the 20^{th} century, the permafrost in the Earth has warmed by nearly 6 Celsius. Furthermore, the projections of scientists estimate that if the Earth continues to become warm, the permafrost will melt more. This melting will affect the sea and ocean water levels and increase the chance of erosion. Also, if the permafrost melts, the amount of releasing greenhouse gases will affect the Earth 25 times more than CO2 (carbon dioxide).

One of the reasons for choosing permafrost as a new output is the future effects on the Earth. The definition of the range depends on how many percentages of permafrost melt so that the range can change between 0% and 100%.

3.4 Membership Functions

There are many membership function generation methods such as direct rating, polling, reverse rating, interval estimation, membership function exemplification, pairwise comparison, and use of artificial intelligence [21]. The selection of elicitation techniques is limited to the interpretation of fuzzy membership functions. To interpret fuzzy membership functions, the likelihood, random set, similarity, utility, and measurement views exist [21]. Direct rating, reverse rating, and the pairwise comparison is suggested in the previous literature to be appropriate elicitation methods because these methods attempt to rate the degree of membership on some scale, whether it is considered being objective or subjective [21]. In this article, interval estimation has been chosen for the generation of membership functions. Interval estimation has been completed based on NASA's statistical data [18].

The Generalized Bell membership function has been chosen for all inputs and outputs. The reason is that the generalized bell membership function has smooth and concise notation. Also, "the generalized bell membership functions are becoming increasingly effective for specifying fuzzy sets" [32]. One of the input's memberships functions is in Figure 4, while Figure 5 presents one of the output's memberships functions.

3.5 Fuzzy Conditional Statements Selection

Fuzzy conditional statements define the performance of the Multiple-Input-Multiple-Output Mamdani Fuzzy Inference System. The fuzzy conditional statements are called If-Then rules.

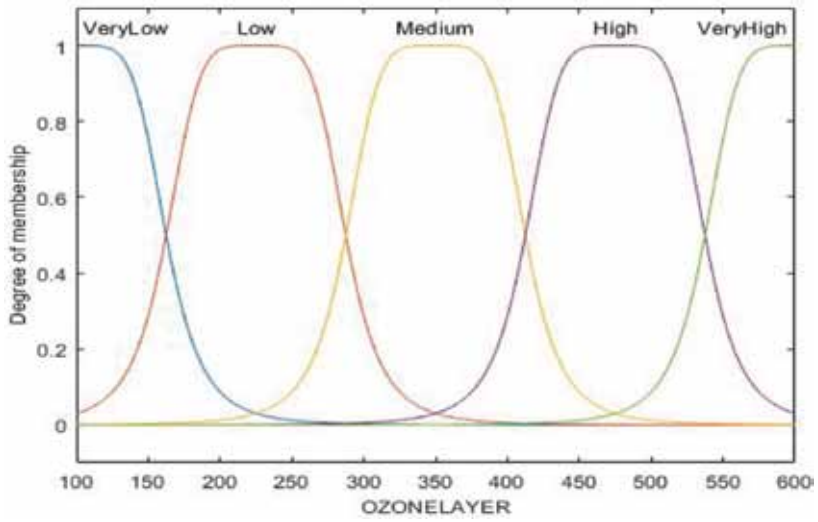

FIGURE 5
The plot of an output's membership functions

Thus, analysis of the impact of climate change depends on the limited data and knowledge under uncertainty and vagueness. Rules are selected according to relationships between inputs and outputs. In the proposed Fuzzy Inference System model, 729 rules are used. For example, "if CO2 Level is low, Global Temperature Changes are low, Net Radiation Level is low, Snow Cover Level is low, percentage of Forestland is low, and Natural Forces Level is low; then, Ozone Layer Level is very high, Sea Level is very high, Arctic Ice Sheet Level is very low, Permafrost Level is very low". The rule screen of the developed system is shown in the Appendix. The Fuzzy conditional statements have defined according to previous studies in the literature and expert knowledge. Also, Table 2 illustrates some examples of fuzzy conditional statements in the proposed model.

4 RESULTS

In this section, the graphical presentations of the results obtained from the proposed Fuzzy Inference System (FIS), as implemented in MATLAB® [12], are presented. The illustrations present a better understanding of the system. As the standard FIS, the process can be depicted by surface graphs as in Figure 6; which demonstrates the interactions between inputs and outputs.

The thickness of the Ozone Layer is in the vertical axis in Figure 6 (a), while the horizontal axes demonstrate CO2 Level, and Global Temperature Changes. Also, the changes in Sea Level are illustrated in Figure 6 (b); where the horizontal axis is net radiation, and the vertical axis is the global tempera-

Fuzzy Conditional Statements	
Antecedent or Premise	Consequence or Conclusion
IF CO2 Level is Low and Global Temperature is Low and Snow Cover is Low and Net Radiation is Low and Forestland is Low and Natural Forces are Low	THEN Ozone Layer is Very High, Sea Level is Very High, Arctic Ice Sheet is Very Low, Permafrost Level is Very Low
IF CO2 Level is Low and Global Temperature is Low and Snow Cover is Medium and Net Radiation is High and Forestland is Medium and Natural Forces are Medium	THEN Ozone Layer is Medium, Sea Level is Medium, Arctic Ice Sheet is Medium, Permafrost Level is Medium
IF CO2 Level is Low and Global Temperature is Medium and Snow Cover is High and Net Radiation is Medium and Forestland is Medium and Natural Forces are High	THEN Ozone Layer is Medium, Sea Level is Low, Arctic Ice Sheet is High, Permafrost Level is High
IF CO2 Level is Medium and Global Temperature is Low and Snow Cover is High and Net Radiation is Low and Forestland is Low and Natural Forces are High	THEN Ozone Layer is High, Sea Level is Low, Arctic Ice Sheet is Very High, Permafrost Level is Very High
IF CO2 Level is High and Global Temperature is High and Snow Cover is High and Net Radiation is High and Forestland is High and Natural Forces are High	THEN Ozone Layer is Very Low, Sea Level is High, Arctic Ice Sheet is Low, Permafrost Level is Low

TABLE 2
Example of Fuzzy Conditional Statements

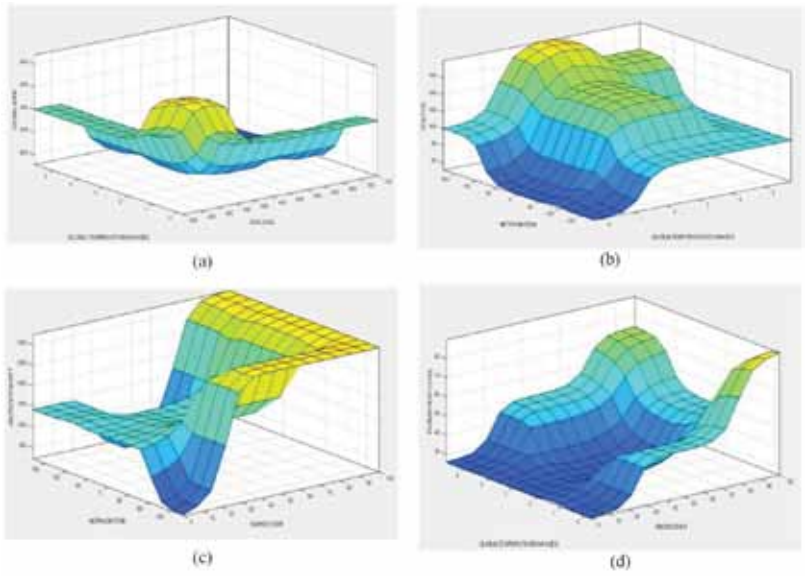

FIGURE 6
The graphical presentations of each output

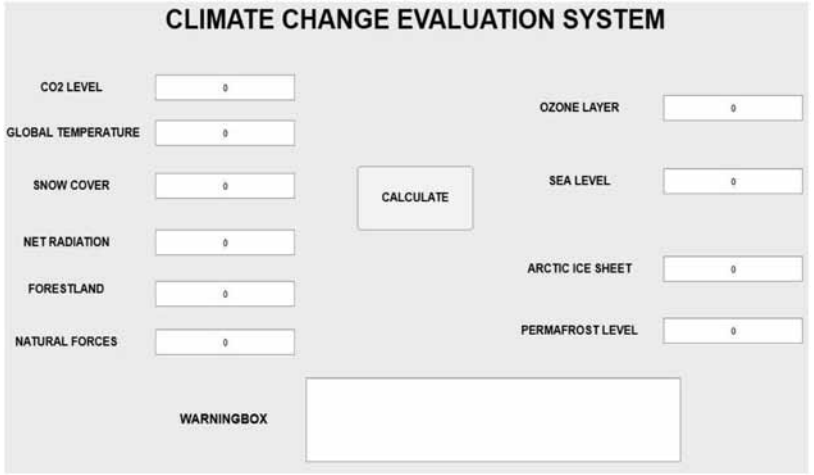

FIGURE 7
Graphical User Interface

ture. In Figure 6 (c), the Arctic Ice Sheet changes according to net radiation and snow cover changes. When the vertical axis is snow cover, and the horizontal axis is global temperature, the changes for the permafrost level are shown in Figure 6 (d).

A graphical user interface was also developed, and the first step of the design is shown in Figure 7. The app designer MATLAB toolbox is normally used for designing user-friendly applications, [33]. The graphical user interface developed here helps to show the developed Fuzzy Inference System results smoothly. In Figure 8, when the user inserts the inputs' value, the results are shown immediately on the right side of the screen.

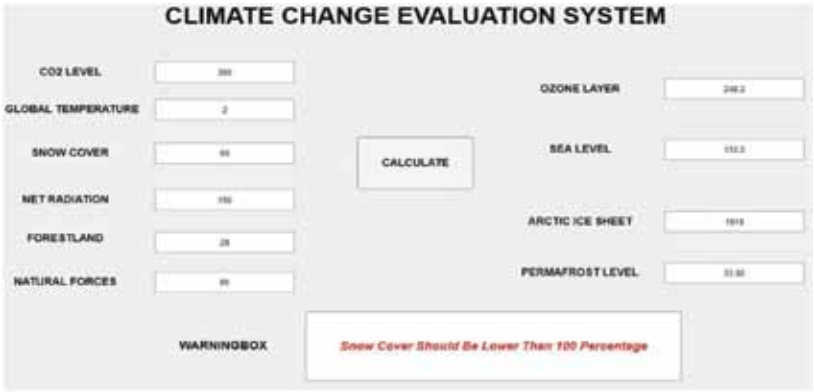

FIGURE 8
Graphical User Interface with results

INPUTS						OUTPUTS			
CO2 Level	Global Temperature	Net Radiation	Snow Cover	Forest Area	Natural Forces	Ozone Layer	Sea Level	Arctic Ice Sheet	Permafrost Level
200	0	-180	0	0	0	556	179.8	302.5	10.08
200	3	0	65	15	50	350	96.22	1557	51.89
500	5	100	50	28	50	191.8	136.7	947.2	31.64
750	5.8	180	100	32	100	139.8	148.6	768.2	25.7
750	2	180	100	32	0	153.6	100.4	1537	51.25

TABLE 3
The trial results

The possible scenarios give an idea of how the proposed system will affect the future estimation of climate change effects on the environment. Although, due to data sources limitations, and no previous similar studies, the system performance is not evaluated.

The Table 3 demonstrates the system results. According to the table, it is observed that the CO2 Level and the Global Temperature Changes have greater influence than other inputs on the outputs. It is essential to mention that Permafrost level changes depend on all inputs. However, the Snow Cover affects Arctic Ice Sheet Level and Permafrost Level drastically. Furthermore, the Ozone Layer Thickness is hugely affected by CO2 Level and Global Temperature changes.

The results in the Table 3 show that when the CO2 Level is the lowest Level, the Global Temperature Level is stable, Net Radiation is the lowest, Snow Cover and Forestland percentages are 0, and the Natural Forces effect is 0%. The Ozone Layer will be in the highest Level, Sea Level will increase by 179.8 mm, Artic Ice Sheet Level will reach the lowest value, and the percentage of Permafrost Level will be 10.08.

The Table 4, Table 5, Table 6, and the Table 7, are other examples of the developed system results. In Table 4, when the CO2 Level is constant as 400 ppm and the Global Temperature changed 2 Celsius, 3 Celsius and 5 Celsius, the other inputs' effects are observed. Net Radiation is another input, which has a larger influence on the outputs of the system. Also, in Table 5, when the CO2 Level increased by 100 ppm and the Global Temperature Changes are the same as Table 4; the outputs' changes are similar to the situation as when the CO2 Level is 400 ppm. In Tables 5 and 6, it established that only changes in CO2 Level would not affect the Earth's environment. The last 100 ppm increase of CO2 Level in Table 7, the Ozone Layer, Permafrost Level and the Arctic Ice Sheet Level reached the lowest value, 165.1 DU, 778.5 Gigatons and 26.05%, respectively, while the total increase of the Sea Level is 147.9 mm.

INPUTS						OUTPUTS			
CO2 Level	Global Temperature	Net Radiation	Snow Cover	Forest Area	Natural Forces	Ozone Layer	Sea Level	Arctic Ice Sheet	Permafrost Level
400	2	-180	25	15	25	368.6	116.3	1257	41.91
400	2	0	50	20	50	246.7	141.3	819.9	27.41
400	2	180	75	25	75	249	119.4	1207	40.3
400	3	-180	25	15	25	368	122.3	1166	38.87
400	3	0	50	20	50	236.9	145.3	818.7	27.37
400	3	180	75	25	75	232.8	119.4	1209	40.3
400	5	-180	25	15	25	367.1	121.5	1176	39.25
400	5	0	50	20	50	237	102.5	1463	48.77
400	5	180	75	25	75	184.7	118	1228	40.99

TABLE 4
The trial results-1

Inputs						Outputs			
CO2 Level	Global Temperature	Net Radiation	Snow Cover	Forest Area	Natural Forces	Ozone Layer	Sea Level	Arctic Ice Sheet	Permafrost Level
500	2	-180	25	15	25	367.3	116.2	1257	41.91
500	2	0	50	20	50	236.8	141.5	818.1	27.35
500	2	180	75	25	75	232.4	125.7	1205	40.17
500	3	-180	25	15	25	351.5	122.3	1166	38.87
500	3	0	50	20	50	229.6	147.6	783.6	26.21
500	3	180	75	25	75	183.9	123.7	1143	38.13
500	5	-180	25	15	25	351	121.5	1176	39.25
500	5	0	50	20	50	229.4	102.5	1463	48.77
500	5	180	75	25	75	183.9	123.7	1143	38.13

TABLE 5
The trial results-2

According to the tables (Table 4, Table 5, Table 6 and Table 7), it observed that the Ozone Layer is decreased drastically from 367 DU to 165 DU. Also, the Sea Level increased from 116 mm to 150 mm. However, the Arctic Ice sheet and Permafrost is also changing, the change of the Ozone Layer and the Sea Level are alarming for the future of the Earth.

Inputs						Outputs			
CO2 Level	Global Temperature	Net Radiation	Snow Cover	Forest Area	Natural Forces	Ozone Layer	Sea Level	Arctic Ice Sheet	Permafrost Level
600	2	-180	25	15	25	367.3	116.3	1257	41.91
600	2	0	50	20	50	249.2	133	893	29.84
600	2	180	75	25	75	220	126.2	1205	40.17
600	3	-180	25	15	25	351.5	122.3	1166	38.87
600	3	0	50	20	50	234.9	144.8	825.9	27.61
600	3	180	75	25	75	220.6	126.2	1205	40.17
600	5	-180	25	15	25	350	121.5	1176	39.25
600	5	0	50	20	50	233.2	116.9	1246	41.55
600	5	180	75	25	75	183.8	127.5	1087	36.25

TABLE 6
The trial results-3

Inputs						Outputs			
CO2 Level	Global Temperature	Net Radiation	Snow Cover	Forest Area	Natural Forces	Ozone Layer	Sea Level	Arctic Ice Sheet	Permafrost Level
700	2	-180	25	15	25	367.3	116.3	1257	41.91
700	2	0	50	20	50	236.8	141.5	818.1	27.35
700	2	180	75	25	75	184	126.2	1205	40.17
700	3	-180	25	15	25	351.5	122.3	1166	38.87
700	3	0	50	20	50	229.6	147.9	778.5	26.04
700	3	180	75	25	75	165.1	126.2	1116	37.19
700	5	-180	25	15	25	350	140.5	890.5	29.75
700	5	0	50	20	50	228.8	147.9	778.9	26.05
700	5	180	75	25	75	165.1	146.6	799.6	26.68

TABLE 7
The trial results-4

5 CONCLUSIONS

This article presents a Multiple-Input-Multiple-Output (MIMO) Mamdani Fuzzy Inference System to model some Climate Change aspects. It is demonstrated that understanding climate change causes and effects could be mod-

elled by using human-like logic under uncertainty and vagueness. In the proposed system, it is observed that the CO2 Level changes affect all outputs significantly; whereas other inputs' effects create less prominent changes but not avoidable. Here, the Ozone Layer and Sea Level are mostly affected by CO2 Level, Global Temperature Changes, Percentage of Forestlands and Net Radiation; while, Snow Cover predominantly affects Arctic Ice Sheets and Permafrost Level along with other inputs.

One of the benefits of the proposed Fuzzy Inference System is that it allows us to consider many inputs and to investigate the relationships between these inputs and outputs.

Still, the major difficulties of the proposed methodology are that: (1) the system result is based on Fuzzy If-Then rules and it may affect the accuracy of the results, (2) the selection of the membership functions and Fuzzy If-Then rules is a sophisticated task, and (3) the quantity and quality of accessible data sources related to the proposed models' inputs and outputs may not be sufficient; and the data in the field may not be adequate to implement other methodologies.

The results obtained by the proposed system show that the influences of the global climate are similar to other current scientific methods. However, the proposed Fuzzy Inference System allows to include elements of uncertainty and vagueness in the input variables considered.

In future works, the system could consider a larger amount of historical data; and it would also include Artificial Neural Networks, or Adaptive Neuro-Fuzzy Inference System Methods. Moreover, it is also envisioned to increase the number of variables and the number of membership functions.

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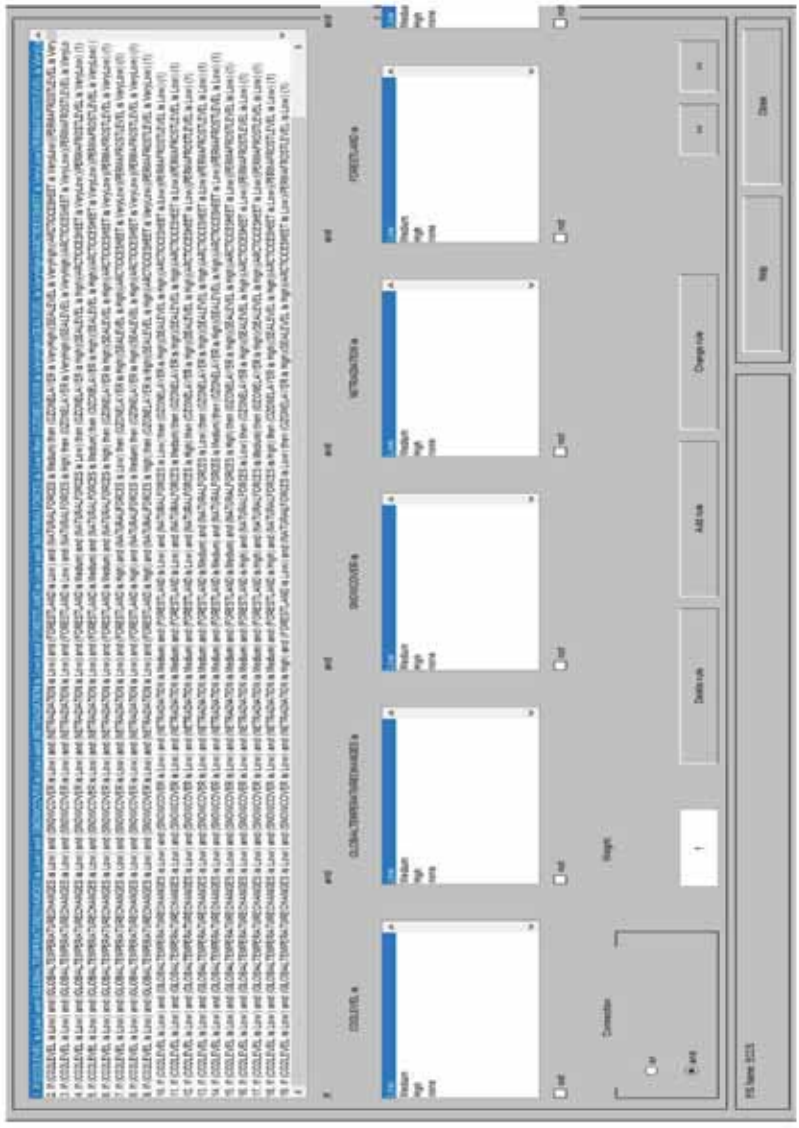
APPENDIX

Example of FIS rules



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