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THESIS - **BACHELOR'S DEGREE PROGRAMME**
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STUDY ON POPULATION'S ATTITUDE TOWARDS CARBON CAPTURE AND STORAGE

FUZZY LOGIC APPROACH

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THESIS
Abstract

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Abstract

The Earth is facing up with climate change issues due to enormous CO_2 emissions, which are result of the burnings of fossil fuels. There are many abatement technologies to tackle this problem and carbon capture and storage technology (CCS) is one of them. However, there are potential risks while keeping CO_2 under the earth's surface as it could leak from failure of the geological media to drinking water aquifers. Therefore, it still leaves a negative effect on the deployment of CCS which has led to Not-In-My-Backyard (NIMBY) opinions. The goal of this project was to develop a tool that can help predict the decision of citizens in the future using an artificial intelligence technique based on fuzzy logic. The data used to design the system was provided by Adjunct lecturer Eric Buah as part of his PhD project. It is an observation of 98 subjects who were observed on a hypothetical CCS project. Using this data, two fuzzy logic-based models were designed and tested by making comparison. The model does not ensure 100% correction because human-thinking is much more different from a machine and hard to predict exactly but it worked well after all as it was able to predict 60-70% correct targets compared to the original data.

Keywords
CO_2, Global warming, Matlab, Artificial Intelligence

CONTENTS

1 INTRODUCTION

1.1 Objectives of the study

Carbon capture and storage (CCS) has emerged as a modern technology to abate the increasing climate problem in addition to renewable energy technologies. The technology consists of the storing and capturing CO_2 from enormous sources such as fossil fuel and power plants. The captured CO_2 is processed and transported throughout pipelines or through ocean and stored in sites underground. Prospective formations where CO_2 can be stored should be aquifers, coal and gas sites or oil fields are depleted, where the CO_2 can be applied for enhanced oil recovery (CO_2-driven EOR). (Eric Buah 2018)

Despite the environmental and social benefits of CCS such as reducing energy greenhouse gas (GHG) emissions to facilitate the transition to a low-carbon society, there are risks and uncertainties associated with the technology. The Intergovernmental Panel on Climate Change report on Carbon capture and storage (CCS) states that, it is highly unlikely that the CO_2 will leak from the geological media. The technical feasibility of the technology is well understood because the oil and gas industry has done this in enhanced oil recovery system for over 40 years. But the lay public perception about the risks associated with the technology is different from that expert. Therefore, it still leaves a negative effect on the deployment of CCS which has led to Not-In-My-Backyard (NIMBY) opinions. NIMBY generally defines a situation where people are ready to support the technology in general but resist the siting of the facilities when proposed near them. (Eric Buah 2018)

International evidence shows that some CCS projects has been resisted due to some of this complex human decision-making behaviours. Given the impact of this behaviour on future projects, decision-makers embracing CCS in their energy planning are compelled to consider and investigate at the project level, whether any individual project would be acceptable to the public or not. It is in this context that this bachelor thesis comes in to develop a tool that can help decision-makers to better predict the future. The focus is on the emotions aroused by the technology and its impacts on decisions to accept or reject the project at the local level. This predictive information can help them to devise interventions for the future to address key concerns to gauge deployment of the technology. The thesis forms part of a larger doctoral project being led by doctoral researcher, Eric Buah, an Adjunct Lecture for Sustainability Engineering and Business at the Savonia UAS.

Methodologically, the proposed tool will be developed using artificial intelligence techniques. Through this methodological approach, this study will focus on using fuzzy logic. Fuzzy logic is a sub-area in the field of artificial intelligence. It aims at designing an intelligent system that allows engineers to model humans vague and imprecise decisions and behaviors. In modelling this qualitative behavior of humans, it also provides a mathematical framework to engineers to model domain expert knowledge to argument the system capability is the task assigned to it.

1.2 Research Methodology/Strategy

The writer uses an artificial intelligence machine learning technique such as clustering algorithm or artificial neural network algorithm to model the impact of stakeholders' affective reaction on acceptance of Energy generation from fossil fuels and biomass combustion with CO_2 Capture and Storage technology. The writer has gained the expertise for the subjects during the Sustainability and Business studies and seminars by Savonia UAS and its associates such as Sumitomo SHI Ltd, former Foster Wheeler Energia Oy, and Andritz Oy.

This thesis has two major goals:

- Design an intelligent machine that could be applied to new data in the social context in which CCS will be deployed, to predict the emotional concern of the citizens on the energy project.
- Develop not only understanding of CCS but also basic skills on how to use MATLAB or Google Open Source machine learning library (TensorFlow) to exploit Big data.

2 GENERAL INFORMATION

2.1 Global CO_2 problems

It has long been known that Global warming is mainly provoked by the greenhouse gases emissions which are Carbon Cioxide, Methane and Nitrous oxide. According to researchers, Carbon dioxide emissions account for the largest proportion in inflicting global warming and CO_2 is derived from power and heat sources and fossil fuels like oil and natural gas. In recent years, the amount of emitted CO_2 has been sharply risen and continue to increase by roughly 3% each year. (time for change 2007)

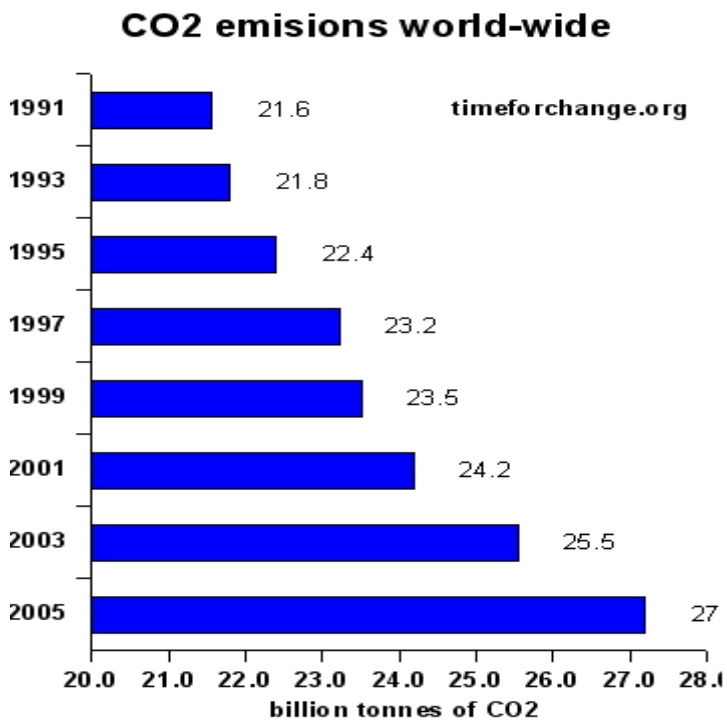

FIGURE 1. CO_2-emissions world-wide by year (time for change 2007)

There are two substantial effects of global warming:

- In 2100, The temperature on the earth is expected to enhance by about 3° to 5° C (5.4° to 9° Fahrenheit).
- In the same year, sea levels are predicted to increase by at least 25 meters (82 feet)

Indeed, increasing global temperatures are bringing a huge number of changes and effects towards the globe. Melting of ice is resulting in rising the sea levels and people are also witnessing the changing in amounts and patterns of precipitation which leads to adjusting of intensity of adverse weather events such as avalanches, hurricanes, droughts and floods. (time for change 2007)

2.2 What is CCS and why do we need CCS?

2.2.1 Definition of CCS

Carbon capture and storage (CCS) is a technological method of preventing large amount carbon dioxide (CO_2) emissions which are inflicted by the burning of fossil fuels from entering the atmosphere. In such a case, CO_2 is collected before it is spread over the world and moved mainly through pipelines or by ships to a carefully selected and secure suitable geological formations underground such as deep saline aquifers, in which the CO_2 is able to be applied for enhanced oil or for permanent storage. (global ccs institute 2018)

Frankly, CCS consists of technological methods that are capable of mitigating large amounts of CO_2 from being released in the atmosphere from the burning of fossil fuels. These technologies have been proven in their results of leaving safety effects for 45 years and have been applied in many years in scale of commercial operation. Apparently, CCS technology is being deployed worldwide in various ways and is already lessening the emissions of greenhouse gases. (global ccs institute 2018)

2.2.2 Why CCS

Recently, there has been a significant increase in the atmospheric concentration of notable greenhouse gases such as methane and CO_2. In fact, these greenhouse gases will leave a huge effect on the attempt to stable the climate. In 2013 study finds that the atmospheric levels of CO_2 are much larger than them compared to the past 800,000 years, at 400 part per million (ppm). Now is the time to abate the carbon dioxide emissions before it is too late. There are three main reasons explaining why the CCS technologies should be applied (global ccs institute 2018):

- Tackling climate change

By using CCS methods, we are able to keep harnessing fossil fuels but decrease greenhouse gas emissions to the atmosphere.

- Industry experience

It is believed that there is an abundance of ongoing industrial-scale CCS projects which are currently operated worldwide by International Industrial Organizations which have many years of experience in handling CO_2 as well as understanding them. Besides, storage locations are carefully chosen and covered by international law enforcement agencies to ensure health and safety and environment protection.

FIGURE 2. A platform for injecting CO_2 into safe, geological storage: Sleipner, Norway. Courtesy of Statoil. (ccs association 2012)

- Affordability

It has been proven that CCS is the most convenient and reasonable way to help alleviate the cost of reducing carbon dioxide emissions. It is believed that factors like the distance from a CO or the features of it that applied to capture CO_2 can result in affecting the cost of a CCS and obviously, the money spent on capturing the carbon dioxide is the largest cost of a CCS project. Recently, research has shown that a project towards CCS sector is supposed to cost around €60 – 90 per a thousand of carbon dioxide and these costs are likely to decrease remarkably to €35 – 50 in 2020s. In addition, conducting CCS on coal fired power plants is also cost-competitive (per tonne of carbon dioxide emission abated) with other forms of low-carbon energy. In prospect, commercial-scale power plants are expected to operate to maximize operations and recognize cost reductions. (ccs association 2012)

2.3 CCS technologies

A complete CCS process should consist of three important steps:

1. Capturing CO_2 from power plants or other centralized sources.
2. Transporting them to appropriate storage locations.
3. Injecting CO_2 into underground storage then monitoring the process of pumping CO_2 and ensure that CO_2 is completely isolated.

1.Capture

The initial step of the CCS process is to recover CO_2 at the gas sites and compress it for transportation and storage. Currently, there are three main methods used to recover CO_2 from huge plants which can take into consideration:

a. Pre-combustion capture.

b. Post-combustion capture

c. Oxy-fuel combustion systems.

2.3.1 Pre-combustion capture

The technology splits CO_2 from the fuel by mixing it with gas to burn and store the extracted CO_2 stream. It is now common to use natural gas conversion technology where hydrogen can be separated out of natural gas by using steam.

Some suggested that separating CO_2 before burning is a necessary technical requirement for the conversion of coal into liquid fuel thanks to chemical reactions. However, the problem is that the process of transforming coal into liquid fuel also releases CO_2, and liquid fuel products while burning is also a source of CO_2. Pre-combustion capture processes applied in liquid fuel production technology from coal will mitigate the total amount of emitted CO_2, however this kind of gas is still a vital product which liquid fuels can be consumed in transportation or electricity generation.

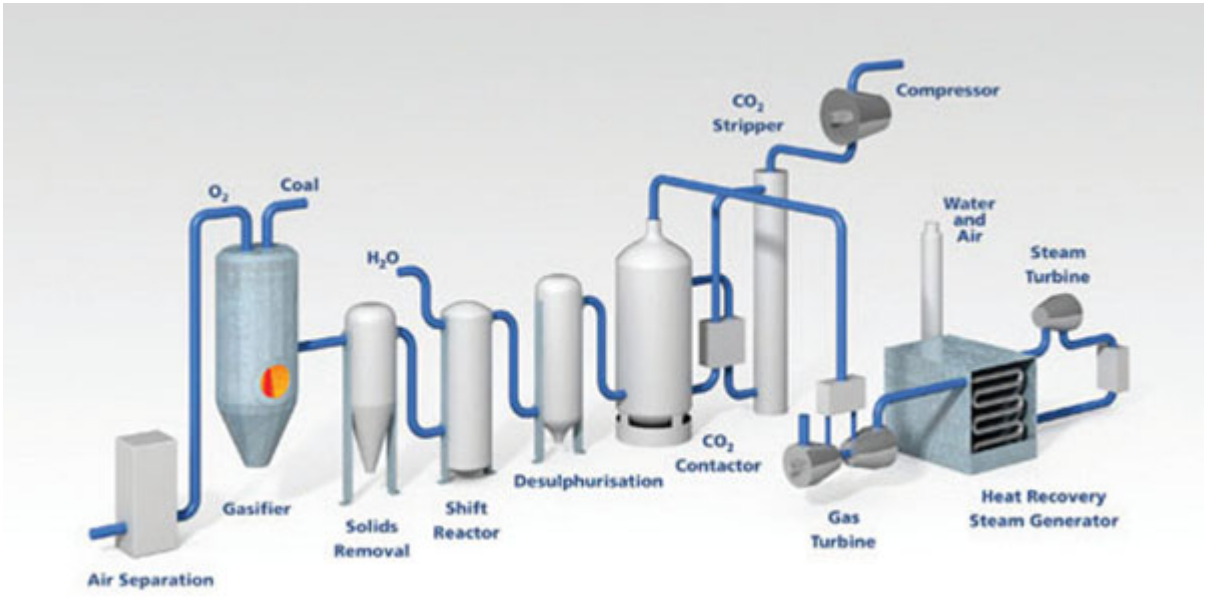

FIGURE 3. A pre-combustion capture system. (Costain, 2015)

2.3.2 Post-combustion capture

Figure 4 illustrates the process of separating CO_2 from the chimney after burning fossil fuels or biomass. There are a lot of commercial technologies that can take this step into consideration, some of them use chemical solvents that are able to capture large amounts of CO_2 from the chimneys.

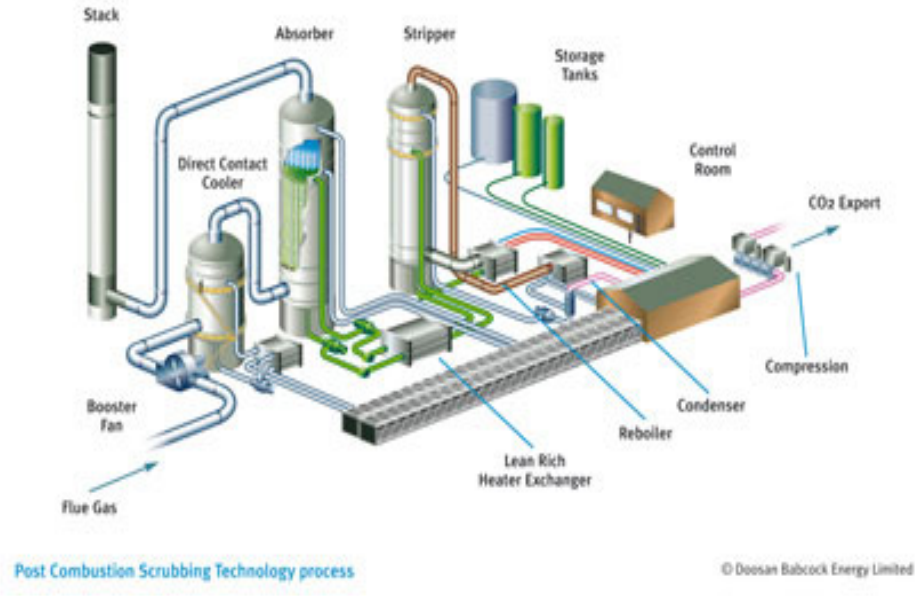

FIGURE 4. Post Combustion Scrubbing Technology. (ccs association 2015)

2.3.3 Oxy-fuel combustion systems

At this process, oxygen will be used, instead of air, as a gas to emit a mixture with a major component of CO_2, and the water is easily separated, then it is easy to store, transport and compress CO_2. This technique is still being researched, partly because the combustion temperature of purity oxygen (about 3,500°C) is too high for the allowed fuel of normal power plants. (ccs association 2015)

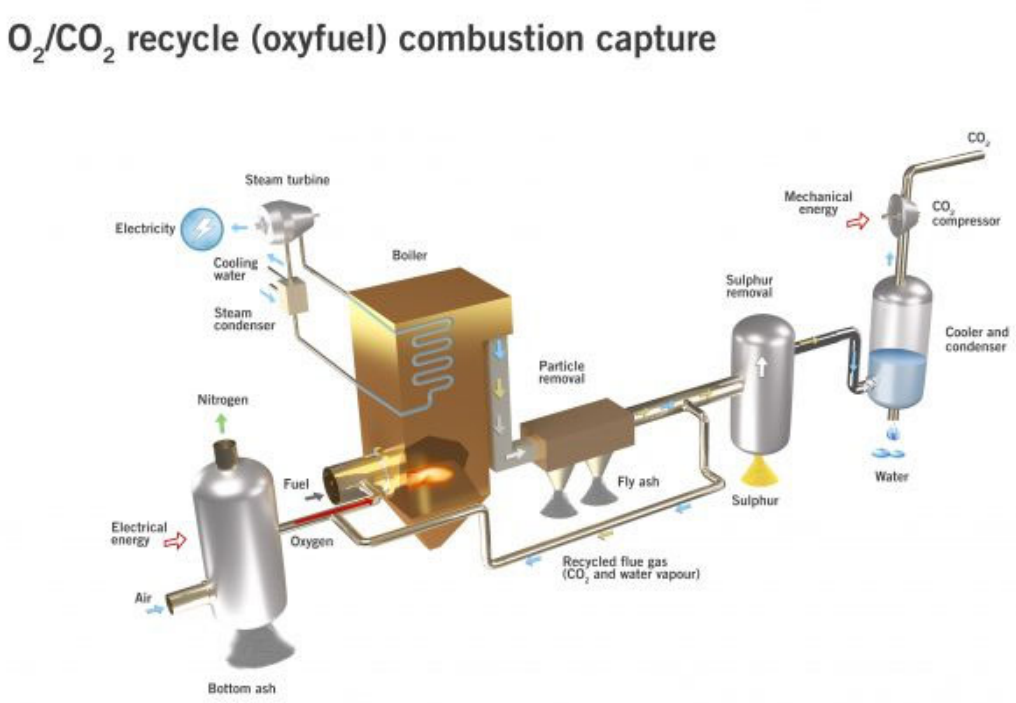

FIGURE 5. Oxy-fuel combustion capture. (global ccs institute 2017)

2. Transport

Some solutions for transporting CO_2 have been used in practice, however, most are only applied on a small scale. Using pipelines is the most popular method of transporting CO_2 across the world. At the moment, there are around 5,800 km of pipelines transporting CO_2 in USA, mainly to serve oil and gas exploitation zones. Similar to transporting petroleum and natural gas, CO_2 transport pipes require attention to design, leakage monitoring and pipe protection from high pressure, especially pipelines across residential areas. Ship transportation can be used to transport CO_2 to another country in small scale. Basically, liquefied petroleum gas, propane and butane are carried by using huge ships. Truck and rail can also be used to transport CO_2, but this option is not economical if CCS operations are deployed on a large scale. The cost of transportation by pipelines varies depending on construction costs, operation fees, maintenance, management and other fees. For this type of transport, the traffic and transport distance are the key factors to determine the cost. In addition, it is necessary to take the geographical position of the pipeline into account (onshore or offshore) and the extent of traffic congestion across the transport route (encountering large mountains and rivers or the covered snow and ice area). Shipping costs are currently only estimated, in fact there is yet transport system for CO_2 in large-scale operating. With distances larger than 1,000 kilometers and quantities lower than several million tons of CO_2 annually, shipping costs may be lower than using pipelines. (ccs association 2015)

FIGURE 6. ONSHORE TRANSPORT. (global ccs institute, 2017)

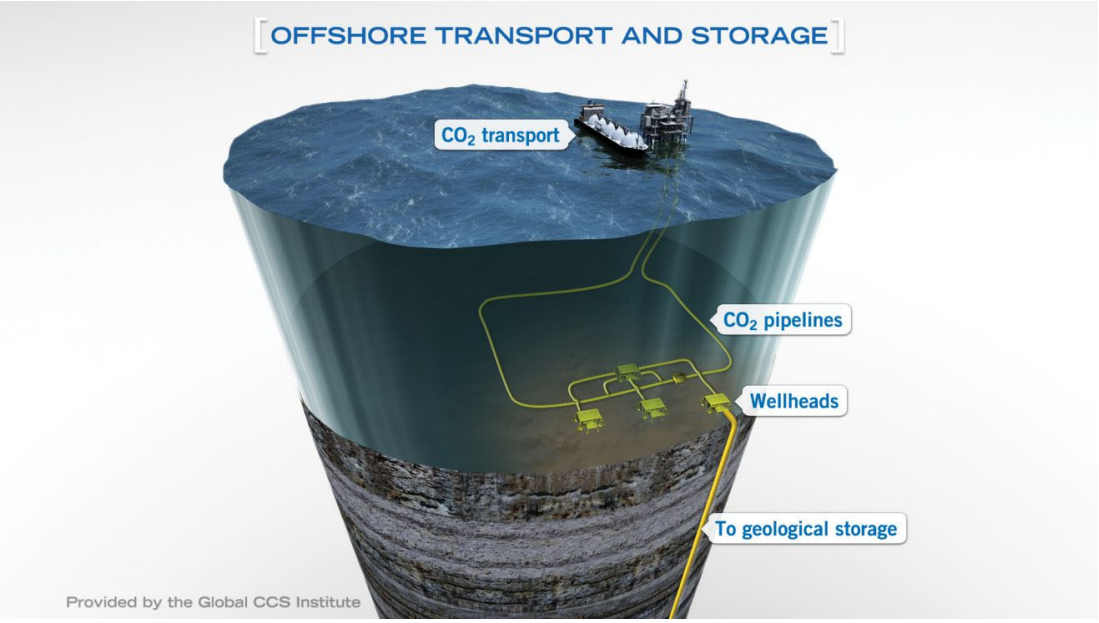

FIGURE 7. OFFSHORE TRANSPORT AND STORAGE. (global ccs institute, 2017)

3. Storage

There are three main geological formations for carbon storage need to take into consideration: depleted petroleum reservoirs, deep saline aquifers and unexploited coal seams.

In this technique, concentrated CO_2 will be pumped to the ground into porous rock formations, depleted oil reservoirs or deep saline aquifers ... When CO_2 is pumped down to 800m into such aquifers, the pressure compresses CO_2 into a dense liquid, so it is less likely to penetrate geology. The techniques of pumping CO_2 into the ground are mainly developed in the oil and gas industry, which has potential applications for long-term storage and then easily monitoring of CO_2 storage. Other technologies, such as natural gas storage, liquid waste pumping and saltwater treatment in oil fields, can also be a useful reference source for CO_2 storage techniques in geological formation. Sedimentary basins are large natural pits on the earth's surface, filled with sediments and liquids, with great potential for CO_2 storage. Additionally, the ability to store CO_2 in geologic formations is very potential if it takes into account sedimentary basins around the world. However, the suitability of geologic formations for CO_2 storage also depends on things, such as distance to CO_2 sources and other factors of the reservoir such as porosity and risk of leakage. (ccs association 2015)

2.3.4 Oil and gas Reservoirs

Injecting CO_2 to petroleum reservoirs so that increase productivity is now commonly used in the oil industry, in fact dense CO_2 will be capable of mixing with the oil and allow the flow of oil less tricky. The USA is currently the leading country in this technology, with about 48 million tons of CO_2 pumped into the ground each year to increase oil and gas production. The pros of this technique towards CO_2 storage is that cost of exploiting oil and gas production can be reduced. However, even

if there is no profit from oil and gas exploitation, it is still possible to pump CO_2 into geologic reservoirs that have been completely depleted for long-term storage. Oil reservoirs are considered potential CO_2 storage locations for many reasons. Firstly, the initial amount of oil and gas did not manage to escape for millions of years, proving the perfect closed structure of the tanks. Secondly, oil exploration surveys have provided geological features of reservoirs and computer models help investigate the movement of hydrocarbons in reservoirs that can be applied to CO_2 pumps later. Finally, it is possible to take advantage of petroleum exploitation infrastructure to conduct CO_2 storage. On the other hand, these characteristics can also be a disadvantage for long-term CO_2 storage. Because the oil drilling holes on the ground can be CO_2 leak points if the pipes are not correctly installed. At the same time, the process of CO_2 injection must be carried out very carefully, avoiding creating too high pressure in the gas reservoirs, causing the stone seams which were sealed after being exploited to be destroyed, creating CO_2 exhaust holes. In addition, deep oil tanks less than 800m are not suitable for storing CO_2 because that depth is not enough to convert this gas to solid liquid and thus can easily escape to the ground. (ccs association 2015)

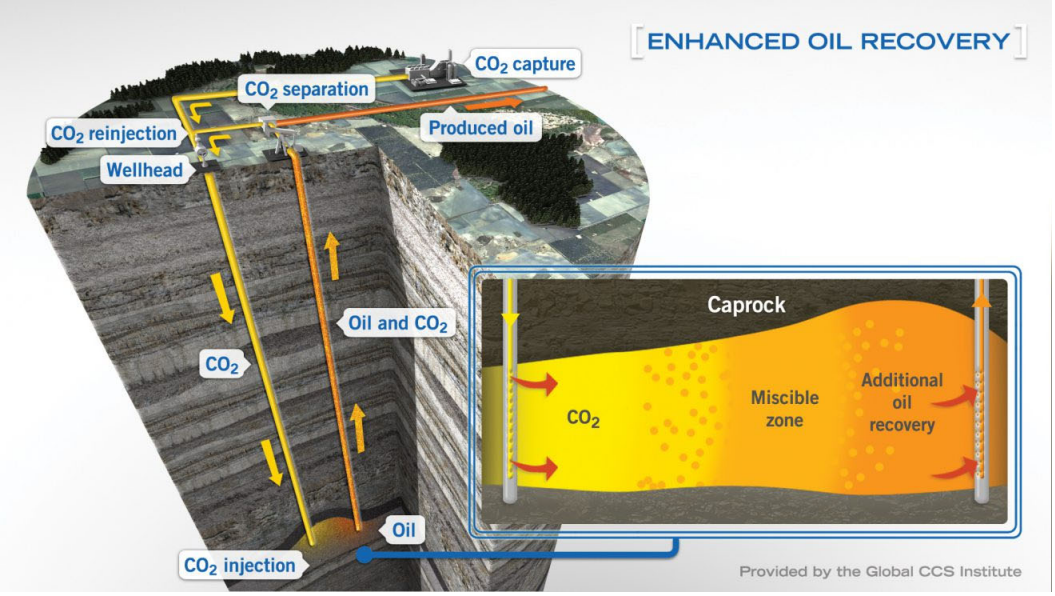

FIGURE 8. Enhanced oil recovery. (global ccs institute, 2017)

2.3.5 Deep saline aquifers

Some deep aquifers which are unable to provide water for domestic and agricultural use, may be an appropriate destination for CO_2. Similar to petroleum reservoirs, saline aquifers can be found on land or offshore. They are usually part of oil bags and airbags, so they have some common characteristics. The oil industry often removes saline during the oil exploiting process by pumping saline from an oil reservoir to a saline aquifer. Although deep-sea water aquifers have great potential for CO_2 storage, this method is still difficult to estimate the reservoir capacity. (global ccs institute, 2017)

2.3.6 Unmineable Coal seams

The coal seams, are not thick enough, are located deep underground or are too solid to make mining impossible, can become CO_2 storage. These coal seams have the ability to penetrate and store gases such as methane. It is a gas that physically binds to these coal seams and can be separated. Studies show that CO_2 seems to close to coal seams than other gases like methane and therefore, especially when pumped into coal seams, CO_2 can push methane out. This gas is then recovered through drilling holes and brought to the surface, bringing huge profits to cover the cost of CO_2 injection. (global ccs institute, 2017)

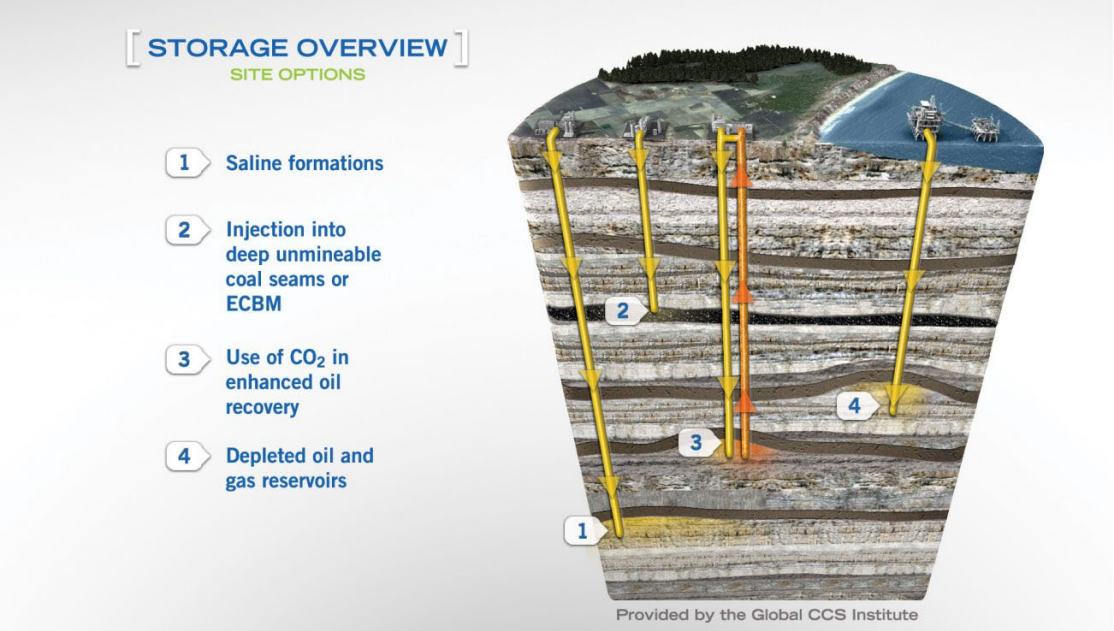

FIGURE 9. Storage overview. (global ccs institute, 2017)

3 ARTIFICAL INTELLIGENCE AND MACHINE LEARNING

3.1 Neuro-fuzzy system

Neuro-fuzzy normally comprises of artificial neural networks and fuzzy logic or we can call neuro-fuzzy hybridization. This system is based on fuzzy sets and a model which includes a set of IF-THEN fuzzy rules. A neuro-fuzzy algorithm is a fuzzy system which is operated by another system called learning algorithm from theory of neural network. The method of learning runs on local information and inflicts changes in the basic fuzzy system. (research gate 2015)

A neuro-fuzzy system has been considered as a 3-layer feedforward neural network or 5-layer architecture. The first layer indicates input variables, meanwhile fuzzy rules are represented by the middle one and the last layer points out output variables. (research gate 2015)

A neuro-fuzzy system is capable of being decoded by a fuzzy rules system. In such a case, sometimes the system might be created from the beginning without training, it means that the system could apply previous data under form of fuzzy rules. (research gate 2015)

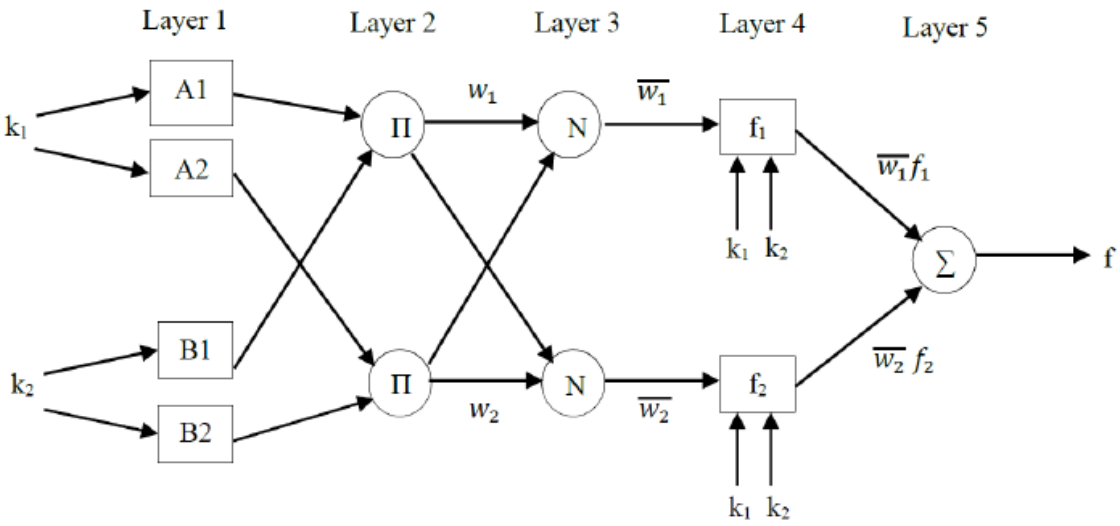

FIGURE 10. The architecture of an adaptive neuro-fuzzy inference system (ANFIS). (research gate 2015)

3.2 Fuzzy clustering algorithm

Fuzzy clustering has been considered as a type of clustering that entitles points of data to be parts of one or even two or more clusters. The most classical algorithm which applies fuzzy clustering algorithm is the Fuzzy C-means Clustering (FCM) Algorithm. It is basically described as follow:

- Define the amount of clusters
- Allocate coefficients in a random way to data points in order to belong to the clusters
- Keep repeating until the algorithms come together from various directions and meet in one point.
- Another area of Fuzzy clustering algorithm is Shape-based fuzzy cluster algorithm which comprises of Circular shaped that procrastinates data point to a round shape, Elliptical shaped that prevents data point to elliptical shape and Generic shaped that allows clusters to form any shape. (Stephanie, 2016)

3.3 Mamdani fuzzy logic and Sugeno fuzzy logic

The fuzzy inference system (FIS) has regarded a procedure which allows mapping in association with a group of inputs to an output space by applying fuzzy logic. The FIS normally includes membership function, fuzzy logic operator and if-then rule. In fact, membership functions are classified into different categories like trimf, gaussmf, trapmf, sigmf and the sigmf and gaussmf are the most prominent applied functions until now. Besides that, Mamdani and Sugeno also known as typical types of fuzzy logic models. Figure 4 depicts the process of Mamdani and Sugeno. Last but not least, the FIS applies if-then rule to define the relationship with conditions of the inputs and the outputs. We have a formula: If x Is 1 then y is 2. In such a case, the FIS defines 1 and 2 are values and it can be said that if cat is big, then dog is small. (Datta, 2005)

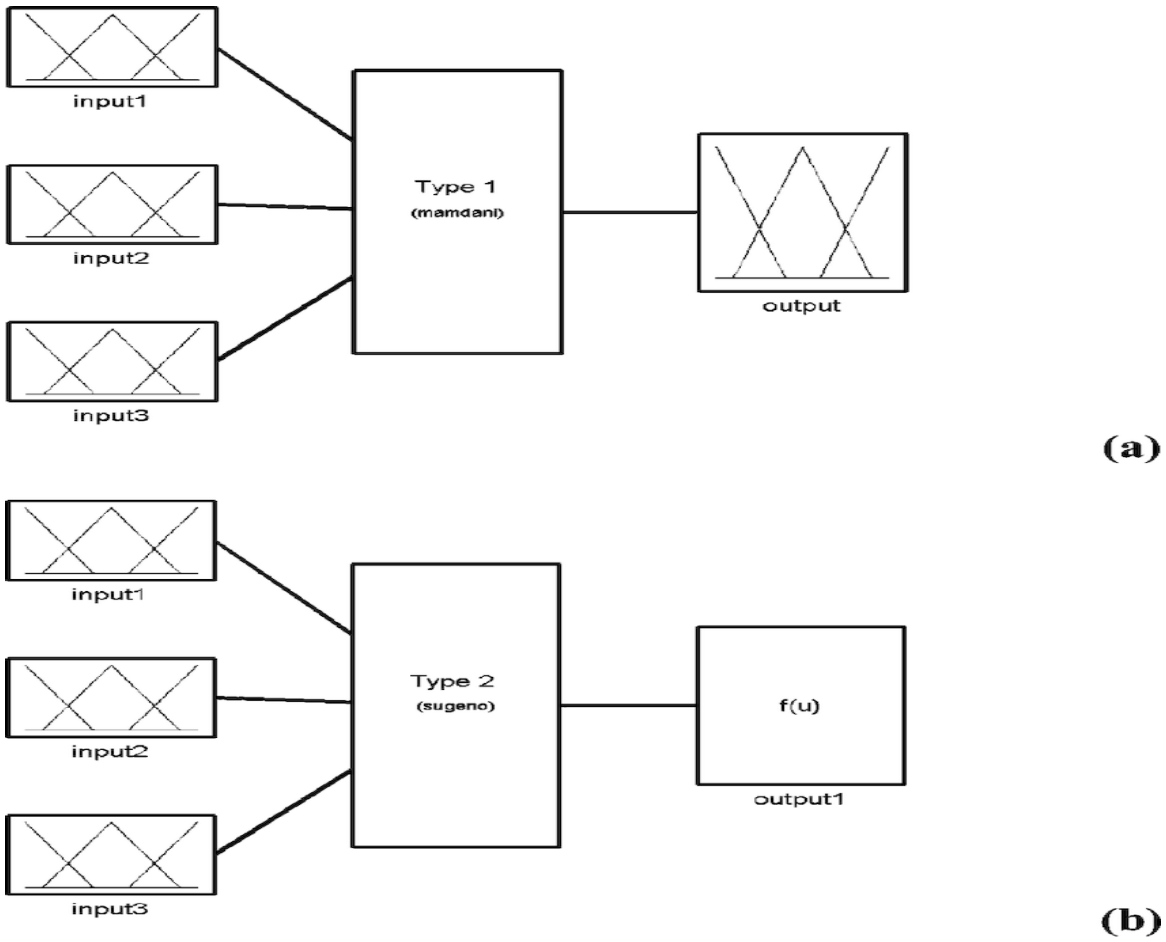

FIGURE 11. FIS using Mamdani and Sugeno (research gate, 2005)

3.4 Knowledge base systems

This system is a software designed to model the problem-solving probability of human. The KBS is a system that allows the modeling of knowledge of communication, applying this knowledge to handle tricky problems in the same field. Two vital factors in the KBS are: expert knowledge and reasoning, corresponding to the system of 2 main types, which are knowledge base and inference engine. (what-when-how, 2005)

The term was first used in accordance with expert systems which is a type of knowledge base designed for a specific application area such as Expert System for Medical Diagnosis, Expert System in tackling problems of Telephone Line, ... The Expert System works as an expert and provides ideas based on the experience of a specialist who has been involved in the Expert System. (what-when-how, 2005)

Meanwhile, knowledge base contains in-depth knowledge related to specific fields like experts. Knowledge base includes: events, laws, concepts and relationships. Inference engine is the knowledge process system based on the modeling according to expert reasoning. The engine works on information on the issue being considered and compared with knowledge stored in the

knowledge base and then draws conclusions. Finally, knowledge engineer who designs, builds and tests expert systems. (what-when-how, 2005)

3.5 Artificial Intelligence

Technology AI simulates human processes of machine thinking and learning, especially computer systems. These processes are about learning (collecting information and using rules of information), reasoning (using rules to achieve a definite conclusion), and correcting errors. Specific applications of AI include expert systems and voice recognition or face detection, object or writing. In 1965, the first concept of AI technology was invented by John McCarthy, a famous American scientist related to computing at The Dartmouth Conference. Up to now, AI technology is a technology that includes things from robotic automation to real robots. (tech talk 2017)

Today AI technology has emerged as a famous technology, receiving the awareness of many people, the concern of organizations about Big Data along with up-to-now technology has thrived a lot, making AI technology becomes popular than ever. (skymind)

3.6 Machine learning

Basically, machine learning is known as the application of algorithms to analyze data, then learn from it, and then make a decision or prediction on related issues. So, instead of coding by manual ways with a certain set of instructions to accomplish a certain task, the machine is trained by taking a large amount of data which help it learns to perform projects more accurately.

Machine learning is also known as a part AI including: logic programming, clustering, reinforcement learning, and Bayesian networks. Up to now, no one has reached the goal of General AI, and even Narrow AI is also far away from reach of the Machine learning approaches. (tech talk 2017)

Take computer vision as an example, although it still requires a lot of manual code expertise to be able to get the job done. Workers will still write classification layers manually as filters so that the program can determine where an object starts and ends. Detecting the shape to determine as if it has eight faces. A classification to identify the letters "STOP". From all classification applications, they will enhance algorithms to make images and learn the ability to identify signs if they are stop signs or not. (tech talk 2017)

Honestly, machine learning is good, but not quite perfect, especially on a foggy day when visibility is not clear or partially obscured by trees. That is why computer vision and image detection are not sympathetic, because it is too sensitive and easy to inflict errors. (skymind).

3.7 Deep learning

Another way to algorithms from the machine-learning community, Artificial Neural Networks, is mentioned for many years. Neural Networks derives from the biological related to the human brain - the connection between neurons. However, not similar to a biological brain which allows neuron to connect to other neurons at a specific distance, artificial neural networks have uncertain layers, connections, and data transmission directions. For example, you can take an image, cut it into a group placed at the first layer of the networks. In the first layer, each neuron transmits data to the second one. The second layer of neurons continue its jobs which last to the last product. (tech talk 2017)

Each neuron performs a function - how to know exactly whether it is related to the task being performed. Take the "stop" sign as an example, the properties of a "Stop" notice board are shredded and checked by neurons - cylindrical shape, red color of combustion engines, featured letters, size of traffic signs, and its movement. The task of the neural network is to conclude whether this is a stop sign or not. It always comes with a probability vector which means that the system can definitely identify 86% that it is a "stop" notice board, 7% that it is a sign of speed limit, the remaining 5% is a small thing stuck in the tree, the mechanism of network will then inform the neural network if it is accurate or not. (tech talk 2017)

Even this example is an improvement, because the neural network has been able to do all but be abandoned by the IT community. It is from the beginning periods of AI and made very few intellectual products. The problem is that the simplest networks also have very high calculations, it is not a proper approach. However, a research group led by Geoffrey Hinton eventually paralleled algorithms for computers to active and prove the concept, but it was not accurate until the GPU was applied. Turning back to the "stop" example, it is good to know that the network is being adjusted, there will be a great number of wrong answers. What it is more important is the practice. It requires to check millions of outcomes, until the weight of the input of neuron is adjusted accurately to make sure it gets the correct answer any time. According to what Andrew Ng did in 2012 at Google, he wants to conduct his research towards neural networks by making them big, increasing the number of neurons, after that run a large amount of data and train it across the system. In his case, it is a picture from 10 million Youtube videos and describing all layers in these neural networks. (tech talk 2017)

Nowadays, the ability to recognize images of machines is practiced through deep learning in some situations better than humans. AlphaGo by Google has been trained to play chess - it adjusts its neural network by fighting against itself. (tech talk 2017)

4 SIMULATION EXPERIMENT AND RESULT

The input represents for the reaction of people regarding to asked question, meanwhile the output expresses the average of all the people's responses from the input. There are totally twenty-four questions conducted to observe people's reaction on the CCS project according to the Excel file I

received from Eric Buah but I merge them into nine questions only. It means that there are nine inputs and one output at the end. The contents of questions are about the trust of city dwellers on projects carried out by Government, Industries, Environmental nongovernment organizations, Environmental Protection Agency and National Scientists engineers along with the risk perception (which may happen) as well as benefits about the CO_2 storage technology.

4.1 Implementation

The experiment was conducted by using MATLAB program which is one the most prominent numerical computing environments. Once using MATLAB efficiently, it is easy to manipulate matrix, carry out algorithms and interact with other programs such as C, C++, C#, Java, Fortran and Python. In such a case, MATLAB allows me to design an intelligent machine that could be applied to new data in the social context in which CCS will be deployed, to predict the emotional concern of the citizens on the energy project and to see whether citizens are happy or not when storing CO_2 in land underneath close to their houses.

My main task was to work with neuro-fuzzy logic, in order to do it, just type "fuzzy" in the command of MATLAB, a window will pop up which allows us to design fuzzy logic.

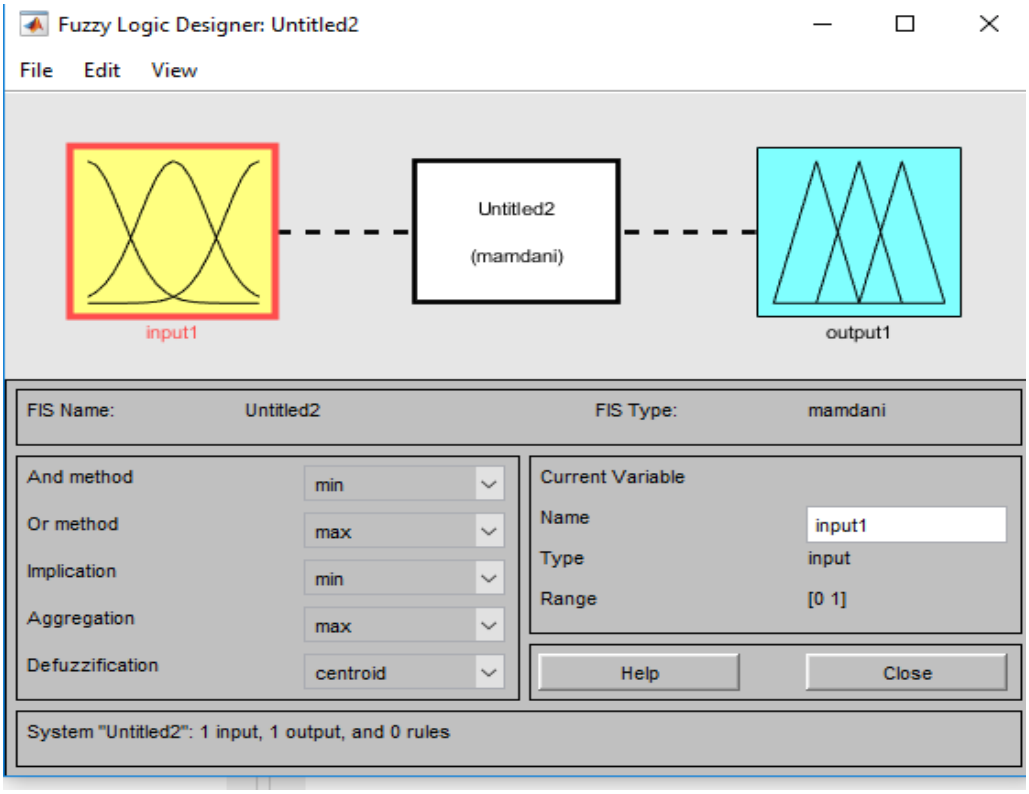

FIGURE 12. Fuzzy logic designer

4.1.1 Self-design model (sugeno):

The first model will be designed manually which means that there is not any data needed to be trained. The model will be trained by using rules.

To begin with, the answers from nine question are transformed to numbers ranging from 0-1 and there are 3 type of questions which are conducted: Trust; Risk and Benefit, each type of question has different kind of response as "Trust" is 0=lower trust; 0.25=somehow trust; 0.5=moderate trust, 0.75=high trust; 1=higher trust (input), "Risk" is 0=lower risk; 0.25=somehow risk; 0.5=moderate risk, 0.75=high risk; 1=higher risk and "Benefit" is same as "Trust"; finally "Output" is 1=worried; 0.75=sad; 0.5=unsure, 0.25=calm; 0=happy.

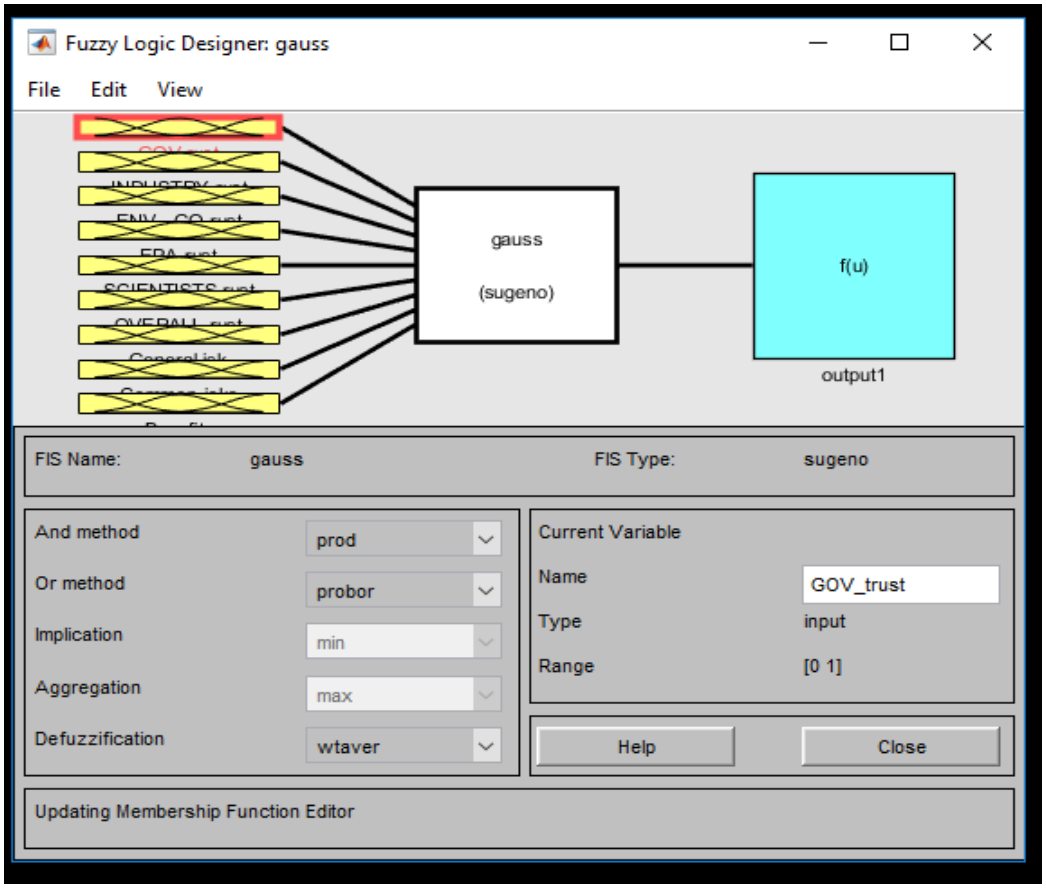

FIGURE 13. Fuzzy logic designer (initial set up)

Type of input data will be set as "gaussmf", meanwhile the membership function (mf) plots of input data are added up to 5 and similarly applied to 9 input sets

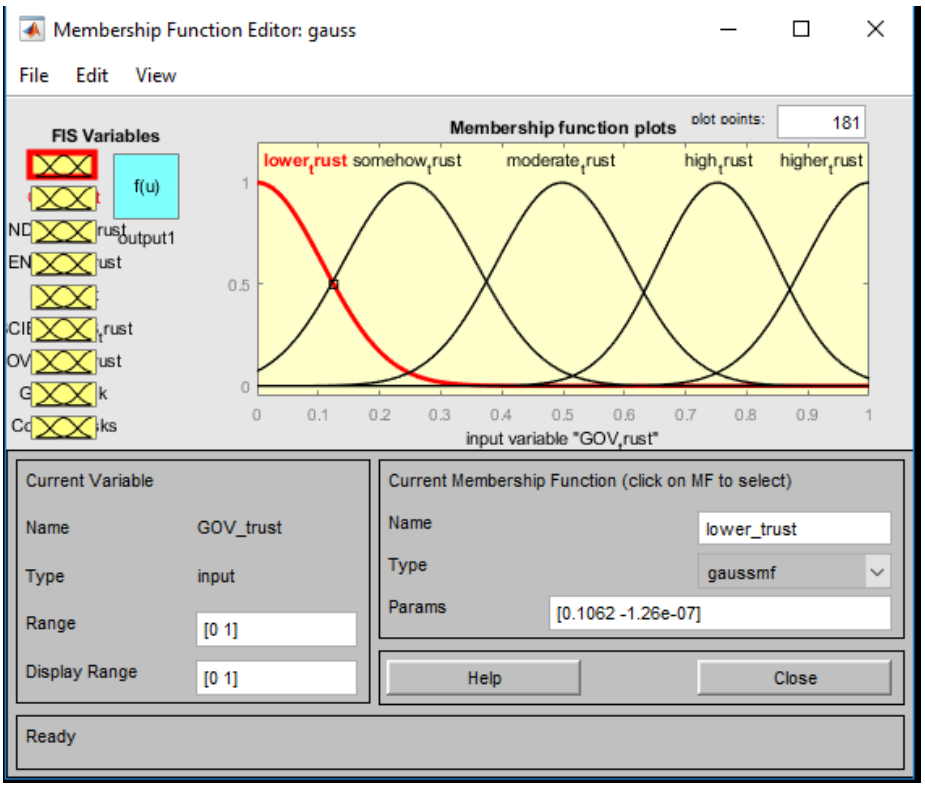

FIGURE 14. Fuzzy logic designer (input data)

Besides, mf plots of output data ranging from "worried" to "happy" (0-1) with the "constant" type.

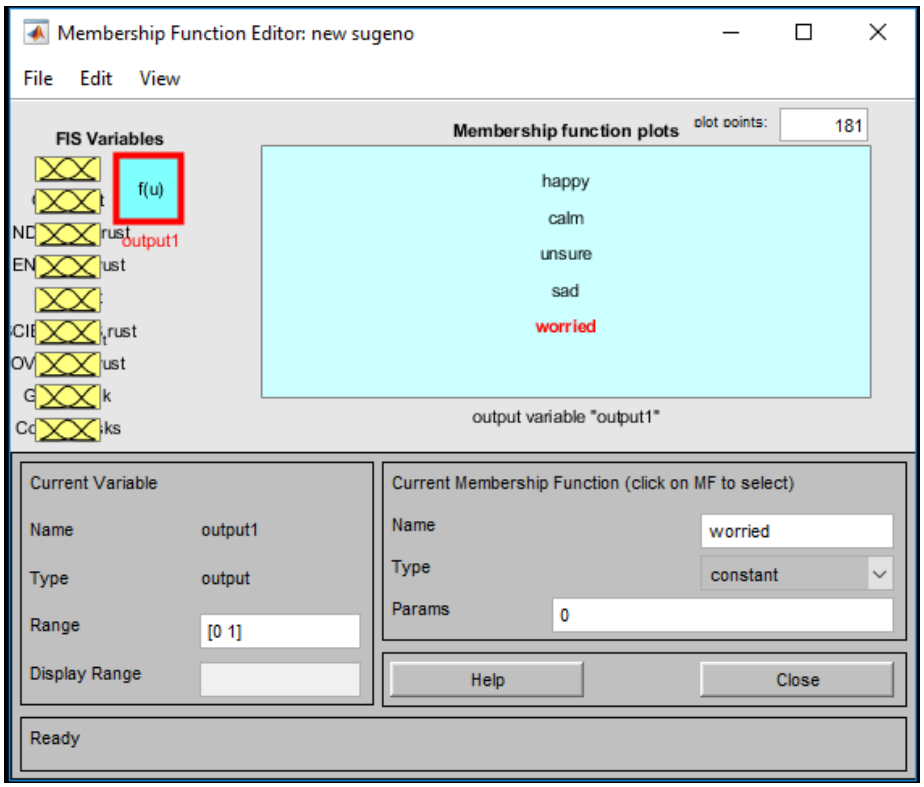

FIGURE 15. Fuzzy logic designer (output data)

Setting up rules for model based on "if-and" rules, as it can be seen that there are totally 10 rules with the connection is "and". Let's assume that the inputs "trust" and "benefit" were group A, the inputs "risks" were group B, and the output is "C", the rules are set up based on the following logic:

Rules 1-5	Rules 6-10
If group A is 1 and group B is 0, C is 0	If group A is 1 and group B is 1, C is 0.5
If group A is 0.75 and group B is 0.25, C is 0.25	If group A is 0.75 and group B is 0.75, C is 0.5
If group A is 0.5 and group B is 0.5, C is 0.5	If group A is 0.5 and group B is 0.5, C is 0.5
If group A is 0.25 and group B is 0.75, C is 0.75	If group A is 0.25 and group B is 0.25, C is 0.5
If group A is 0 and group B is 1, C is 1	If group A is 0 and group B is 0, C is 0.5

TABLE 1. Setting rules

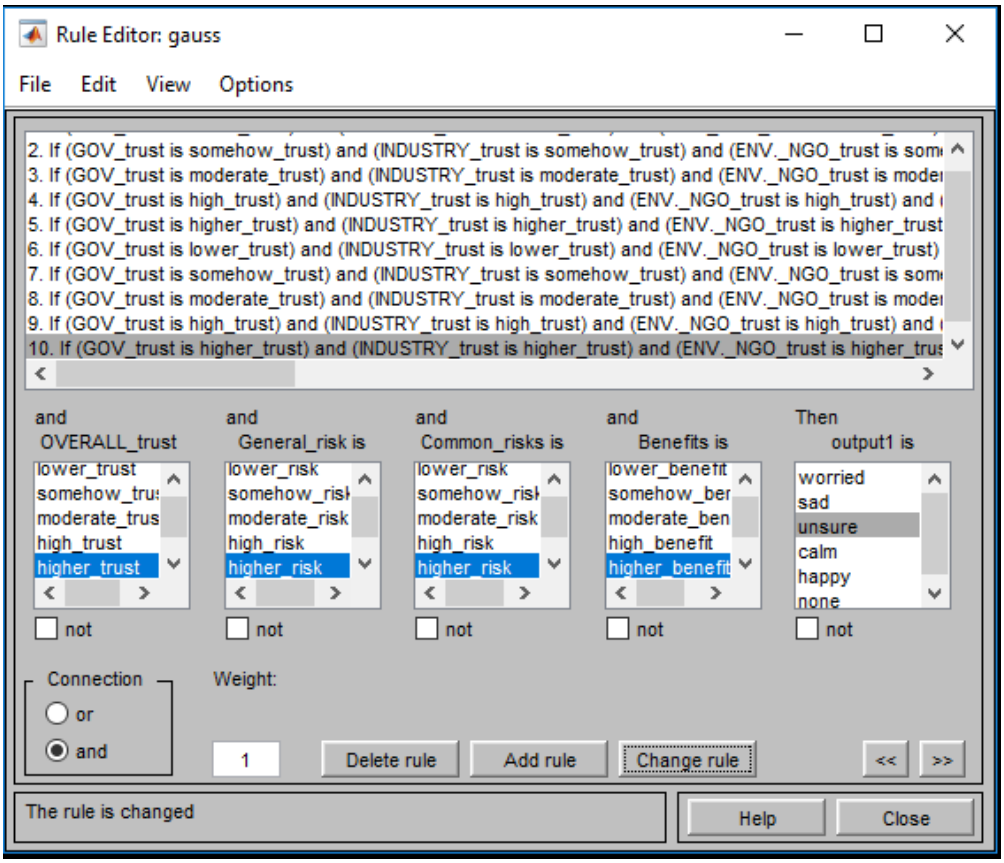

FIGURE 16. Rule Editor

4.1.2 Automatic model:

To start the automatic model, type "anfisedit" on the command of MATLAB, a pop-up window allows programmers to train and test desired data.

Setting up data:

Initially, randomly 85 set data are trained and randomly 10 set data are tested in "Load data" option (highlighted).

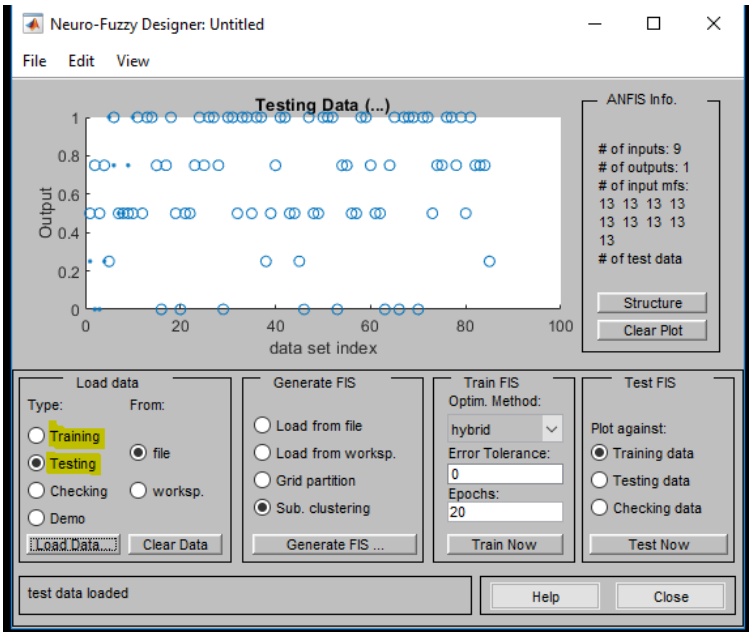

FIGURE 17. Neuro-Fuzzy Designer

The setting process is to start with "Generate FIS" option

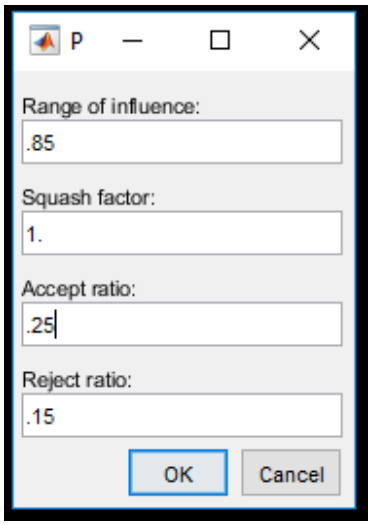

FIGURE 18. Generate FIS with Sub. Clustering

The next step was to train the data by choosing "Train FIS", the below figure indicates the error rate of training data is around 1.5e-05 at Epochs of 20

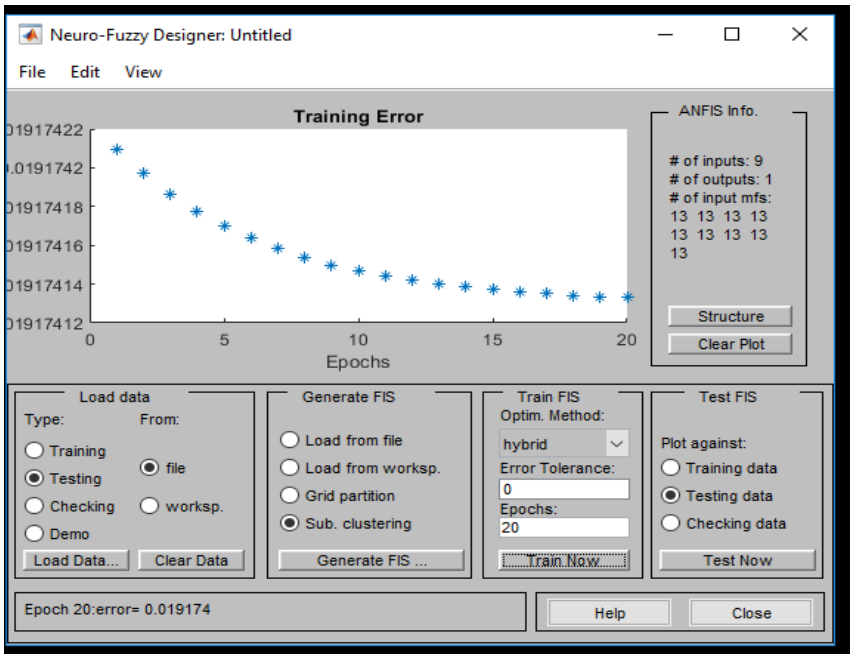

FIGURE 19. Train FIS

The final step of designing a model is to test data against the trained data which can be conducted by clicking on "Test Now" on "Test FIS" option. The average testing error = 0.59. It means that the testing data is around 60% correct compared to the training data (we can check it by checking the red dot and the blue dot, the more the red dot close to the blue dot, the more accurate prediction)

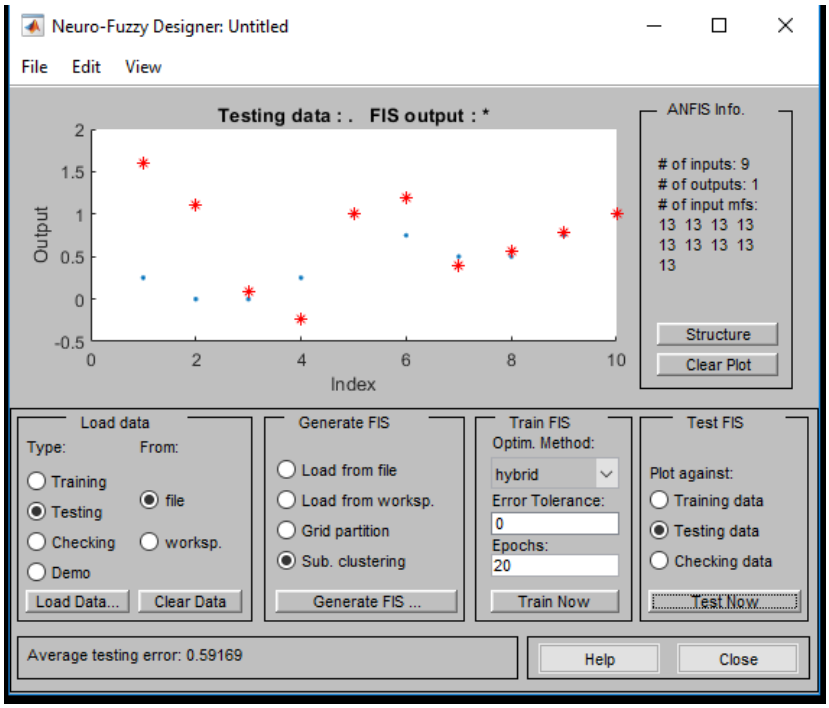

FIGURE 20. Final test with Test FIS

4.2 Result

The result of training a model to predict human behaviors can be checked by the "Rule Viewer" option. To compare "Testing data" against "Training data" (automatic model) or insert data into the "input" option (self-design model), just simply copy the input from excel file then check the output of rule viewer with the output from the excel file.

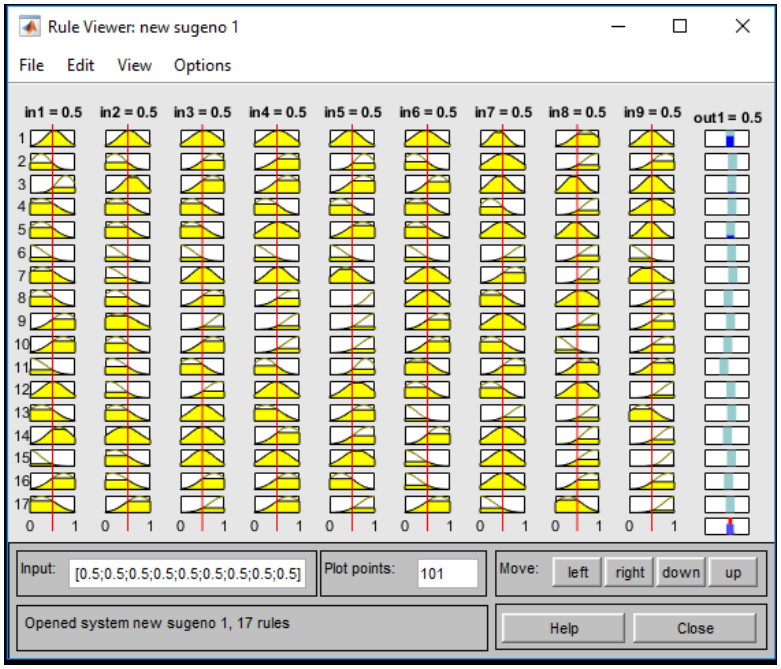

FIGURE 21. Rule Viewer

The margin of wrong number can be considered by the below table

0	0 0.134
0.25	0.135 0.44
0.5	0.45 0.644
0.75	0.645 0.944
1	0.945 1

TABLE 2. Wrong number's margin

4.2.1 Self-design model result:

With 10 rules are stated above, here is come with the final result by checking randomly 10 data, combining with the table of wrong number's margin, there is 80% correct and 20% wrong output.

Input									Output(test data)	Output(excel)
0.25	0	1	1	1	0.25	0.75	1	0.75	1.19	1
0	0.125	0.25	0	0.25	0.25	1	0.8125	0.5	0.628	1
0.25	0.25	0.5	0.5	0.25	0.25	0.5	0.75	0.4375	0.898	0.75
0.5	0.125	0.875	0.5	0.625	0.25	0.25	0.59375	1	0.727	0.75
0	0.25	0.25	1	0.75	0.25	0.5	0.75	0.5	0.677	0.5
0.375	0.5	0.5	0.5	0.5	0.5	0.75	0.75	0.5	0.5	0.5
0.25	0.75	0.75	0.75	0.75	0.75	0.5	0.25	0.75	0.168	0.25
0.75	0.875	0.875	0.875	0.75	0.75	0.75	0.84375	0.6875	0.727	0.25
0.25	0.75	1	0.75	1	0.75	0	0.28125	1	0.0521	0
0.75	0.25	0.75	1	1	0.75	0.25	0.03125	0.875	0.104	0

FIGURE 22. Final result

4.2.2 Automatic model result:

As the average testing error is mentioned above which is around 0.59, and in accordance with the margin of wrong number, there is 50% correct and 50% wrong output and check all 10 testing data

Input									Output(test data)	Output(excel)
0	0	0	0	0	0	1	1	0	1	1
0.125	0.75	0.75	0.75	0.75	0.25	0.75	1	0.875	0.99	1
0.375	0.5	0.75	0.5	0.75	0.25	0.25	1	1	0.778	0.75
0.375	0.25	0.75	0.75	0.5	0.75	0.75	0.9375	0.75	1.1	0.75
0.375	0.5	0.5	0.5	0.5	0.5	0.75	0.75	0.5	0.564	0.5
0.625	0.375	0.5	0.75	0.5	0.25	0.75	0.78125	0.375	0.398	0.5
0.375	0.375	0.5	0.125	0.125	0.75	0.25	0.46875	0.25	1.61	0.25
0.375	0.5	0.75	0.75	0.75	0.75	0.25	0.28125	0.625	-0.231	0.25
0	0.5	0.5	0.75	0.75	0.5	0	0.5	1	1.1	0
0.75	0.75	0.75	0.875	1	0.75	0.25	0.3125	0.6875	0.06	0

FIGURE 18. Final result

4.3 Discussion of result

Artificial intelligence (AI) is becoming more and more popular in every aspect of life. However, to create AI models is not as simple as we often see in the media. Moreover, building AI models well enough to successfully apply to real life is a difficult challenge. After the implementation, in case of self-design model, it is seemingly easier than the automatic model to train as it can predict 80% correct outcomes. The reason why it cannot be reached to 100% is that there are not enough rules to cover the outcomes. Because I have tested another model with 2 inputs only and 1 output and to cover all the rules to make sure 100% accurate outcomes, I must add at least 35 rules. It can be imaginable that how many rules should be added to make sure 100% accurate outcomes with the model of 9 inputs? Meanwhile in case of automatic model, the data range is not large enough for the program to test data which resulted in 60% correct only and 40% wrong, the required data for training data are probably up to 1000. Besides, it is obvious that indecisive feelings are difficult to be predicted, not even human experts. More importantly, what make us to know which one is the best model is how they perform on the test data hidden from them.

5 CONCLUSION

The objective of this project was to build conceptual bridges between social science research on CCS acceptance and artificial intelligence to design a rule-based decision-making tool using computational intelligence of fuzzy logic was achieved. The skills in machine learning help me improve knowledge towards mechanical engineer industry. Specifically, if a mechanical device or engineering project can collect lots of data, applying machine learning could find patterns and reveal problems that might otherwise show up only after long periods of testing. Whether it's evaluating a new aircraft structure or engine design, there is great potential. Honestly, Machine learning is not just for those who are specialists in AI. I believe that There may be a big future demand for people like me who have both mechanical engineering and machine learning expertise.

The thesis is finished and I have learned a great number of valuable things from my two supervisors, especially how to develop an AI model. Besides, it accidentally evokes my motivation and curiosity towards machine learning, I will definitely spend more time to learn it all the way to become a machine learning expert.

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