IoT Knots

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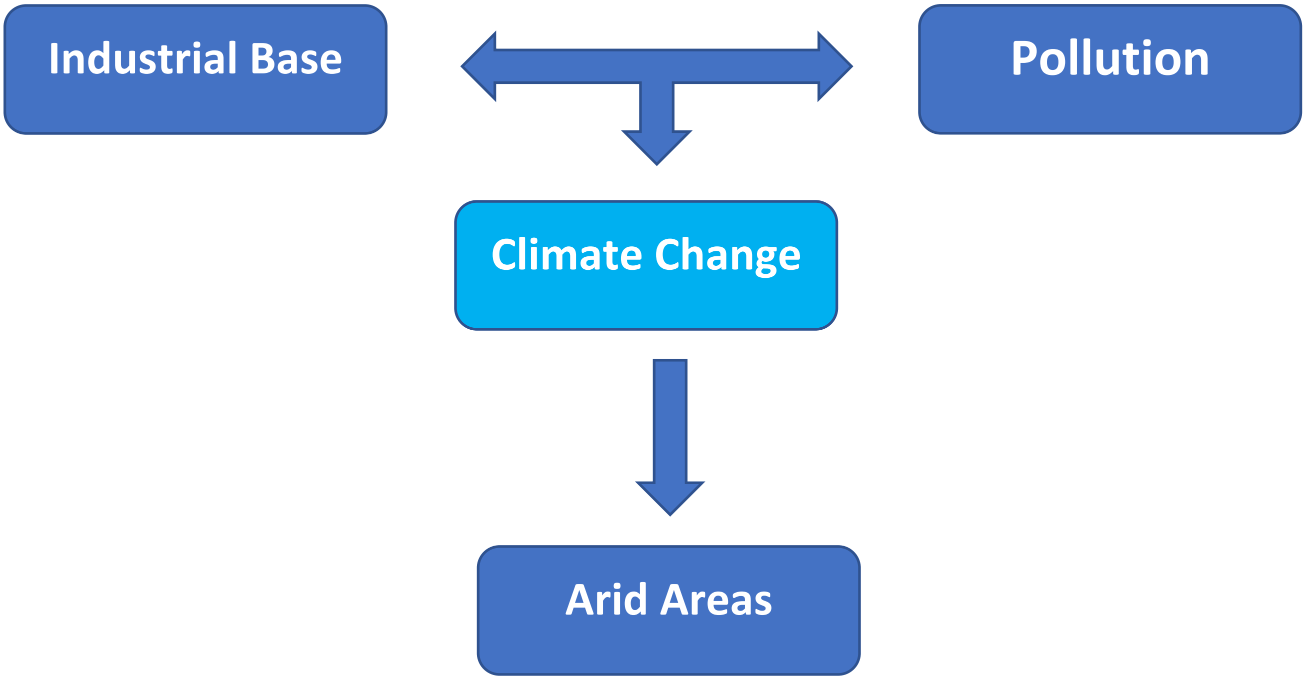
Introduction

Egypt has the goal of achieving sustainable development, where it has all the required natural and artificial resources; however, it faces some major problems that are called “Grand Challenges”. There are about eleven Grand Challenges, where relevant grand challenges will be discussed only. The phenomenon of climate change is connected to all these grand challenges. Some grand challenges cause climate change as industry and pollution while others will face an increase in severity due to climate change as arid areas. Climate change together with these grand challenges affects numerous sectors. Some of these sectors deeply affect the well-being of humans as food and water security. This project aims to gather data about climate change using an IoT system to help Egypt achieve sustainable development, overcome those challenges, and mitigate climate change.



Chapter 1

I. Present and Justify a Problem and Solution Requirements

1.1 Grand Challenges

1.1.1 Mitigating the Effects of Climate change

Climate change threatens the whole world on multiple levels. The effects of climate change are the most severe compared to the other grand challenges facing Egypt. If the problem of climate change isn't addressed and decisive decisions are not taken within the next **8 to 12 years**, Egypt will face devastating problems ranging from food and water insecurity to expected sea level rise and major and loss. Although these problems would cripple the economy in Egypt, mitigating climate change is a complex process that needs a comprehensive understanding of the challenge and its relation to other problems.

Climate change refers to the long-term changes in temperature and weather patterns. Changes in weather are a normal part of the environment and the solar cycle; however, climate change causes these changes to be more rapid and severe. With more rapid changes the ecosystems won't have time to adapt and recover. The average temperature rose with the continuous increase in greenhouse gases mainly CO_2. The temperature surged by **more than 1.5 degrees Celsius since 1880 as shown in figure (1).**

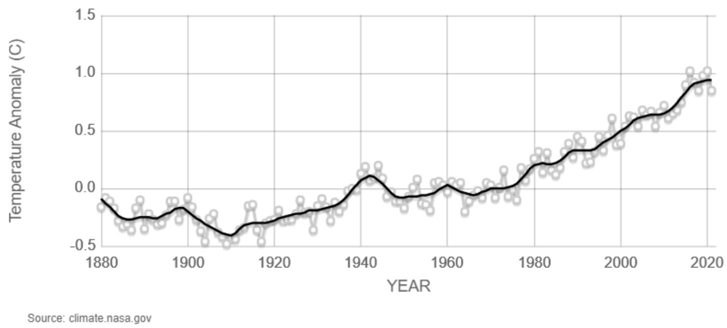


Figure 1 Increase in Temperature per Year

Some countries contribute to climate change more than others. Similarly, the effects of climate change differ from one country to another. Egypt as other developing country didn't contribute much to the increasing greenhouse gases emissions with an average of **250 metric tons in 2021 as shown in figure (2).** But it will be one of the most vulnerable countries to the climate change caused by developed countries. Climate change will affect multiple major sectors in Egypt and the relation between them.

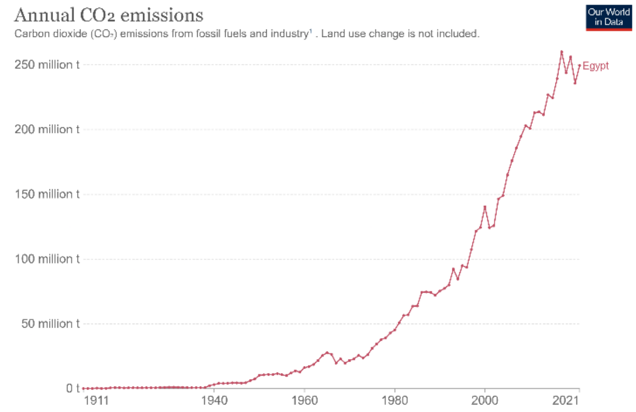


Figure 2 Increase in Carbon Dioxide Emissions in Egypt per Year

When the global temperature rises it directly or indirectly changes the ecosystem. In Egypt one of the most affected sectors would be agriculture. Agriculture plays a vital role in Egypt's economy contributing roughly **15%** of the Gross Domestic Product (GDP) and employing about **30%** of the national workforce. The main reasons for the adverse effects on agriculture are changes in soil characteristics, crop productivity, and water resources. These effects can be countered with using other plant species or changing the time of agricultural activities. However, extreme weather events as heat waves will cause bud breaks that will affect the final quality of crops. This will be accompanied with an increase in disease outbreaks as most crop diseases thrive at higher CO_2 levels.

One of the other aspects that make Egypt highly vulnerable to climate change is its extending coasts of **3,500 Km.** An estimated 53% of the Egyptian population live within **100 Km** of the coast. With the continuous warming of temperature, the sea level will rise submerging the coastal regions of Egypt. he Nile Delta region is characterized as one of the most vulnerable regions to climate change. A lot of the main industrial facilities along with fisheries are located along the coastlines of Egypt. With an expected sea level rise of **1.0-meter**, **6,100,100** people will be affected with a loss of agriculture land of **4,500 km^2** as **shown in figure (3).**

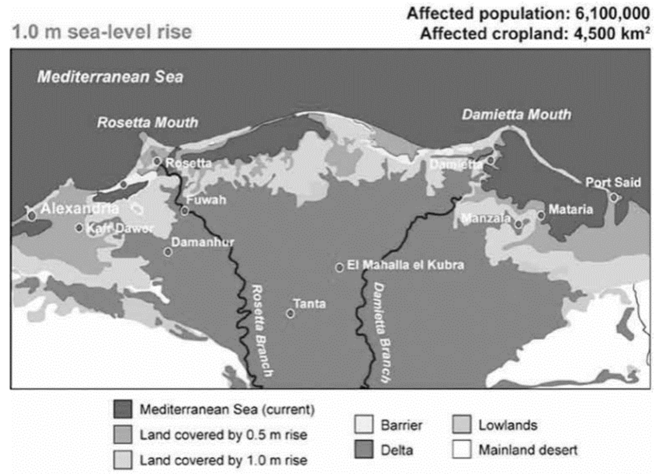


Figure 3 Scenario if the Sea Level Rose by 1 meter

Causes:

- **Generating Power:** Generating electricity and heat by burning fossil fuels is one of the top contributors to global emissions. Most electricity is still generated by burning coal, oil, or gas, which produces carbon dioxide and nitrous oxide as **shown in figure (4).** These greenhouse gases trap the infrared radiation causing a subtle increase in temperature.

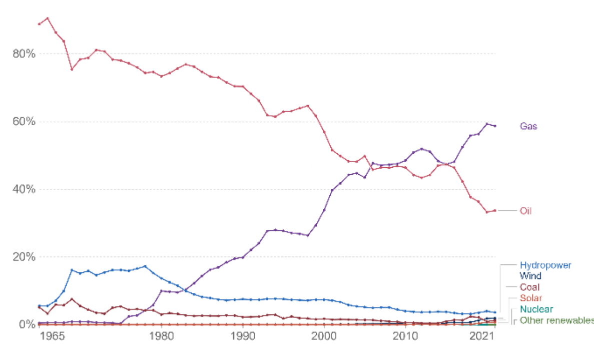


Figure 4 Sources of Green Electricity

- **Cutting down forests:** Forests are continually cut down to create farms or urbanization. When trees are cut, they release the carbon they have been storing. Each year approximately 12 million hectares of forest are destroyed. Since forests absorb carbon dioxide, destroying them also limits nature's ability to keep emissions out of the atmosphere
- **Transportation:** Most means of transportation run with fossil fuels. Transportations accounts for about one fifth of CO_2 emissions with aviation being the highest contributor compared to other means of transport as **shown in figure (5)**. In Cairo there are around 2.3 million licensed vehicles on the streets.

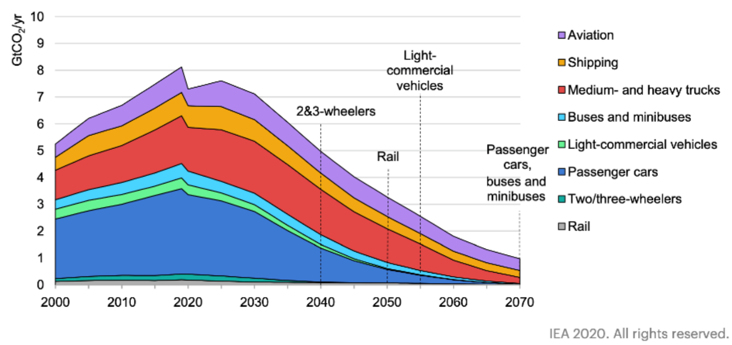


Figure 5 Contributors to CO2 emissions

Impacts:

- **Rising sea levels**: With the continuous warming of the climate, the ice at the two poles continues melting which will cause the coastal areas to be submerged. In Egypt the sea level is expected to rise over **100cm** resulting in the loss of **70km** of the northern coast.
- **Food insecurity**: Egypt faces an instability in food production with 5.2 people undernourished in 2019-2020 as **shown in figure (6)**. Food insecurity will continue to grow with the challenges imposed on agriculture by climate change. Additionally, extreme weather environments and heat waves have the potential to cause more damage in the coming years.

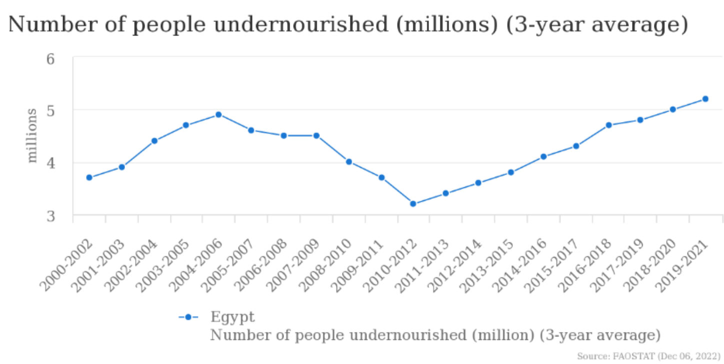


Figure 6 Number of undernourished people in Egypt (3-year-average)

- **Increased drought:** Rising temperatures will pose major threats to the limited water resources of Egypt. Also, this will affect industry, agriculture, and all water dependent sectors.

1.1.2 Increase Industrial Base for Egypt

The industrial sector is the pillar of the development of any country as it contributes to the production of many of the everyday products and puts the products of agriculture into real action. The industrial base in many developing countries, especially Egypt, suffers from significant problems; for example, the process of industrialization in Egypt depends on utilizing technology, natural resources, and labor, but Egypt is a country with very limited natural resources, and the current change in climate, which makes natural resources scarcer and labor less active, adds to Egypt's suffering.

Although Egypt's industrial contribution in the GDP is increasing, it is not sufficient. **From 2010 to 2020**, the share of industrial processes in the Gross domestic product (GDP) has increased in **2020**, contributing with **32.01%** of the share of the GDP **as shown in figure (7)**. This is not the suitable percentage for a country that aims to be among the top industrial countries in the world. In addition to the slim GDP share, industry in Egypt is mostly concentrated in Greater Cairo with a percentage of **41%,** signifying the low spread of economic sectors in Egypt. All of those factors emphasize the need to solve the bad impacts of the industrial sector and work on getting rid of its causes.

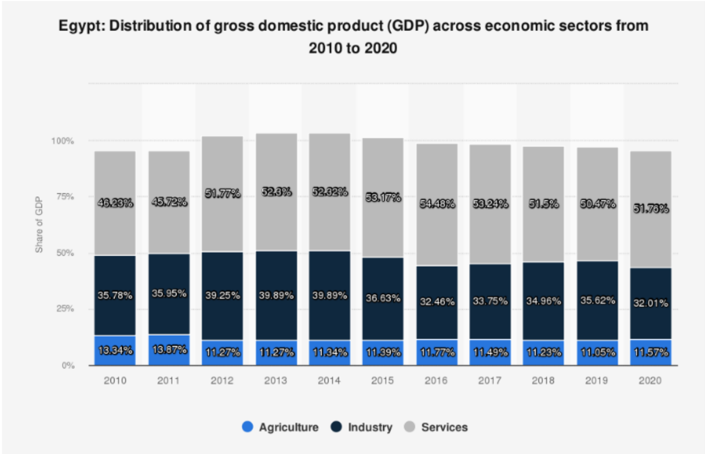


Figure 7 Distribution of the GDP across economic sectors from 2010 to 2020

Causes:

- **Depletion of energy resources:** Egypt's industrial field depends on **32.70%** of the total energy of Egypt which represents about a third of the total energy **as shown in figure (8)**. Egypt mainly depends on non-renewable resources of energy, and as time passes, it decreases; therefore, the efficiency of industrial fields decreases with it.

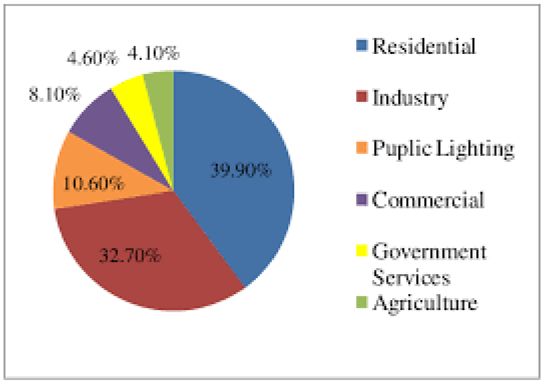


Figure 8 Energy Consumption in Egypt by Sector

- **The lack of modern technology used in factories:** The main industries in Egypt are food processing, tourism, chemicals, pharmaceuticals, construction, cement, metals, light manufacturing, and textiles. All of these Industries need modern technology and expert engineers. The problem is that Egypt seeks expensive Foreign technology, and it costs a lot to import.

- **Deficiencies in the number of experienced labors and their productivity:** Egypt is a highly-populated country; however, the number of factories is limited, and most of them have low-magnitude salaries, bad management, and no technological experience. Consequently, the government looks for Foreign Experts in the industry field who need a high salary, affecting the economic income. Extreme weather causes the productivity of workers to decrease and their working periods to shorten.

Impacts:

- **Low economic income**: The efficiency of the industrial sector has a large impact on the economy of the country, and the efficiency is low because of the lack of modern technologies used in factories. When the efficiency of the industrial field is low, the country's economic income subsequently becomes low.

- **Emigration of the labors:** Because of the economic problems in Egypt, laborers have a low-income salary and lack social insurance. Thus, most of the skilled laborers emigrate to other countries where abundant welfare salaries exist in most factories and industries.

- **Deterioration of the Climate:** Poor industrial regions usually have poorer harmful gases filters, which consequently makes the fact **that 62% of** climate change is because of the CO_2 emissions from fossil fuel burning for industrial processes. Related gases from other industrial processes contribute with a fair amount, **as shown in figure 9.** Since climate change causes the deterioration of industry, industrial processes' contribution to climate change should be limited

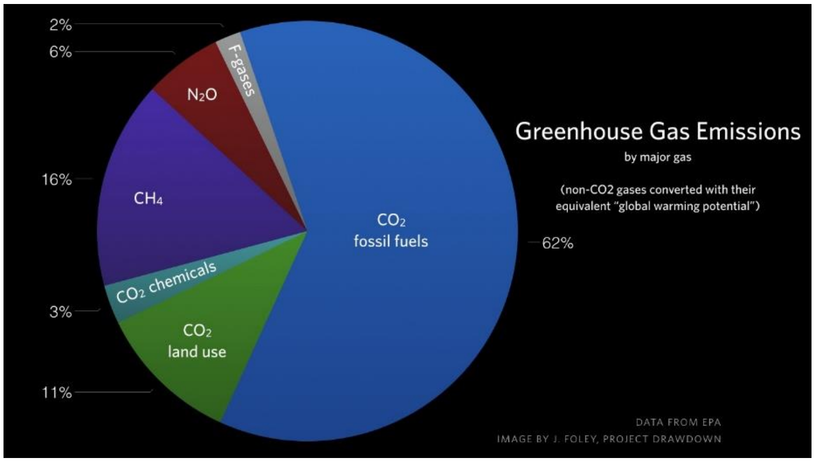


Figure 9 Greenhouse Gases by major gas in Egypt

1.1.3 Reduce Pollution

Among the variety of grand challenges impeding Egypt from achieving its sustainable development goals, Pollution is the most prominent issue. What makes pollution difficult to handle is its variety of causes and types. For illustration, Pollution types range from land surface contamination by solid wastes to the death of marine creatures as a result of the disposal of toxic pollutants in water. Air Pollution is a prevalent issue caused by most urban, industrial, and even natural activities such as volcanic and nuclear emissions. Air pollution can take many forms due to its numerous causes. The presence of pollutants in the atmosphere is referred to as air pollution. These contaminations include toxic gases (such as sulfur dioxide (SO_2)), pesticides, debris, and fractional solids. Solving Air pollution is becoming extremely necessary as it is regarded as one of the main driving forces behind climate change nowadays. For instance, It contributes to **11.65%** of death cases globally. The corresponding map **(figure 10)** shows the death rates from air pollution in the world.

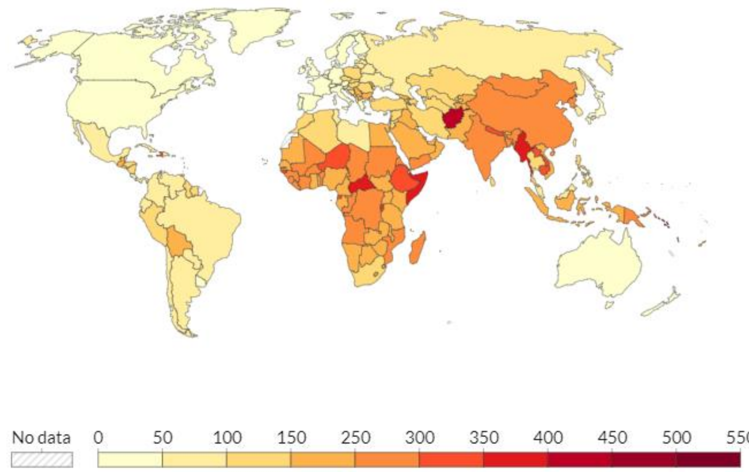


Figure 10 Death Rates from Air Pollution in the world

High levels of contamination are common in developing countries, including Egypt. However, unlike other developing countries, Egypt faces numerous obstacles that make overcoming pollution a difficult task. For instance, **figure (11)** shows how Egypt's population growth significantly increased between 1950 and 2020 when it reached **103 per km^2.** This significant surge coincided with rising rates of air pollution in Egypt. **Figure number (11)** emphasizes that the rise in the population was associated with increasing levels of greenhouse gases from different

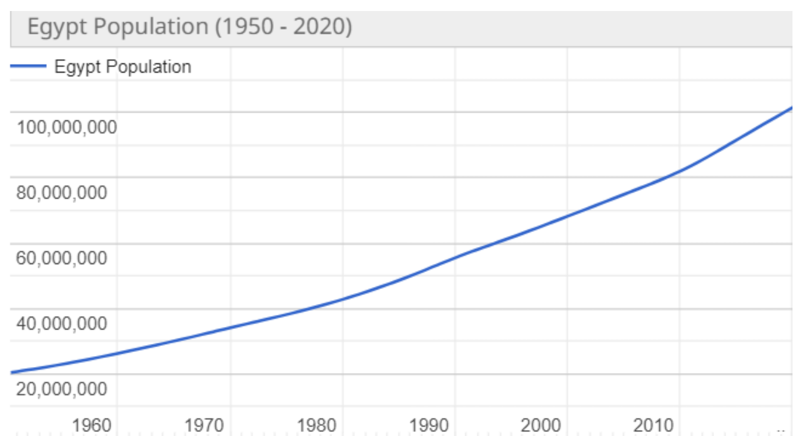


Figure 11 Egypt's Population Growth from 1950 to 2020

sources; the concentration of greenhouse gases in Egypt's atmosphere reached **29.1 µg/m in 2021.**

Causes:

- **Intense burning of fossil fuels:** The combustion of fossil fuels inside factories and vehicles contributes significantly to air pollution. Coal and other petroleum derivatives emit greenhouse gases during combustion, causing massive pollution. Sulfur dioxide, carbon monoxide, and nitrogen oxide are all produced during the combustion process and have negative health effects on living organisms. As an illustration, the CO_2 gas's concentration increased during the previous years from about **130,000 Kt** of CO_2 to **352,000 Kt** in the last 30 years as **shown in figure 12**.

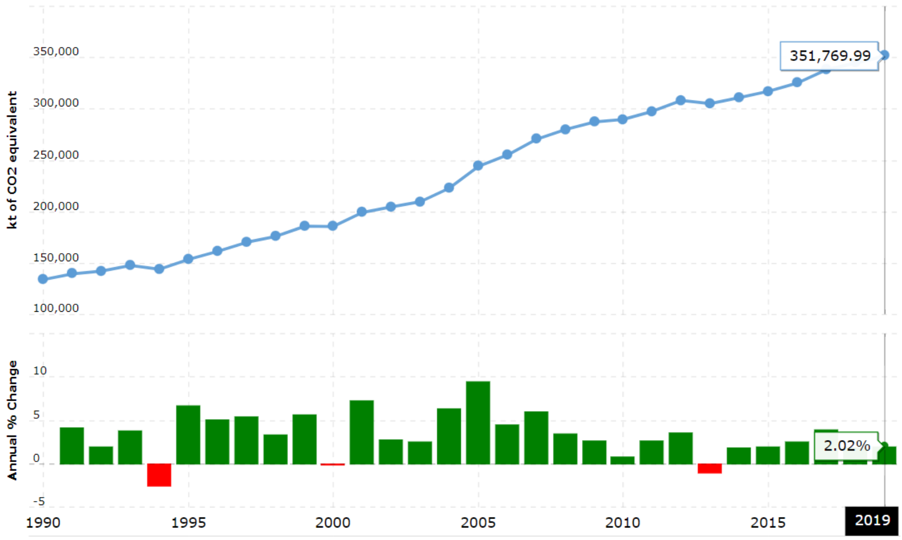


Figure 12 increase in CO_2 Concentation per Year in Kt

- **Uncontrolled Industrial Activities:** The production of chemicals and textiles in the Egyptian industrial sector emit a large amount of CO, hydrocarbons, chemicals, and organic compounds into the environment. These harmful emissions pose several threats to microorganisms. Bacteria and fungi play critical roles in nature's biogeochemical cycles such as the nitrogen fixation cycle. They are the most important indicators of abnormal environmental conditions. The decay of these microorganisms in the environment produces methane gas, which is highly toxic. Breathing toxic gases such as methane can be fatal.

Impacts:

- **Climate change:** Climate Change: GHG is the primary product of air pollution. Following some intense chemical reactions between the GHG, they release Ozone gas, which causes a depletion in the stratosphere, resulting in a condition known as an Ozone hole. Ozone holes can induce severe climatic change, which is defined as temperature variations over a specific time period.

- **Average public health deterioration:** Air pollution has many significant effects on the environment, but the most striking, and also the most obvious, effect is the deterioration of average public health. The majority of the prevalent diseases in Egypt (primarily chronic respiratory diseases) are caused as both direct and indirect effects of air and water pollution.

- **Economic growth limitation**: Pollution put a huge burden on the economic growth of developing countries like Egypt. Crop yield loss, deficiencies in the productivity of industrialized activities, and the accumulation of Labor related problems, high health expenditure, for instance, all are direct consequences of air pollution. Economic limitations could result in a big decline in the market value of the currency and other serious issues associated with trading and development.

1.1.4 Improve Use of Arid Areas

Arid areas are defined by high temperatures, poor soil, a lack of rainfall, and low soil moisture. Because of all of these characteristics, arid areas are largely uninhabited. The arid regions also have limited energy resources and facilities, causing residents to migrate to urban areas with better living conditions. The growing number of migrants magnifies the complications of urban congestion Egypt has an area of about **1.01 million km^2**, and **96%** of it is arid as **shown in figure 13**, with the remaining **4%** divided between semi-arid and green lands. The majority of Egypt's population concentrates in the delta of the Nile river which accounts for **2.4%** of Egypt's land area. The corresponding map shows the population density of Egypt. The gradual conversion of habitable lands into arid lands puts Egypt under the stress of prospective economic issues due to the loss of both vegetation and agricultural activities. Additionally, this conversion affects the ecosystem badly, putting some essential species on the brim of being endangered by either destroying their habits or reducing their food resources.

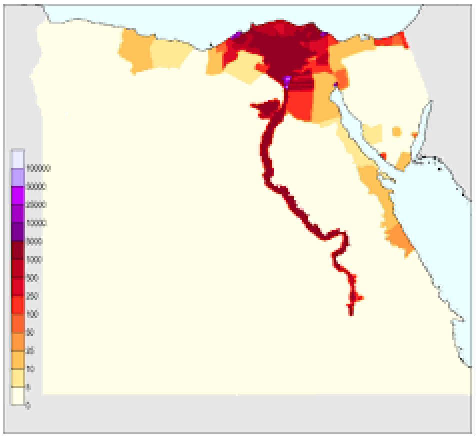


Figure 13 96% of Earth's are is still arid

Causes:

- **Soil Erosion :**Windblown sand rocks break plants from their roots, negatively affecting soil and forming a solid crust on the soil by sandstone particles. Wind erosion is regarded as one of the major causes of soil erosion in areas covering more than **90%** in the eastern and western deserts, as well as Sinai. These areas have a vulnerable ecosystem, severe drought, and a lack of vegetation cover. The wind erosion ratio in Egypt is approximately **5.5 tonnes** per hectare annually oases areas of the western desert and **71-100 tonnes per hectare** each year in areas of rainfed agriculture on the northwest coast, indicating that wind erosion risks in these areas are moderate to severe.
- **Desertification :** It is a process in which the land is transformed into a desert as a result of a variety of human and natural factors. Desertification has a significant impact on soil, causing soil degradation and reducing the soil's

ability to produce land, reducing agricultural productivity and ultimately leading to the abandonment of the soil.

- **Climate change:** The significant surge in Egypt ‘s temperature is attributed mainly to climate change in recent years. The rise of the temperature leads to the deterioration of the soil vegetation and greenery portions. Furthermore, acidic rain, which resulted from mixing the atmospheric air and greenhouse gases, could wear away the soil and expose what is beneath the surface.

Impacts:

- **Cultivation difficulty :**Agriculture in arid areas is difficult due to the negative water balance; arid areas receive **200 ml** of precipitation per year. An absence of clouds, high temperatures, and sandlots of sun encourage high rates of evapotranspiration, making agriculture difficult in arid areas.
- **Urban congestion :** Egyptians migrate to the green lands of the Nile delta, leaving vast swaths of arid regions behind. Their migration develop urban congestion which ultimately can lead to the depleation of water resources , emergance of other serious disorders, and high inempolyment rates.
- **Diffculty of reclamation:** Converting arid lands back into their orginal state requires a lot of money and advanced technological techniques which is not a feasible solution in devloping countries like Egypt.

1.2 Problem To be Solved

1.2.1 "Applying Communication and Information Technologies to Mitigate Climate Change Negative Impacts on Sea and Air"

Renowned for its effects on various aspects of nature, climate change affects a lot of nature landforms from seas to air. Climate change's effects aren't limited to polluting seas and air only, but consequently extend to other niches such as health and marine organisms' lives. Over time, many variably effective solutions were developed to fight the negative impacts of climate change, and in the age of 5G, it is the suitable time to delve deep into using IoT and statistical analysis to fight climate change, hoping for better circumstances.

Due to taking **in 30%** of the carbon dioxide emissions, sea used to lighten the effects of CO_2 on the earth; however, limits are being exceeded, and the absorbed CO_2 interacts with water, forming carbonic acid that decreases the sea water's pH (equation shown in figure x). The lower, acidic pH harms marine organisms and makes them unable to build their skeleton and shells. In addition to CO_2, sea absorbed a lot of the greenhouse gases' heat, specifically **90%**. That caused ice to melt and sea level to rise at an average of **4.5 millimeter per year** for every year between **2013 and 2021**, exposing the coastal cities to various, recurrent floods. That heat energy made the sea's temperature increase by **1.1ºC**, destroying **60%** of the world's marine ecosystems.

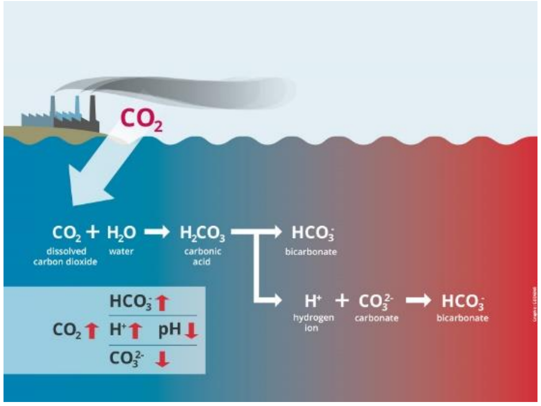


Figure 14 Dissolving of CO_2 in Seawater

Air's quality is mainly affected by either harmful gases (such as ground ozone) or particulate matter (a mixture of solid particles and liquid droplets), known as PM. PM has various types that are classified according to the size of their grains into ultrafine, fine, and coarse. Both of the harmful gases and PM cause a wide range of diseases from premature death to decreased lung function. Similar to the sea, air quality is largely affected by climate change. That's mainly because the chemicals that harm both air quality and climate change are connected. As an illustration, fossil fuels' burning that gives out carbon dioxide also gives out nitrogen oxide (NO), which causes the harmful ground ozone gas and nitrate aerosols (a type of fine PM of radius less than **2.5 micrometers**) to build up.

In 1997, Egypt established its environment ministry which marked the first obvious contribution against the devastating climate change effects on the environment. In the **25 years** between the establishment of the environment ministry and hosting the COP-27 conference, Egypt led myriads of projects like The Inclusive Housing Finance Program that supports sustainable building materials, The Participatory Development Program in Urban Areas that aims to adapt slums to climate change, and many others. Although those projects did real-world change, they faced the localization problem: their effect and controls were limited to a small place. In addition, they didn't give insights about what should be done in the future. IoT, network, and data analysis applications will perfectly be controlled from any place despite how far it is. In addition, they can give predictions and insights about future actions that could be taken to prevent further harm.

Whether it's for sea or air, IoT and statistical analysis would offer the key to solve the problems of climate change. In addition, they would help to predict the future and put sustainable plans that will save marine organisms, plants, and Egyptians themselves.

1.2.2 Positive Consequences (If solved):

- **Pursuing Long-Time Sustainable Plans:** Away from that past that constantly implied that technology opposes sustainability, technological devices became a pillar that supports sustainable plans. Technology contributed to air-quality monitoring systems, smart sustainable houses, and other cool innovations, and if technological advancements are constantly used along with precise statistical methods, long-time plans would feasible as statistics help anticipate future actions and achieve sustainability.

- **Modified Economic Status:** The rising temperatures cause discomfort to tourists and workers, diminishing tourism and costing the country some precious working hours. In addition, factories and businesses in Egypt may have their workflow disrupted for days because of floods.

- **Better Technological Base:**
  To monitor climate change, the Egyptian government would have to install optic fiber cables, Wi-Fi modems, and electricity. That better infrastructure and technological base will be the best start for many industrial projects that Egypt normally lack.

1.2.3 Negative Consequences (If not solved):

- **Continued Suffering of Ecosystems and Living Organisms:** Climate Change strongly makes organisms suffer in both sea and water. Marine organisms will reach a **99%** death rate if the average seawater temperature increased by additional **0.9ºC**. Climate Change's effects that range from droughts to decreased air quality can harm humans, land organisms, and many more if those effects are left without solutions.

- **Decreased Food Supplies:** Climate Change harshly affects food supplies in the world, putting the poor's lives into danger. For starters, yield growth for several grains such as wheat and maize has been diminishing due to the effects of climate change, and global measures assure that the declination percentage will reach 30% if no actions are done. The effects of climate change aren't limited to plants only, but it also extends to cattle, fish, and others.

- **Deterioration of the Infrastructure:**
  Although infrastructure almost always contribute to climate change, it is affected by it, too. For example, transportation contributed with **25-35%** of the CO_2 emissions in Egypt. On the other hand, Egyptian floods threatens the existence of airports, which are usually on the coast. Airports aren't the only type of infrastructure affected by climate change in Egypt as buildings and roads are among the various victims.

1.3 Research

1.3.1 Topics Related to the Problem

1.3.1.1 Particulate Matter:

Particulate Matter (known as PM) is a scientific term that is assigned for a mixture of solid particles and liquid droplets found in air. Some of those particles (such as dust) are large enough to be seen with naked eyes; however, others are smaller and can be only seen with an electronic microscope. The small particles are classified into three groups: coarse, fine, and ultrafine, **shown in figure 15**. Coarse particles (PM_{10}) has a maximum diameter of 10 micrometers. Fine particles ($PM_{2.5}$) and ultrafine particles ($PM_{0.1}$) have diameters of **2.5 micrometers** and **0.1 micrometers,** respectively. PM forms due to various reasons, and climate change strongly participates in many ways. For example, incomplete burning, such as that in some factories and wildfires, forms elementary. In addition, burning fossil fuels increases carbon dioxide and nitrogen oxide emissions, which causes nitrate aerosols ($PM_{2.5}$) to build up. Particulate Matter are really important to solve as they participate in climate changes via many ways, and one of them is that elementary carbon is considered one of the top 3 global warming causes. Since PM could be inhaled, they reach lungs and bloodstream. In addition, $PM_{2.5}$ pose the greatest danger due to being able to reach heart.

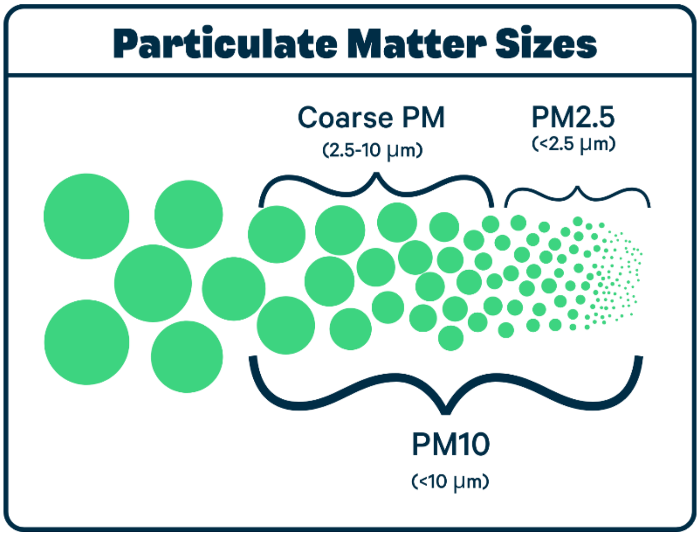


Figure 15 Particulate Matter Types with Sizes

1.3.1.2 Ocean Acidification:

The ocean absorbs **30%** of the CO_2 in the atmosphere, which led to the **30%** increase in the ocean's acidity. Since human's activities constantly increase, ocean is reaching a larger risk. CO_2 leads to an increase in the acidity due to a series of chemical reactions (**summarized in figure 16**) that starts with carbon dioxide dissolving in water and forming carbonic acid. That carbonic acid later dissociates into hydrogen ions and bicarbonate ions (HCO_3^-). Hydrogen ions increase the water's acidity and binds with available carbonate ions in the ocean. Since carbonate ions are being consumed, calcifying animals (animals that develop calcium-based shells like the oysters) lack minerals to form their shells. The effect of CO_2 on marine organisms isn't limited to calcifying animals, but it also extends to non-calcifying animals. Some fish, for example clownfish, have problems with identifying predators in acidified water, putting the whole food web into risk.

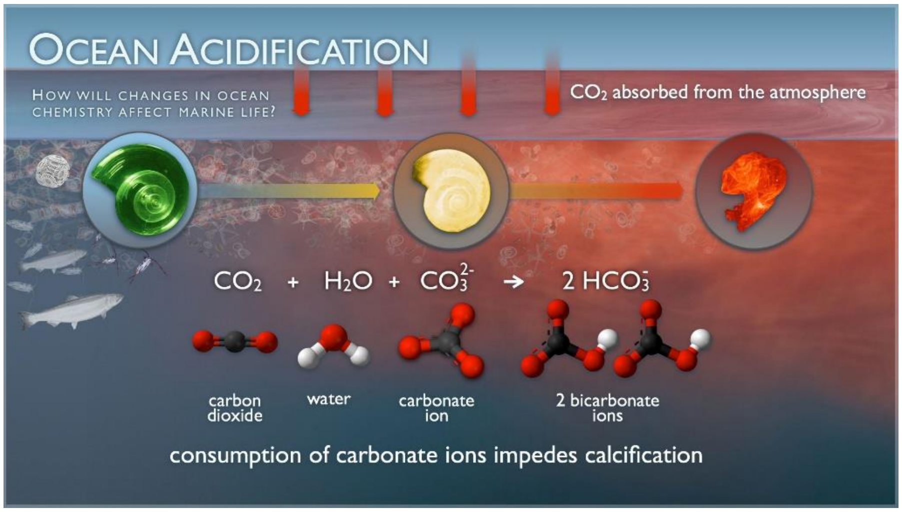


Figure 16 Ocean Acidification Effect on Calcifying Organisms

1.3.1.3 Lacking Development Plans:

Years ago, Egypt has been planning for its sustainable development; however, many plans have been failing, and one of the key causes is inaccurate predictions and anticipation. Egypt's government does many inaccurate anticipations due to the lack of accurate, well collected data. The Central Agency for Public Mobilization and Statistics, the Central Auditing Organization, and the Ministry of Planning and Economic Development all have inaccurate plans, data, or statistics that are associated with one of the previous pieces of news that are related to their workflow. Whether it was for the lack of participation of Egyptians in public questionnaires, problems in questionnaire collections process, or even errors in the analysis process, data seems to pose a great threat to the process of putting well-defined and strictly anticipated development plans, and a project that utilizes IoT for mitigating climate change effects would be the start of a myriads of development plans.

1.3.1.4 Cities Drowning:

Climate Change makes the sea level rise, and if the climate change situation remained as it is **for 50 years**, the average sea temperature will acquire an increase of **3ºC**. That temperature surge will accompany events that signal great increases in the water level, drowning full cities like Alexandria. Now, Alexandria faces recurrent floods in the winter, but after those **50 years**, most of the city (**as shown in figure 17**) will drown, threatening the lives **of 3 million** people. Although the Egyptian government seems silent, it spends 700 million Egyptian Pounds to end those citizens' suffering, and the apparent inactivity mostly comes from the poor plans or the inadequate execution. Additional statistical analysis and improved IoT use would mostly help Alexandria thrive.

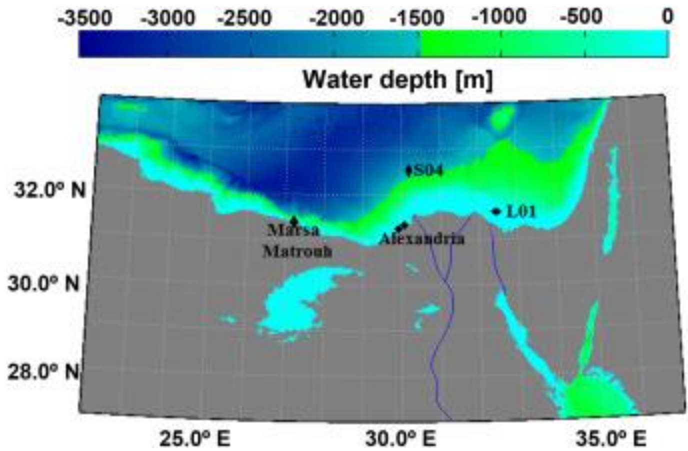


Figure 17 Anticipated Scenario for Alexandria after 50 years

1.3.2 Topics related to the solution

1.3.2.1 The Internet of Things (IoT):

IoT refers to the massive network of physical devices which continuously collect and exchange data with other devices and systems through the internet without human involvement **as shown in figure (18).** Almost anything can be changed into an IoT device if it can communicate information wirelessly, which can be done through sensors and low-cost computer chips. IoT devices uses sensors to collect data about its environment, monitor it and make changes. This data is then transferred to databases to be processed and analyzed. After the data is analyzed, the system can make predictions or changes using the concluded information. In other words, IoT devices merges the physical and digital worlds. Digital IoT devices can record, monitor, and adjust interactions between the connected devices making changes in the real world using the analyzed information and data recorded.

Figure 18 Illustration for the Various Connections in the IoT

IoT can play a vital role in mitigating the severe effects of climate change. By using IoT devices accurate data can be recorded and analyzed. IoT devices can allow much broader climate change studies, with a large number of sensors connected wirelessly that communicate a huge amount of data periodically. With all this data, different aspects of climate change can be accurately monitored and studied. Also, using IoT devices will allow for more reliable predictions and conclusions, because of accurate and up-to-date data.

1.3.2.2 ESP module and sensing technologies:

To build an IoT system to mitigate climate change, sensors and wireless communication are both needed. Through the years, sensors have evolved and became cheaper. Some of the sensors used for climate change are temperature, humidity, moisture, pH, and depth. These sensors can be connected to an Arduino board to collect the data and analyze it. However, to transfer data wirelessly ESP boards would be more convenient. ESP (**shown in figure 19**) is a system on a chip (SOC) produced for IoT application by Espressif Systems. These modules contain a Wi-Fi microchip to transfer data wirelessly to the database.

Figure 19 ESP Board

The processor of this module is based on the Tensilica Xtensa Diamond Standard **106 micro** and operates easily at **80 MHz.** There are several modules with different specifications and pins ranging from **8 to 14**. These modules are used extensively across IoT systems because of their low cost, small size, and adaptability with embedded devices.

1.3.2.3 Databases:

All the information gathered through the sensors in the IoT system needs to be organized one way or another. Databases, **shown in figure (20)**, can be thought of as an organized collection of information. A database is organized for easy access, management, and updating. In a project that mitigates climate change effects using an IoT solution, databases can be beneficial in comparing and relating very large amounts of data. By using databases, more accurate conclusions and predictions can be inferred from the information gathered by the sensors. Databases can also increase efficiency greatly because the stored data can be operated on by another program to perform data analysis instead of having multiple operations at various places. They can also ensure the consistency of the data across platforms by comparing them.

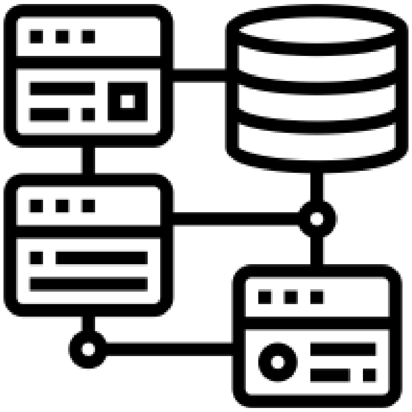


Figure 20 Databases' connection

1.3.2.4 Data Analysis and Statistics:

Figure 21 Statistical Analysis Graph

The sensors in IoT devices collects an immeasurable amount of data each second. However, the data in this form is useless, no predictions or conclusions can be inferred from the data that is displayed in the database. Additionally, the data needs “cleaning” to get rid of duplicate and abnormal data. So, after the raw data is collected the data is analyzed and statistical operations are applied on it (**shown in figure (21)**). Some statistical operations include finding the mean, mode, standard deviation, and correlation. By applying statistical analysis patterns and distribution of climate change data can be understood. This means that the important information is extracted from the data to make insights and predictions. This analyzed data can be visually modeled in graphs or charts to make it easier for understanding. After the data is statistically analyzed and modeled, informed decisions can be made to mitigate climate change effectively. Data bout the temperature after analyzing and modeling can give indicators about crop yield, marine ecosystems, or disease transmission.

1.4 Other Solutions Already Tried

1.4.1 Indian Ocean Tsunami Warning and Mitigation System (IOTWMS)

The Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) was formed in response to the tragic tsunami **on December 26th, 2004**, in which over **250,000 lives** were lost around the Indian Ocean region. The UNESCO/Intergovernmental Oceanographic Commission (IOC) started this project as an IoT system to save lives by predicting future tsunamis. This system can be used in the future to relocate coastal residents by predicting the effect of climate change on extreme weather events and sea level rise.

Mechanism:

The IOTWMS has three main pillars: 1) Risk Assessment and Reduction (collect data and undertake risk assessment), 2) Detection, Warning and Dissemination (develop hazard detection, monitoring and early warning services and communicate threat information and early warnings. 3)Awareness and Response (build national and community response capabilities) **shown in figure (22).**

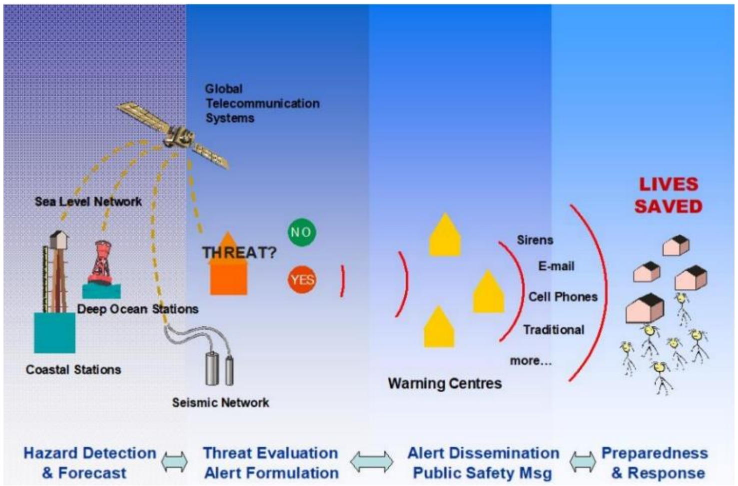


Figure 22 Mechanism of the IOTWMS

First, risk assessment and reduction. The IOTWMS through international and national collaboration has collected a large database of previous tsunamis and seismic activities. The database is then used to create models to predict future tsunamis resulting from seismic activities.

Second, detection, warning, and dissemination. Collecting accurate data is an essential part of any risk management system. Without accurate data, a lot of lives can be lost, or the system will be deemed unreliable because of wrong assessments. To collect accurate data concerning tsunamis the IOTWMS has three types of sensors: an advanced seismographic sensing network, real-time sea-level observation network covering the Indian Ocean basin, deep sea pressure sensors capable of detecting the tsunami as it travels over the deep ocean. When the sensors collect seismic activity and fluctuations in sea level, they use the models to predict the height and arrival times of tsunamis. This early warning system can then alert the authorities for predictable destructive tsunamis with accurate estimations.

Third, awareness and response. The IOTWMS would be meaningless without capable response system. After the IOTWMS predicts the magnitude of the tsunami a proper response system must evacuate the people to safety. Evacuation planning, simulations and drills, clear understanding of public warnings and coordinated response are important elements in the chain of events. In order to avoid the development of chaotic situations, proper cooperation between governmental and non-governmental organizations is necessary.

This system can be used to predict the uncertainties in sea related disaster that will result from climate change. By predicting the amount of sea level rise, and unexpected events beforehand, a lot of lives can be saved.

Points of strength:

- **Advanced sensing technology**: The IOTWMS uses three different types of sensors to collect a wide variety of data. By comparing the different collected from different sources the system can make more accurate predictions and conclusions.

- **Extensive database:** The project uses two databases to collect readings from seismic sensors and the data from sea indicators. By having an extensive database from different international sources more models can be made to predict future tsunami events.

- **Reliable responsive systems:** By cooperating between governmental, non-governmental, and volunteer organization the IOTWMS system ensures evacuating people in time before tsunamis.

Points of weaknesses:

- **Budget:** The budget of the IOTWMS is very large to collect data from different places and sources. Additionally, having a robust responsive system is expensive which poses restrictions on deploying the system on poor environments.

- **International Collaboration:** Having an extensive database and collecting information internationally needs a lot of cooperation across countries. The IOTWMS has **28 centers** as **shown in figure (23).** This isn't easily accomplished on other projects.

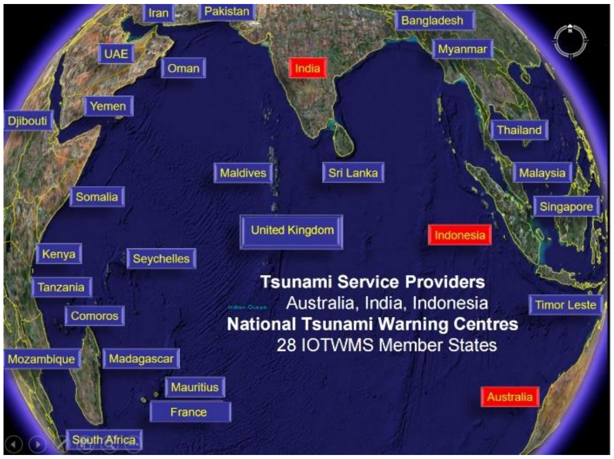


Figure 23 The locations of the 28 centers of the IOTWMS project

1.4.2 Brazil - Agro 4.0

Since the majority of small farms in Brazil rely on rain-fed agriculture, they are extremely vulnerable to the changing patterns of water availability and precipitation caused by climate change, and they lack access to technical or financial assistance that could assist them in investing in more climate-resilient agriculture. Setting up innovative irrigation water management systems (irrigation, drainage, and water conservation and control) aids in crop production stability by maintaining soil conditions close to optimum for crop growth, thereby contributing to the mitigation of negative climate change issues.

Thus, Agro 4.0 is a systematical approach that incorporates data analysis and the internet of things (IoT) technologies to have the ability to investigate, evaluate, and develop a management system that aims to achieve sustainability in agricultural activities in Brazilian areas. It provides tools for assembling, analyzing, and modeling programs that target agricultural regions' sustainability. Agro 4.0, for instance, allows different properties to be compared in terms of their Assessment Report based on the Index of Sustainable Agroecosystems (ISA). Besides that, the system can identify agricultural production. The system identifies Problems frequently occurring in sustainable development, and managers are advised on how to correct the situation. Finally, Agro 4.0 aid intensively in the decision-making process based on reliable and accurate data.

Mechanism:

Agro 4.0’s mechanism (**shown in figure 24**) starts with identifying multiple variables such as humidity, temperature, and other variables concerning the validity of the process of production. Then, it would gather variables with more relevance and, momentarily, disregard the others to minimize the number of input variables being processed and analyzed.

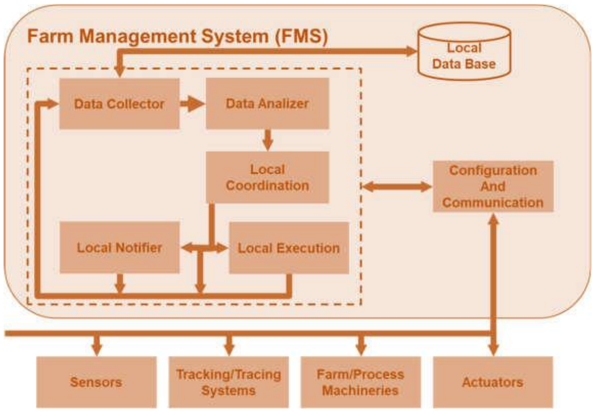


Figure 24 Mechanism of the Agro 4.0 solution

The system utilizes data analysis and Ai techniques in formulating possible scenarios according to the input data. These scenarios will be assessed based on the standard sustainability indices (ISA) for the sake of determining possible impacts.

Agro 4.0, thereafter, starts envisioning and structuring the appropriate decision for sustainability. For example, it would decide to decrease the temperature of surroundings, using an IoT thermostat just in case of a significant surge in temperature that would lead to damaging crops or increasing carbon emissions from other sources.

Points of Strength:

- **The Environmental impact :**Agricultural activities involve some harmful impacts on the environment such as the extensive usage of pesticide and the disposal of the remnants of wastes on water resources. Agro 4.0 eliminates all of these issues by putting certain limits on pesticide usage to obtain sustainability**.**
- **Increasing production rates :**Implementing Agro 4.0 in the Brazilian agricultural sector has enhanced the net production of crops. Also, the system minimizes the requirements of cultivation to the minimum threshold for the purpose of reducing expenses**.**
- **The reduction of climate change effects on crop production:** Agro 4.0 system modulates the decisions produced in response to climate fluctuations. For instance, if relative humidity (RH) ratios increase, the system would adjust the use of pesticides and fertilizers to demolish the bacteria produced.

Points of weakness:

- **Highly developed infrastructure:** Although the system is highly efficient and reliable, it requires an expensive and advanced infrastructure and technologies to enable accurate data transmission and analysis. This kind of infrastructure is not available in developing countries, including Egypt.
- **Signal traffic:** Because Agro 4.0 is a bidirectional system (involves connections from users to executing devices and vice versa), it is more likely to develop signal interference and a high noise ratio.

1.4.3 Africa: ATMOS41

ATMOS41 is an All-in-one weather monitoring tool, which means it's a small station with 12 sensors (Solar Radiation, Precipitation, and Air Temperature – among many more) that collect data about various climate change parameters and transfers them to any computer via a logger device in a single cable saving more place in the logger for other sensors. Power is connected to the bottom of the device that **is shown in figure 25**.

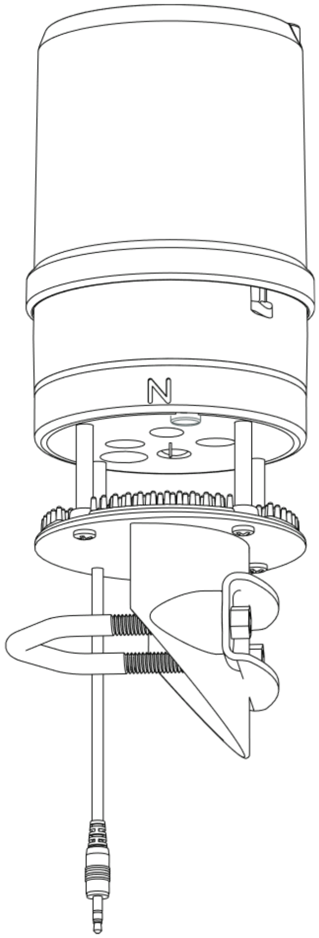


Figure 25 The structure of the ATMOS41 project

Mechanism:

ATMOS41 has three setup stages: installation, communication, and analysis. For the installation stage, the ATMOS41 device has to be put in a place that is far from obstruction. In addition, no sensors should be hidden, especially the solar radiation sensor that an unstable tree can cause inconsistent readings. The system should be shielded and put on a tripod to offer protection for the whole device.

For the communication step, the device should be connected to the data logger that receives the sensors' readings and delivers them to the computer device. Those data could be also accessed via the ZENTRA utility mobile app, too. For the analysis part, the collected could be analyzed, graphed, and put under heavy statistical analysis on the computer device. ATMOS41 is associated in many researches, and one of them investigated the accuracy of that solution in comparison to another high-power station, marking that solution as highly accurate for its small size.

Points of Strength:

- **Easy to be used:** The solution has the sensors and the other components integrated in it, requiring minimal setup and the least work and technical knowledge. In addition, consisting of an intact unit made the Atmos41 device more accessible as it doesn't need any sort of construction.

- **Durable:** Consisting of a single unit, the solution is hard to wear or be damaged. In addition, it was designed for harsh African climates with characters that maintain its life. For example, it has a big operating temperature range that is **110ºC**, ranging from **-50ºC to 60ºC**.

Points of weakness:

- **Scalability:** All-in-one weather are adjusted to work without much setup; however, they are always hard to be upgraded. Adding an additional sensor to the machine requires an additional logger with more setup and extra costs.

- **Price:** The whole unit costs **2000 euros**. That price, in spite of being a bit cheap compared to similar products, is expensive for the poor countries that requires the solution the most. The issue of price is constantly being under extensive research to be solved.

- **Some Limitations:** In spite of constantly being durable, the ATMOS41 device has some limitations with some extremes of the nature. Due to being designed for work in harsh climates, it isn't prepared with a heater that would be beneficial with ice accumulation. In addition, the sensors don't work well during severe storms that have heavy rain and strong wind and isn't well-prepared for electromagnetic interference.

1.4.4 USA-Smart factory (Industry 4.0)

Smart Factory is an American IoT project that envisions a manufacturing environment as a fully automated and intelligent network of systems that allows facilities, machines, and transportation chains to be managed without human interference. A smart factory doesn't use the intricate network of systems in single machines only but in groups of machines called "factory production circuits." This, in turn, requires elaborate and advanced machine learning, allowing operations to be carried out more efficiently and with price reductions less than those that would be required if manufacturing processes were merely supervised by individuals. The main elements of the smart factory are **shown in figure 26.**

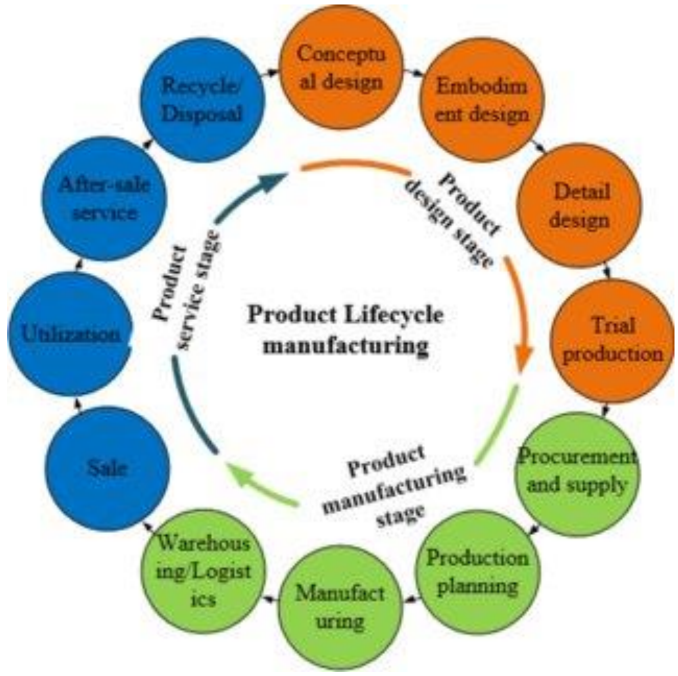


Figure 26 Industry 4.0 Product Lifecycle

Mechanism:

To enhance the productivity of the manufacturing sector in the USA and other developed countries, the smart factory incorporates both digital and physical systems in addition to the Internet of Things (IoT), wireless connections, sensors, and data collection programs (**shown in figure 27**).

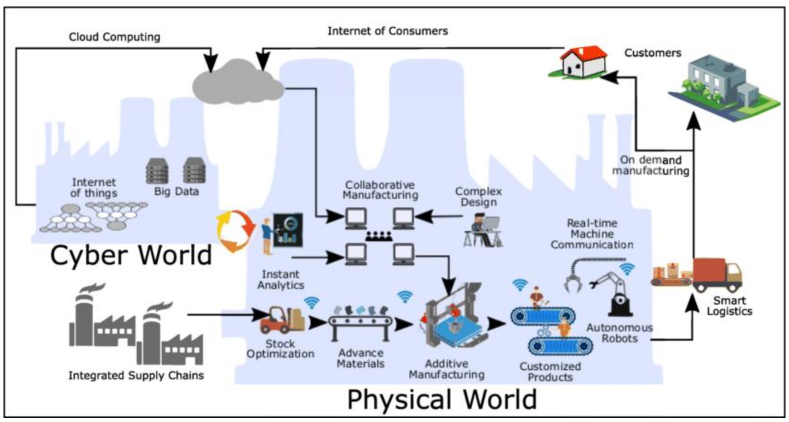


Figure 27 Connections of Components in Industry 4.0

Sensors on devices and machines gather information that can be used to track processes at various stages of the manufacturing process. Sensors, for example, can monitor temperature or other parameters. These sensors can be connected to a network to provide centralized monitoring across multiple machines.

Integrated AI-powered operational systems have the speed, power, and flexibility to not only gather and analyze discrete data sets but also to provide insightful information and responsive recommendations. Ai is constantly optimizing and informing the smart machines and intelligent systems with insights within a smart factory.

The Industrial IoT (IIoT) generally uses sensor technologies and cloud services to automate the majority of the work needed to monitor and identify progress in a production process. It transports data and insights from the single machines and groups of production lines to the factory's supervisors and vice versa.

Sophisticated condition monitoring is among the most significant advantages that machine learning brings to the smart factory. Detections can be sent out prior to system failure by assessing and monitoring manufacturing processes and noticing failure signals that appeared in previous known processes. Depending on the specific circumstances, computer-controlled-controlled maintenance may be performed.

Points of strength:

- **Improvised decision-making process:** One of the main goals of generally implementing smart factories and IIoT is to enhance the decisions being taken by the users of the system. This is done through the accurate data sets measured from several variables**.**
- **Reduced energy, labor, and material usage:** By nearly automating the whole line of production in smart factories, the manufacturing process is becoming highly efficient in terms of saving energy and time. Also, Industry 4.0 saves much of materials by eliminating any faults in outputs.
- **Waste-free and Eco-friendly:** Unlike traditional factories, smart ones have significantly less harmful impact on the environment as they reduce the amount of fossil fuels burned inside the production processes. Also, they are mitigating climate change by lowering the quantities of greenhouse gases being released from factories.

Points of weakness:

- **The high cost of installment:** Smart factories require not only advanced technologies but also a lot of money to be installed and operated.

Additionally, strong infrastructure is essential to effectively operate smart factories.

- **Considerable uncertainty about data protection and security:** Although the data are easily transmitted between users and the compartments of smart factories, they are vulnerable to a variety of issues regarding both the safety and the interferences between signals.

Chapter 2

II. Generating and Defending a Solution

2.1 Solution Requirements

Affordability: For a solution to be considered as effective, its implementation must be affordable. Thus, cost-effectiveness is a crucial factor that should be taken carefully in consideration before utilizing any solution. In developing countries, the price for installing and operating any solution usually presents a challenge for the solution's prospect success. Consequently, The IoT-controlled solution is significant efficient in terms of reducing costs of the constructing components and encompassing a wide array of data analysis features for climatic variables.

Sustainability: Sustainability means meeting current needs without compromising future generations' ability to meet their own. For illustration, the primary purpose of mitigating climate change through the solution is to achieve sustainability in environmental resources. The solution utilizes a delicate IoT -system in monitoring and detecting climate changes, aiding users in deciding the best decision for sustainability attainment to ensure that future generations are not harmed.

Availability: One of the most important aspects of a way to solve is being available at various locations. A widely available solution makes it easier for more individuals to benefit from it. Besides that, As the issues of climatic changes are reaching their calumniation nowadays, necessitating solutions to be readily available. To obtain such a solution, the materials used in the in the project are abundant in the desired sites of implementations. Additionally, the solution aims to amplify the knowledge of current climate issues to as many individuals as possible.

Eco-friendly: The solution is working on demolishing all harmful impacts on surrounding environment through being totally eco-friendly. The materials used in constructing the solution have a non-polluting impacts and byproducts after operating. Furthermore, The IoT system would fully automate the operating processes through internet which means reducing the need of non-renewable energy resources.

Accuracy: Through carefully calibrated and fine-tuned sensors, the solution's IoT system measures all of variables being changing as a result of climate change at regular time intervals. Afterwards, it delivers these measurements into data analysis techniques to create a reliable and accurate results.

Accessibility: One of the crucial factors that affect the solution's success is how easily it is accessed. The solution has the potential to reach a wide range of people through a developed website that enable user to expose readily to variables changing in certain regions.

2.2 Design Requirements

Since the solution will mainly depend on analyzing data to get the various trends that exist between them, the data must be as accurate as possible, and the design requirements were put to support the accuracy of the project's data. The two chosen design requirements are Percent Accuracy and Dynamic Range.

Percent Accuracy:

Percent Accuracy measures the accuracy of the prototype in measuring the values of various input materials. This will be measured via operating the prototype on reference solutions or materials and comparing the value of the prototype's output (V_o) to the value of the reference (V_R) solution via the following equation: $100 - \frac{V_R - V_O}{V_R} \times 100$. The accuracy should me maximum for the prototype to be considered successful.

Dynamic Range:

Dynamic Range gives an indication of the range through which the prototype can handle inputs by subtracting the lowest value that the prototype can measure from the highest value that the prototype can measure. To assert the success of the prototype's measurement of a certain parameter, the calculated dynamic range should be larger than the range measured for that parameter in nature.

2.3 Selection of Solution

Egypt is one of the most vulnerable developing countries to the effects of climate change. One of the most notable threats is the rise of sea level. Being surrounded by the Mediterranean Sea from the north and the Red Sea from the east, large chunks of Egyptian land will be completely submerged. Without proper planning, facilities which represent the core of Egyptian economy can be lost. Some of these facilities are factories, houses, tourist destinations, and agricultural land.

To predict the effects of climate change, the first step is collecting data. By gathering accurate and reliable data conclusions about the future state of climate factors and coastal areas can be inferred. Sensors measuring the change of air quality, temperature, sea level, and sea acidity are needed to form a complete picture about the complex effects of climate change. These sensors can gather periodic data with fixed intervals between them.

An IoT system has the potential to mitigate the future effects of climate change by providing an understanding of the present and a vision for the future. The IoT system will gather the data from the sensors in a comprehensive database. All the data from different sensors and locations will be organized in one place which will in turn maximize the efficiency of the IoT system. The data can be communicated wirelessly through Wi-Fi. Different locations can feasibly send their data at the same time by connecting to the internet. After gathering the data and organized it, statistical data analysis can be done on the database. The analysis can use basic statistical operations to provide important information about the patterns and distribution of the data.

After statistically analyzing the data, the observed patterns can be visually translated into graphs. The IoT system can have a website that features the data and the graphs along with the conclusions inferred from them for users that can benefit from such pieces of information. The website can be easily accessed through mobile devices or other smart devices.

So, the IoT system will periodically collect large amounts of data representing different climate change parameters. These data will be continuously updated on the database where statistical analysis is done. The result will be graphs depicting the patterns of the collected data. Conclusions and predictions can be done after studying the graphs. These conclusions have the potential to save a lot of unnecessary loss in facilities and land.

2.4 Selection of Prototype

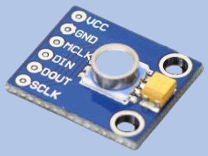
The prototype consists of a container with a polycarbonate separator that divides it into two compartments: one for water that models the sea and the other for sand that models the sea's beach. In the water compartment, there is a big ice cube that models the polar ice. In addition to the ice cube, pH sensor (indicates dissolved CO_2) and water level (detects rise in sea level due to ice poles melting) sensor occupy a place in the water compartment. In In the sand compartment, there exists a candle that models the greenhouse effect as it emits heat and harmful gases. In addition to the candle, there exists an air quality sensor (detects CO_2) and temperature sensor (indicates temperature increase of the greenhouse effect). Whenever, the prototype is tested, it's enough to light the candle to emit heat and CO_2, which consequently appear on the reading of both the air quality sensor and the temperature sensor. CO_2 dissolves in water, decreasing the readings of the pH sensor. Furthermore, heat melts the ice cubes, increasing the reading of the water level sensor. To receive the readings, ESP8266 module is connected to those sensors. After receiving the readings, the module sends them to the Firebase Database via Wi-Fi connection. The Firebase Database stores data each two seconds, and those data are represented in interactive graphs in the team's website using the Chart.js library.

There are two design requirements: the first is accuracy by percent and the second is the dynamic range of the sensors. The accuracy by percent is done by using a reference parameter for each sensor. For example, **4 pH** buffer solution for the pH sensor, **23ºC** temperature of the room for the temperature sensor, and **20 cm** height water solution for the water level sensor. The percent accuracy is calculated via the relation $100 - \frac{V_R - V_O}{V_R} \times 100$, where VR is the reference value and VO is the observed value. The second design requirement (dynamic range) is the difference between the highest and lowest values that the prototype can measure. The maximum was calculated by using each sensor till that sensor's reading stopped changing, and the minimum was calculated with the same way but with opposite direction. For example, the temperature sensor was both heated and cooled till the readings stopped changing. To be considered successful, the prototype should register a range that is wider than the range in the Mediterranean Sea.

Chapter 3

III. Constructing and Testing a Prototype

3.1 Materials and Methods

Name	Quantity	Description	Price	Image
ESP 8266 (Wi-Fi module)	1	Microcontroller that accesses Wi-Fi networks and sensors' data	150 EGP	
Air quality sensor MQ135	1	Detects CO_2, ammonia gas, and other gases.	60 EGP	
pH sensor	1	Calculates water's pH	650 EGP	
Temperature sensor DHT22	1	Measures temperature and detects changes.	125 EGP	
Water depth (level) sensor	1	Measures water level up to 10m.	290 EGP	
JavaScript Programming Language	N/A	Handles user input and data's reception and representation using chart.js library.	N/A	
Firebase Real-time Database	N/A	Stores data and handles data access	N/A	

3.1.1 Materials Table

3.1.2 Methods

1) A non-relational database was made using "Google Firebase" **(shown in Figure 28)** to store the data from the sensors in JSON format and handle data fetch requests.

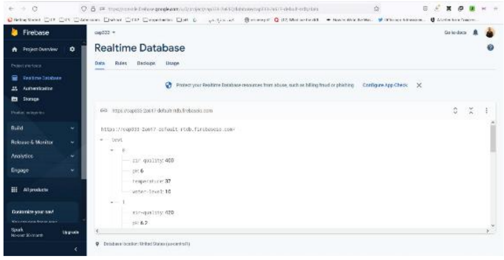


Figure 28 Firebase Database

2) The pH sensor, air quality sensor, water level sensor, and temperature sensor were all connected to the bread board (placed at the middle of the container) that connects them to the ESP **as shown in figure (29)**

Figure 29 Connection of Sensors to ESP

3) The ESP was connected to the database to send the sensors' data wirelessly via Wi-Fi connection each two seconds **as shown in figure (30)**.

Figure 30 Arduino Codes of ESP Database Connection

4) To make the model, **shown in figure (31)**, depict the Mediterranean Coastal areas and greenhouse effect, the plastic container was filled with sand and water that symbolize coastal areas, ice cubes that symbolize the melting ice at the two poles, and a candle that models the increasing CO_2 and temperature.

5) To receive the model's readings, an interactive front-end interface was built using HTML, CSS, and JavaScript and connected to the firebase database.

Figure 31 Model Depicting Climate Change

6) The interface was improved by adding the functionality of displaying the fetched JSON data from the firebase server by utilizing the Chart.js Library **as shown in figure (32)**.

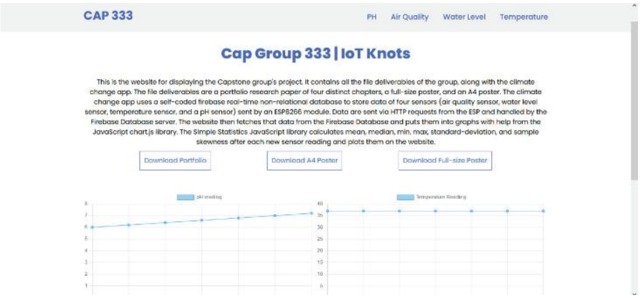


Figure 32 Graphical User Interface

3.1.3 Safety Precautions

The team followed all the standard safety precautions to limit the accidents that would threaten the well-being of the members.

1. Wearing gloves during all the steps of constructing the prototype, except when working with electronics to prevent the accidental melting of the gloves' plastic.

2. The team ensured the presence of fire extinguishers in case of unexpected fires and worked within the accepted safe temperatures.

3. The lab instruments were used inside the parameters of the school labs and weren't taken out under any circumstances.

4. The electronics were insulated and separated from the water to prevent electric shocks or first-degree burns.

5. Goggles were used to protect from exposure to chemicals and protect eyesight from accidents.

3.2 Test Plan

3.2.1 Design Requirements:

1) Percent Accuracy

2) Dynamic Range

3.2.2 Test Plan Steps:

1) To measure the accuracy of each sensor's measurement, a suitable reference measurement was chosen. For the pH, temperature, and water level sensors, reference values of **pH 4** buffer solution, **23°C** temperature, and **20 cm** of water were used respectively. The absolute of the average of three observed values (V_0) was subtracted from the reference value (V_R), divided by the reference value, and multiplied by 100 and then subtracted from 100 to calculate percent accuracy. The equation is $100 - ([V_R - V_O]/V_R \times 100)$ = percent accuracy

2) The pH sensor, air quality, and temperature sensors were tested by increasing the parameter and decreasing it to the threshold of the sensor when no change in value is noticed. The maximum measured value and minimum value were subtracted to calculate the dynamic range of the sensors. Then, the dynamic range was compared to the range of respective parameters in the Mediterranean Sea (Port Said) environment.

3.3 Data Collection

3.3.1 Negative results:

At first, a MySQL database, with a Nodejs API that manages the requests, was used to store the sensors' data, and the database worked optimally on the computer; however, on uploading it to a hosting, the team faced problems with the limitations of the used free hosting (infinityfree.net). All free hosting providers don't allow receiving HTTP requests (GET and POST) from things that aren't browsers (ESP8266 & the used interactive front-end). In addition, they don't provide the ability to host both MySQL and Nodejs together. Since paying for hosting would surge the project's costs up, firebase was the optimal choice: it didn't require an API as it handled requests with minimal setup and was free for the small project. After using the Firebase Database, the project worked optimally on the internet and positive results were achieved.

3.3.2 Positive results:

The results of the following table show that the pH sensor, water level, and temperature sensors achieved high accuracy with low percent error after testing them with reference values of **4 pH** buffer solutions, **20 cm** water, and **23°C** temperature respectively. The positive results show that the prototype can achieve accurate and reliable results **as shown in table (2)**.

Sensor Name	Reference Value	Measured Value	Percent Accuracy
pH	4 pH	3.9pH, 4.2pH, 4.3pH	96.67%
Water Level	20cm	20cm, 21cm, 23cm	93.33%
Temperature	23 °C	23°C, 25°C, 20°C	98.55%

Table (2): Results of the Sensors' Accuracy

The dynamic range of the sensors was calculated and compared to the range of the parameters in Port Said. The dynamic range of the pH sensor was measured to be **7 pH (9.2 pH – 2.2 pH)** as **shown in figure (33)**, the temperature had a range of **79°C (from 3°C to 82°C)** as **shown in figure (34)**, which is suitable for the Mediterranean Sea whose pH is between **8.03 and 8.53 pH** and the temperature of air in Port Said which is in the range of **12ºC - 32ºC**. The following graphs show that the sensors have a very suitable dynamic range and can be feasibly implemented in coastal areas.

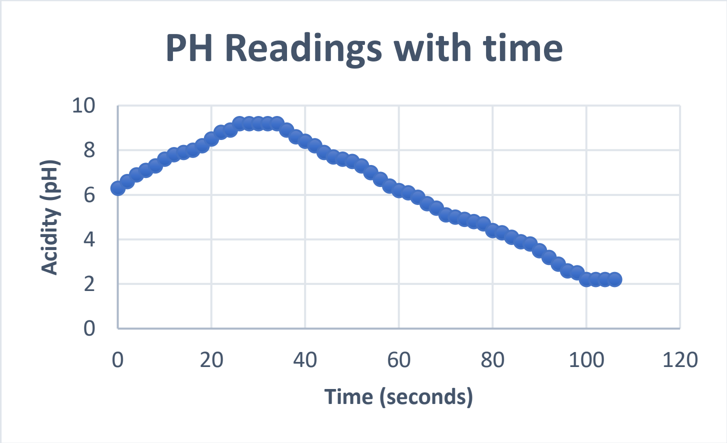


Figure 34 Dynamic Range of the pH Sensor

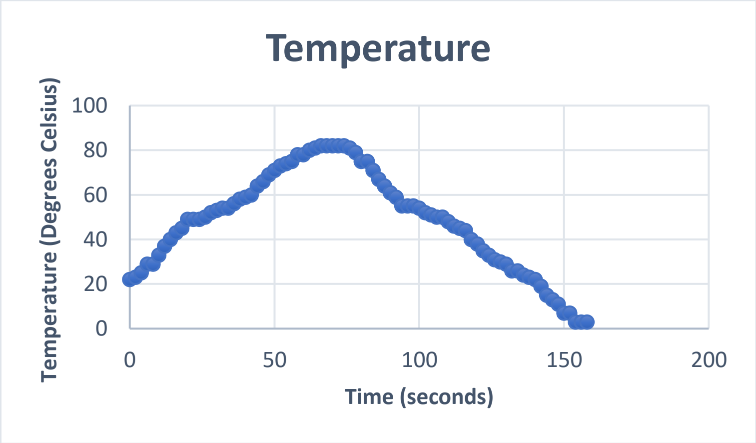


Figure 33 Dynamic Range of the temperature sensor

Chapter 4

IV. Evaluation, Reflection, Recommendations

4.1 Analysis and Discussion

4.1.1 Analysis Topics

Interdependent parameters:

Understanding climate change is a complex process that involves the reaction between numerous parameters. When one parameter changes, it can affect one or more parameters. Thus, the project measures four parameters: air quality, temperature, sea level, and pH to deepen the understanding of these interdependent parameters and the effect they have on each other. When taking actions to mitigate climate change based on the data of the prototype, the decisions can be more accurate and precise than other projects that measure only one or two parameters.

Effect of air quality on temperature:

Measuring air quality includes detecting greenhouse gas emissions. The Earth absorbs half the energy incoming from the sun and the rest is radiated back. When photons hit greenhouse gas molecules, they absorb the light causing the bonds between the atoms to vibrate. This traps the energy that was exiting into space and, in turn, heats the atmosphere. Additionally, greenhouse gases only absorb the rays radiated back from the earth, so, it acts as a "greenhouse" gradually increasing the temperature **as shown in figure (35)**. That's why the model's cycle starts with the ignition of a candle that stimulates greenhouse emissions, altering both the temperature registered by the used temperature sensor and the air quality reading registered by the air quality sensor.

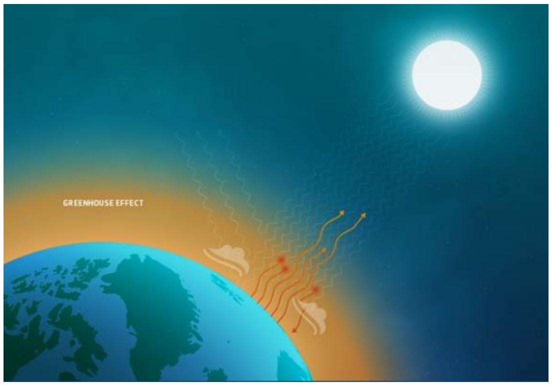


Figure 35 Greenhouse Effect & Increasing Temperature

Effect of temperature on water level:

As temperature increases, the sea level increases through two mechanisms. The first mechanism is, the melting of ice: when the temperature increases, the ice begins to melt, increasing the level of the sea. Second, thermal expansion: when the temperature of water increases, its volume expands which also leads to an increase in sea level. That part is simulated in the prototype by the melting of an ice cube after exposure to the greenhouse effect by the candle flame, increasing the water level sensor's reading.

Effect of air quality (CO_2) on sea's acidity (Chemistry LO 2.03):

Sea water naturally absorbs carbon dioxide from the atmosphere, and as the amount of CO_2 increases in the atmosphere, the amount absorbed by the ocean increases. Carbon dioxide (CO_2) dissolves in water and reacts to form carbonic acid (H_2CO_3) which is weak and dissociates into hydrogen ions (H^+) and bicarbonate ion (HCO_3^-) as shown in the following **figure (36)**. Therefore, as CO_2 increases in the atmosphere, the pH of the sea decreases. That's why the pH sensor's reading drops with the increasing CO_2.

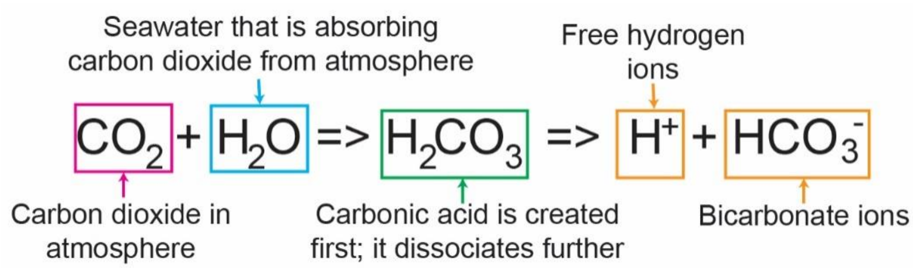


Figure 36 Reaction of Carbon Dioxide with Water

Communication (Physics LO 3.04 & 3.05):

ADC (Analog to Digital conversion)

For the sake of easiness and convenience, the project requires all its sections: sensors, the database, and the user interface to be wirelessly connected. This could not be accomplished unless they all were linked through the internet or, in other words, an IoT system. Different sorts of signals which can have any value are gathered by each of the four sensors in the prototype, known as analog signals. The used temperature sensor might give any value within its range. However, analog signals generally are vulnerable to attenuation and interference with noise. The **following figure (37)** displays how noise affects informational signals. Thus, Analog sensors must be converted into digital signals that can only be either **"1"** or **"0"**. ESP8266 is a microcontroller board that acts as a hub that assembles analog data from sensors; it has an Analog-Digital-Converter (ADC), and the only way to achieve this conversion by following three steps:

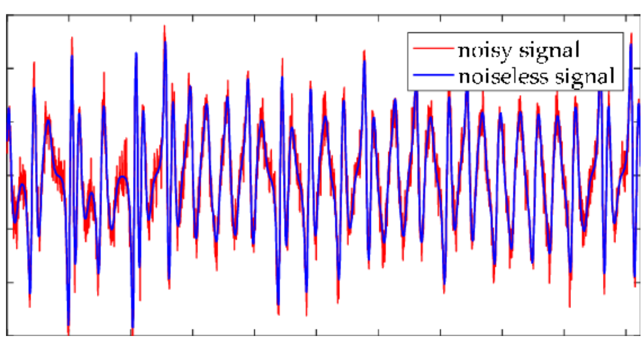


Figure 37 Effect of Noise on Informational Signals

1- Sampling of analog signals at regular time intervals, adjusting to Nyquist law of sampling.
2- Quantization into discrete units.
3- Encoding to binary numbers. The process is **shown in figure (38)**.

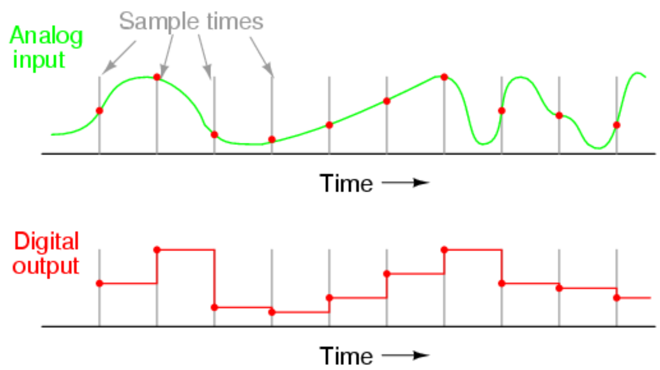


Figure 38 Analog to Digital Conversion

Antenna and Coverage Range:

ESP8266 has a Wi-Fi chip that encodes digital signals into a radio frequency to be transmitted wirelessly. The signals are then decoded to convert them back into digital signals. To transmit and receive signals, an antenna is embedded inside the microcontroller board. In the case of transmission, it converts electrical impulses into radio frequencies since electromagnetic waves are much faster and more reliable than electrical signals. When the electrical impulses vibrate electrons inside the antenna, they generate electromagnetic radiations which travel in the form of radio waves [WI-FI]. But in the case of reception, the Antenna does the reverse of that conversion process. The coverage range of the antenna (**d**) depends on the length of that antenna (**h**) and the radius of the planet (**R**). The higher the length of the antenna, the wider the effective area of transmission as **shown in figure (39).**

$$d = \sqrt{2hR}$$

Figure 39 Calculating Coverage Distance by Length of Antenna

Firebase Database (CS LO 2.02):

Databases are collections of stored data, usually organized on a computer or a server. There are two main types of databases: relational databases (data organized into rows and columns) and non-relational databases (data organized into many types). The database used in our project is a non-relational database that stores data into key-value pairs **shown in figure (40)**. Non-relational databases are easier to setup, and more scalable than relational databases.

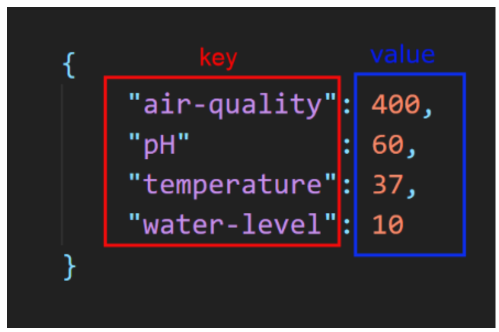


Figure 40 Stored Key-Value Pairs

Among the available non-relational databases, a Google service, with the name “firebase”, was chosen as the project’s database. That’s because it’s free for the small-sized solutions as this project, efficient with codes, and runs in real-time which means that whenever the data changes on the server, that change appears on each user's device.

The Firebase database consists of a collection for each day that the prototype is used on, and that collection contains a set of updates. Each of those updates consists of a reading from each of the used four sensors: air quality, water level, humidity, and pH. Those collections represent the database's main data that appears on the website.

Connection Logical Flow:

Readings from the sensors are sent by the ESP board to the database. Since the ESP8266 board is a cheap Wi-Fi chip that is built with microcontroller capabilities and connects to internet, it has the responsibility of implementing the communication part of the IoT system. Despite having the ability to connect to internet, an ESP wouldn't directly connect to the database but require coding a full API program. That requirement gives Firebase an additional strength point as it works as an API with minimal setup. Each two seconds, the ESP board gets readings from the sensors and saves them into the Firebase Database Collection. Those data become available for the website to fetch and put into graphs. The full data cycle is **shown in figure (41).**

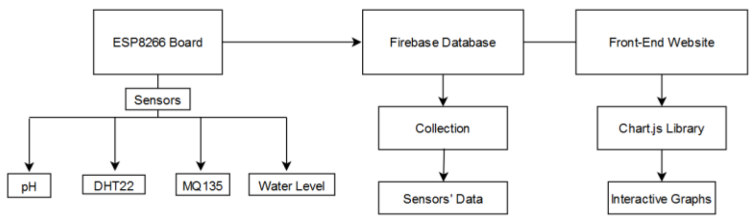


Figure 41 Connection Logical Flowchart

Graphical User Interface (GUI) (CS LO 1.05 & 1.06):

Both the Firebase Database and the accompanying utilities form the backend of the program which is the part of the program that is written and doesn't appear to the user. On the other hand, the parts that appear to the user are called the frontend, and in this project, the frontend is an interactive HTML, CSS, and JavaScript website that works on all types of devices. The website consists of a landing page and a page for each sensor. As with those of the ESP8266 board, the website's requests would be handled by the Firebase Database, and the resources requested by the board would be always sent in the form of a JavaScript Object that could be stored into an

Figure 42 Code of Chart.js Library

Array and depicted by the Chart.js library into line graphs – code **shown in figure (42)**. Some statistical parameters were inferred by the use of the Simple Statistics Library as that library has functions for mean, median, max, min, and standard deviation, utilizing them for the usage of users and for getting other statistical analysis parameters like the Standard Error of the Mean.

Descriptive statistics (Math LO 1.02):

Descriptive statistics aids in deciphering patterns or trends in data. Describing data sufficiently requires three things. The first requirement is the measure of central tendency, which is a descriptive summary of the dataset through a single value that reflects the center of the data distribution. For measuring central tendency, the project measures the mean and median of the data. The mean is calculated by dividing the summation of the elements in a set by the total number of elements. The median is the data value which lies at the middle of the dataset values.

The second requirement is the shape of the data. The project represents the collected data as a graph. By calculating the mean and median of the data, the shape of the graph can be inferred and understood algebraically. If the mean is smaller than the median then the graph is skewed left, which means that higher value data has higher frequency in the dataset and vice versa. If the water level parameter is greatly skewed to the left, this means that the water level is increasing at an alarming rate. The system of the project can conclude that actions should be taken to limit the rapid increase of the parameter.

Third requirement, the measure of the spread of the data and variability. Standard deviation can be used to measure the dispersion of the data from the mean using the equation **in figure (43)**. Data variation can serve as an indicator of rapidly changing parameters. Climate change causes an increase in the variation of earth parameters. The project measures the increase of temperature over time. Temperature increases in nature with time, but a notable increase in the variation of temperature data means that the temperature parameter is increasing far more than the natural standards. The project can conclude that the parameter may outgrow the capability of nature to restore it to natural standards.

$$SD = \sqrt{\frac{\sum (x_i - \overline{x})^2}{N}}$$

Figure 43 Equation of Standard Deviation

Inferential statistics:

The project makes conclusions about climate change using data taken from sample models. Inferential statistics can be used to measure the difference between the sample measurements and real measures involving large amounts of data. One of the operations of inferential statistics is the Standard Error of the Mean (SEM). It gives an estimate of how accurate the mean of the sample used in the test is when comparing it to the real mean of the whole set of data. The standard error of the mean can be calculated by dividing the standard deviation by the square root of the sample size as **shown in figure (43)**.

$$SEM = \frac{\sigma}{\sqrt{N}}$$

Figure 44 Equation of the Standard Error of the Mean

After analyzing the results, it was found that the prototype achieved the design requirements of accuracy and suitable dynamic range. Deducing from this the project can be applied systemically in Egypt to mitigate climate change using IoT. This will lead to improving the technological base and making informed and objective decisions.

4.1.2 Conclusion

Egypt's pursuits toward prosperity and sustainability are opposed by challenging climatic fluctuations. The northern coast of Egypt is indeed the most affected region by the negative impacts of climate change because of interactions between several variables. The lack of advanced communication systems aiding in taking appropriate decisions worsens the effects of climate change. By implementing IoT approaches, the project, which provides an enriched database with data collected by sensors, showcased a notable potential for mitigating climate change. The prototype's interactive interface enables intended users to make objective decisions concerning climate change. The prototype has successfully satisfied its design requirement: sensors' dynamic range was considerably wider than the range of the coastal areas, and the data was accurate, having negligible error values.

4.2 Recommendation

4.2.1 Prototype Recommendation & Real-life Application

4.2.1.1 Fluke 985 Particle Counter:

One of the essential objectives of the project is to determine the concentrations of greenhouse gases and other fractional solid particles suspended in the atmosphere. It is strongly recommended to use Fluke 985 particle counter, **illustrated in figure (21)**, for delicate measurement of the gases' concentrations. Unlike the air quality sensor, Fluke 985 could detect very tiny particles with a range of **0.3-10** μm, providing the project with the capability to observe changing trends in gas concentrations. It has a counting rate of 5 Counts/ minute. It can ensure that all of the assembled data are precise by noticing how the data deviates as more counts are identified. Aside from its cost, Fluke 985 involves ethernet communication which marks it as a non–IoT system. Converting from ethernet to wireless connections is not convenient and might be costly.

Figure 45 Fluke 985 Particle Counter Photo

4.2.1.2 MySQL:

When the project gets bigger, it will have more data which requires paid Firebase plans that are too expensive. MySQL **(shown in figure 22)** solves that problem as it is a free, open-source relational (data organized into rows & columns) database management system. A database management system is a software built upon SQL (Structured Query Language, the most popular database language) to facilitate data querying and control instead of coding everything in the harder SQL lines. MySQL has a reliable ability to scale with bigger applications; however, it has the problem of requiring a full API that accepts requests. Due to that reason, firebase was preferred for the small project as Firebase can handle data requests with coding an API.

Figure 46 MySQL Database Logo

4.2.1.3 Real-life Application:

Port Said is the most suitable location to install the project. Located in the northern regions of the Nile delta, Port Said is one of the most two vulnerable spots to experience a severe rise in the level of the Mediterranean Sea. It is a region with low land elevations; moreover, it has high rates of land subsidence and deep depressions in lands due to the removal of underground water. This amplifies the negative impacts of increasing sea levels on population and manufacturing activities. It is estimated that Port Said ‘s sea level is going to increase by **50 cm** by the arrival of the next century. This would force seashores to retread by **21.26%** percent, **as shown in figure (23)**. To cover the **30 Km** of Coastal Area that Port Said has, a total of 3000 units of the project would be needed as the ESP used in the prototype handles Wi-Fi connection for about **10 meters**. Using a total of **3000 prototype units**, each at a distance of **10 meters**, would cost **3,800,000 Egyptian Pounds** to implement the project of covering the whole Port Said coast with the project and getting data for analysis. The project would use the graph patterns to give conclusions for actions that people can take to mitigate the problem.

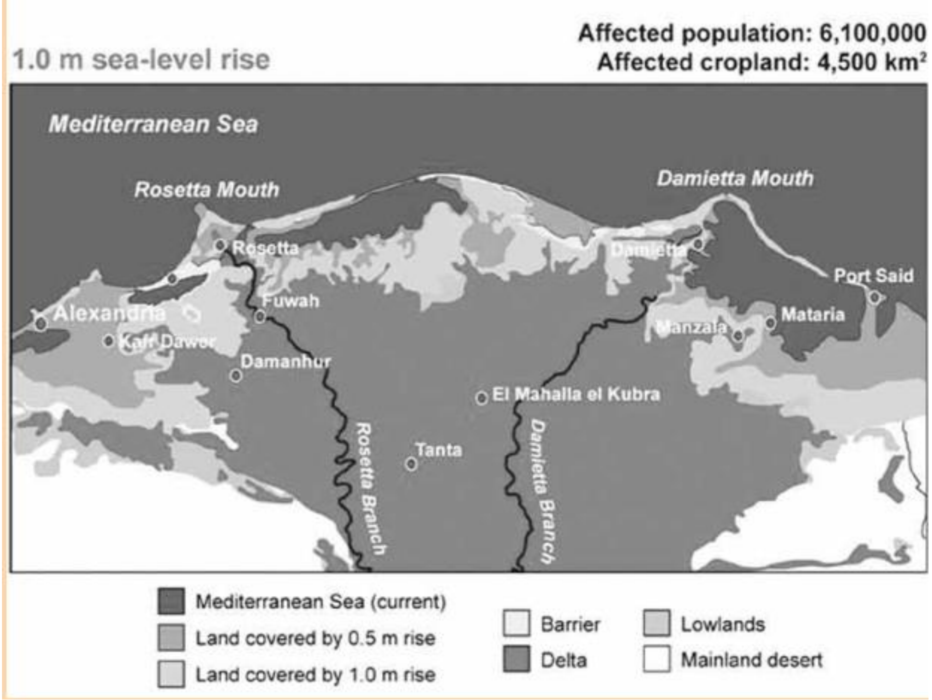


Figure 47 Port Said After Sea Rise

4.2.2 Recommendation to other teams

The scientific process is a continuous process. Each one builds upon the knowledge of its predecessor. The same goes for this project. If a team was to build this project, they should start from the point where this project stopped. The team should learn from the previous mistakes and avoid repeating them. This is the same for any other project. This allows the project to get developed and sustained as possible. Furthermore, it prevents time loss and unnecessary mistakes. If a team were to start to build this project, there should be some points to consider before building it.

The first thing, they should avoid past mistakes. They should use Firebase from the start as it is easy and convenient. The other team shouldn’t waste their time using MySQL until they have a paid version that can be used in IoT systems. Also, any other team should consider using a more powerful heat source than the candle. Using a more powerful heat source will decrease the time taken for the test plan and increase the efficiency and accuracy of the results. Additionally, it is preferable to use Fluke 985 particle counter instead of the MQ135 air quality sensor which will increase the accuracy of the results greatly.

4.2.3 Project's Benefit to be Better STEM School Students

The project had a great influence on the team from the scientific, engineering, and social aspects. First is the scientific aspect. the team learned many new scientific concepts that are proven to be useful. Some of these scientific concepts include the Internet of Things and how it is used in real life in numerous sectors, Climate Change and its inevitable threat to the world, how to work with ESP and build an interactive website using a comprehensive database to collect data and use statistical analysis to analyze the patterns of the data.

. The second is the engineering aspect, to build the prototype the team learned to find engineering solutions to make the prototype as effective as possible. The team also learned the EDP process and how to build a project in a correct scientific sequence. Critical thinking was one of the most important things that we learned.

The third is the social concept. The team learned how to communicate efficiently. We also learned how to tolerate each other's mistakes and accept opposing opinions.

4.3 Learning Outcomes

4.3.1: Learning Outcomes Table

Learning Outcome	Utilized concept[s]	Content of the learning outcome	Implementation
Chemistry (CH.3.05)	• The Universal gas laws • Charles's law • Boyle's law • Avogadro's law • Lussig's law	CH3.05 covers all the aspects of gases and provides all the laws used to predict the behaviors of gases in both ideal and real situations	This L.O. helped in determining the relations between several variables and their effects on climate change.
Chemistry (CH 2.03)	• Nature of acids & pH scale	It delves deep into the properties and the behaviors of acids and bases	This L.O. was very beneficial in understanding the reaction of carbon dioxide and water: weak acid dissociation. Also, The nature of pH scale and its measurement.
Physics (PH 3.04)	• Basic elements of communication • Antenna	It examines the properties of communication systems	Since the project's main theme is the utilization of communication systems, it was essential to use that Lo in establishing connections between the prototype's sections. Additionally, It demonstrates the antenna which is embedded in the microcontroller board, and its functions in

			receiving and transmitting signals.
Biology (Bi 1.13)	• Carbon cycle • Human Impact on reservoirs of carbon	Bi 1.13 explains the connections between the carbon cycles and the global climate change	It helped in examining the effects of increasing carbon dioxide concentrations on the temperature and the pH of water which affect badly the life of marines.
Physics (PH 3.05)	• Analog to digital conversion • Sampling • WI-FI • Encoding and decoding	It provides a further investigation into communication systems and gives insights of Wi-Fi.	Ph 3.04 aided heavily in making all the compartments of the prototype wirelessly connect through WI FI radio waves. Furthermore, it demonstrated how to convert analog data assembled from sensors to digital signals to be transmitted easily without attenuation
Technology (CS 2.02)	• Firebase database	This L.O. explains the concepts of analyzing and storing data inside the database.	It helped in making an extensive database to store data assembled from sensors, and this database could be linked to users through an interactive interface.
Technology (CS 1.05 & 1.06)	• Graphic user interface	It demonstrates the techniques of constructing a graphic user interface through programming	It assisted in enabling the user to be easily exposed with conclusions about climate change through an

		languages.	interactive front-End built with HTML & CSS & JavaScript
Physics(Ph 3.07)	• Constructive and destructive interferences • Superposition of waves	Ph 3.07 states that waves are generally vulnerable to interference with random signals.	This L.O. helped in determining the signal-to-noise ratios which indicates how accurate is the data collected.
Earth science (ES 3.02)	• Global positioning system	This L.O demonstrates the various techniques of locating objects using satellites	It made the process of noticing changes occurring in the coastal area possible by regularly determining the location of the shoreline relative to specific targets.
Math (MA 1.02)	• Mean • Mode • Median • Standard deviation • Skewed graphs	It gives insights into several statistical concepts about descriptive statistics and how they could be applied in real life situations	To analyze the data assembled through the sensing system, It was mandatory to use descriptive statistical methods. Thus, this lo provided us with a plenty of concepts like mean and standard deviation to accurately examine and analyze these data.

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