Glowing Wind

Group 10101

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Chapter 1:

Present and Justify a Problem and Solution Requirements

<u>Egypt Grand Challenges</u>

Introduction

Egypt faces challenges known as "Grand Challenges", **shown in Figure 1**. These Grand Challenges lead to the deterioration of its economic, scientific, cultural, and technological infrastructure. Egypt hopes to solve these problems by 2030, as a part of Vision 2030.

Figure 1: Egypt's Grand Challenges

For instance, decreased alternative energy source utilization can lead to climate change, due to pollution spread from fossil fuel burning. It can also lead to decreased working opportunities, causing migration to other countries, and thus industry deterioration. Population growth is also mostly the result of poor education and bad cultural traditions, which can be attributed to an underdeveloped scientific and technological environment. Climate change and population growth both lead to mass migration from highly affected areas to lesser affected areas. Climate change also leads to decreased agricultural production, negatively affecting its base. Egypt's industry is also affected by its scientific and technological environment. Thus, Egypt’s Grand Challenges are highly affected by each other and dealing with one of them contribute to solving the other challenges.

Improve the use of alternative energies

Recently, many countries have tended to use alternative energy sources which are mainly renewable and clean sources of energy, such as wind, sunlight, green hydrogen, and many others, instead of using non-renewable fossil fuels that pollute the environment, such as petroleum oil and coal. According to ScienceDirect, renewable energy production in Egypt in 2021 was 19.2 GW. But Egypt aims to increase this production to 50.5 gigawatts (GW) in the years 2029/2030 and 62.6 GW in the years 2034/2035. Renewable energy will account for 42% of total Egyptian electricity output in this situation by 2035 according to the World Energy Outlook and the International Trade Administration.

Renewable energy sources, like all energy sources, have their pros and cons. Among their pros are that they don't run out, they are reliable sources of energy, they are environmentally friendly, they increase countries' economic independence, and they increase public health due to less pollution.

However, they have many cons as well. Renewable energy is not always available, it is strongly dependent on weather conditions. The initial cost of renewable energy is high, considering the small amount of energy we can get from renewable technologies. The manufacturing and installation processes of renewable energy devices, such as PV panels, can be relatively expensive. Renewable energy sites require much space, in comparison with traditional power stations, more land has to be used for establishing renewable energy farms. renewable energy decreases pollution, however, renewable energy devices are subject to some concerns because manufacturing them may cause pollution.

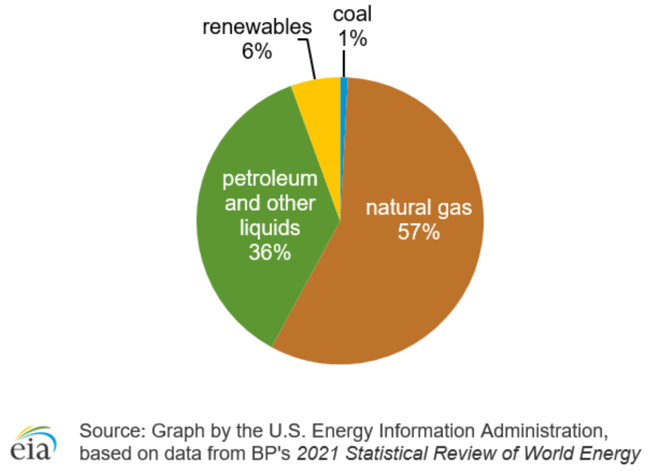

Figure 2: Sources of electricity generation in 2020

Causes

Economic Constraints

Economic constraints play a significant role in limiting the generation and usage of alternative energy sources in Egypt. Egypt faces financial problems that make it difficult to spend money on renewable energy projects, such as solar or wind power. For example, according to the World Bank, in 2019, Egypt spent approximately 14% of its budget on the energy sector, with a primary focus on traditional energy sources like petroleum oil, and gas. Thus, there is a lack of funding for new renewable energy initiatives. Additionally, the costs of establishing solar panels or wind turbines are considerable, furthermore increasing financial barriers. In 2020, according to the International Renewable Energy Agency, only 6% of the consumed electricity in Egypt was generated from renewable sources, **as shown in Figure 2.**

Lack of Infrastructure

The lack of suitable infrastructure is another reason for the lack of alternative energy in Egypt. According to the International Renewable Energy Agency in 2020, Just 1% of Electricity in Egypt was generated from solar energy, and less than 1% was from wind power. That shows that there are not enough sites for energy production from clean sources. The infrastructure is the main reason for that. Infrastructure is the roads, buildings, bridges, or power lines that are important for energy production. Now, Egypt is developing its infrastructure, and that will help in increasing energy production using clean sources.

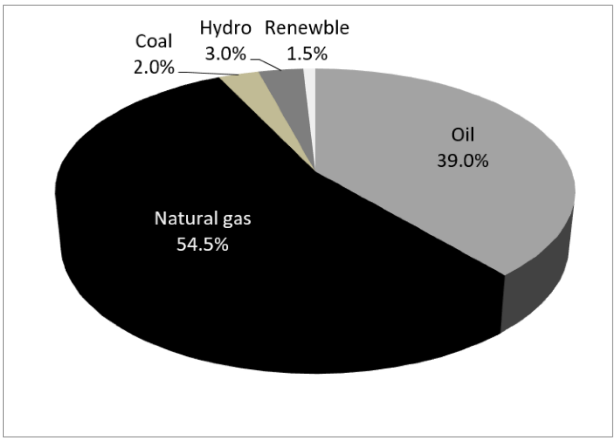

Figure 3: Energy consumption by source in Egypt

Impacts

Dependency on Fossil Fuels

The scarcity of alternative energy usage in Egypt has multiple impacts including the dependence on fossil fuels and other forms of nonrenewable energy sources in many fields. According to the U.S. Energy Information Administration, **as shown in Figure 3**, in 2019, 54.5% of the electrical consumption in Egypt was generated from natural gas, and 39% was generated from oil. Such dependence on fossil fuels is responsible for hazardous consequences like climate change and pollution. Another significant risk is the notifiable decrease in the availability of fossil fuels, making it an obstacle for factories and personal use to get energy. Leading to an increase in the cost of energy. Thus, energy production should be directed toward renewable sources.

Environmental Degradation

The lack of use of alternative energy in Egypt contributes to environmental degradation. According to the European Parliamentary Research Service, Egypt's total GHG (Green House Gases) emissions rose from 134 million tons (Mt) of carbon dioxide equivalent (CO2e) in 1990, to 352 Mt CO2e in 2019, **as shown in Figure 4.** The burning of fossil fuels, such as coal and oil, for electricity generation and transportation releases pollutants that damage air quality and cause climate change. Furthermore, the mining and combustion of fossil fuels can have harmful effects on local ecosystems and biodiversity. Without transitioning to cleaner alternative energy sources like solar or wind power, Egypt's heavy reliance on fossil fuels continues to pose significant environmental risks and challenges for sustainable development

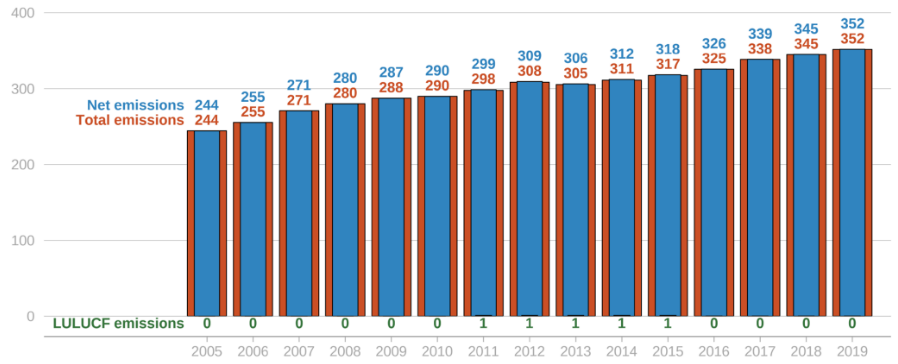

Figure 4 :Emissions of greenhouse gases in Egypt

<u>Fewer job opportunities</u>

The lack of alternative energy leads to fewer job opportunities in Egypt. The renewable energy field had more than 11.5 million employees in 2020 according to the International Renewable Energy Agency. But in Egypt, due to the limited spread of alternative energy, job opportunities in the renewable energy field remain low. Without increasing renewable energy projects, like solar panels and wind turbines, job opportunities in related fields; such as manufacturing, installation, and maintenance; are missed. This harms the Egyptian economic growth and employment opportunities for the Egyptians.

Deal with population growth and its consequences

Egypt is the third country in Africa with respect to population, following Nigeria and Ethiopia. Over the past decades, Egypt's population has been rising at a very high rate. The population rose from 43.7 million in 1980 to 114.5 million in 2024. The annual growth rate is 1.57% in 2024, which is equivalent to 1.8 million, whereas it was 2.44 % in 1980, about 1 million. Approximately 41.5% of the population is urban, often crowded conditions. In 2022, The rural population was 57% of the total population. According to World Population Prospects 2022 by the United Nations, it's estimated that Egypt's population will increase to 160 million by 2050 **as shown in Figure 5.**

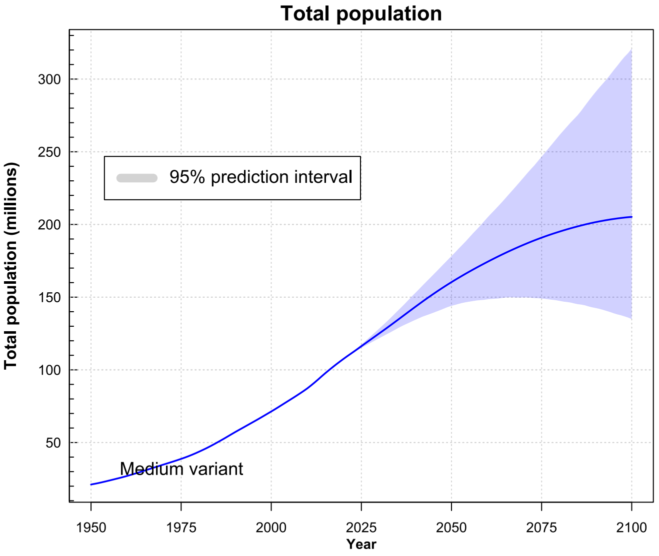

Figure 5 : Egypt's total population overtime with future expectations

Egypt's population distribution is extremely uneven, **as shown in figure 6**. Inhabited land in Egypt represents only 6.8% of its total land area, which equals 1,002,000 square kilometers. The actual population density, which is the total population divided by inhabited area, is about 1700 person per square kilometer whereas the theoretical density, total population divided by total area, is 115 p/km^2.

Cairo, Alexandria, and Giza are the main metropolitan areas in Egypt. Cairo is one of the most overcrowded cities in the world, where its population density is approximately 19,000 person per square kilometer. Population density exceeds 100,000 p/km^2 in some areas in Cairo and Alexandria.

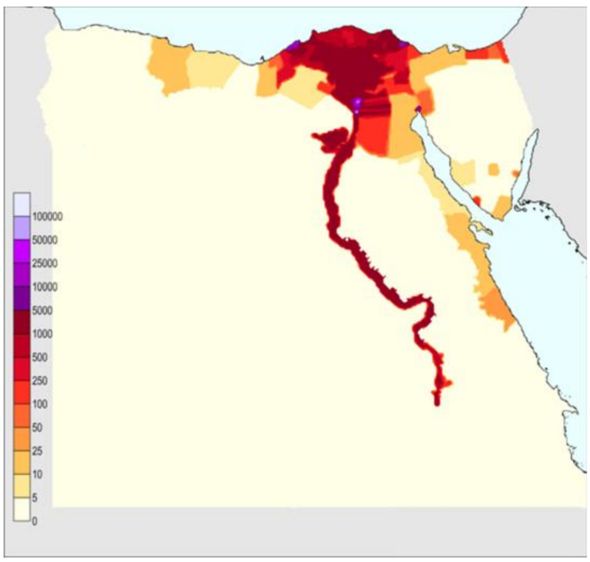

Figure 6 :Egypt's population density map.

Egypt's resources are limited compared to its huge population. The environment and natural resources are strained by the fast population growth, which demands more production to meet the basic needs and employment of the people.

Causes

High Fertility Rate

Fertility rate is the average number of children born to a woman in her reproductive years. According to the United Nations Population Fund (UNFPF), Egypt's fertility rate is 2.8 children per woman as of 2023. This means that 2,448,253 children are born annually. Although this rate is declining from 1980 **as shown in Figure 7**, it's still higher than the replacement level fertility rate (2.1 children per woman), which is the rate at which the population can maintain its size without migration. This high fertility level is due to some key factors, including traditions, education, and poverty. For example, rural and upper Egypt are still dominated by ideas and beliefs that emphasize the importance of family whose number of children is increasing. These beliefs relate to the fact that large families can employ their children at an early age to help in agriculture, thus they represent their economic power.

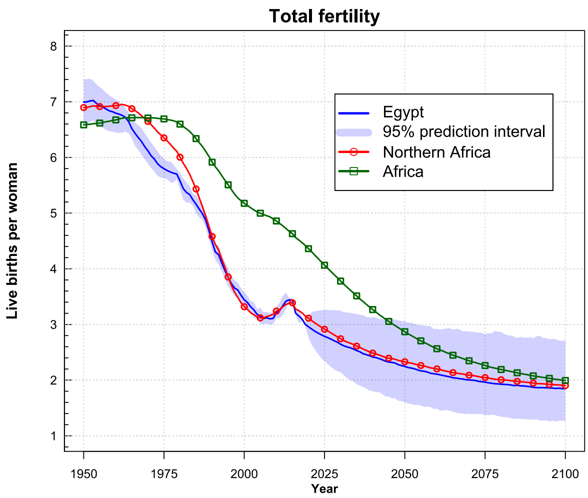

Figure 7: Egypt's fertility rate.

Forced Displacement and Migration

According to the United Nations High Commissioner for Refugees (UNHCR), forced displacement occurs when individuals and communities have been forced or obliged to flee or to leave their homes or places of habitual residence. This is in order to avoid the effects of some events, such as armed conflict, generalized violence, human rights abuses, natural or man-made disasters, or development projects. In 2022, the International Organization for Migration (IOM) estimated the total number of international migrants residing in Egypt to be 9 million migrants and refugees, accounting for about 9% of the total population. The outbreak of armed conflict in Sudan on 15 April 2023 led to the fleeing of large numbers of civilians to Egypt and neighbor countries. The total number of

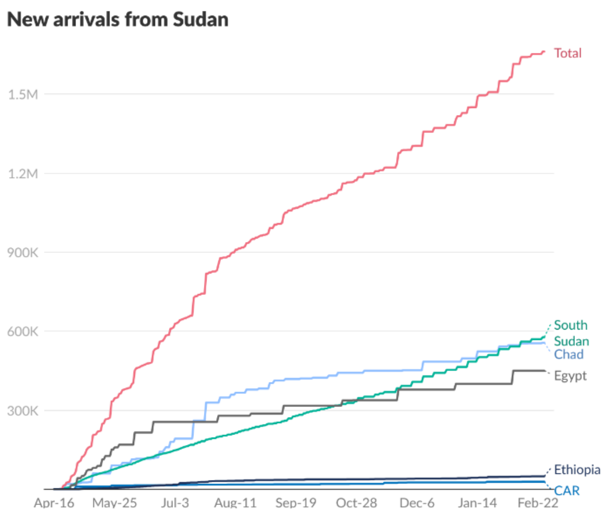

Figure 8: Total number of refugees from Sudan.

newly arrived refugees from Sudan is 460,000 as of 31 Jan. 2024 **as shown in Figure 8**, according to UNHCR. Egypt also hosts 154,794 Syrian refugees and 114,230 from various nationalities.

Child Marriage

Cultures and traditions are key factors that affect fertility rate, contributing to population increase. Child marriage refers to children who get married before the age of 18, as agreed in the International Convention on the Rights of the Child. Although the Egyptian Child Law, passed in 2008, prevents marriage under 18 years for both genders, children marriage is still being practiced in some regions in the c ountry, especially Upper Egypt. According to a 2017 census by the Central Agency for Public Mobilization and Statistics (CAPMAS), nearly 4% of girls between age 15 to 17 and 11% of adolescent girls 15-19 years are either currently married or were married before **as shown in Figure 9**. Marriage at early age is associated with a longer period of exposure to the possibility of pregnancy and thus higher fertility levels.

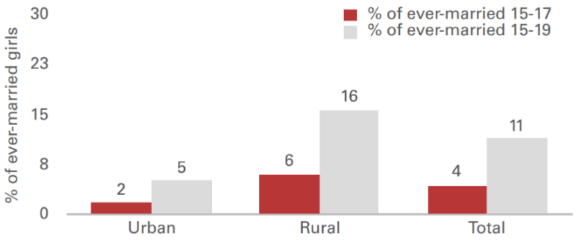

Figure 9: Prevalence of child marriage, by urban/rural residence, 2017

Impacts

Unemployment

The labor force is the number of people who are 15 to 60 years and are working, not working, or searching for work. Unemployment refers specifically to those jobless or seeking a job in the labor force. The labor force of Egypt, in 2022, was 32.6 million with an unemployment rate of 7.2% **as shown in Figure 10**. Such high unemployment rate is due to rapid population growth accompanied with few available job opportunities. Economic deterioration has also affected unemployment rate. Egypt's economy has faced foreign exchange crisis and

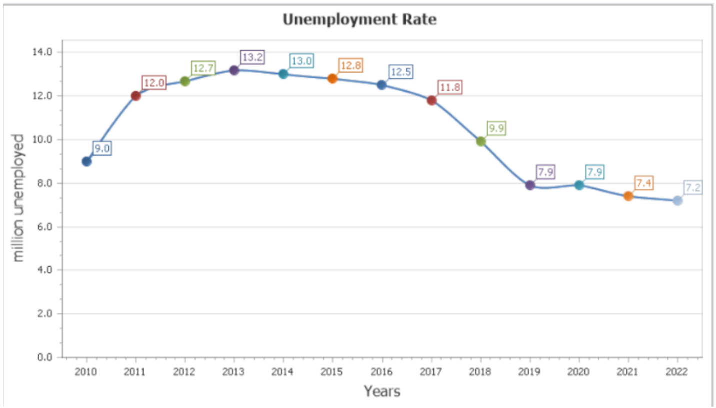

Figure 10: Unemployment rate in Egypt.

fiscal pressure due to global shocks. These challenges forced Egyptian businesses to reduce employment. Thus, the number of job opportunities is approximately constant whereas the population is increasing.

Poverty

In 2020, Egypt's national poverty line, the estimated minimum level of income needed to secure the necessities of life, stood at 10,300 Egyptian pounds. The projected poverty rate in 2022 was 27.3% of the total population **as shown in Figure 11**. Population growth causes overpopulation, which increases demand over supply on consumable products, forcing Egypt to import, which in turn increases prices. Rising prices, in addition to unemployment and salaries decrease, make a significant percentage of Egyptians become under poverty line.

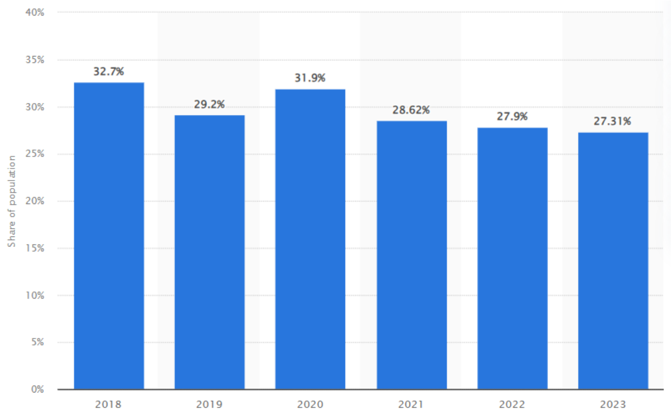

Figure 11: Poverty rate in Egypt

Slums

Due to rapid population growth, people migrate from rural areas to urban cities searching for job opportunities and better life conditions. This has led to increased urban poverty, overcrowding, and thus emergence of slum areas. According to the UN-Habitat, a slum is a contiguous settlement whose inhabitants are described as having inadequate housing and basic services. A slum household lacks either safe drinking water or access to improved sanitation and other basic infrastructure, or both. It's also characterized by overcrowding, having a hazardous location, and insecurity of tenure. Slums mainly exist around urban cities in Egypt. Slums constitute about 38% of the total area of urban communities.

Improve the scientific and technological environment for all

The presence of a strong scientific and technological environment is crucial for the advancement of a nation, as it opens the door to ingenuity. Egypt faces a problem in the development and application of scientific research which has led to its downfall in many regions, including but not limited to, economics, quality of life, transportation, healthcare, and education.

According to World Bank, the number of researchers in Egypt in 2021 was 822 per million inhabitants. This number is low when compared with other countries, such as Belgium, which has 6,586 researchers per million inhabitants. In 2018, only 128 research articles were published per million people in Egypt, while the United States and Switzerland, countries with good scientific momentum, released 1,273 and 2,511 research articles per million people respectively.

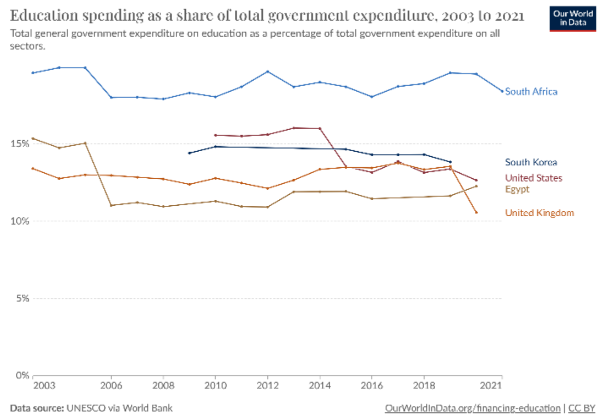

Figure 12: Education spending as a share of total government expenditure

In addition, education spending in Egypt is considered incredibly low, being at only 12%, **as shown in Figure 12**, of total government expenditure, where the United States is at 13.5% of total government expenditure. This is emphasized in the initial cost per primary students, which is 1,109 USD in Egypt, and 11,687 in the United States. This has led to small teacher wages, thus less work ethic, and school maintenance deterioration due to limited funding. Both lead to decreased quality of education, which negatively affects the scientific and technological environment.

As stated by the Ministry of Communication in 2021, 64 of families own computers. In addition, Internet availability to Egypt's population has only recently increased, where, in 2020, 71% of the population had access to the internet **as shown in Figure 13.** This contributes to worsening of the technological environment.

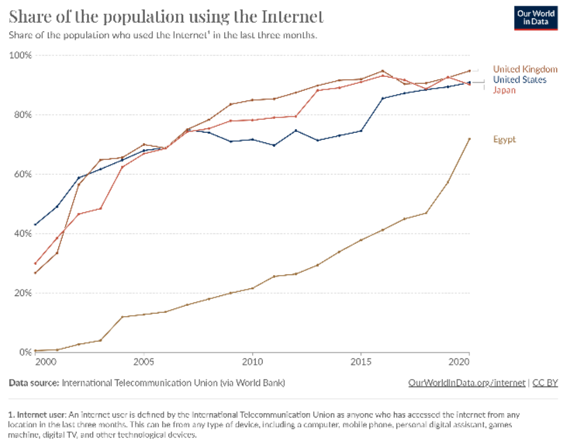

Figure 13: Share of the population using the Internet

Causes

Inflation

High inflation rates can lead to uncertainty in the economy, making it difficult for institutions and individuals to plan for the future. This uncertainty can deter investment in research and development, as these activities require significant upfront costs with benefits that are often realized in the long term. Worsening of Egypt's financial aspects has led to decreases in funding for academic institutions, decreasing research opportunities. **As shown in Figure 14**, average prices increased from 150.6 to 197.6 units in the time from Jan 2023 to Jan 2024. Decreases in such opportunities has made the field of scientific research non-viable due to anxiety of its future.

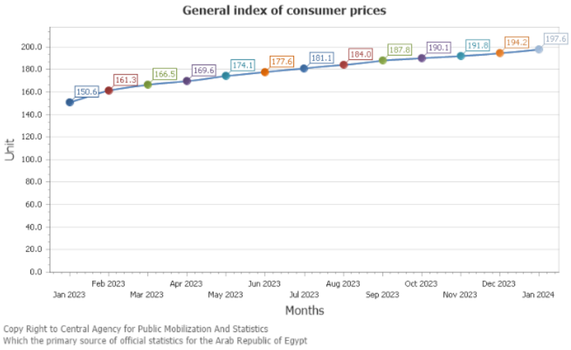

Figure 14: General index of consumer prices

Low Participation in Scientific Colleges

According to the Ministry of Higher Education and Scientific Research (MOHESR), the total number of univisities in Egypt is 54 universities, 27 governmental and 27 private. Scientific, natural, engineering, medical and agricultural sciences colleges, represent 51.6% while theoritical, social sciences, and humanities schools make up 48.4% of the total number of colleges. As reported by CAPMAS, the total number of students enrolled in higher education reached 3.4 million students during the academic year 2020/2021, with 50% of them enrolled in social sciences and 24.9% in humanitites **as shown in Figure 15**. Natural sciences accounted for 4.1% of enrolled students, medical and health sciences 11.1%, engineering sciences 6.3%, and agricultural and veterinary sciences repre 3.4%. As shown, the percentage of scientific colleges students is low, which is reflected in research and development in Egypt.

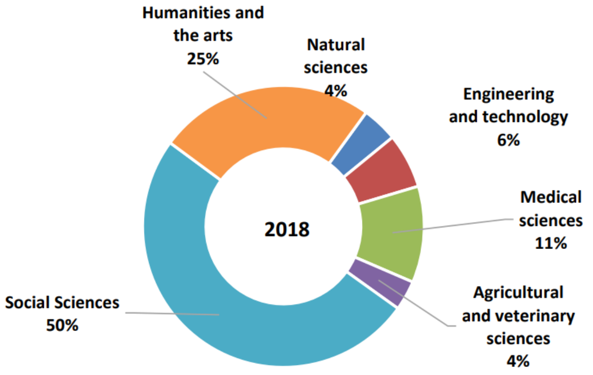

Figure 15: Students enrollment in universities by field of science

Brain Drain Phenomenon

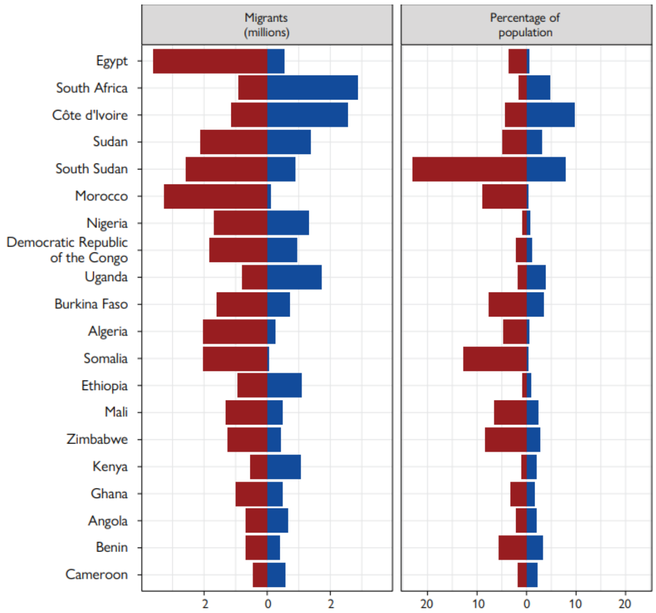

Figure 16: Top 20 African migrant countries, 2020

Brain Drain phenomenon refers to the emigration of highly trained or intelligent people from a particular country. The departure of highly skilled workers can lead to a decrease in human capital, potential tax revenues, and potential development due to the loss of research abilities of this human capita. In 2020, Egypt had the largest number of people living abroad in Africa **as shown in Figure 16.** In Egypt, about 110,000 doctors, which is nearly half of Egypt's estimated 215,000 doctors, have left the country in the past three years.

Impacts

Low Innovation

In 2020, the United States filed over 800 patents per million people, whereas Egypt only filed 9 applications per million people **as shown in Figure 17**. The large difference in patent applications shows Egypt's weak innovation level, where it was ranked the 94th in the Global Innovation Index. As reported by the Ministry of Higher Education and Scientific Research, the majority of patents were submitted by non-residents in Egypt (54%), while 46% were submitted by residents. In addition, the majority of Egyption application were submitted by companies, followed by individuals, then research centers, while Egyptian universities did not submit any application in 2018.

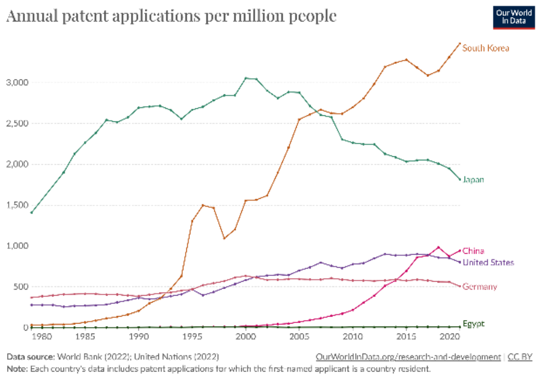

Figure 17: Annual patent applications per million people

Industrial Productivity and Quality

Industries rely heavily on advancements in science and technology for improving productivity, enhancing product quality, and developing innovative solutions. The lack of technological advancements can lead to outdated manufacturing processes, resulting in lower efficiency and output. Without access to advanced technologies and scientific expertise, industries may struggle to meet international quality standards. Moreover, the limited scientific and technological environment can hinder the development of high-tech industries in Egypt. These industries, such as information technology, biotechnology, and renewable energy, are key drivers of economic growth in the 21st century

Reduce and adapt to the effect of climatic change

Climate change, according to the United Nations (UN), is defined as the changing of the atmosphere's composition due to natural causes such as solar activity and volcanos, or anthropogenic causes, which started from the 1800s forward, due to the industrial evolution, such as the burning of natural gas, coal, and petroleum oil.

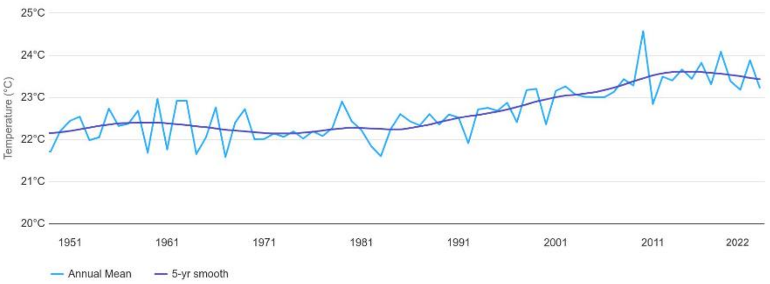

Figure 18 :mean temperature of surface air Annual

The ND-GAIN index, which ranks countries based on vulnerability to Climate Change, considers Egypt the 93rd most vulnerable country to Climate Change. **As shown in Figure 18**, annual mean temperatures increased from 22.44°C in 1951 to 23.23°C in 2022. This adds to Egypt's already hot and dry climate, where desert area temperatures can fluctuate from 7°C to 44°C. It's expected by the year 2050, if climate change is not addressed, that temperatures increase to 6 degrees Celsius above pre-industrial levels.

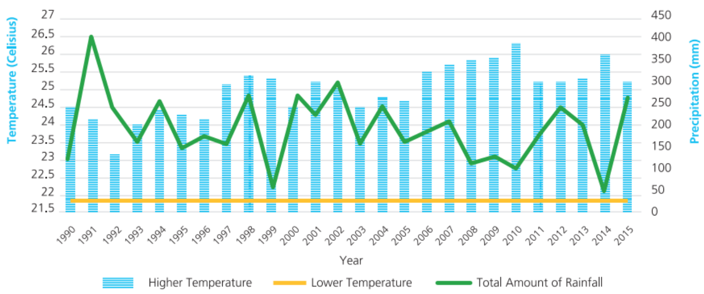

Figure 19: Average annual precipitation and temperature trends in Alexandria (BUR, p.31)

In Egypt’s first biennial report in 2015, rainfall in Alexandria was reported to reach 250 millimeters, **as shown in Figure 19**, while in Cairo it was only 10 millimeters. This is mainly due to climate change, which has increased precipitation rates over coastal cities.

Causes

<u>Energy Industry</u>

Temperature increases resulting from Climate Change ensure the importance of decreasing fossil fuel usage, which produces Greenhouse gasses. According to our world in data, in 2022, nearly 88%, **as shown in Figure 20**, of

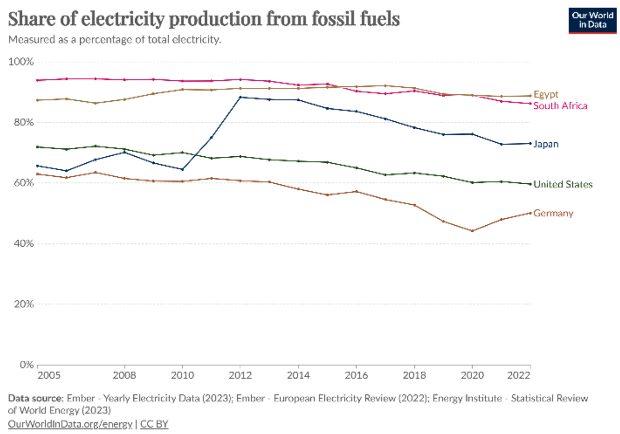

Figure 20: Share of electricity production from fossil fuels

Egypt's electricity came from fossil fuels, where 71% of the energy produced from fossil fuels comes from gas, which is Egypt's main energy source, producing 121 million tons of Carbon Dioxide Gas.

Fugitive emissions of Methane

Fugitive emissions are caused by the leakage of substances like natural gas, where natural gas consists of a minimum of 75% methane gas. Fugitive emissions have led to the emission of approximately 29 tons of methane gas **as shown in Figure 21**. Even if Methane gas lasts less in the atmosphere, it's 84 times more potent than carbon dioxide over a 20-year period.

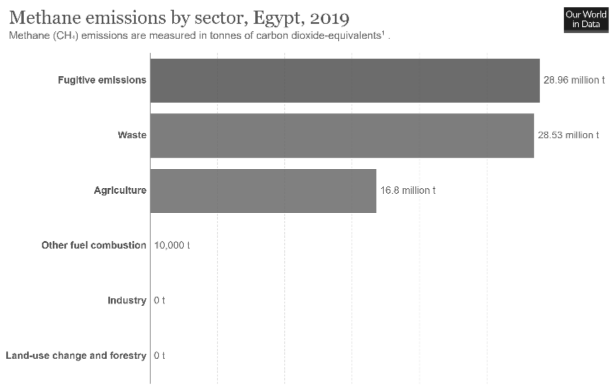

Figure 21:Methane emissions by sector

Fertilizers

When fertilizing with manure, Nitrous Oxide first must become synthetic for it to be absorbed by plants. Until that is achieved, a lot of it escapes as it's very mobile. Nitrous Oxide has stayed in the atmosphere for over 100 years, it is also much worse than other gases such as carbon dioxide as it is 300 times better at trapping heat. Agriculture has produced over 15 million tons of nitrous oxide **as shown in Figure 22**. which equates to 4500 million tons of carbon dioxide when multiplied by 300.

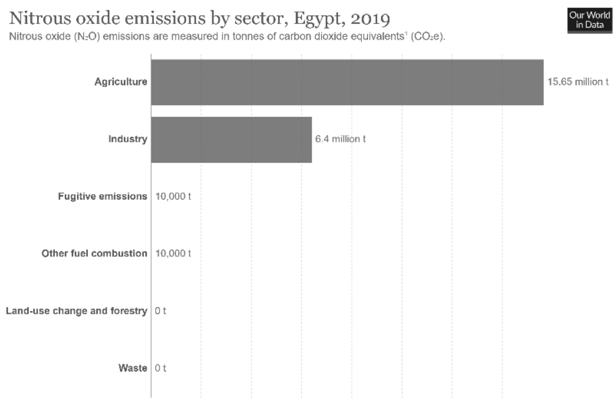

Figure 22: Nitrous oxide emissions by sector

Impacts

Increase in the amount of precipitation

A report by the Intergovernmental Panel for Climate Change (IPCC) stated that climate change has led to a decrease in precipitation rates over time, this is exclusive to northern Africa, where no other countries have shown decreased precipitation rates due to climate change. This could cause droughts leading to the death of many plants, and thus huge supply deficiencies, possibly turning into an economic crisis.

Melting of the polar regions

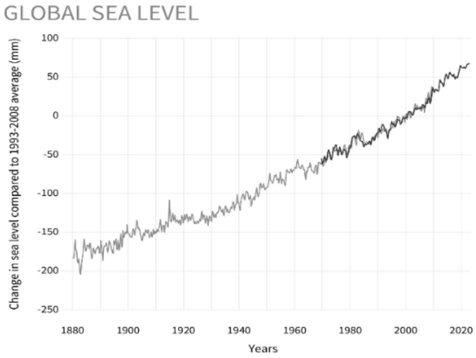

Figure 23: Global Sea Level

Global sea level has risen by 23 centimeters since 1880 and it hasn't stopped **as shown in Figure 23**, reports say that it's accelerating. Rising sea levels pose a threat to everyone including Egypt. Almost 15% of the population of Egypt lives around the coastlines. The Nile is especially prone to flooding from the melting of the polar regions, as one-fourth of the Nile delta would be flooded.

Food insecurity

Food production and supply would be affected by the flooding of agricultural land. By the time the Mediterranean Sea level rises by one 1 meter due to the melting of the ice in the two poles, one-fourth of the Nile Delta would be flooded. This puts Egypt’s agricultural production at risk, where nearly half of Egypt's crops, including wheat, bananas, and rice, are grown in the Nile Delta. The remaining areas that are not underwater would also be affected by salt water from the Mediterranean Sea contaminating aquifers, which are used for consumption. It could also contaminate clean water, which is used for agriculture, leading to further food scarcity.

Increase the industrial and agricultural bases of Egypt

Egypt's industrial sector plays a vital role in its economic development, contributing approximately 15% of the gross domestic product (GDP), **as shown in Figure 24**, and employing millions of workers. However, Egypt also faces many challenges in its industrial development, such as low productivity, high energy costs, environmental degradation, and regional disparities. Agriculture is a major component of the Egyptian economy, contributing 11.3% of the country's GDP. The agricultural sector represents 28% of all jobs, whereas more than 55% of jobs in Upper Egypt are related to agriculture.

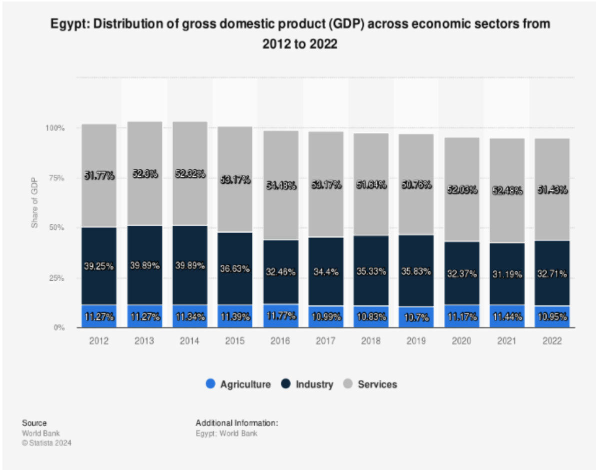

Figure 24 Egypt's GDP by economic sector

Egypt relies heavily on the Nile River for irrigation purposes, and water scarcity poses a major challenge, as Egypt's total income from Nile water reaches 55.5 billion cubic meters annually. The weight of water consumption was as follows, agricultural needs are 54.4 billion cubic meters annually, drinking needs are 2.9 billion cubic meters annually, and industry needs are 3.9 billion cubic meters annually.

Factories may suffer from a lack of water needed for cooling operations or for the production processes themselves. They can contribute to farmland degradation, where they can pollute the surrounding environment with toxic chemicals that destroy soil fertility, decreasing crop production. This may also contaminate food. Factories can also pollute water by dumping contaminated water, gases, chemicals, heavy metals, or radioactive materials, mainly because dumping such materials is cheaper than treating them.

In addition, many industries rely on locally produced agricultural raw materials, and if farmland deteriorates, the production of these materials may decline, impacting the associated processing industries.

Causes

<u>Urban encroachment</u>

Urban encroachment poses a great danger to productive agricultural lands, despite a law prohibiting construction on productive agricultural lands. There were no significant preventive measures against most encroachment cases on productive agricultural land. This leads to an annual loss of 20,000 to 100,000 acres of agricultural land due to urbanization.

Climate change

Fluctuations in temperature and rainfall patterns affect growing seasons and lead to reduced production. Rising temperatures increase the demand for cooling in factories, leading to higher energy costs. Climate change degrades soil quality, reducing agricultural yields. Changes in climate, such as floods or drought, lead to land degradation and the loss of produce that was grown on the land.

Lack of agricultural land

Egypt faces a major problem of land shortage in terms of cultivated and uncultivated lands. This has led to an increase in human pressure on environmental systems to a large extension of degraded lands due to the growth of the population which will need food, fuel, and some requirements, and an increase in demand for land for the population. And infrastructure, and this reduces the areas of agricultural land. This demand is expected to rise to 50% and 30% by 2030. Deterioration of both types of soil because of the unstained use of fertilizers and pesticides .

Impacts

Food insecurity

Egypt relies heavily on the agricultural and industrial sectors to obtain food. This affects the country’s ability to secure food for its population, and this leads to Egypt’s insecurity and food being exposed to danger. Food security affects health, growth, education, and economic productivity. Food insecurity leads to a group of problems such as stunting, obesity, and chronic diseases. It also leads to decreased economic productivity and increased poverty rates.

Economy

Poor agriculture and industry lead to the production of small quantities of the same available resources, and this reduces the overall productivity of the economy. It will reduce the ability to export products, and this will lead to a decline in revenues from foreign trade, which will subsequently affect Egypt’s economy. Poor agricultural and industrial sectors increase unemployment rates and there will be a decline in labor demand in agriculture and industry. Poor agricultural and industrial sectors reduce sustainable economic growth and attract foreign investment, and this reduces the opportunities available to develop infrastructure and strengthen the economy in general.

Problem to be solved

Lack of Energy Availability to Power Lights at STEM October School

Development of new technologies and techniques for energy generation, through improving Egypt's scientific and technological environment, provides us with more effective alternative energy sources for different cases.

Worldwide, over 1600 TW (Terawatts) were used in lighting mechanisms in 2020. Worlddata.info states that Egypt consumes 149.08 billion kWh of power. According to a paper done in 2017, Egypt contains 26,881,533 households, where lighting comprises 20-35% of residential power consumption. The same paper also calculated the average $\frac{KWh}{m^2}$ in Egypt to be 10. Another previous paper states that 6% of Egypt's consumption goes to street lighting, and that lighting overall, in residential, commercial, and government buildings, in addition to streets, consumes nearly 25% of electrical energy in Egypt, amounting to 37.25 kWh.

As this paper focuses on STEM October, it was found, after on-ground research, that the school contains many unworking lamp posts. Reasons for such range from decreasing electrical consumption, as, according to school officials, electricity bills exceed 60,000 Egyptian pounds monthly without the usage of such lamp posts, to malfunctioning conduction wires. This makes many areas within school boundaries dark. Providing new sustainable methods to generate electricity for each post/complex would help in decreasing their load on power grids.

This results in negative consequences, as will be mentioned later, but more importantly, leads to the problem to be solved: Providing alternative energy sources for light posts.

Positive consequences

Increased feeling of safety

Well-lit areas provide feelings of safety for humans, specifically children and teenagers. A study done in 2003 showed that 73% of interviewees agreed that better street lighting would increase child safety. In the case of STEM October, students may feel scared to go out to certain laboratories at night, or generally sit in dark areas. Thus, illuminating such areas provides them with safety through increased visibility and awareness of surroundings.

Decreased greenhouse pollution

Our World in Data states that 88.8% of Egypt's energy comes from fossil fuels, with the remaining percentage coming from renewable sources. Providing alternative sources for lamp posts will decrease their dependence on energy produced from fossil fuels and other environmentally damaging energy sources, as long as the solution used is carbon neutral. This decreases greenhouse gas emissions, thus indirectly helping in solving the grand challenge of climate change.

Discouragement of wild animal activity

STEM October lies in a highly non-residential area, and is neighbored by a large, deserted previously touristic area called The Cosmic Village. This village has become overtime invaded with wild animals, like dogs and bats. Lots of times, animals encroach on the school's lands, through holes in the walls, endangering students. Having a well-lit campus will discourage wild animals from nesting, further increasing safety.

Negative consequences

Reduced control of schedule

STEM Students often have busy schedules that require staying up until late hours. Turning off lamp posts and/or other light sources inhibits such behavior. Not having comfortable yet strong lighting systems makes it harder for students to manage their time, as they can't sleep when it feels beneficial and study when beneficial.

Increased energy consumption

Having large distances separate between sources of power and their places of usage, light posts in this case, leads to the loss of energy in the form of emitting heat. According to World Bank, Egypt lost 11% of total electrical energy output in 2014 to this phenomenon. Decreasing distances would save energy which could be utilized in other instances.

Research

Topics related to the problem

Impact of Inadequate Lighting on Safety

Insufficient lighting contributes to significant risks to road safety, especially during nighttime driving. According to data from the National Highway Traffic Safety Administration (NHTSA), approximately 50% of traffic fatalities occur at night, despite nighttime driving representing only 25% of total driving time. Poorly lit roads lead to low visibility and thus prevent the drivers from perceiving hazards. This contributes to a higher incidence of traffic accidents and fatalities.

Effects of Poor Lighting on Academic Performance

Lightning conditions greatly affect the educational environment for the students and their academic performance. Research published in the Journal of Environmental Psychology indicates that students in classrooms with adequate natural light or artificial lighting perform better academically compared to those in poorly lit classrooms. Proper lighting enhances visibility, reduces eye strain, reduces fatigue, and promotes alertness and focus, all of which are crucial for effective learning.

Challenges of Insufficient Lighting in Residential Areas

Dim-lightened areas in residential neighborhoods contribute to many different challenges. These challenges include increased danger of crimes that may disturb the community's well-being. A study conducted by the Urban Institute in 2004 found that neighborhoods with insufficient street lighting experience higher rates of crimes, including housebreaking and vandalism, compared to well-lightened neighborhoods. Additionally, a survey conducted by the American Planning Association revealed that 87% of residents feel safer in well-lit neighborhoods compared to poorly lit ones. Insufficient lighting not only increase safety concerns but also undermines residents' sense of security and quality of life.

Topics related to the solution

Parabolic Reflector

A parabolic reflector, or mirror, is a reflective surface whose cross-section takes the shape of a parabola and is used to collect or concentrate energy. A parabola is a U-shaped curve where any point is equidistant from a fixed point, called the Focus, and a straight line, called the Directrix. The main property of this reflector's geometric shape is that any incoming ray parallel to its axis will be reflected toward the focus **as shown in Figure 25**. Conversely, any beam that passes through the focus will be reflected parallel to the axis. Since many energy types, like light; sound; or radio waves, can be reflected in such manner, parabolic reflectors can be used to concentrate and collect solar energy entering the reflector at a certain angle. Solar furnaces, for example, are applications of parabolic reflectors used to concentrate solar radiation received in a big area to a focal point in order to achieve very high temperatures. It can be used in electricity generation, material heating, and food cooking.

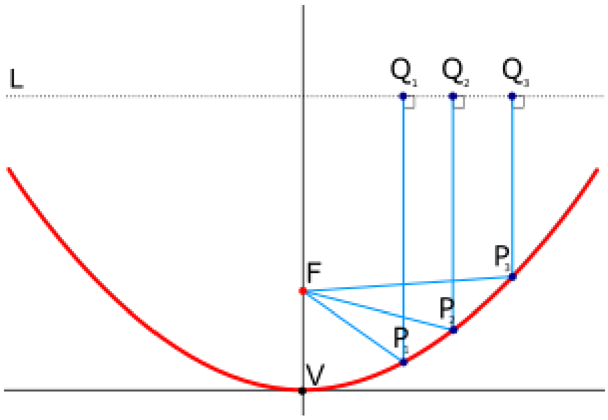

Figure 25: A cross section of a parabolic reflector showing its reflective properties.

Thermoelectric Effect

The phenomenon of the direct conversion of temperature difference to electric voltage is called the thermoelectric effect, or the Peltier–Seebeck effect. It includes three independently identified phenomena: the Seebeck effect, the Peltier effect, and the Thomson effect. The Seebeck effect, discovered by Thomas Seebeck in 1821, is the process where the temperature difference between two distinct electrical semiconductors or conductors generates a voltage difference between them. The electrons in the warmer regions tend to move to the colder side, thus, generating an electric current. Conversely, the Peltier effect, discovered by Jean-Charles Peltier in 1834, occurs when a voltage is applied to a thermoelectric device, heat is transferred from one side to the other, forming a temperature difference. The conductors try to return to the electron equilibrium which existed before the current was applied. They do this by absorbing energy at one connector and releasing it at the other. The Thomson effect, observed by William Thomson in 1851, is any current-carrying conductor, with a temperature difference between two points, will either absorb or emit heat, depending on the material.

Steam Turbine

A steam turbine, which was invented by Sir Charles Parsons in 1884, is a rotary engine that converts thermal energy from pressurized steam to mechanical energy or electrical energy. The simplest form of a steam turbine consists of a boiler, turbine, condenser, feed pump, and multiple auxiliary devices. Steam turbines depend on the Rankine cycle, **shown in Figure 26**, for operation. In this cycle, water is heated to generate high pressure stream, which is then expanded through a series of turbines where steam energy is converted to mechanical power used to drive an electrical generator.

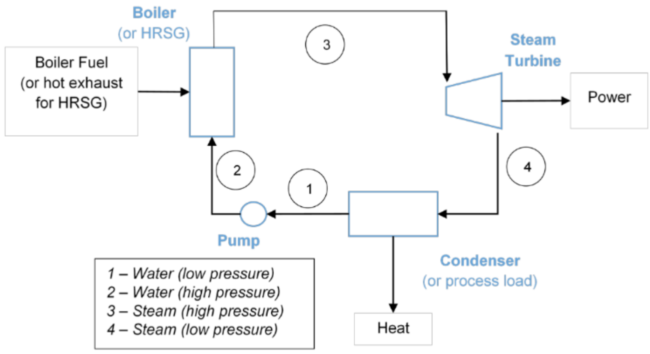

Figure 26: Components of Steam Turbine and the Rankine cycle

Other Solutions Already Tried

El-Zafarana Wind Farm

Figure 27: El Zafarana Wind Farm.

El Zafarana Wind Plant, shown in **Figure 27**, is located in Ras Gharib, which belongs to the Red Sea Governorate. It captures the powerful wind that blows over the Red Sea's coast. It covers a vast area of about 100 square kilometers. It is considered a home to more than 550 towering turbines. El Zafarana has been considered a sign for clean energy since it started operation in 2001, generating about 1.3 gigawatts (GW), which is enough to power over 100,000 homes and businesses. It is considered the second-largest wind power plant in the east of Africa. With wind speeds averaging around 9 meters per second, the plant serves as evidence of Egypt's dedication to renewable energy, paving the way for a brighter, more sustainable future.

Mechanism.

At the core of the El Zafarana Wind Plant stand its imposing turbines, soaring structures towering up to 80 meters in height. These turbines act as enormous machines designed to harness the kinetic energy of the wind. When the wind blows, it pushes the turbine blades into motion. Each turbine is paired with a generator, a device that converts the rotational energy of the blades into electrical energy. With each revolution, the generator yields up to 2.5 megawatts (MW) of power, which is then transmitted through a network of cables and wires to power homes and cities throughout Egypt. The turbines are equipped with advanced technologies that enable them to adapt to changing wind conditions, optimizing their energy capture and efficiency. This harmonious interplay of nature and engineering emphasizes the vital role of wind energy in shaping Egypt's sustainable future.

Points of strength.

Favorable Wind Resources

Located in the Gulf of Suez region, the project benefits from consistent and strong wind conditions, with average wind speeds exceeding 9 meters per second. This favorable wind resource ensures reliable and substantial energy generation capacity throughout the year.

Cutting-Edge Technology

El Zafarana Wind Plant employs advanced turbine designs equipped with innovative features such as variable blade pitch and aerodynamic enhancements, optimizing energy capture efficiency and overall performance.

Advanced Turbine Technology

The El Zafarana Wind Plant features state-of-the-art turbines equipped with innovative blade designs tailored to harness the unique wind conditions of the Gulf of Suez region. These turbines incorporate advanced aerodynamic features and variable blade pitch control systems, maximizing energy capture efficiency and enhancing overall performance.

Points of weakness.

Grid Integration Complexity

Integrating a large-scale wind farm into the existing electrical grid entails technical challenges such as grid stability management, voltage regulation, and synchronization. Ensuring smooth grid integration requires significant investments in grid infrastructure upgrades and smart grid technologies.

Operational Maintenance Demands

Operating and maintaining wind turbines necessitates regular inspections, repairs, and component replacements to ensure optimal performance and longevity. The remote location of El Zafarana Wind Plant may increase logistical challenges and maintenance costs, requiring skilled personnel and specialized equipment.

Environmental Considerations

While wind energy is considered environmentally friendly compared to conventional fossil fuel-based power generation, the installation and operation of wind turbines may have localized environmental impacts. These include habitat disruption, bird and bat collisions, and visual landscape changes. Implementing comprehensive environmental impact assessments and mitigation measures is essential to minimize adverse effects and ensure sustainable project development.

Gabal El Zeit Wind Farm

Figure 28: Gabal El Zeit Wund Farm

Gabal El Zeit Wind Farm, **shown in Figure 28**, is located in kilo 118, Gabal El Zeit area, south of Ras Gharib city, along the Red Sea Coast. It covers about 100 square kilometers. The farm is considered one of the largest plants that generate electricity, according to the area, the number of turbines, and the capacities generated from the station. The farm turbines are more than 300 turbines. The farm's total capacity reaches 580 megawatts (MW). The station includes 580 projects. The first of which includes 120 turbines with a capacity of 240 MW. 100 turbines were connected to the national electricity grid, and the second project includes 110 turbines with a capacity of 220 MW, connecting 75 turbines to the grid with a capacity of 150 MW. The third project includes 60 under-construction turbines with a capacity of 120 MW. The station, implemented by the Spanish company “Gamesa” before being merged with the German company "Siemens", contains three administrative buildings, including a building for the monitor and control room for all turbines simultaneously.

Mechanism

At the Gabal El Zeit Wind Farm, electricity is generated through the operation of wind turbines. These turbines consist of large blades attached to a rotor, which is connected to a generator. When the wind blows, it causes the blades to rotate. This rotational motion of the blades drives the rotor, which in turn spins the generator. Inside the generator, electromagnetic induction occurs, where the rotating motion of the rotor creates a magnetic field. This magnetic field induces an electric current to flow within the generator's coils, generating electricity. The electricity produced is then transmitted through power lines to the grid for distribution to consumers. The wind farm's turbines are positioned strategically to capture the maximum amount of wind energy, taking advantage of Egypt's favorable wind conditions. With advancements in turbine technology, such as larger blade designs and improved efficiency, the Gabal El Zeit Wind Farm can generate significant amounts of clean, renewable electricity to meet the region's energy needs.

Points of strength

Ecosystem safety

The station contains a system of monitoring migratory birds, through the radar to stop the turbines when the birds fly and then reoperate them, a system used for the first time in the world.

Cutting-edge Turbine Technology

Gabal El Zeit Wind Farm has horizontal-axis wind turbines. They have large rotor diameters and high hub heights to harness the region's abundant wind resources efficiently. This technology ensures maximum energy capture and output, optimizing the project's overall performance.

Integrated Energy Storage Systems

The project includes special energy storage solutions, such as battery storage systems, to reduce intermittency issues inherent in wind power generation. These systems store excessive electricity during periods of high wind output and discharge it during low-wind periods. This enhances the grid stability and enables reliable electricity supply to consumers.

Points of weakness

High cost

Despite technological advancements, the construction cost of the project is relatively high. Gabal El Zeit wind farm costs about 12 billion pounds. It also requires regular maintenance to ensure optimal performance and longevity. The remote location of Gabal El Zeit Wind Farm could result in higher operational costs due to transportation logistics and access to specialized technicians for maintenance and repairs.

Transmission Infrastructure Limitations

The Gabal El Zeit Wind Farm faces challenges in transmitting generated electricity to distant urban areas due to limited transmission infrastructure in remote locations, potentially leading to energy loss and increased costs.

The Noor-Ouarzazate Solar Complex

Figure 29: The Quarzazate solar power station

The Ouarzazate Solar Power Station (OSPS) is the largest concentrating solar power in the world with a total capacity of 580 Megawatts (MW). It’s located less than 6 miles from the town of Ouarzazate. OSPS is the first major project in the Morrocco’s commitment to increase the share of renewable energy generation top 52 percent by 2050. The OSPS avoids greenhouse gas emissions by approximately 690,000 tons of CO2 equivalent annually. OSPS takes up an area of 30 million m^2. The station is divided into four separate solar power plants, numbered from I to IV **as shown in Figure 29**, each using various technologies. Noor Ouarzazate I and II depend on parabolic trough technology, whereas Noor Ouarzazate III utilizes concentrated solar power tower technology. Nour Ouarzazate IV is a hybrid photovoltaic plant.

Mechanism

The Noor I plant utilizes half a million 12-meter-high parabolic troughs arranged in 800 rows on an area of 4.8 million m^2. The effective reflective area (ERA) of the troughs is 1,308,000 m^2. The installed capacity of the plant is 160 Megawatts and it provides storage for electrical energy for 3 hours after sunset. The annual electricity production is 618 GWh. The parabolic troughs concentrate solar rays in a central tube filled with a heat transfer fluid (HTF), which is a synthetic oil. The fluid, heated to 393º C, is transported through pipelines to the steam turbine, where it is used to convert water into high-pressure steam. This steam drives a multi-turbine connected to a generator that produces electricity. After that, a cooling tower is used to cool the steam where it is condensed back into water. A heat exchanger is used to heat salt using the HTF. A heat storage system utilizes this salt mixture to reheat the HTF when solar radiation is insufficient. The water used in the plant is derived from the Mansour Eddabhi reservoir, located 12 km from the plant, and is stored in tanks with a total capacity of 300,000 cubic meters.

The Noor II is the second phase of the OSPS project, covering an area of 6.1 million m^2. Its installed capacity is 200 MW and produces 600 GWh of electricity annually. This plant uses parabolic troughs with an ERA of 1.8 million m^2. It provides electricity supply for 7 to 8 hours. The production mechanism is similar to The Noor I plant. The Noor II plant uses water-free air cooling, which reduces water consumption by about 80%.

Figure 30: The Quarzazates Noor III CSP plant

The Noor III is based on CSP tower technology, **as shown in Figure 30**, with air cooling. It covers an area of 5.82 million m^2 and has an installed capacity of 150 MW. The annual electricity production is 500 GWh. The plant utilizes 7,400 heliostats with an ERA of 178.5 m^2. The heliostats are equipped with a highly accurate hydraulically-driven sun tracking system. The mirrors reflect solar radiation toward a receiver in the tower, where the HTF is heated. The liquid temperature reaches 565º C. Then water is converted into steam to drive a steam turbine. This technology generates a supply of electricity for up to 7 hours.

The Noor Ouarzazate IV photovoltaic plant is the last power plant in the OSPS project. Its installed capacity is 72 MW and it covers an area of 1.37 million m^2 with an annual electricity production of 120 GWh. The plant utilizes hybrid photovoltaic technology to convert solar energy directly into electricity using semiconductor cells.

Points of Strength

Location's High Annual Solar Intensity

The location of OSPS was chosen near the town of Ouarzazate since the annual solar radiation intensity is 2,635 kilowatts per square meter. This is one of the highest intensities in the world, where the sun shines almost 365 days a year. Solar radiation intensity is directly proportional to the plant's production, as increased solar radiation results in high energy generation.

Large Electrical Capacity

The Ouarzazate Solar Power Station is the second largest solar thermal power station in the world in terms of electrical capacity of the OSPS is 580 megawatts. In 2018, the station was able to provide electricity for 1.1 million Moroccan houses.

Storage System

All plants in the OSPS are equipped with energy storage systems to that they can operate during peak hours and after sunset. The storage systems utilize a eutectic salt mixture made of 60% sodium nitrate and 40% potassium nitrate. 140,000 tons of salt are used in the entire complex.

Points of Weakness

High Maintenance Cost

According to the National Renewable Energy Laboratory (NREL), the total cost of the first three stations, Noor I to III, was 3,210.51 million USD. OSPS consumes up to 3 million m^3 of water annually. In addition, it requires up to 19 tons of diesel fuel per day to keep the salt mixture used in the storage system above 110º C and the synthetic oil used as a heat transfer fluid above 8º C.

Sandy Environment

The OSPS is located in an area of sandy environment, which contributes to additional maintenance challenges. Because of that, the parabolic troughs, heliostats, and photovoltaic cells used in the plant need to be cleaned regularly to keep their performance. This also requires a large amount of water.

Power Transportation over Long Distances

The Noor Ouarzazate Solar Complex generates electricity in a remote location, and transporting this power to urban centers can be logistically challenging. Longdistance transmission lines are needed, which can be costly and require significant infrastructure investment.

Eole C project

The “Eole C” project, **shown in Figure 31,** in Cap-Chat is known to be the largest vertically installed wind turbine in the world. It consists of 133 VAWT nodes with a total capacity of 4.5 MW. This grassroots project has been and remains committed to providing an endless amount of clean energy by converting wind energy into electricity through the use of vertical-axis turbines.

Figure 31: Eole C wind turbine

Mechanism

In contrast to older technology of horizontal axis wind turbines (HAWTs), where the axis of the blades is oriented horizontally, VAWTs have the blades positioned along the vertical axis. Using this model, they can capture wind energy from the direction no matter which way the wind is blowing.

VAWTs functionally harness the effects of gas lift to generate power. The generation of lift force by the blades when they encounter the wind at any angle results from the wind flowing over the curved or straight blades.

Unlike traditional HAWTs that are powered by a complex and elaborate frame system, the newly designed VAWTs use airflow with an advanced air torque generation system, making the device self-powered without the need for external power sources. Their ability to interact with lower energy such as wind speed also allows low-speed winds to start rotating is advantageous.

The VAWT model works on the principle of lift that was experimented on in France in the 1920s by Georges Darius.

Points of strength

URBAN FRIENDLY

VAWTs are specially designed for hard-to-install sites, and they can operate even near a power grid, in windy or turbulent wind conditions.

Low Noise

Another great advantage of VAWT is its strength in sound producing much less noise than HAWTs, making it the ultimate choice for eco-friendly housing developments.

No yaw mechanism needed

While VAWTs use the wind to rotate without a yaw mechanism, HAWTs use the yaw mechanism to avoid the wind. This difference makes VAWTs the cheaper choice.

Scalability

Through the implementation of the Eole C wind turbine, wind farms based on VAWTs can be mass-produced beyond a pilot scale, was proven.

Points of weakness

Lower efficiency

Low turbulence is mostly the reason behind their lower level of efficiency compared to more aerodynamic efficient HAWTs.

Maintenance complexities:

VAWTs are very difficult to build and repair although their vertical ownership of the turbine itself is the main challenge.

Limited Commercial Deployment

Eole's Type C WATV is great, but there are few common placements for utility-scale WATVs with HAWTs that share 90%.

Gansu Wind Farm

The Gansu Wind Farm Project, also known as Jiuquan Wind Power Base, is remarkable in the western province of Gansu, China. Gansu Wind Farm is located in the desert areas near Jiuquan City. It extends over two regions: Guacho Province and Yamen City. The region has abundant wind resources, making it an ideal location to harness wind energy. The Gansu Wind Farm has been approved by the Chinese government as one of six national wind energy megaprojects aimed at changing the rules of the game. Its current capacity is 20 GW. The estimated cost of this huge project is about 120 billion Chinese yuan (about 17.5 billion dollars).

The Gansu Wind Farm includes horizontal wind turbines and a few vertical ones. The Gansu Wind Farm has deployed a large number of Vestas V90 and V100 wind turbines. These turbines are known for their robust design, high capacity, and ability to perform well in a wide range of wind conditions.

Mechanism

There are more than 7,000 wind turbines. Turbine Manufacturers: These turbines come from different manufacturers, including Goldwind, Vestas, Sinovel, and others. The Gansu wind power plant system, as an illustration, implements the wind energy conversion standard approaches. That is the logic of how it works and the main constituents of the process.

1. Rotor and blades: The structure of the rotor is either 2 or above blades connected to the center shaft through the shaft. Air movement gives kinetic energy to blades, which bear down on them to make them spin. Blade design is the key element of the system to get to the best performance. Nowadays blades benefit from advanced airfoil design to have the highest lift-to-drag ratio possible.

2. Gearbox and generator: By the grip of the gearbox the blade's rotational energy is transferred. Through the use of the gearbox, the speed is increased to slide into place, and agree with the unit. The wind turbine is directly connected to the generator, which in turn extracts the kinetic energy from the turbine shaft and converts it into electrical energy. The majority of wind turbines use synchronous or permanent magnet generators as their main source of electric energy production.

3. Yaw system: The turbine is installed on the tower and can move around a vertical spindle that passes through it through the axis of rotation. The sensors and the yaw motor report the direction of the wind, which is picked up by the wind and the yaw motor is responsible for adjusting the direction of the turbine.

4. Pitch control: The movement regulation, namely pitch adjustment in wind turbines, serves to increase power output. Pitch is the blades relative to the wind, and angle is the blades' rotation around the vertical axis. The blades are rotated forward so that they are tilted farther from the wind stream to prevent too much speed.

5. The nacelle and turret: In the nacelle of the wind turbine will be the most important components: gearbox, generator, yaw motor, and control systems. It is located at the top of the tower and goes around with the wind behind it. The guyed class tower helps to raise the height for the strong winds to be captured at the higher altitudes.

6. Connection to the grid: The power from these wind turbines courses through cables to the tower below. The next phase of connecting to the local electricity grid. Power electronics can communicate the desired frequency and voltage level with the power grid.

Points of strength

Large-scale renewable energy generation:

This gives the Gansu wind farm an installed capacity of more than 20,000 MW, having one of the largest wind energy projects around today. This huge power plant produces a huge volume of renewable energy which subsequently results in reducing the emission of greenhouse gases and the dependence on fossil fuels through the wide generation of clean energy.

Energy security and independence:

A wind farm in Gansu is one of the significant roles in the scenario of enhancement of energy security and independence in China. The depreciation of energy resources and decrease of dependence on gas importers will produce a system with increased robustness and more independence.

Economic development and job creation:

The 8000MW Gansu Wind Farm, which is one of the large-scale wind energy projects, can attract investments that lead to the creation of jobs, development of local industries, and promote economic growth in a wider area. Traditionally, establishing and managing wind power projects create employment options and add to the local economic development.

Use of horizontal wind turbines:

Land-based horizontal wind turbines are well equipped for application in areas with small land resources. They are suitable for both urban and rural areas, as the space free flowing in these locations serves as a perfect place for installation. Thus, these power plants can be installed anywhere in the city as well as in the countryside.

Points of weakness

Grid integration challenges:

An advanced renewable energy system like Gansu generally will affect the operations of the grid. The weather variance can disturb the power network stability, thereby requiring better grid infrastructure as well as advanced grid management systems to stabilize the grid and balance supply and demand smoothly.

Impact on land and environment:

The creation of large wind farms, even miles of turbines, might take too much land which will negatively affect land usage and ecosystems. The Gansu Wind Farm has a significant presupposition in terms of land coverage, as the installation of wind turbines plus the construction of correspondent access roads may lead to the fragmentation of wildlife habitat, the disturbance of wildlife movement, and the visual effects of the landscape.

Visual Impact and Noise:

The very sight of wind turbines, especially when it comes to the installation of a large number of turbines, can change a landscape creating a new perspective. Furthermore, running wind turbines continue to produce noise, however, modeled designs target lowering the noise levels.

Initial capital investment:

Wind farms like Gansu that are built on a large scale require a huge investment. Although the wind energy cost is declining per se, starting financial capital cost can still be quite high and therefore may need to be supported by financial or investment incentives to make the project economically stand on its own.

Chapter 2:
Generating and Defending a Solution

Solution Requirements

Cost Effectiveness

The chosen solution should be cost-effective, meaning that it saves or makes more money when compared to its initial cost. This can be achieved, for example, by using cheap and efficient materials.

Eco-friendliness

The solution affects the environment negatively, whether during construction or operating period. The construction method or the mechanism of the solution shouldn't involve any emissions of harmful substances or pollutants. The materials used should be natural, recycled, or recyclable.

Availability of Materials

The materials or methods which are used in the solution should be widely available to make it able to be used in different areas across the world. This will contribute to solving the prescribed problem in different countries, not only in Egypt.

Safety

The solution should be user-friendly and safe to people who use it. It shouldn't emit any poisonous gases. Any leak or explosion from the solution should be prevented. Extreme temperatures of the solution must not affect users.

Sustainability

The solution should be able to operate for long time without need for regular maintenance in order to decrease the overall cost of it. Weather and environmental conditions shouldn't affect the efficiency of the solution.

Design Requirements

- The selected solution should produce a minimum amount of electricity of 150 Joules in at most 5 minutes, which is equivalent to 0.5 watts.
- The design must prove to be efficient in generating energy. It should aim to convert at least 10% of absorbed energy into electrical energy.
- The selected solution should utilize the school environment or student activities as a source of energy.
- The materials used in the prototype should be recycled or natural.

- The energy produced must be stored in an electric storage device, a battery for example.
- The electricity generated or stored should be used in other applications, such as lightening or charging devices.
- The prototype must have an overlap ratio in the range from 20% to 30% to achieve maximum efficiency, as was proved in previous research papers.

Selection of Solution

In searching for a possible solution, options were discarded until one remained, wind energy. Wind energy was chosen for its reliability, carbon neutrality, material minimalism, and structural simplicity.

As the chosen location is STEM October, a boarding school, making minimum sound is important, as students can stay at the school for multiple weeks at a time. STEM October is also far from water bodies, making air omni-directional. Additionally, the cheaper a solution is the easier it will be for the school to continue using it.

Wind turbines have two types, horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs). HAWTs are more scalable than VAWTs, have higher efficiency, and are generally cheaper to construct due to the large number of factories specialized in them. On the other hand, HAWTs are highly directional, while VAWTs are omni-directional. Additionally, VAWTs make less sound than HAWTs and are easier to maintain. This makes VAWTs fitter for STEM October.

VAWTs consist of two types, drag-type and lift-type. They are also called Savonius and Darrieus turbines respectively, after their respective inventors. Savonius turbines require minimal air velocity to start due to the high drag difference between blades. Savonius turbines usually max their speed very quickly relative to wind speeds, while Darrieus turbines can accelerate further. The location, STEM October, doesn't have fast wind speeds, thus making Savonius turbines the selected solution.

Savonius turbines work by utilizing the low drag in a convex side and high drag in a concave side. These two drag forces lead to different and opposing torques, thus, to increase efficiency, it's crucial to increase one torque, called primary, moreover the direction of primary rotation, and decrease the other, called opposing, as much as possible, **as shown in figure 32**, as their difference is directly responsible for the rotations per minute of the Savonius turbine. Aerodynamic flow is allowed by making way for streamlines to flow between blades. Two blades were used instead of more, as having more surfaces would only increase opposing torque. The Savonius turbine also allows for multiple layers, which was done.

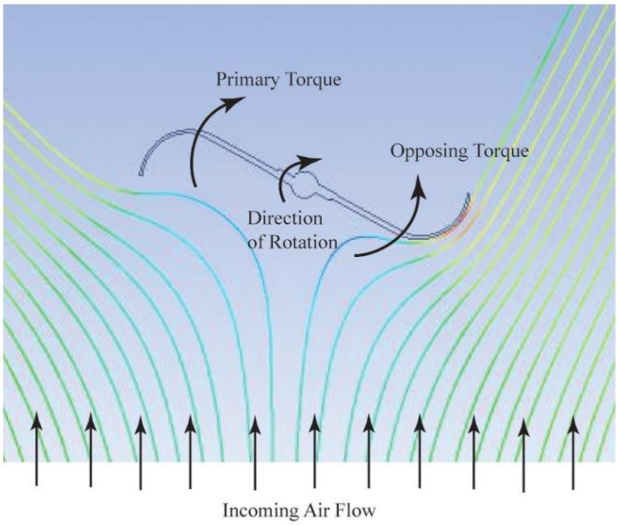

Figure 32: Vertical cross section of savonius turbine

The wind turbine will be made from lightweight material. It mainly consists of 2 plastic cylindrical surfaces per layer, a wooden shaft to transmit rotational energy, a wooden frame with attached ball bearings, allowing the shaft to be suspended and thus the turbine, a generator to change rotational energy into electrical energy, and a battery to store any leftover electricity for later less-windy times.

Selection of Prototype

The selected solution is a vertical axis wind turbine (VAWT) of the Savonius type. A 3D model of the prototype **is shown in Figure 33**. The Savonius wind turbine has a shape of half-cylindrical blades attached to the opposite sides of a vertical shaft **as shown in Figure 34.** Each pair of blades is supported by two bases on the top and the bottom, which are connected to a stick that works as an axis or a shaft. The entire turbine is installed on a wooden frame to hold it and allow it to rotate freely. A generator is connected to the shaft so that as it rotates, mechanical energy is converted to electricity by the generator. The generator is connected to a battery to store the produced energy.

Figure 33 : A 3D model of the protoype

As the wind blows into the turbine and comes into contact with the concave and convex surfaces of the blades, drag and lift forces are exerted on those surfaces. The drag force is the main driving force of the Savonius turbine. It's responsible for the starting torque of the turbine, while the maintenance of the rotation is mainly due to the lift force. This allows the turbine to rotate and the mechanical energy is transferred to the generator. The generator converts this energy to electricity, which is stored in the battery.

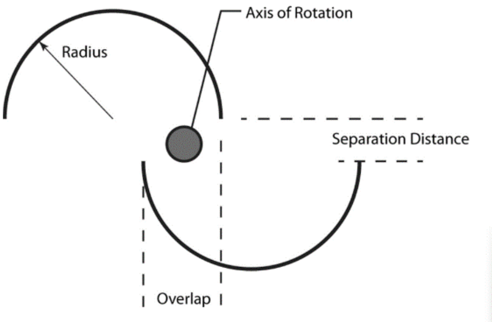

Figure 34 : A top-down view of the Savonius wind turbine

The dimensions of the prototype are as follows. The blades are 25 cm in height and 27 in diameter, as higher cross-sectional area increases generated power. The height of the axis is 120 cm and the diameter of the base is 52 cm. Two sides of the wooden frame are 100 cm height and the others are 60 cm length. The ball bearings are of 2 cm diameter as well as the axis.

The materials used to construct the prototype are all recycled or natural. A wooden broom stick will be used as a shaft. Two plastic buckets will be cut into halves to form the blades. The bases will be made of recycled polystyrene foam. A fan motor will be used to convert the mechanical energy to electricity. Wood planks of different dimensions will be used to form the frame, and nails were used to connect them. Ball bearings will be used to allow the rotation of the turbine. Glue will be used to assemble different parts of the prototype. A battery is used to store the generated electricity.

Chapter 3:

Constructing and Testing a Prototype

Materials and Methods

Table 1: The materials used in the prototype

Item	Quantity	Description	Usage	Cost	Source	Picture
Plastic buckets	2 buckets	Old buckets made of plastic.	Plastic buckets were used to form the blades.	–	Donated	
Polystyrene foam	3 sheets	(60×60) cm foam sheets.	Foam was used to make the bases.	–	Donated	
Wooden planks	4 planks	2 planks (100×10) cm. 2 planks (70×10) cm.	Wood planks were used to construct the frame (holder) of the turbine.	250	Carpenter	
Broom stick	1 stick	A used broom stick with length 120 cm.	A broom stick was used as the axis of the generator.	–	Donated	
DC generator	1 generator	DC motor, 12-24 V, was use as a generator.	A DC motor was used as a generator to convert mechanical energy to electricity.	50 EGP	Electronics store (used)	

Gears	1 large gear 1 small gear	Two gears were made using recycled plastic by 3-D printer.	Two gears, with a ratio 4:1, were used to increase the number of rotations per minute (rpm).	–	3-D printed (school Fab Lab)	
Ball bearings	2 bearings	Ball bearings were taken from an old toy.	Ball bearings were fixed to the frame to hold the turbine suspended.	–	Recycled	
White glue	0.25 kg		White glue was used to connect different parts of the turbine.	–	Donated	
Lithium-ion battery	1 battery	3.7 Volts 1200 milliamperes.	Lithium-ion battery was used to store the generated electricity.	90 EGP	Electronics store	
Nails	22 nails with different sizes	Nails made of iron.	Nails were used to stick the wood frame together.	–	Donated	

90° nail brackets	8 angles	Angles made of iron.	Angles were used to keep the frame and the generator holder at right angles.	_	Donated	

Methods

Figure 35: A 3D model of the prototype.

1. A 3D model of the prototype, **shown in Figure 35**, was made to help in construction and simulation.
2. Two plastic buckets were cut into halves to form the blades with a height of 25 cm and a diameter of 27 cm.
3. Circular bases of a diameter of 52 cm were made of polystyrene foam slabs.
4. Glue was used to fix the blades to the bases and to connect the two layers of the turbine.
5. A wooden broomstick was inserted in the turbine's center through the foam slabs to form the shaft.
6. Two foam squares of side length 15 cm and thickness 3 cm were connected to the two ends of the turbine using white glue to support it.

Figure 36: Ball bearing after fixing it to the frame.

7. A hole of diameter 2.5 cm was drilled in two wooden planks of length 62 cm and width 10 cm.
8. Ball bearings were secured in the previous planks using nails **as shown in Figure 36.**
9. Two wooden planks of length 100 cm were connected with the aforementioned planks to construct the frame of the turbine.
10. The turbine was installed in the frame, **as shown in Figure 37,** and bearings were adjusted to suspend the shaft well.

Figure 37: The turbine installed in the frame.

Figure 38: The generator fixed to the frame

11. Two gears, with a ratio 4:1, were used. The larger one was connected to the shaft and the smaller to a generator, with both connected via their teeth.
12. The generator was fixed to the frame, **as shown in Figure 38**, so that it rotated with the turbine.

Safety Precautions

Gloves were used during assembling of the prototype for protection against injuries that result from using hammers and screwdrivers. Coats were also always worn during the construction process to ensure protection from any material spills. Medical masks were used because painting the prototype was considered to emit harmful gases.

Test Plan

Design Requirements

- The selected solution should produce a minimum amount of electricity of 150 Joules in at most 5 minutes, which is equivalent to 0.5 watts.
- The design must prove to be efficient in generating energy. It should aim to convert at least 10% of absorbed energy into electrical energy.
- The energy produced must be stored in an electric storage device, a battery for example.
- The electricity generated or stored should be used in other applications, such as lightening or charging devices.
- The overlap ratio must be between 20% and 30%, calculated to be the optimal range by previous research papers.

Test Plan

A set of criteria were set to ensure the prototype's feasibility, allowing improvement on points of possible weakness.

Figure 39: The multimeter connected to the generator

1. A multimeter was used, **as shown in Figure 39**, to measure the current and voltage every second for 5 minutes. The average for voltage and current was calculated using a computer program. Then, the watt value was calculated with the equation $W = VI$, where W is power, V is potential difference, and I is current intensity, to make sure it fulfills the minimum, 0.5 $watts$.
2. To calculate efficiency, power input was calculated using the equation $P_{in} = \frac{1}{2}\rho AV^3$, where P_{in} is power input, ρ is air density, A is the area of the turbine blade, and V is wind speed. Overall turbine efficiency was calculated using the equation $C_p = \frac{P_{out}}{p_{in}}$, where C_p is the power coefficient, or turbine efficiency, P_{out} is the power outputted, measured using the previous criteria, and P_{in} is the power inputted. C_p value was made sure to not be less than 0.1.
3. A battery was charged by using the prototype's energy output, then a light-emitting diode (LED) was connected to the battery, **as shown in Figure 40,** to

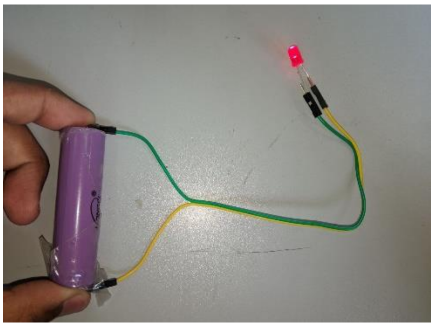

Figure 40: The LED lighted by the charged battery.

check if the energy produced could be successfully used in other applications.

4. The overlap ratio was calculated to ensure if it fell in the optimal range between 20% and 30%.

Data Collection

Measuring Tool

A measuring tape with an uncertainty of $\pm 0.05\ cm$ was used to measure the dimensions of different parts of the prototype. A multimeter was used to measure the current intensity with an uncertainty of $\pm(1\% + 2\ dgt)\ Amp$ and the potential difference with an uncertainty of $\pm(0.5\% + \ 2dgt)\ Volt$.

Negative Results

Colloidal resin, the substance used at first to stick the blades, ate away the bases, which decreased aerodynamic efficiency. One of the blades wasn’t fixed well to the bases, which led to its breaking when exposed to a high-speed wind. The gears were first positioned incorrectly, which led to the stopping of the smaller gear, thus leading to the loss of energy.

Positive Results

The prototype fulfilled the design requirements, where it generated an average of 1.47 ± 0.11 watt over a span of 5 minutes, or a total of 441 ± 33 joules. The efficiency was calculated to be $(17 \pm 1.3)\%$, with a maximum of 7.28 volts and 0.58 amperes achieved. **Figure 41** displays the graph of potential difference values, while **Figure 42** presents the graph of current intensity. **Table 2** shows the actual values of potential difference, and the values of current intensity **are shown in Table 3**. The overlap ratio was calculated to be $(29 + 0.52)\%$, lying in the optimal range of 20% to 30%.

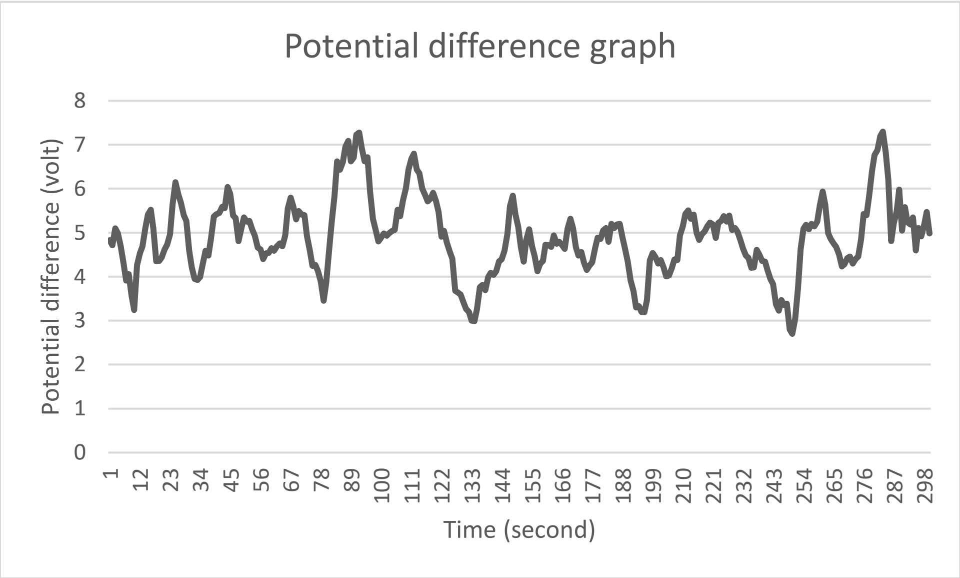

Figure 42: Potential difference graph

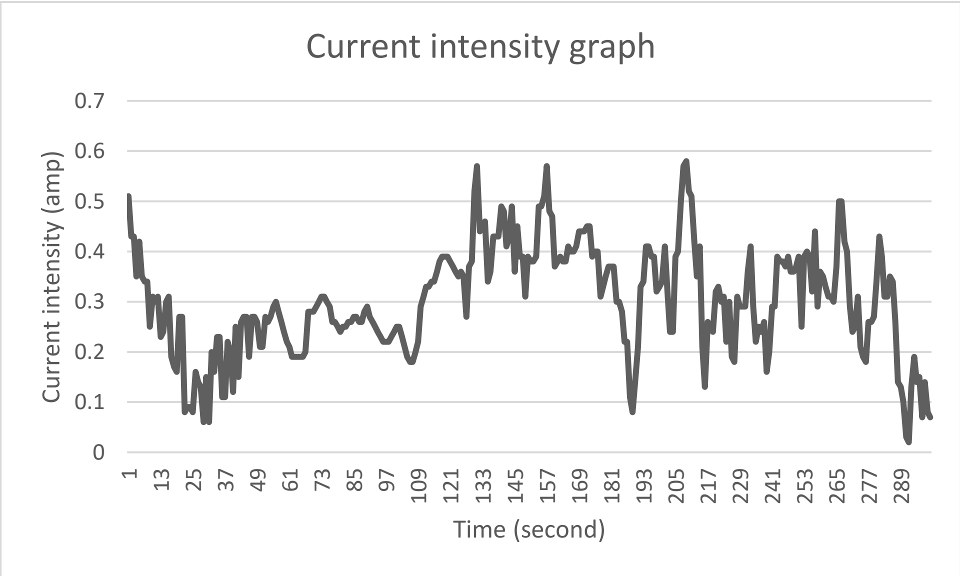

Figure 41: Current intensity graph

Table 2: Potential difference values

4.83 ± 0.04415	5.25 ± 0.04625	4.98 ± 0.0449	4.68 ± 0.0434	4.3 ± 0.0415	3.04 ± 0.0352
4.71 ± 0.04355	5.27 ± 0.04635	4.93 ± 0.04465	4.34 ± 0.0417	4.38 ± 0.0419	3.75 ± 0.03875
5.1 ± 0.0455	5.07 ± 0.04535	4.99 ± 0.04495	4.84 ± 0.0442	4.21 ± 0.04105	4.62 ± 0.0431
4.99 ± 0.04495	4.93 ± 0.04465	5.04 ± 0.0452	5.08 ± 0.0454	4.01 ± 0.04005	5.09 ± 0.04545
4.69 ± 0.04345	4.66 ± 0.0433	5.06 ± 0.0453	4.69 ± 0.04345	4.03 ± 0.04015	5.18 ± 0.0459
4.34 ± 0.0417	4.62 ± 0.0431	5.52 ± 0.0476	4.47 ± 0.04235	4.18 ± 0.0409	5.08 ± 0.0454
3.91 ± 0.03955	4.4 ± 0.042	5.38 ± 0.0469	4.12 ± 0.0406	4.39 ± 0.04195	5.2 ± 0.046
4.06 ± 0.0403	4.53 ± 0.04265	5.74 ± 0.0487	4.29 ± 0.04145	4.38 ± 0.0419	5.14 ± 0.0457
3.56 ± 0.0378	4.54 ± 0.0427	6.01 ± 0.05005	4.36 ± 0.0418	4.94 ± 0.0447	5.25 ± 0.04625
3.24 ± 0.0362	4.65 ± 0.04325	6.43 ± 0.05215	4.73 ± 0.04365	5.14 ± 0.0457	5.62 ± 0.0481
4.26 ± 0.0413	4.59 ± 0.04295	6.68 ± 0.0534	4.72 ± 0.0436	5.43 ± 0.04715	5.94 ± 0.0497
4.53 ± 0.04265	4.69 ± 0.04345	6.8 ± 0.054	4.68 ± 0.0434	5.51 ± 0.04755	5.64 ± 0.0482
4.69 ± 0.04345	4.76 ± 0.0438	6.43 ± 0.05215	4.94 ± 0.0447	5.32 ± 0.0466	4.99 ± 0.04495
5.11 ± 0.04555	4.69 ± 0.04345	6.35 ± 0.05175	4.75 ± 0.04375	5.41 ± 0.04705	4.86 ± 0.0443
5.41 ± 0.04705	4.94 ± 0.0447	6 ± 0.05	4.79 ± 0.04395	5 ± 0.045	4.76 ± 0.0438
5.52 ± 0.0476	5.55 ± 0.04775	5.86 ± 0.0493	4.71 ± 0.04355	4.84 ± 0.0442	4.68 ± 0.0434
5.09 ± 0.04545	5.8 ± 0.049	5.71 ± 0.04855	4.63 ± 0.04315	4.97 ± 0.04485	4.51 ± 0.04255
4.35 ± 0.04175	5.6 ± 0.048	5.78 ± 0.0489	5.09 ± 0.04545	5.03 ± 0.04515	4.23 ± 0.04115
4.36 ± 0.0418	5.3 ± 0.0465	5.91 ± 0.04955	5.32 ± 0.0466	5.15 ± 0.04575	4.28 ± 0.0414
4.44 ± 0.0422	5.49 ± 0.04745	5.72 ± 0.0486	5.11 ± 0.04555	5.23 ± 0.04615	4.42 ± 0.0421
4.62 ± 0.0431	5.41 ± 0.04705	5.47 ± 0.04735	4.67 ± 0.04335	5.19 ± 0.04595	4.46 ± 0.0423
4.73 ± 0.04365	5.4 ± 0.047	4.91 ± 0.04455	4.48 ± 0.0424	4.88 ± 0.0444	4.3 ± 0.0415
4.96 ± 0.0448	4.92 ± 0.0446	5.04 ± 0.0452	4.56 ± 0.0428	5.22 ± 0.0461	4.39 ± 0.04195
5.64 ± 0.0482	4.59 ± 0.04295	4.77 ± 0.04385	4.33 ± 0.04165	5.27 ± 0.04635	4.46 ± 0.0423
6.15 ± 0.05075	4.25 ± 0.04125	4.57 ± 0.04285	4.15 ± 0.04075	5.38 ± 0.0469	4.85 ± 0.04425
5.87 ± 0.04935	4.27 ± 0.04135	4.41 ± 0.04205	4.25 ± 0.04125	5.25 ± 0.04625	5.43 ± 0.04715
5.68 ± 0.0484	4.13 ± 0.04065	3.68 ± 0.0384	4.33 ± 0.04165	5.39 ± 0.04695	5.4 ± 0.047
5.4 ± 0.047	3.89 ± 0.03945	3.64 ± 0.0382	4.65 ± 0.04325	5.06 ± 0.0453	5.83 ± 0.04915
5.27 ± 0.04635	3.45 ± 0.03725	3.59 ± 0.03795	4.89 ± 0.04445	5.11 ± 0.04555	6.4 ± 0.052
4.59 ± 0.04295	3.86 ± 0.0393	3.43 ± 0.03715	4.86 ± 0.0443	5.02 ± 0.0451	6.77 ± 0.05385
4.21 ± 0.04105	4.6 ± 0.043	3.26 ± 0.0363	5.05 ± 0.04525	4.83 ± 0.04415	6.88 ± 0.0544
3.95 ± 0.03975	5.23 ± 0.04615	3.2 ± 0.036	5.11 ± 0.04555	4.64 ± 0.0432	7.2 ± 0.056
3.93 ± 0.03965	5.84 ± 0.0492	3 ± 0.035	4.79 ± 0.04395	4.48 ± 0.0424	7.3 ± 0.0565
3.99 ± 0.03995	6.62 ± 0.0531	2.99 ± 0.03495	5.2 ± 0.046	4.43 ± 0.04215	6.83 ± 0.05415
4.31 ± 0.04155	6.43 ± 0.05215	3.26 ± 0.0363	5.11 ± 0.04555	4.2 ± 0.041	6.21 ± 0.05105
4.59 ± 0.04295	6.61 ± 0.05305	3.76 ± 0.0388	5.19 ± 0.04595	4.21 ± 0.04105	4.81 ± 0.04405
4.48 ± 0.0424	6.96 ± 0.0548	3.81 ± 0.03905	5.2 ± 0.046	4.61 ± 0.04305	5.21 ± 0.04605
4.87 ± 0.04435	7.09 ± 0.05545	3.69 ± 0.03845	4.91 ± 0.04455	4.49 ± 0.04245	5.48 ± 0.0474
5.37 ± 0.04685	6.62 ± 0.0531	3.99 ± 0.03995	4.62 ± 0.0431	4.36 ± 0.0418	5.98 ± 0.0499
5.42 ± 0.0471	6.71 ± 0.05355	4.09 ± 0.04045	4.34 ± 0.0417	4.34 ± 0.0417	5.05 ± 0.04525
5.45 ± 0.04725	7.23 ± 0.05615	4.04 ± 0.0402	3.91 ± 0.03955	4.14 ± 0.0407	5.58 ± 0.0479
5.59 ± 0.04795	7.28 ± 0.0564	4.12 ± 0.0406	3.67 ± 0.03835	3.94 ± 0.0397	5.24 ± 0.0462
5.56 ± 0.0478	6.93 ± 0.05465	4.35 ± 0.04175	3.3 ± 0.0365	3.83 ± 0.03915	5.19 ± 0.04595
6.04 ± 0.0502	6.62 ± 0.0531	4.39 ± 0.04195	3.33 ± 0.03665	3.37 ± 0.03685	5.35 ± 0.04675
5.89 ± 0.04945	6.72 ± 0.0536	4.59 ± 0.04295	3.2 ± 0.036	3.23 ± 0.03615	4.6 ± 0.043
5.39 ± 0.04695	5.94 ± 0.0497	4.97 ± 0.04485	3.19 ± 0.03595	3.47 ± 0.03735	5.11 ± 0.04555
5.33 ± 0.04665	5.31 ± 0.04655	5.6 ± 0.048	3.47 ± 0.03735	3.35 ± 0.03675	4.92 ± 0.0446
4.81 ± 0.04405	5.08 ± 0.0454	5.84 ± 0.0492	4.37 ± 0.04185	3.39 ± 0.03695	5.18 ± 0.0459
5.1 ± 0.0455	4.8 ± 0.044	5.42 ± 0.0471	4.54 ± 0.0427	2.8 ± 0.034	5.47 ± 0.04735
5.35 ± 0.04675	4.88 ± 0.0444	5.13 ± 0.04565	4.45 ± 0.04225	2.7 ± 0.0335	4.98 ± 0.0449

Table 3: Current intensity values

0.51 ± 0.0251	0.21 ± 0.0221	0.25 ± 0.0225	0.38 ± 0.0238	0.41 ± 0.0241	0.39 ± 0.0239
0.43 ± 0.0243	0.27 ± 0.0227	0.25 ± 0.0225	0.38 ± 0.0238	0.32 ± 0.0232	0.25 ± 0.0225
0.43 ± 0.0243	0.26 ± 0.0226	0.23 ± 0.0223	0.39 ± 0.0239	0.24 ± 0.0224	0.39 ± 0.0239
0.35 ± 0.0235	0.27 ± 0.0227	0.21 ± 0.0221	0.49 ± 0.0249	0.24 ± 0.0224	0.4 ± 0.024
0.42 ± 0.0242	0.29 ± 0.0229	0.19 ± 0.0219	0.49 ± 0.0249	0.39 ± 0.0239	0.39 ± 0.0239
0.35 ± 0.0235	0.3 ± 0.023	0.18 ± 0.0218	0.51 ± 0.0251	0.4 ± 0.024	0.32 ± 0.0232
0.34 ± 0.0234	0.28 ± 0.0228	0.18 ± 0.0218	0.57 ± 0.0257	0.5 ± 0.025	0.44 ± 0.0244
0.34 ± 0.0234	0.26 ± 0.0226	0.2 ± 0.022	0.48 ± 0.0248	0.57 ± 0.0257	0.29 ± 0.0229
0.25 ± 0.0225	0.24 ± 0.0224	0.22 ± 0.0222	0.47 ± 0.0247	0.58 ± 0.0258	0.36 ± 0.0236
0.31 ± 0.0231	0.22 ± 0.0222	0.29 ± 0.0229	0.37 ± 0.0237	0.52 ± 0.0252	0.35 ± 0.0235
0.3 ± 0.023	0.21 ± 0.0221	0.31 ± 0.0231	0.38 ± 0.0238	0.51 ± 0.0251	0.33 ± 0.0233
0.31 ± 0.0231	0.19 ± 0.0219	0.33 ± 0.0233	0.39 ± 0.0239	0.42 ± 0.0242	0.31 ± 0.0231
0.23 ± 0.0223	0.19 ± 0.0219	0.33 ± 0.0233	0.38 ± 0.0238	0.35 ± 0.0235	0.31 ± 0.0231
0.24 ± 0.0224	0.19 ± 0.0219	0.34 ± 0.0234	0.38 ± 0.0238	0.41 ± 0.0241	0.3 ± 0.023
0.3 ± 0.023	0.19 ± 0.0219	0.34 ± 0.0234	0.41 ± 0.0241	0.21 ± 0.0221	0.37 ± 0.0237
0.31 ± 0.0231	0.19 ± 0.0219	0.36 ± 0.0236	0.4 ± 0.024	0.13 ± 0.0213	0.5 ± 0.025
0.19 ± 0.0219	0.2 ± 0.022	0.38 ± 0.0238	0.4 ± 0.024	0.26 ± 0.0226	0.5 ± 0.025
0.17 ± 0.0217	0.28 ± 0.0228	0.39 ± 0.0239	0.41 ± 0.0241	0.25 ± 0.0225	0.42 ± 0.0242
0.16 ± 0.0216	0.28 ± 0.0228	0.39 ± 0.0239	0.44 ± 0.0244	0.24 ± 0.0224	0.4 ± 0.024
0.27 ± 0.0227	0.28 ± 0.0228	0.39 ± 0.0239	0.44 ± 0.0244	0.32 ± 0.0232	0.29 ± 0.0229
0.27 ± 0.0227	0.29 ± 0.0229	0.38 ± 0.0238	0.44 ± 0.0244	0.33 ± 0.0233	0.24 ± 0.0224
0.08 ± 0.0208	0.3 ± 0.023	0.37 ± 0.0237	0.45 ± 0.0245	0.3 ± 0.023	0.25 ± 0.0225
0.09 ± 0.0209	0.31 ± 0.0231	0.36 ± 0.0236	0.45 ± 0.0245	0.31 ± 0.0231	0.31 ± 0.0231
0.09 ± 0.0209	0.31 ± 0.0231	0.35 ± 0.0235	0.39 ± 0.0239	0.22 ± 0.0222	0.21 ± 0.0221
0.08 ± 0.0208	0.3 ± 0.023	0.36 ± 0.0236	0.4 ± 0.024	0.3 ± 0.023	0.19 ± 0.0219
0.16 ± 0.0216	0.29 ± 0.0229	0.35 ± 0.0235	0.4 ± 0.024	0.19 ± 0.0219	0.18 ± 0.0218
0.14 ± 0.0214	0.26 ± 0.0226	0.27 ± 0.0227	0.31 ± 0.0231	0.18 ± 0.0218	0.26 ± 0.0226
0.13 ± 0.0213	0.26 ± 0.0226	0.37 ± 0.0237	0.33 ± 0.0233	0.31 ± 0.0231	0.26 ± 0.0226
0.06 ± 0.0206	0.25 ± 0.0225	0.38 ± 0.0238	0.35 ± 0.0235	0.29 ± 0.0229	0.27 ± 0.0227
0.15 ± 0.0215	0.24 ± 0.0224	0.52 ± 0.0252	0.37 ± 0.0237	0.29 ± 0.0229	0.34 ± 0.0234
0.06 ± 0.0206	0.25 ± 0.0225	0.57 ± 0.0257	0.37 ± 0.0237	0.29 ± 0.0229	0.43 ± 0.0243
0.2 ± 0.022	0.25 ± 0.0225	0.44 ± 0.0244	0.37 ± 0.0237	0.36 ± 0.0236	0.39 ± 0.0239
0.16 ± 0.0216	0.26 ± 0.0226	0.45 ± 0.0245	0.3 ± 0.023	0.41 ± 0.0241	0.31 ± 0.0231
0.23 ± 0.0223	0.26 ± 0.0226	0.46 ± 0.0246	0.3 ± 0.023	0.29 ± 0.0229	0.31 ± 0.0231
0.23 ± 0.0223	0.27 ± 0.0227	0.34 ± 0.0234	0.28 ± 0.0228	0.22 ± 0.0222	0.35 ± 0.0235
0.11 ± 0.0211	0.27 ± 0.0227	0.36 ± 0.0236	0.22 ± 0.0222	0.25 ± 0.0225	0.34 ± 0.0234
0.11 ± 0.0211	0.26 ± 0.0226	0.43 ± 0.0243	0.22 ± 0.0222	0.24 ± 0.0224	0.26 ± 0.0226
0.22 ± 0.0222	0.26 ± 0.0226	0.43 ± 0.0243	0.11 ± 0.0211	0.26 ± 0.0226	0.14 ± 0.0214
0.2 ± 0.022	0.28 ± 0.0228	0.43 ± 0.0243	0.08 ± 0.0208	0.16 ± 0.0216	0.13 ± 0.0213
0.12 ± 0.0212	0.29 ± 0.0229	0.49 ± 0.0249	0.14 ± 0.0214	0.2 ± 0.022	0.1 ± 0.021
0.25 ± 0.0225	0.27 ± 0.0227	0.48 ± 0.0248	0.21 ± 0.0221	0.29 ± 0.0229	0.03 ± 0.0203
0.15 ± 0.0215	0.26 ± 0.0226	0.41 ± 0.0241	0.33 ± 0.0233	0.29 ± 0.0229	0.02 ± 0.0202
0.26 ± 0.0226	0.25 ± 0.0225	0.43 ± 0.0243	0.34 ± 0.0234	0.39 ± 0.0239	0.13 ± 0.0213
0.27 ± 0.0227	0.24 ± 0.0224	0.49 ± 0.0249	0.41 ± 0.0241	0.38 ± 0.0238	0.19 ± 0.0219
0.27 ± 0.0227	0.23 ± 0.0223	0.36 ± 0.0236	0.41 ± 0.0241	0.38 ± 0.0238	0.14 ± 0.0214
0.19 ± 0.0219	0.22 ± 0.0222	0.45 ± 0.0245	0.39 ± 0.0239	0.37 ± 0.0237	0.15 ± 0.0215
0.27 ± 0.0227	0.22 ± 0.0222	0.39 ± 0.0239	0.39 ± 0.0239	0.39 ± 0.0239	0.07 ± 0.0207
0.27 ± 0.0227	0.22 ± 0.0222	0.39 ± 0.0239	0.32 ± 0.0232	0.36 ± 0.0236	0.14 ± 0.0214
0.26 ± 0.0226	0.23 ± 0.0223	0.31 ± 0.0231	0.33 ± 0.0233	0.36 ± 0.0236	0.08 ± 0.0208
0.21 ± 0.0221	0.24 ± 0.0224	0.39 ± 0.0239	0.34 ± 0.0234	0.37 ± 0.0237	0.07 ± 0.0207

Chapter 4:

Evaluation, Reflection, Recommendations and Discussion

Analysis and Discussion

Analysis

Effect of blade overlap on blade efficiency

The prototype's efficiency was optimized by overlapping the blades over each other, **as shown in figure 43**. This improved aerodynamic flow, as it gives incoming wind currents a path to follow unto the concave side of the right blade, further increasing drag force producing the primary torque. **Figure 43** shows an approximation of the distribution of an incoming air current, where air approaches at $\theta = 0°$ in the upper drawing and $\theta = 90°$ in the lower drawing.

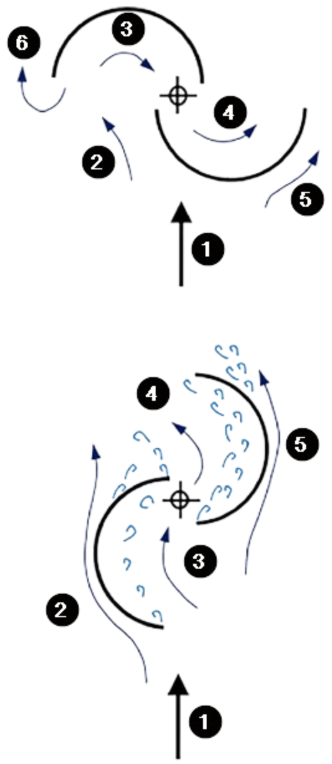

Figure 43: Effects of blade overlap on the distribution of incoming air currents.

In the lower drawing, as discussed in PH.1.09, separation regions are caused by the detachment of the boundary between flowing fluids, in this case air, and the object, in this case the blade. It causes turbulent flow in those spots, symbolized in the figure with eddies .

Upon the interaction of a fluid with an object, depending on the shape of the object and texture, drag and lift forces result. Drag is in a direction parallel to the flow, while lift is perpendicular to the flow. In the prototype, drag force is classified into two: opposing and primary. Primary drag is in the direction of main rotation, and opposing is in the opposite direction. The net drag force is their difference, and it represents the real force which will affect the turbine. Meaning that minimizing opposing drag and increasing primary drag both increase turbine efficiency. The net drag force results in torque, which rotates the turbine, in addition to lift force resulting from the recirculation of air in the upper drawing and current distribution in the lower drawing, due to the overlap opening. **In figure 43**, currents 3 and 4 result in primary drag in both drawings. In the upper drawing, only current 5 causes opposing drag force, while in the lower drawing, currents 2 and 5 result in opposing drag force. (Simon Prince, 2020, pp. 2-4)

The overlap ratio is a relation between the diameter of the base and the overlap distance. The overlap distance is the length of the diameter part that's in the overlap. It was calculated using the following equation:

$$\alpha = AC + BD - D_{AB} = 2d - D_{AB} = 2 \cdot \big((27 \pm 0.1)\ cm\big) - (42 \pm 0.1)\ cm$$
$$= (12 \pm 0.22)\ cm$$

As represented in figure 44, AC and BD are diameters, and since they are equal, they are equated to $2d$, and D_{AB} is the distance between point A and B.

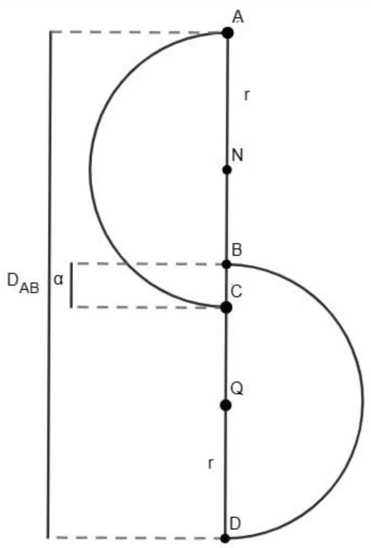

Figure 44: Vertical cross-sectional drawing of the turbine's blades.

The overlap coefficient/ratio can be calculated by the following equation (Khandakar Niaz Morshed, 2013, pp. 4):

$$C = \frac{\alpha}{D_{AB}} = \frac{(12 \pm 0.22)\ cm}{(42 \pm 0.1)\ cm} = 0.29 \pm 0.0052$$
$$= (29 \pm 0.52)\%$$

where C is the overlap coefficient and α is the overlap distance. Previous research papers have shown by experimentation that the optimal overlap coefficient range is between 20% and 30%, (Mohd Zamri Ibrahim, 2013, pp. 3) thus the coefficient is in such optimal range. Past papers have shown that optimal overlap ratios can increase efficiency by upwards of ~28%. (J. Thiyagaraj, 2021, pp. 6)

Power coefficient calculation

In order to ensure the prototype fulfilled design requirements and had relatively high efficiency, the power contained in the wind at that time had to be calculated, which 100% of it would be acquired as electricity if no loss of energy occurred. To calculate it, the swept area must be calculated, or A_s. First, the height of a blade was measured, then multiplied it by 2 since a double layer turbine is used.

$$h = 2 \cdot h_b = 2 \cdot \big((25 \pm 0.1)\ cm\big) = (50 \pm 0.2)\ cm$$

Where h_b is the height of a blade. And h is the total height of the double layer, excluding the separating base.

Then, A_s was calculated using the following equation: (Khandakar Niaz Morshed, 2013, pp. 4)

$$A_s = h \cdot D_{AB} = (50 \pm 0.2)\ cm \cdot (42 \pm 0.1)\ cm = (2100 \pm 9.78)\ cm^2$$
$$= (0.21 \pm 0.00098)\ m^2$$

Wind velocity was retrieved from a wind map, which showed that air speed, or v_w, was $4\frac{m}{s}$ at the time of the test plan in STEM October school.

Using all aforementioned calculations and measurements, the power contained in wind, or P_w, was calculated using the equation: (Alexander Kalmikov, 2017, pp. 4)

$$P_w = \frac{1}{2} \cdot \rho_w \cdot A_S \cdot v_w^3 = \frac{1}{2} \cdot 1.293\frac{kg}{m^3} \cdot (0.21 \pm 0.00098)\, m^2 \cdot \left(4\frac{m}{s}\right)^3$$
$$= (8.69 \pm 0.04)\, watt$$

where P_w is wind power and ρ_w is the density of the wind, with an average value of $1.293\frac{kg}{m^3}$ at a temperature of 273 K and a pressure of 101.325 kPa. (Nasa, 2019)

Using P_w, the coefficient of power, or efficiency in terms of wind turbines, was able to be calculated using the following equation: (Khandakar Niaz Morshed, 2013, pp. 4)

$$C_p = \frac{P_t}{P_w} = \frac{(1.47 \pm 0.11)\, watt}{(8.69 \pm 0.04)\, watt} = 0.17 \pm 0.013 = (17 \pm 1.3)\%$$

where C_p is the coefficient of power, P_t is power outputted from the wind turbine, and P_w is power contained in wind.

Rotations per minute increase by gear ratio

As discussed in PH 1.05, gear ratios increase rotations per minute. Two gears were 3D printed from a fabrication lab using PLA+. To calculate the gear ratio, the amount of gear teeth on each was counted, where the larger gear had $t_l = 32$ and the smaller $t_s = 8$.

By dividing the larger gear teeth number by the smaller, the gear ratio is obtained:

$$G_r = \frac{t_l}{t_s} \cdot 100 = \frac{32}{8} \cdot 100 = 400\%$$

This means that the gear ratio quadruples rotations per minute.

Inner-working of motor

A generator was used to generate electrical energy from rotation. **Figure 45** shows a cross section of a generator. The prototype causes the rotation of rotors, which are connected to windings.

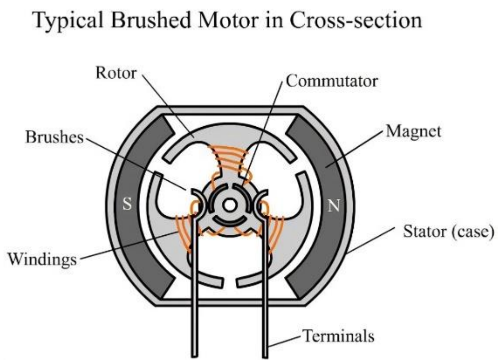

Figure 45: A cross section of the internal structure of a motor

Windings are bundles of copper wires, with magnets on the outside in the figure, but inside in this case, for electric current to pass through. Upon rotating the windings through torque transmitted by the rotors, the torque, or kinetic energy, is converted into electrical energy via electromagnetic induction. This is due to the switching of specific parts of the windings from the south pole into the north pole and vice versa, pushing and pulling loose electrons in the copper, which generates an electrical current. (eia, 2022)

Conclusions

The challenge addressed in this project is finding an alternative source of energy to power lights at nighttime in STEM October school. The solution chosen was building a Savonius vertical axis wind turbine to generate the needed electricity. Despite negative results, the prototype successfully achieved the design requirements. The generated electricity was approximately 441 joules in 5 minutes and its efficiency was about 17% by using only recycled or natural materials. This proved the prototype's ability to light LED, as was done in the test plan. In comparison with the studied prior solutions, El-Zafarana Wind Farm, the prototype achieved its points of strength and avoided its points of weakness. The prototype has a lower cost, and the generated electricity can be stored and then used easily with the storage battery system.

Recommendations

Real-life Application

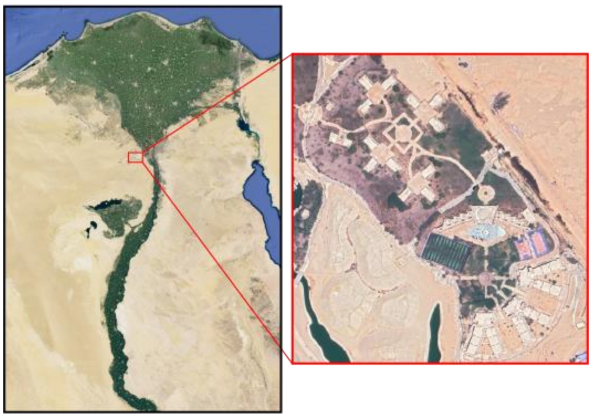

Figure 46: Location of STEM October school.

The recommended location to apply the solution is STEM High School for Boys - 6th of October, **shown in Figure 46.** The school contains many lamp posts which are either unworking or turned off in order to decrease energy consumption. Installing the turbine on these lamp posts will provide a free source of energy as well as better lighting in the area. The dimensions of the turbine are as follows: the turbine's height will be 100 cm and the base width will be 52 cm. The blades will be 25 cm in height and 27 cm in diameter. The turbine will consist of 3 layers of blades.

Fibonacci-spiral shaped blades

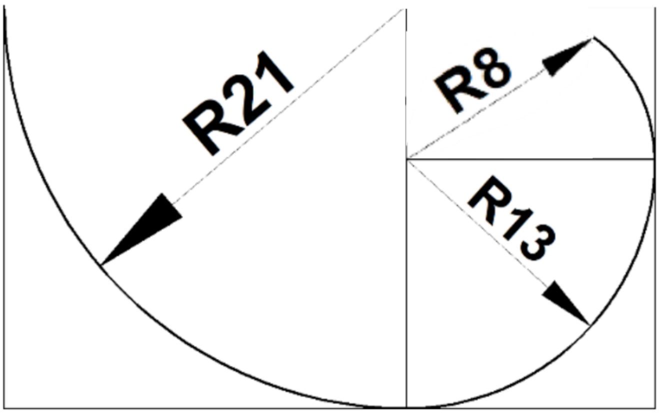

Figure 47: Suggested shape for the recommended fibonacci-spiral shaped blades

The Fibonacci spiral shape is found in many occurrences in nature and is thus a result of billions of years of evolution. It follows the shape of the Fibonacci sequence, which adds each two numbers in the following way: 1, 1, 2, 3, 5, 8, 13, 21 …. The shape makes multiple circles with radii of the sequence's numbers, **as shown in figure 47.** Multiple papers have been published on the effect of making wind turbines Fibonacci shaped, and experimentation showed that using Fibonacci-shaped blades can increase efficiency by 17.4%, at a tip speed ratio of 1, over standard Savonius blades. Applying this will require using materials with high deformity, such as thin iron metallic sheets, as iron can be easily permanently bent into required shapes.

Implementation of wind deflectors

Using a deflector in front of the returning blade, **as shown in Figure 48**, which causes opposing torque, can lead to an increase in efficiency by decreasing drag force acting on such blade, while deflecting wind onto the advancing, or primary torque blade, further increasing acceleration. Previous research papers have shown that using a plate with 0.9 porosity increased efficiency by an average of ~10% compared with a solid plate. Putting the deflector at a 90º angle with incoming air also improves efficiency. A relation between the length of the deflector and the diameter of the turbine's blades was also found, where the optimal $\frac{L}{D}$ ratio was found to be 0.99. The optimal height of the deflector was also related to the diameter, and via experimentation, the optimal $\frac{h}{D}$ turned out to be 0.257. By substituting using the prototype dimensions, where D $= (0.42 \pm 0.001)\, m$, then $L = (0.42 \pm 0.00099)\, m$ and $h = (0.11 \pm 0.000257)\, m$.

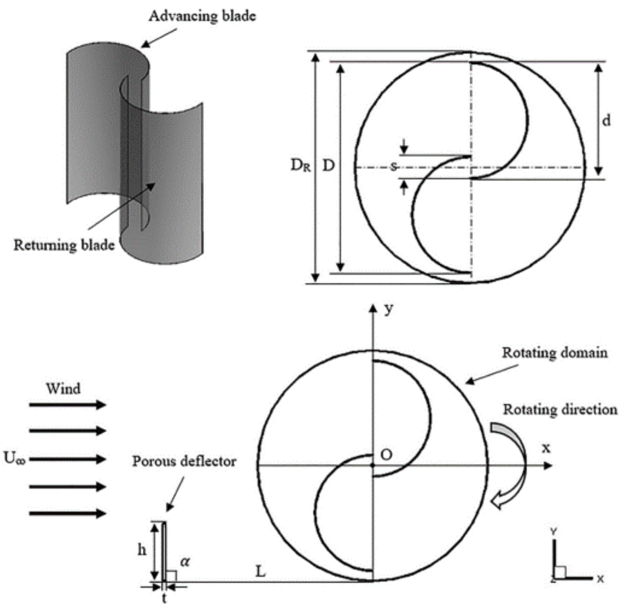

Figure 48: Vertical cross sections of a wind turbine with a porous deflector.

Recommendations to Future Teams

We recommend to initiate an in-depth planning phase, encompassing all aspects of Savonius wind turbines, such as design, materials, performance, and safety measures. You need to develop a detailed project plan, outlining timelines, milestones, and resource requirements. You have to develop design of blades, in order to increase efficiency. More strong, reliable materials should be used. Try to avoid the negative results we faced in our project. You should search new developments in the field of vertical axis wind turbines, to improve the prototype, via the application of the aforementioned recommendations. A good time plan will help you to complete the project perfectly.

Project's Positive Influence

Our team at STEM school has had a real-life changing event while designing and constructing a real-life project and a prototype for a wind turbine. This project has not only helped us to understand scientific and engineering concepts profoundly, but it has also improved our abilities to work together and communicate effectively. This project has opened up a whole new world of scientific exploration, encompassing fields such as physics. We had a better understanding to energy sources and how to improve the future of this field. The project also improved our soft skills such as communication, creativity, and teamwork.

Learning Outcomes

L.O	Description
PH. 1.02	PH 1.02 explains the different types of forces, such as drag and lift, which the prototype utilizes to generate torque.
PH. 1.05	The mechanical advantage of the gears was calculated using PH 1.05, as it discussed simple machines, such as gears, and their mechanical advantages.
PH. 1.09	The blade overlap was designed with laminar and turbulent flow in mind, which was specifically discussed in PH 1.09.
SS. Mo.1	Wind velocity was retrieved from online GIS services, which were primarily discussed in SS module 1.
CH. 1.01	CH 1.01 explains how to deal with uncertainties and significant figures, which were essential to decreasing measuring errors, and calculating multimeter error.
CS. 1.09	CS.1.09 explains the thought process of writing program code, thus It was essential for calculating multimeter uncertainty and the readings average.
ENW.1.2.4	ENW.1.2.4 in English discusses producing a clear and coherent writing, in which the development, organization, and style are appropriate to task, purpose and audience. Academic writing was used overall the portfolio.
CH. 1.09	Selection of materials was done by using CH 1.09 which discuss the properties of materials, and which one is suitable for each purpose.
ES. 1.10	Alternative energy systems were discussed in this L.O which helped us choosing the suitable location and the system of generating electricity
MA. 1.02	This L.O showed different types of graphs, and which one is suitable for each data. This helped us to represent the graph of the output potential difference and current intensity.

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