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FEASIBILITY ANALYSIS OF CSP TECHNOLOGY COUPLED WITH TES SYSTEM FOR POWER GENERATION IN INDUSTRIAL PLANTS OF BANGLADESH

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Bachelor of Science in Mechanical Engineering

DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING

May (2022)

CERTIFICATE OF RESEARCH

This thesis titled "FEASIBILITY ANALYSIS OF CSP TECHNOLOGY COUPLED WITH TES SYSTEM FOR POWER GENERATION IN INDUSTRIAL PLANTS OF BANGLADESH" submitted by FAHIM AHMED (170011001) and MITIN MUBARRAT (170011056) has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical Engineering.

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DECLARATION

I hereby declare that this thesis entitled "Feasibility Analysis of CSP Technology Coupled with TES System for Power Generation in Industrial Plants of Bangladesh" is an authentic report of study carried out as requirement for the award of degree B.Sc. (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka, under the supervision of [DR. MOHAMMAD AHSAN HABIB], Professor, MPE, IUT in the year 2022

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

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ABSTRACT

Different technologies and approaches to diverse methodology may be used to convert solar energy into electrical power, making it an important renewable energy source across the world. Photovoltaic (PV) conversion and Concentrating Solar Power (CSP) are two separate technologies for converting solar energy into electricity. In the realm of solar energy harvesting, Concentrating Solar Power (CSP) is seen as a key future option. It is more efficient and lasts longer than PV cells. CSP plants with integrated thermal energy storage (TES) technology can provide up to 12 hours of power reserve under optimal circumstances. We sought to find the optimum place in Bangladesh for a feasibility study based on the place's high average temperature and the amount of flat land that was available. Following our comparisons, we believe Kushtia may be the location we've been seeking. As part of this project, we built and optimized a 10 MW Power Tower Molten Salt-based stand-alone CSP power plant with 12 hours of thermal storage for Kushtia in System Advisory Model (SAM). It was decided that the stated site should have a DNI design point value of 950 W/m2. With a power cycle efficiency of 40.58 percent, the optimized plant's gross power cycle output is determined. There are two key obstacles for developing any CSP-based power plant: cost and the overall area it covers. The break-even threshold for this specific plant against conventional unit cost has been calculated in this study using extensive numerical analysis. The proposed power station is compared to a standard 10 MW steam power plant to evaluate its environmental and economic benefits and drawbacks. Future CSP researchers will benefit from this paper's thorough overview of the technology and research in this area. Additionally, Bangladesh's solar thermal power plant development and innovation is encouraged by this plant's feasibility study.

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Nomenclature

CSP	Concentrating Solar Power
TES	Thermal Energy Storage
MSPT	Molten Salt Power Tower
PV	Photo Voltaic
PTC	Parabolic Through Collector
SPT	Solar Power Tower
PDC	Parabolic Dish Collector
LFR	Linear Fresnel Reflector
LCOE	Levelized Cost of Energy
PCM	Phase Change Material
DNI	Direct Normal Irradiation
GHI	Global Horizontal Irradiation
HTF	Heat Transfer Fluid
SM	Solar Multiple
SHS	Sensible Heat Storage
LHS	Latent Heat Storage
HTF	Heat Transfer Fluid
DNI	Direct Normal Irradiance
PV	Photo Voltaic
EOR	Enhanced Oil Recovery
CR	Central Receiving
LCA	Life Cycle Assessment
sCO2	Supercritical Carbon Dioxide
GDP	Gross Domestic Product
SAM	System Advisory Model
NASA	National Aeronautics and Space Administration
IEA	International Energy Agency
CAPEX	Capital Expenditure
OPEX	Operational Expenditure

kNO_3	Potassium Nitrate
$NaNO_3$	Sodium Nitrate
Mtoe	Mega tons of oil equivalent
MMscfd	Million standard cubic feet per day
MWe	Megawatt electrical
MWt	Megawatt thermal
max	Maximum
min	Minimum

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND:

For many centuries, people have relied on non-renewable power sources including coal, oil, and natural gas. The known supplies of these power sources have been exhausted to a large extent due to their widespread use. Coal, petroleum, natural gas, and the like are examples of traditional energy sources.

0.64 tons of CO2 were released per capita by Bangladesh in 2020. There was an average yearly growth rate of 5.48 percent in Bangladesh's per capita CO2 emissions between 1970 and 2020 from 0.05 tons to 0.64 tons. The proportion that might not seem like lot, but if we compare it to the curve's yearly increase, it's terrifying! [1]

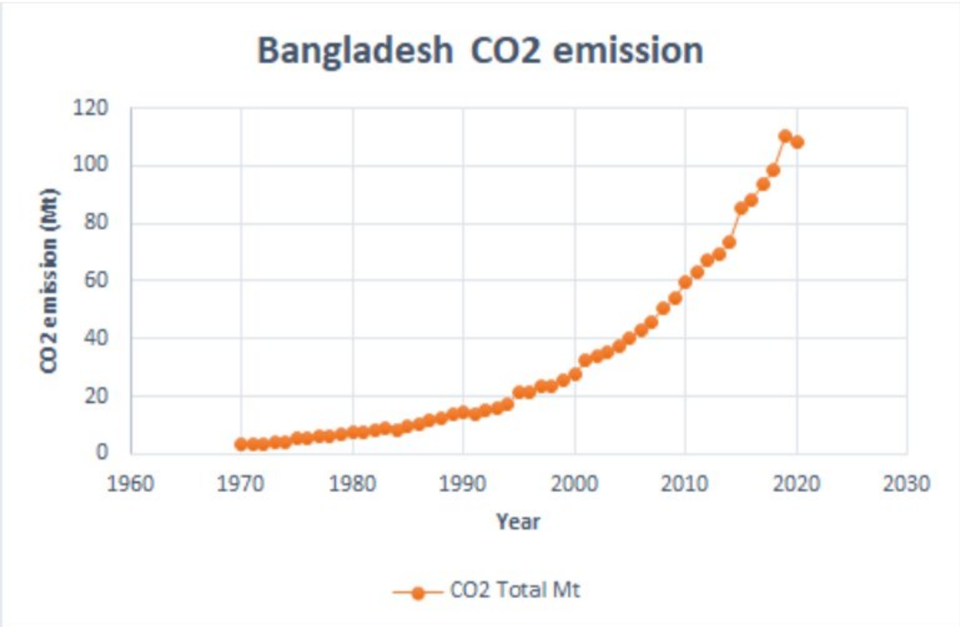

Figure 1: CO_2 Emission of Bangladesh [1]

Nonrenewable fossil fuels are becoming more and more expensive, while the supply of nonrenewable fossil energy is diminishing. Renewable resources are also cleaner. They can be regenerated or resupplied. Renewable energy sources include biomass, water, geothermal, wind, and solar.

1.2 CSP: A PROMISING REPLACEMENT

To meet human energy needs, the sun's power may be used in two different ways. One is solar photovoltaic (PV), which utilizes photovoltaic (PV) panels to collect solar energy, which is then turned directly into electricity and fed into the grids. The alternative concentrated solar power (CSP). Reflector arrangements are used to focus sun power into a single receiver in the solar thermal systems.

The steam produced by these CSP systems may drive a turbine, which in turn powers a generator, generating electricity. An estimate from the International Energy Agency (IEA) projects that by 2050, photovoltaic (PV) systems will provide up to 16 percent of the world's power, while solar thermal systems can provide up to 11 percent (Suruhanjaya Tenaga, 2016). The referred figures demonstrate how encouraging the solar energy territory may be for this world's electrical contribution, especially in light of the depletion of nonrenewable energy supplies (such as oil, fossil fuel, coal and natural gas).

Global demand for CSP services has increased dramatically in the recent decade. CSP technology has a number of advantages, including the ability to produce on-demand electricity and the ability to integrate with other energy systems. When integrated with thermal energy storage (TES) technology, a CSP plant may continue producing power under wet weather conditions and at night or early morning mist when energy stipulation is high. As an added benefit, CSP plants may be used to supplement reinforcement energy origins like energy from fossil fuel or in conjunction with fossil fuel plants in pursuance of minimizing carbon dioxide emissions. Currently, CSP industry is on a strong path of growth, laying the groundwork for future expansion. The CSP industry's continued expansion is essential if the world is to reach a 100 percent renewable energy share by 2050.

1.3 TIME FOR BANGLADESH

As a result of the year-round high levels of solar radiation seen in various parts of the country, Bangladesh has one of the world's greatest solar energy potentials. While the solar photovoltaic (PV) and solar thermal (ST) sectors have been extensively researched and applied in Bangladesh's energy producing sector, with an average of 5KWh/m2 of solar energy per square meter, Bangladesh is a suitable place to build CSP projects.

1.4 OBJECTIVES:

MSPT technology is being used in this research to see if it is feasible to build a possible solar thermal power plant in Bangladesh. Many factors are taken into account in this process, such as local weather and environment compatibility; sufficient space; and other supporting infrastructures such as access to proper highways. The goal of this thesis is to identify the concentrated solar power plant with the best performance of the TES technology. Therefore, a number of critical TES system characteristics are examined to understand how they affect the plant's performance (as the annual generation of energy). The project's all-inclusive goals are outlined in the following sections:

-Determine whether or whether it is feasible to build an MSPT-based CSP power plant in Bangladesh, depending on plant location’s topography and meteorological conditions.

-Assessing solar salts as an HTF, find best TES system for a CSP power plant.

-To determine the optimization of the power plant, the positions of heliostat fields and other properties.

-As a comparison to the conventional system, we must assess the costs in depth.

1.5 SCOPE OF RESEARCH:

The goal of this study is to identify the best possible parameters for a Bangladesh-based CSP powerplant where focus on the capacity as 10 MW. The research is focused on identifying the ideal optimization of this plant for the feasibility analysis. By adjusting a few settings of the TES system, two distinct types of systems and three different gross outputs of power plants may be tested. SAM is still in a development place which focuses user demands to anticipate the performance of the power plant. As a result, the extent of this investigation is given below:

- To evaluate the performance of three types of gross outputs. The following is a list of the parameters used in the tests:
    - Two-tank direct storage
    - Solar salt, or molten nitrate salt, is another name for this salt.
- To examine the impact of varying the parameters and gross outputs based on demand.

- To find the optimal combination of the parameters chosen for the plant's TES system.

1.6 OUTLINE

In this thesis book, the study's results and findings are presented in a succinct manner. This paper discusses CSP, model design, comparisons of several plants with the traditional steam power plant, and a full economic assessment. The five (5) sections that make up this book are organized thematically.

This project is introduced in the first chapter. An overview of the project and the book have been discussed. The current state of Bangladesh's power generation and the potential of CSP are described in this article.

A review of prior studies relevant to this one may be found in the chapter two. CSP, TES systems, and an old-fashioned steam power plant were all studied in the literature study.

The experiment's approach is explained in the third chapter. Power plants for two different purposes were created using two separate software packages.

The findings of our experiment are discussed in the fourth chapter. An analysis of the data has been completed and the graphs have been shown. The comparison was between a conventional plant and a CSP plant, and the findings were interesting.

The book's conclusion is offered in the fifth chapter, which discusses a summary of our effort and its outcomes.

Throughout the book, relevant graphs and tables are provided and their contents are indexed. End of the book contains the references to the research articles that we used in our experiment.

CHAPTER 2

LITERATURE REVIEW

2.1 POWER GENERATION SCENARIO OF BANGLADESH

Bangladesh has a middle-income status. Her GDP growth rate is world-leading. GDP growth can only be maintained if a country continues to grow. Growth in the country is mostly fueled by the availability and affordability of energy. In order to meet the country's growing energy demands and transition from a middle-income to a developed position, efficient energy use is essential. [2]

Over 62% of Bangladesh's energy needs are met by natural gas. Fuels like oil, coal, and biomass are critical. We have a significant coal reserve in our nation, but we produce and consume very little of it. Natural gas reserves, on the other hand, are small, despite the fact that it is the most widely produced and consumed fuel. In addition, oil and LPG are imported to meet the country's energy needs. In addition, the government has begun importing LNG to meet increased gas demand. In order to keep up with demand, electricity is imported from India as well as other places.

SHS, both on and off the grid, generate power. 401.26 MW of solar electricity is currently being generated. There are also bio-gas facilities included in certain poultry and dairy farms for cooking and generating energy. These plants are now generating about 1.03 MW of electricity. Bio-Mass Gasification is now being used to produce electricity by the government. [3]

The anticipated total energy consumption is 55.50 MTOE. The yearly rate of increase in energy consumption is 6. In comparison to its South Asian neighbors, Bangladesh consumes 334 kgoe (Kilogram Oil Equivalent) less energy per person and generates 512 kWh (Access to Electricity:97%).

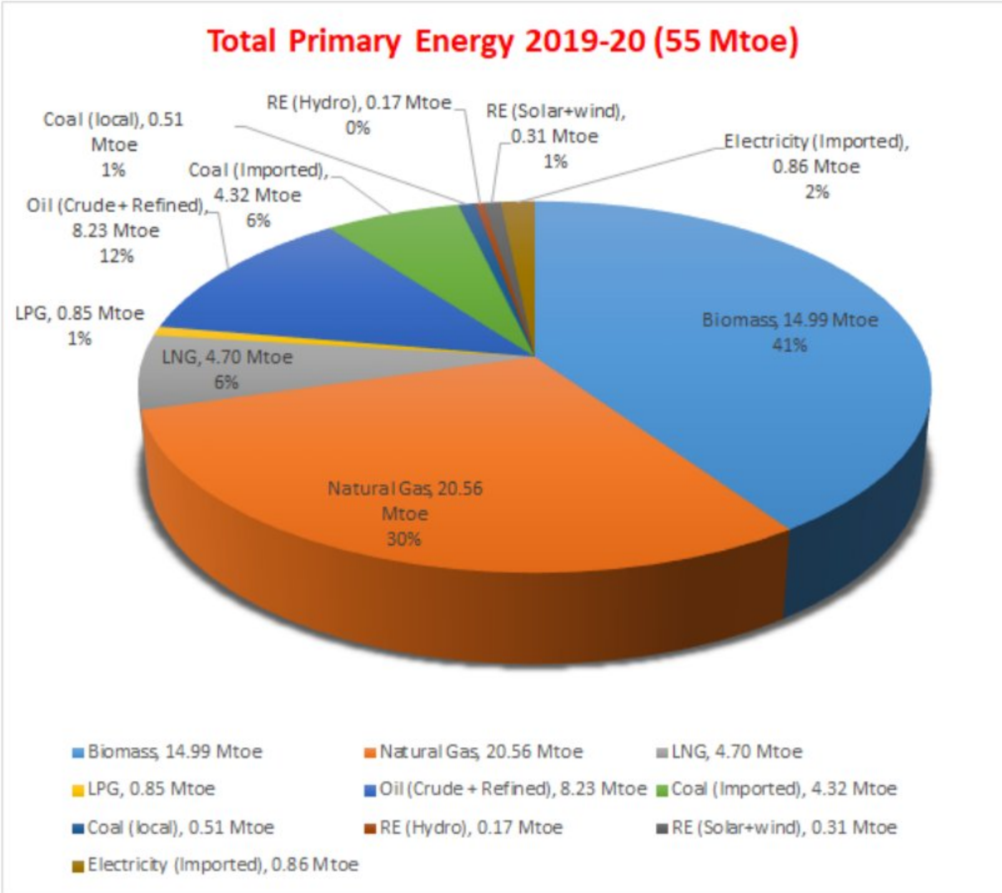

Figure 2: Share of total primary energy (2019-20) [4]

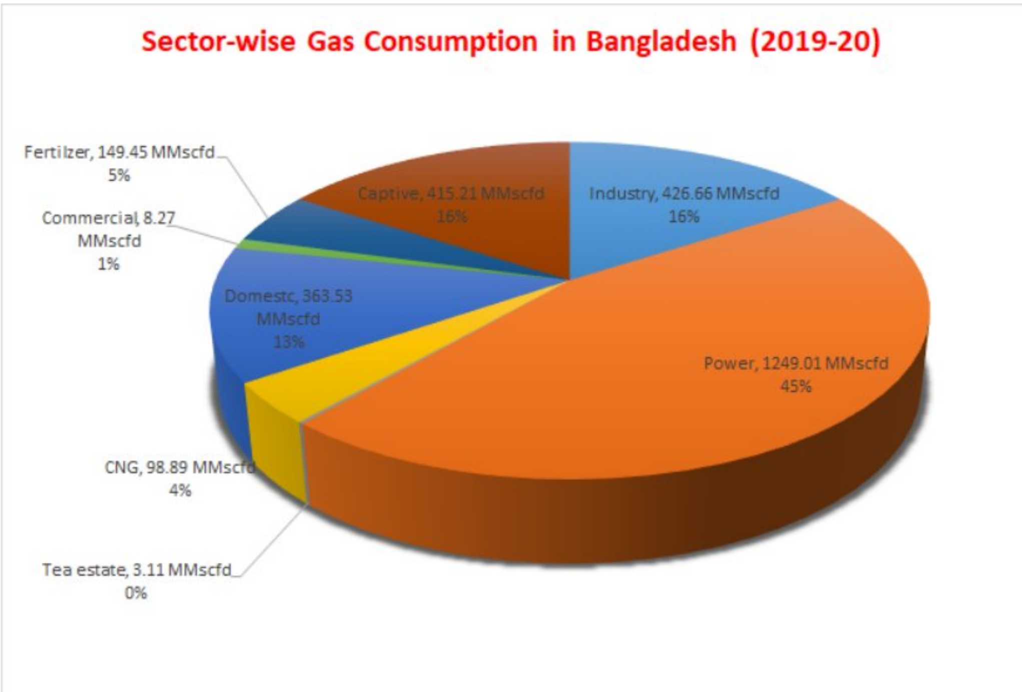

Figure 3: Share of total commercial energy (2019-20) [4]

There are currently 2978 MMcfd of natural gas being produced on a regular basis. There were 994 BCF of naturally occurring gas produced in 2019-20; 46% was used for electricity, 5% for fertilizer, 16% was captive power, 17% was industrial, 13% was residential, and 4% was CNG. Natural gas is the primary feedstock for each of the seven urea fertilizer businesses. The country's industrial growth has been considerably boosted by inexpensive heating and captive power production provided by natural gas. 13 percent of the population has profited from the use of piped natural gas at home. CNG is the fuel of choice for about 504,293 of the country's autos. Dhaka's air quality improved and foreign currency was saved when CNG facilities were built early in the past decade.

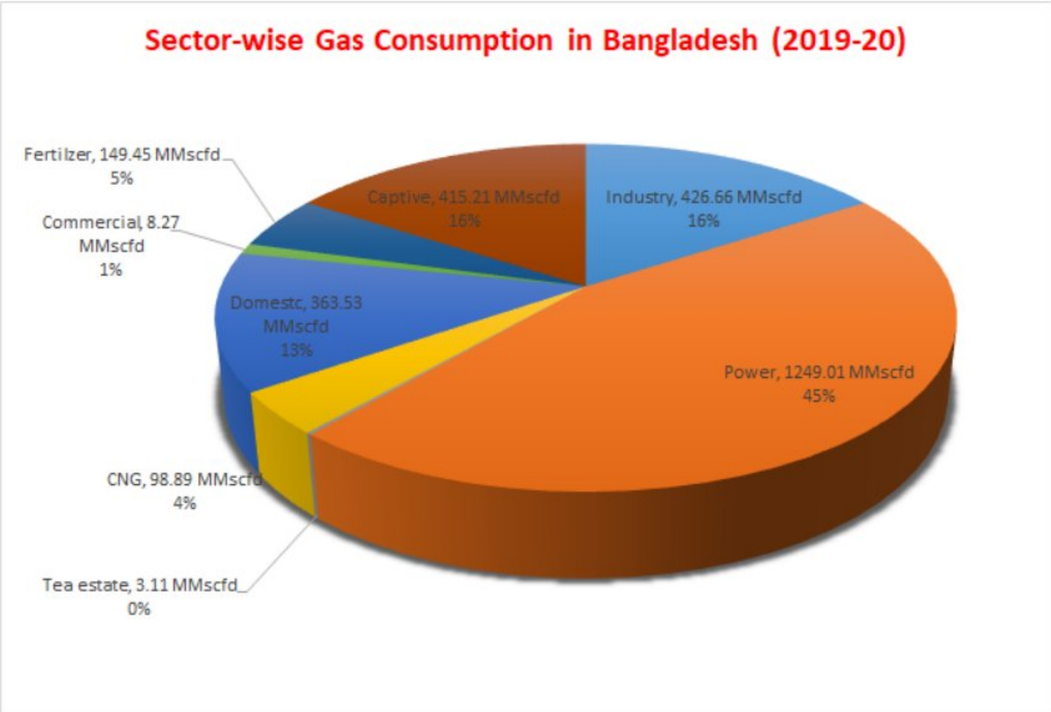

Figure 4: Sector wise Gas Consumption (2019-20) [4]

In order to satisfy demand, electricity is imported from India. Sustainable development and lowering carbon emissions need the use of renewable energy instead of fossil fuels like gas, coal, and oil. There is a slew of countries that are turning to renewable sources of energy in order to satisfy their current energy demands. Renewable energy is used in Bangladesh, albeit only to a minimal degree. The Rooppur nuclear plant, for example, has been developed by the government, as well as solar irrigation systems. Considering CSP power plants is long overdue.

2.2 CSP TECHNOLOGIES:

Solar energy is produced via CSP systems, which employ mirrors or optics to focus a huge space of sun ray onto a receiver. Heat engines (often steam turbines) and chemical processes are both capable of creating electricity by transforming focused light into heat, and both have the potential to do so (energy received from solar-thermal).[5]

Energy storage has the prospective to enhance, also stabilize power networks since it not only helps to balance supply and demand, but it also aids in energy conservation. The period of time which the energy will be stored, the cost, the temperatures that will be required for supply and consumption. The utilize of TES devices to generate heat during the warm-up process may help to cut fuel usage and emissions even more! Driving without waiting for the engine to warm up and pre-heat is a thing of the past for most people these days. When operating in cold weather, it is possible to increase battery performance by employing a TES device to fast heat the batteries. The employment of a TES device may aid in the refreezing of the windshield and the improvement of passenger comfort. As a result of their potential to alleviate environmental challenges and boost energy efficiency, TES devices have been the subject of much research. A TES device is a device that permits thermal energy (heat) to be kept in cold or hot materials for later use. Conserving energy is possible using TES devices, which is particularly advantageous for renewable energy systems. TES devices are available for purchase online. They may also be used to solve the issue of a cool engine starter that occurs. Because of the vast number of applications for which TES may be utilized in the automobile industry, it is becoming more popular.[6] To begin, waste heat generated during the normal functioning of an engine may be utilized to charge a TES device. TES devices might also be used to generate heat for warm-up purposes, which would minimize the amount of fuel used and the number of pollutants produced. No need to wait for the engine to warm up or pre-heat before getting into the car.

2.2.1 Availability and accessibility of current technologies

CSP is an electrical generator. A huge region of sun ray is reduced on a tiny area using tracking mirrors or lenses. In a traditional power plant, the focused light is utilized to heat the fuel (solar thermoelectricity). They are also utilized to offer process cooling, such as solar air conditioning, for industrial use.

These technologies include:

1. The PTC
2. The PDC
3. The LFR
4. The SPT

Because concentrators follow the sun and concentrate light differently, their peak temperatures and thermodynamic efficiency vary. New CSP technologies are making systems more cost-effective.

In recent events in China, Installed CSP capacity is dominated by India and South Africa. CSP capacity increased by 110 MWe in 2016, bringing worldwide capacity to over 4,800 MWe. This was the slowest yearly gain in worldwide capacity in ten years, but activity anticipates a 900-percent increase in 2017.

In the next years, CSP's progress into high-DNI emerging nations with calculated and economic synergy with CSP technology. In this regard, CSP receives enhanced governmental assistance in nations with relatively small oil and gas supplies, power grid constraints, or energy storage needs.

Figure 5: The most common types of CSP technology; (a) SPT, (b) PTC, (c) PDC, (d) LFR

Solar radiation is focused into a receiver by means of four well-known CSP technologies, as indicated in Figure 1. Concentrated sunlight may be captured by linear receiver (LFR) and PTCs (parabolic trough collectors) that use an evacuated glass tube as the receiver. Theoretical concentration ratios are intrinsic limits of these approaches. Predominant nowadays is the use of PTC and central towers. 30 more PTC plants are planned, despite the fact that the total power capacity planned for power tower capacity (5,383 MWhe)[7] is twice that of PTs (2,681 MWhe). The 89 and 207 MWhe outputs of PTC and power tower plants are also worth mentioning. The commercialization of LFR and parabolic dishes is lagging behind the other technologies, despite the existence of several projects worldwide. With the combination of TES and conventional fuels, CSP is the most dependable sustainable energy source available.

2.2.2 The worth of CSP

CSP provides complimentary services and benefits in order to aid in the growth of the local economy and the advancement of social progress.

CSP makes advantage of the sun as a locally available, renewable energy source. It is possible that using solar energy instead of imported fossil fuels may benefit nations that rely on fossil fuel imports in improving their current account balance. By minimizing the uncertainty around future producing costs, it may be possible to enhance access to finance while also lowering total system costs. Comparing CSP with TES to solar photovoltaics, CSP with TES has the potential to operate more flexibly and for longer periods of time.

The following sections are devoted to the most essential characteristics of CSP.

2.2.3 CSP is a renewable energy source that improves grid resilience

CSP with storing energy is a versatile renewable resource that can respond swiftly to demand and system operator demands.

The development of wind and solar PV has emphasized the need for renewable resources that can help power networks operate more efficiently and reliably, as well as the premium these assets may attract. Because wind and solar PV are changeable, their production varies with the availability of sunlight and wind. When the sun is at its strongest, PV production peaks at noon, and then gradually declines throughout the day until it approaches zero at night.

As the percentage of renewable energy sources increases, so does the requirement to balance hourly changes in production. Variable renewables' production swings need careful management and, if not planned for, might cause brownouts and blackouts.

TES in combination with CSP enables power stations to store solar energy and then redistribute electricity as required to adjust for fluctuations in renewable energy output. Most obviously, when PV output dips late in the afternoon and demand is met by CSP and TES, And the other way around, too. Even at night, CSP may be capable of storing heat generated by solar panels, which may be utilized whenever of the day or at night. The effects of low-variable renewable sources like wind and solar PV, distributed energy clean energy sources like CSP, biomass and hydro, as well as flexible supplementary assets like electrical and chemical storage (batteries) and demand-side management, such as management control, would be beneficial for countries seeking to replace fossil fuels with low-cost clean power.

2.2.4 CSP allows networks to use more renewable energy and decreases curtailment

Without flexible generating assets or energy storage technologies, a lot of fluctuating renewable energy output may go to waste. It's called curtailment. This reduces the curtailment of variable renewables and allows the grid to accommodate additional renewables.

Reduced curtailment is critical for MENA renewable energy supply. Prices between \$0.02/kWh and \$0.03/kWh have recently been bid for large-scale PV projects in MENA, demonstrating that PV is the cheapest option to produce power in this region. Adding additional PV without implementing other precautions would ultimately result in substantial curtailment.

2.3 DESCRIPTION OF TECHNOLOGY (CSP)

2.3.1 PTC

Unlike other solar collectors, parabolic troughs feature a mirror-lined surface that makes them exceptionally reflective in the sun. The focus line, which is where hot objects are placed, is the point at which sunlight enters the reflector in a supervision parallel to the symmetry plane of the mirror. The meal is put on the focal line of a trough in a parabolic solar system, which cooks the food while it is facing the sun, like in the following example.

Located at its focal point, a tube filled with fluid stretches the whole length of the trough from end to end. The sun's rays heat the fluid in the tube, causing it to boil at a high temperature. In certain cases, hot fluid may be utilized to power machines or produce electricity. This is the most often seen and well-known form of a parabolic trough.

It is possible to increase thermal efficiency by as much as 80% by heating steam with a heat transfer fluid.

In general, collector to grid efficiency is comparable to PV, but lower than Stirling Dish Concentrators. PV is the same as PV, although Stirling Dish Concentrators are better. These plants' produced energy is stored in massive thermocline tanks filled with silica sand and quartzite rock. The next step is to add the heat transfer fluid, which is often molten nitrate salt. SEGS, which has a capacity of 354 MW, Solana Producing Station, which has a volume of 280 MW, and the Genesis Solar Energy Project, which has a capacity of 250 MW, are among the biggest power plants on solar thermal in the world in 2014.

2.3.2 Enclosed Through

It's in a glasshouse-like greenhouse to capture solar energy. Protecting the concentrated solar system in a glasshouse ensures its stability and performance. The glasshouse's ceiling is adorned with curved solar-reflecting mirrors. The mirrors are positioned to optimum sunlight collection using a single-axis tracking algorithm. In the glasshouse, the mirrors focus the sunlight on the network of fixed steel pipes. The pipe carries water that is boiled to produce steam when exposed to high sunlight. Protecting the reflectors from the wind enables them to heat up faster and reduces dust buildup.

For EOR, Glass Point Solar claims their method can generate heat for under $5 every sunny condition, comparable to other traditional solar thermal solutions.

2.3.3 SPT

Earlier versions made use of focused rays to heat water and power a turbine using the steam generated from it. As a working fluid, some contemporary designs employ sodium liquid, while others use potassium and sodium nitrate molten salts (40 and 60 percent, respectively). It is possible that these working fluids may be used to store heat before boiling water for turbines. Despite the fact that the sun.

2.3.2.1 Design Aspects of Solar Power Tower

- As an alternative to water-cooling, some concentrated solar power towers are air-cooled. Flat glass is being used over curved glass.
- With thermal storage, one can keep generating power even when there is no ray of sunshine.
- All plant activities include heliostat array placements, alerts, data collecting, and transmission.
- Installations typically need 150-320 hectares (1,500,000 m2) (3,200,000 m2).

2.3.4 LFR

Linear Fresnel reflector (LFR) technology may be found in a compact linear Fresnel reflector (CLFR). They are called after a Fresnel lens, which combines several tiny, thin lens pieces to resemble a larger simple lens. These mirrors can magnify the sun's rays by 30 times.

Linear Fresnel reflectors employ long, narrow mirror segments to concentrate sunlight onto a stationary absorber. This concentrated energy is absorbed into a thermal fluid. The fluid then powers a steam generator through a heat exchanger. Unlike regular LFRs, the CLFR uses numerous absorbers near the mirrors.

2.3.4.1 Design Aspects of Fresnel reflectors

2.3.4.1.1 Reflectors:

The sun rays are directed towards the absorber with the use of reflectors. When compared to standard parabolic trough mirror systems, all LFRs benefit from the use of "Fresnel reflectors," which are transparent reflectors that reflect light back into the system. Using the Fresnel lens effect in these reflectors, it is feasible to fabricate a focusing reflector with a high opening and a short central length for use as a focusing mirror. The ability to save money on parabolic mirrors with drooping glass is a substantial advantage. The use of nanotechnology has lately resulted in a reduction in the cost of parabolic reflectors.

The rays that reach the mirrors move with the sun throughout the day as it travels across the sky. A fundamental issue for any solar concentrator is the inability to collect enough sunlight. It is common practice to orient a CLFR's reflector array north-south and spin it in a north-south direction using a computer. Maintaining the ideal incident angle for sunlight and reflectors allows for the most efficient transfer of energy.

2.3.4.1.2 Absorbers

To one side of the reflective surfaces, an absorber Thermal fluid flows through this tube as a result of the radiation it receives. The CLFR absorber consists of an inverted air chamber and a steam tube cap that are both insulated (Fig.4). Simple, inexpensive, and with excellent thermal qualities, this design is by varying the tilt of their mirrors.

Several absorber design elements must be tuned for optimal CLFR performance.

As a starting point, increasing the transferred heat from the soaker to the thermal fluid is a necessity. There must be consideration given to the facet of the steam tubes. The energy absorption/emission ratio is improved by using a selective surface. Another need is that the surface of the absorber be evenly heated. Surface degradation is accelerated when the temperature is unevenly distributed. Instead of a single absorber near the mirrors, the CLFR makes use of numerous. In Fig. 7. The advantages of this setup are many. First, alternate inclinations reduce the impact of reflectors limiting sunlight to nearby reflectors, enhancing system efficiency. Second, many absorbers reduce installation ground area requirements. This lowers land acquisition and preparation costs. Finally, putting the panels near together decreases the length of absorber lines, lowering heat losses and total system costs.

2.3.5 Dish Stirling

It makes use of a massively reflective parabolic dish for this purpose. In order to make use of the heat, a receiver converts it into a useful form. Stirling engines are often used in Dish-Stirling Systems; however, steam engines are also used. An electric generator may be powered by the rotational kinetic energy they produce.

To generate 500 megawatts of electricity, Southern California Edison announced in 2005 that it will purchase 20,000 Stirling Energy Systems' solar-powered Stirling engines the course of 20 years. The first 1.5-megawatt Stirling power plant in Peoria, Arizona, was completed in January 2010 by Stirling Energy Systems and Tessera Solar.

This development subsidiary of Stirling Energy sold two major projects to AES and K. Road in early 2011. The Maricopa facility was bought and dismantled by the United States in 2012. A new generation of Stirling engines has been introduced by United Sun

Systems. LCOE is reduced to USD 0.02, thanks to the ground-breaking CSP-Stirling technology.

2.4 CSP OPPORTUNITIES IN BANGLADESH

- Bangladesh is blessed with an abundance of sun radiation. Direct Normal Irradiations (DNI) of 2000 KWh/m2 are required for CSP technology on a yearly average basis.
- Because labor costs in Bangladesh are lower than in any other industrialized nation, a cost reduction of 15 percent may be feasible in certain cases.
- Glass and steel sheets are the primary raw materials used in the construction of most CSP power facilities.
- Bangladesh has achieved self-sufficiency in the manufacturing of glass. Glasses are now being sold to a plethora of nations. In Bangladesh, there are more than 400 steel re-rolling companies that are in operation.

Table 1: Comparison of papers related to CSP

Time	Author	Prompt Title	Findings
2008	Hang Q, et al.[8]	CSP's prospects in China	CSP technologies can be easily implemented in China's northern and western regions; large-scale and commercial CSP technology adoption requires government backing and strategy.
2009	Li J. [9]	China's CSP rollout efforts	Applying CSP for China's power production and heat delivery, with a focus on buildings and industry sectors, may effectively reduce GHG emissions. Stepping up to remove funding constraints, CSP requires institutional and energy pricing

			change.
2009	Kandilli C, et al. [10]	Assessment and modeling of CSP optical fiber systems.	The use of reflecting materials in receivers and the length of fiber-optic bundles are also areas where design optimization is possible.
2011	Xie WT, et al. [11]	Lenses made by Fresnel	Non-imaging LFR devices have the ability to generate enormous amounts of commercial electricity.
2011	Ummadisingu A, Soni M. [12]	CSP has a lot of promise in India	Even in Rajasthan and Gujarat, CSP has the credibility to become a major role model in the Indian energy source. Government regulation, industry-university collaboration and feed-in tariffs all contribute to the implementation of CSP for electricity production.
2011	Kaygusuz K. [13]	Turkey's CSP potential	In Turkey, Southern & South-eastern proportion are prospective CSP plots because of abundant radiation from the sun and the existence of extensive wasteland.
2012	Romero M, Steinfeld A.[14]	Production of thermochemical fuels and CSP technical improvement	Large-scale demonstration of solar hydrogen, synthesis gas, and hydrocarbon fuel from H2O and CO2 via two-step reduction-oxidation cycles is a huge possibility.
2012	Pavlović TM,	CSP technologies'	All three of these (PTC, SPD & LFR) power plants were found to be appropriate for

	Radonjić IS, Milosavljević DD, Pantić LS [15]	description and functioning principles, as well as their prospective deployment in Serbia	Serbia. SPD CSP power plants may be used in rural areas that are disconnected from the grid.
2012	Burkhardt JJ, Heath G, Cohen E. [16]	PTC and SPT CSP technologies have been subjected to a life cycle evaluation (LCA).	To release the GHG emissions phenomena, a full-scale LCA analysis must be done for each new CSP power plant project.
2012	Pitz-Paal R, et al. [17]	Development issues and a look ahead to 2050	The number of stochastic model simulations for renewable energy sources has increased throughout the EU, Middle East, and EU-MENA. Europe should investigate co-financing options for big CSP facilities in the Middle East and North Africa (MENA). public-private partnerships in the US and internationally
2013	Kuravi S, et al. [18]	TES design methodologies	Combining multiple kinds of TES systems might cut costs and improve CSP plant performance. potential for TES storage media research in terms of thermal performance and cost.

2013	Zhang H, et al. [19]	SPT design technique and CSP technologies	Yearly, monthly, and daily levels of direct (beam) solar irradiation may be used to estimate a CSP plant's power production; technical advancements for SPT type power plants can be achieved by design optimization
2013	Py X, Azoumah Y, Olives R. [20]	The progress of CSP technology and its applicability in West African nations	Integrated components should leverage novel materials and design techniques to reduce costs and environmental impacts while improving performance. Solar resources in the solar-belt nations must be assessed. Furthermore, CSP technologies are not well suited to these nations in terms of size, materials, and equipment. European countries have chances for emerging enterprises to advance CSP process and component development.
2014	Ho CK, Iverson BD [21]	High-temperature power cycles used in SPT designs.	Tubular receivers used in the SPT may be enhanced. More research is needed to determine which working fluid to use in the SPT facility based on storage capacity (number of hours).
2014	Dunham MT, Iverson BD [22]	The use of high-efficiency thermodynamic cycle in CSP power plant	With a better thermal efficiency, a steam Rankine system can raise temperatures to over 600°C.The Brayton cycle for CO2 recompression has a high thermal efficiency over 600 °C. When establishing the maximum receiver operating temperature, the unique nature of the thermodynamic cycle arrangement must be taken into account

			(under various Carnot assumptions)
2014	Li C-J, Li P, et al.[23]	High-temperature HTF characteristics & applications	More research is needed on the corrosive environment used in pipelines and containers as a result of exposure to various salts.
2014	Wetzel T, et al. [24]	Metals in liquid form as HTF	As a high-temperature heat transfer fluid (HTF) for the central receiver of a CSP plant, liquid metal is a feasible alternative to conventional HTFs, and it contributes to a lower overall cost of ownership.
2014	Komendantova N, Patt A. [25]	Transfer of CSP-related technologies to North African nations in order to create jobs	Through horizontal knowledge transfer, North African firms may manufacture CSP plant-related components.
2015	Vignarooban K, et al. [26]	HTFs	For widespread commercial use, the corrosive properties of molten salts to metal alloys need to be addressed further. To attain a higher working temperature (800 °C), HTF based on molten salts will be employed. Carbonate or chloride-based salts have been proposed, but more research is needed.
2015	Xu B, et	PCM's TES	It is possible to significantly reduce the

	al. [27]	application	volume of the storage tank by using PCM as latent and sensible heat storage.
2015	Colmenar-Santos A, Bonilla-Gómez [28]	In Spain, CSP is combined with a biogas system.	Hybridization extends plant operating hours and lowers operating costs compared to molten-salt TES.
2016	Prieto C, Cooper P [29]	Technology review of Thermochemical energy storage	At the research plant level, calcium carbonate must be reactivated to unlock the full potential of CSP's thermal-heat storage system.
2016	Ehtiwesh IAS, Coelho MC [30]	Cycles of energy and the environment	Due to initial investment and storage system costs, PTC plants are more cost-effective than other CSP technologies in terms of DNI, regardless of land usage (such as the coastline of Libya, for example).
2016	Xu X, et al. [17]	Arid-area CSP difficulties and opportunity	To deal with water scarcity, desert CSP facilities may utilize dry cooling or CSP-desalination cogeneration.
2016	Rascón DS, Ferreira AD, da Silva MG	A central receiver CSP plant's occupational health and	Computer models can mimic extreme weather. Testing the receiver and heliostat surface installations for working conditions and

	[31]	safety	safety
2017	Fuqiang W, Ziming C [32]	PTC collector progress	Among the topics to be researched are the following: Techniques for increasing operating temperatures, a second factor is that large-scale HTF applications need newer HTFs. Metal tube receiver material that can withstand high temperatures characteristics of molten salt in corrosion a water/steam system with high temperatures and pressures a vantage point from which to manage tube receivers' temperature uniformity high thermomechanical properties of low-cost metals. Tube receiver deflection and glass shards are among the issues. Tear in the fabric of the cover
2017	Kommala pati R, Kadiyala [33]	CO2 emissions from CS during its lifetime	Research on SPD CSP's environmental impact should involve life cycle assessment (LCA).
2017	Dowling AW, Zheng T, Zavala VM [34]	As a matter of fact, CSP's economic analysts	Three areas need further research to enhance techno-economic assessments: standardized models and approaches optimizing the power market using new methods action policy. Economic assessments quantify uncertainty and risk. assumptions

2017	Kumar A, Prakash O [35]	India's CSP Progress	• CSP plants are favored sites in Rajasthan, Gujarat, and Andhra Pradesh.
2018	Bouhal T, Agrouaz Y, Kouskso u [36]	Assessing the technical feasibility of CSP in Morocco	Thermal HTF selection is a major consideration for PTC CSP. the worldwide CSP project's commercial and political atmosphere
2018	del Río P, Peñasco C [37]	CSP drivers and constraints in the European Uninon–	It is necessary to investigate the drivers and problems of four CSP technologies, as well as their interactions with the EU's CSP policy mix.

2.5 TYPES OF TES

TES is a necessity for CSP dispatchability. TES is cheap and easy to install, making CSP different from other renewable energy options. Thermochemical thermal storage methods include sensible, latent, and composite systems. Thermal energy is stored in a thermal storage media by varying its temperature. Thermal storage medium varies in temperature as they store and release energy. There were no further discrepancies discovered. This kind of thermal storage is inexpensive and easy to install. A wide variety of storage mediums are available for application, including water, mist, synthetic oil, molten salt, and gravel. As a heat transmission fluid, this research used the molten nitrate salts of this investigation. As long as the temp is high enough, the matter in question will stay in that condition. Several raw compounds, including fluoride, chlorine, phosphate, sulfate, and nitrate, as well as Al-Si and Pb-Bi alloys, may be used to store heat in solid form. To maximize the benefits of different thermal storage materials while minimizing their drawbacks, they are composited. Composite materials include nonmetallic inorganic materials and PCM composites. Osorio et al. constructed and tested a sCO2 central receiver Brayton power cycle CSP system, as well as many molten-salt TES tanks to produce temperature stratification, which enhanced device efficiency. Liquid sodium was selected as the HTF for the receiver because of its strong heat transmission qualities.

Commercial TES technologies for solar thermal power plants using molten salts outperformed non-molten salt systems. In a molten salt tower plant, an indirect TES system gives the same advantages as a direct TES system. For storage capacities under three hours, the steam accumulator, direct molten salt, and indirect systems all have lower heating costs (see figure). This is the most cost-effective technology for all storage capacity situations, according to TES' Levelized Cost of Power analysis. In terms of buffer storage (less than 3 hours), the steam accumulator TES system is the best option. It is possible to store enormous amounts of data with Direct Molten Salt Storage (DMS). The TES system may be adjusted in many ways based on the facility's capacity and productivity. The aim of a solar thermal power plant may influence its ideal design. Several considerations must be examined before determining the best HTF and TES system settings. Designing a power plant has never been easier thanks to simulation technologies.

2.5.1 The different kinds of TES

Thermal storage systems are categorized into distinct groups based on their operating temperature range, storage mechanism, circulation type, and storage time length.

Based on the temperature at which they operate

Medium-temperature, Low-temperature, and high-temperature TES systems are the three types of TES systems. Low-temperature storage systems are those that operate between 20 and 100 degrees Celsius, medium-temperature storage systems are those that operate between 100 and 200 degrees Celsius, and high-temperature thermal storage systems are those that operate beyond 250 degrees Celsius. HTF is required for collectors or heating devices provide thermal energy, and it is chosen according to the TES system's operational temperature range. Thermal oils can only be stored at a certain temperature range, and its block of thermal applications are limited to temperatures of steam, roughly 350°C. Storing energy at high pressure and temperature with steam as an HTF is reduced due to the need for increased pressure containers and handling equipment. Molten salts may be used as a storing medium also an HTF up to 560 degrees Celsius, and they can be used in conventional advanced Rankin cycle turbines. Powders are now employed as HTFs to transmit heat to a storing medium for innovative HTFs, and they are useful for greater-efficiency production of power cycles and high-temperature storages. For very-high-temperature storing systems, gas or air is utilized as HTF; unfortunately, storage is not viable at these temperatures; instead, turbines of gas or engines using Stirling cycle can be employed at such temperatures.

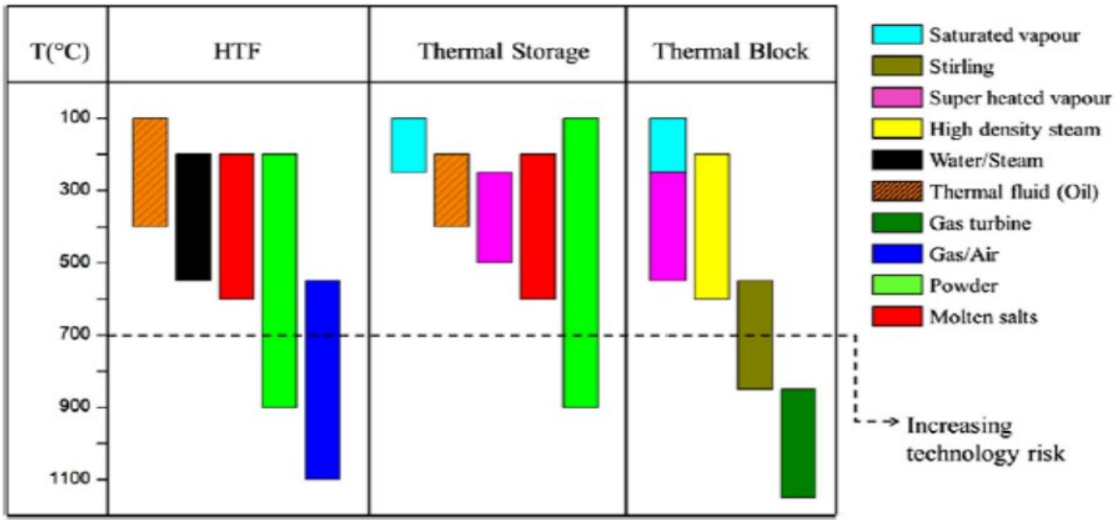

Figure 6: Thermal storage system categories based on their operating temperatures condition [38]

2.5.2 Depending on their storing mechanism

As shown in Figure 7, TES systems are categorized into three major types based on the storage mechanism: SHS, LHS and thermochemical storage. SHS refers to the swap in internal energy of a storage media caused by a change in activity of molecule without a change in the structure of molecule. It's also known as a shift in storage media temperature that doesn't involve any phase transitions or chemical reactions. LHS is the amount of energy received or released by the storing material during phase transition or a change in structure of molecule. The quantity of energy received or discharged by the storing medium during reversible exothermic/endothermic chemical processes involving atom shift is called as a thermochemical energy storing medium.

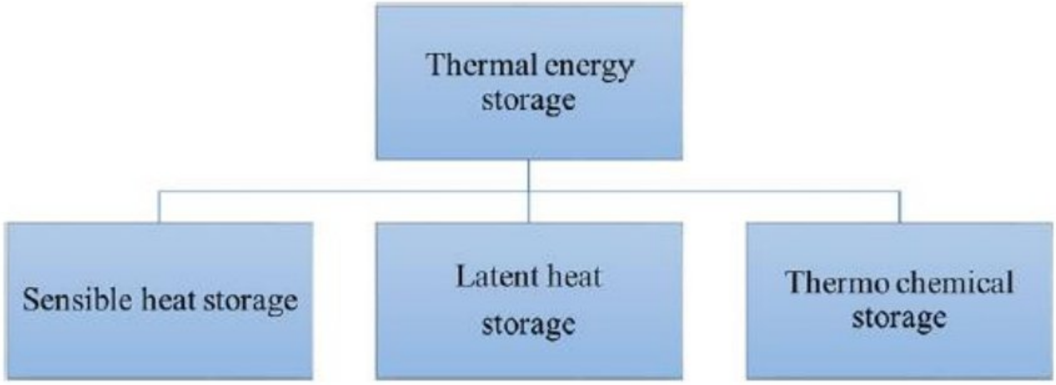

Figure 7: Categorization of TES based on storage mechanism

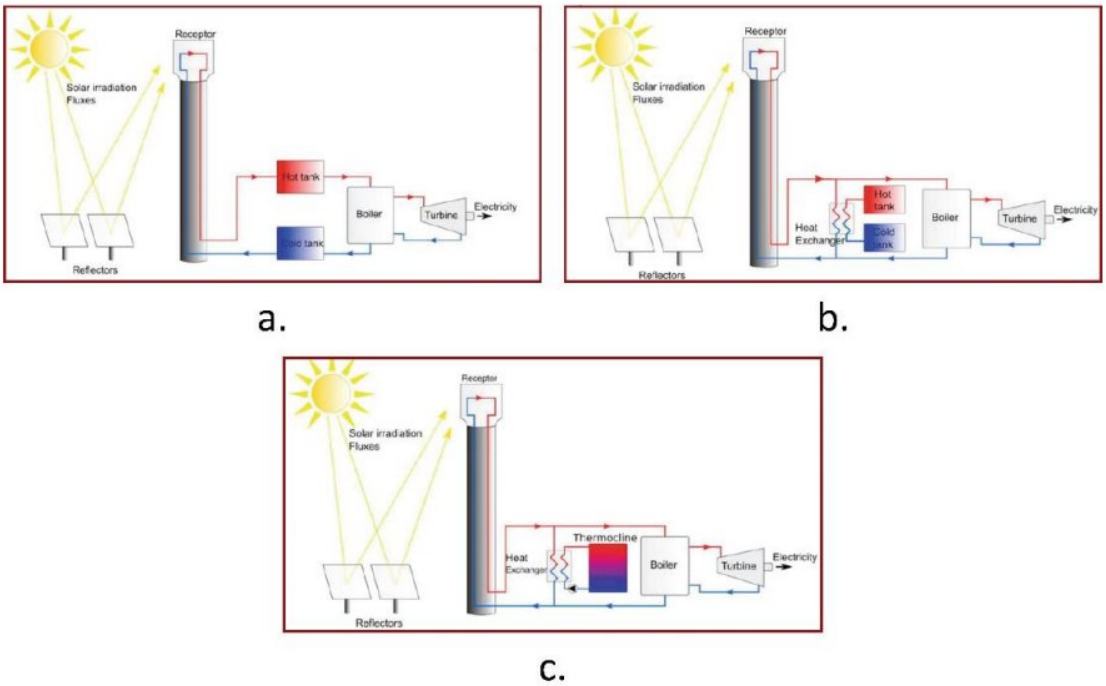

Figure 8: (a) Two direct tanks, (b) Two indirect tanks and (c) The thermocline system; TES in CSP plant [39]

2.6 STEAM POWER PLANT

2.6.1 Rankine cycle:

For my Power Plant, we decided to utilize a Steam Turbine Power Plant operating on a Rankine Cycle rather than a Gas Turbine Power Plant working on a Brayton Cycle since the Rankine Cycle requires less Work Input than the Brayton Cycle. The Brayton cycle use air as the working fluid, whereas the Rankine cycle utilizes steam or water as the working fluid. Rankine cycle has a lower Back Work Ratio because gas (air) has a greater specific volume in the compressor than liquid (water) in the pump. A substantial amount of Work may be generated by the Rankine and Brayton cycles, even though they both use working fluid that enters the turbine as gas that has a larger specific volume. It is therefore more common to use steam power plants for generating energy. Brayton cycle, on the other hand, uses a larger pressure ratio than the Rankine cycle for the same output. [40]

2.6.2 Working Fluid:

As we indicated previously, in our power production Rankine cycle, we chose water, which is the most used working fluid for big Rankine cycles as our working fluid. In the boiler, water is turned into steam and then condensed once more in the condenser at the end of the cycle. Water was my first choice due to its low cost and high level of safety (non-flammable and non-toxic).

2.6.3 Fuel:

For the generation of electric power, thermal power plants rely heavily on coal. Coal-fired thermal power plants grind the raw coal into flour before feeding it into the furnaces. It is during the pulverization process that the clay particles encased in the coal fractures are removed from the coal itself. These noncombustible materials, including clay, are produced during the burning of coal in a furnace. In coal-fired thermal power plants, the amount of coal ash generated ranges from 5 percent to 45 percent, depending on the kind and source of coal used as fuel. Coal may be extracted from the ground in four different ways. One form of coal is lignite. In terms of carbon content and powder content, lignite, or brown coal, is the least carbon-rich and the most powder-rich of all coals. A kilojoule-per-pound (kJ/kg) figure for lignite can range anywhere from 8000 to 12000. At a temperature range of 480°C to 550°C, it is capable of burning. On an ash and moisture-free basis, lignite's volatile matter concentration is in the region of 45 to 55 percent. As a result, it's extremely flammable. At Bangladesh, lignite may be found in Lamakata, Bandarban, Patiya, and Lubachhara, among other places. There are around 3500 kcal/kg of Brown coal or lignite, which we shall utilize in our computation. [41] As a result, we propose to run our power plant on brown coal or lignite.

2.6.4 Introduction

In order to generate energy, the steam power plant is essential. This power plant is responsible for meeting the vast majority of the nation's electrical needs. A thermal power plant is another name for this facility. The importance of steam-fired power plants is rising in the world of electricity generation. The Rankine cycle is used in steam power plants or thermal power plants. A project like this one expose students to the intricacies of systems like this one. [42]

The alternator's primary mover revolves as a result of steam pressure. A condenser collects condensed steam, which is subsequently fed back into the boiler. Electrical power is generated by the alternator's rotor turning. There are several advantages to using thermal power plants to generate electricity, which is why they are the most used method. [42]

2.6.5 The efficiency of Steam Power Plant

- For the coal-fired power plant, the Rankine cycle is a modified version of the original cycle.
- The coal power plant's total efficiency ranges from 31% to 42%. Steam's superheat pressures, superheat temperatures, and reheat temperatures are used to compute this.
- When operating at steam pressures of 170 bar, superheat temperatures of 570 degrees Celsius, and reheat temperatures of 570 degrees Celsius, the majority of big power plants can achieve efficiencies ranging from 35 to 38 percent.
- Super critical power plants with steam pressures of 220 bar and superheat/reheat temperatures of 600/600 °C may achieve an efficiency of 42 percent.
- Utilizing steam temperatures of 600/600°C and 300 bar of pressure, ultra-super critical power plants may achieve an efficiency range of 45 to 48 percent.

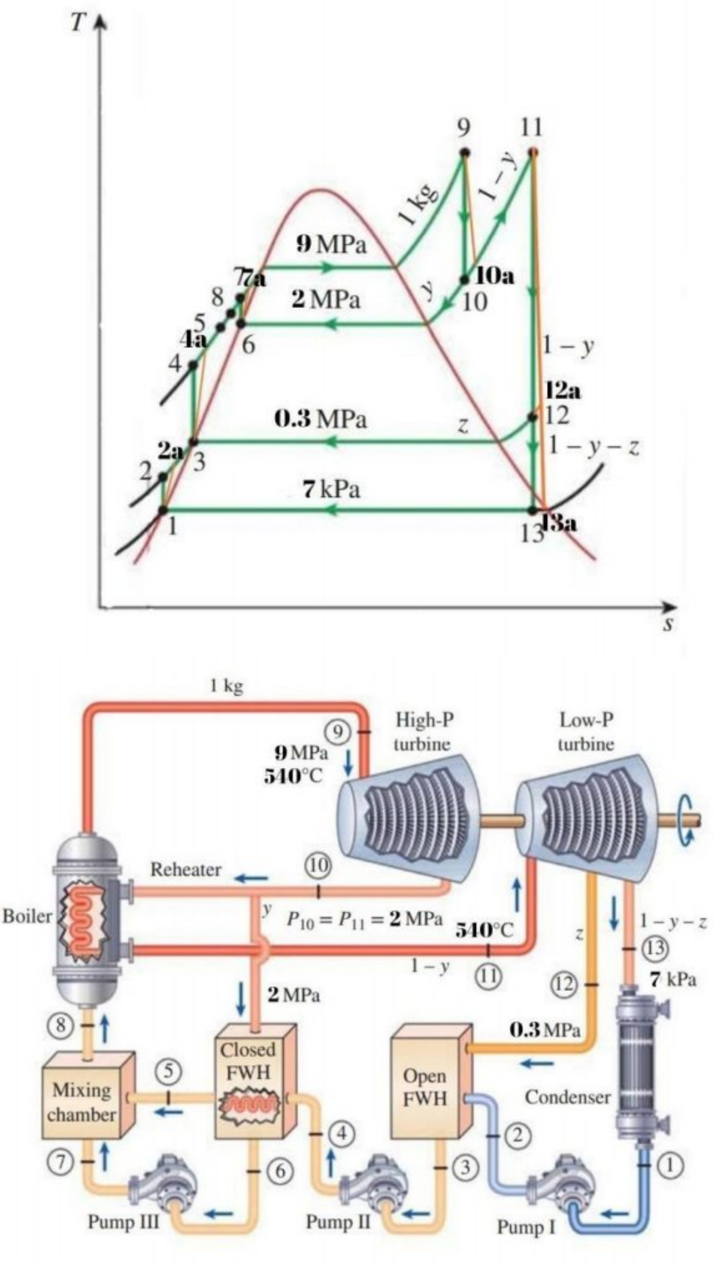

Figure 9: Schematic and Appropriate Property (T-s) diagram for the designed cycle. [40]

CHAPTER 3

RESEARCH DESIGN

3.1 SITE AND EXPEDIENTS

A set of data that includes all the weather information of a certain location is required by the SAM program in order to assess a place. A potential solar thermal power station must be located in a region with consistently high temperatures all over the year. And the location must be dry too, with only a small quantity of rainfall every year. With regard to the site of power plants, they should be within the allowed annual collective sun's range of DNI. Here, Table 2 depicts DNI-based criterion for selection in more detail. [43]

Table 2: ***In case of site selection the range of collective yearly solar DNI*** [44]

Condition	Unit ($kWh/m^2 \cdot a$)
Bad	DNI < 1600
Good	DNI = 1600 – 2000
Better	DNI > 2000

For this thesis project according to the selection criteria mentioned above and based on our observation on the need for a potential Concentrated Solar Powerplant, we have narrowed down the site selection process into three distinct sites. Kushtia (23.88°N, 89.13°E), Sylhet (24.89°N, 91.87°E) and Gazipur (23.99°N, 90.42°E), these locations were under our considerations for selecting the site for setting up the Concentrated Solar Powerplant.

In case of Kushtia, it has been recorded that the highest temperature is 41° in Celsius. Below, Figure 10 indicates max, min, and avg temperature. And Figure 11 shows average Monthly temperature. Kushtia is also one of the stuffiest towns in Bangladesh, with an average rainfall of just 1476.55 mm per year. In the material, "Rainfall reports." Figure 12 shows the average rainfall and number of wet days in Kushtia over the years. In addition, the figure 13 shows the average monthly rainfall in Kushtia.

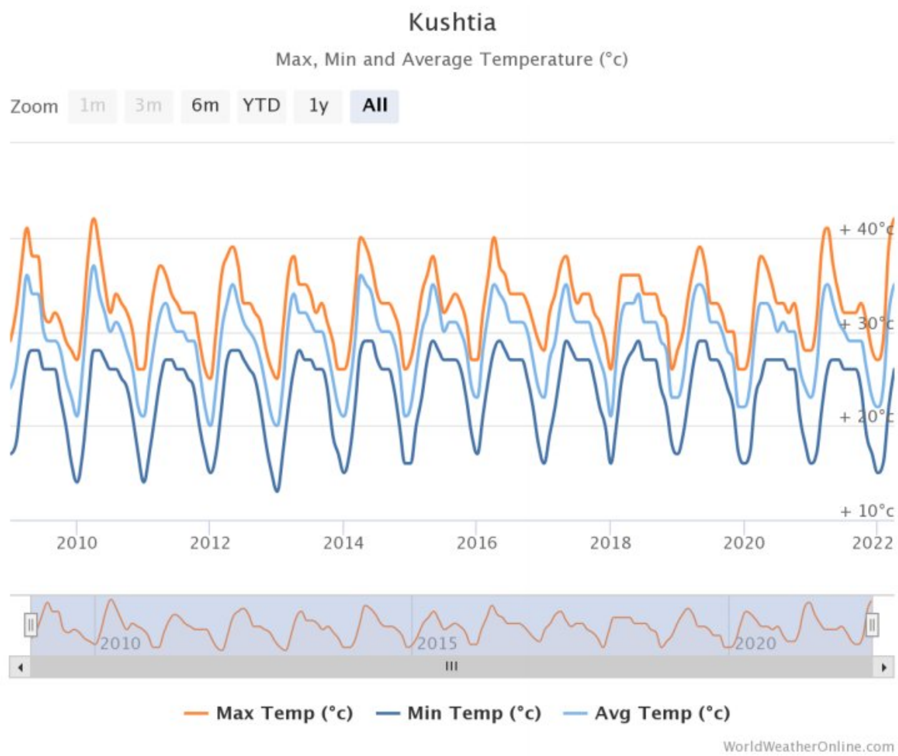

Figure 10: ***Max, min, and average temp of Kushtia (data period 2009 to 2022).*** [45]

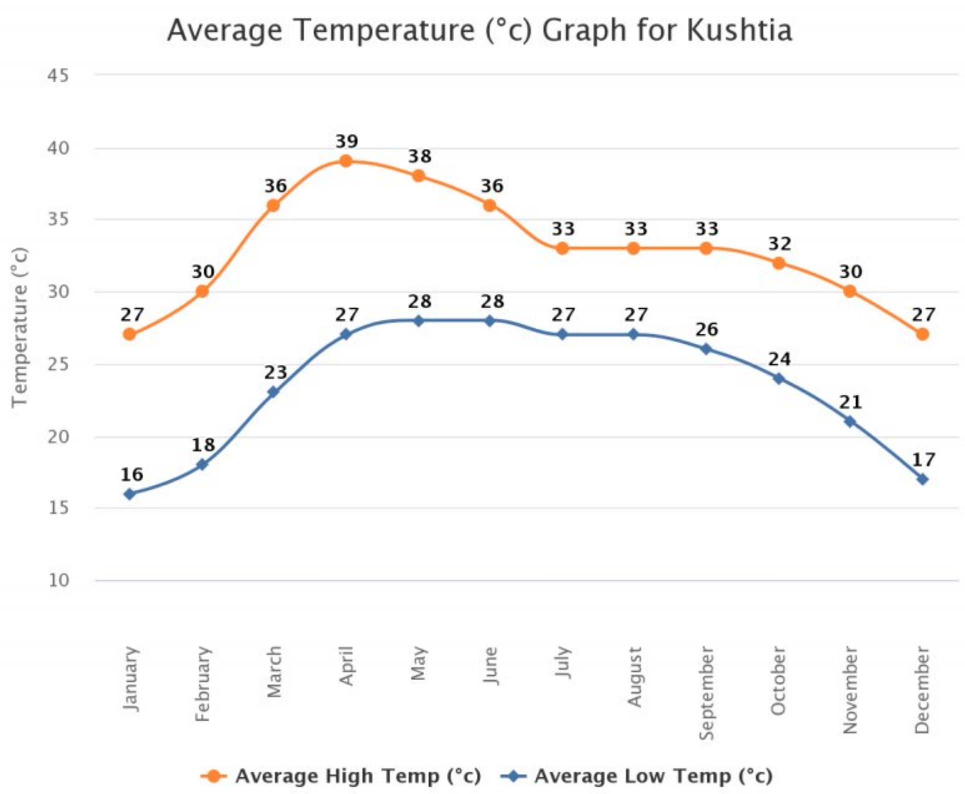

Figure 11: ***Monthly Average Temperature of Kushtia*** [45]

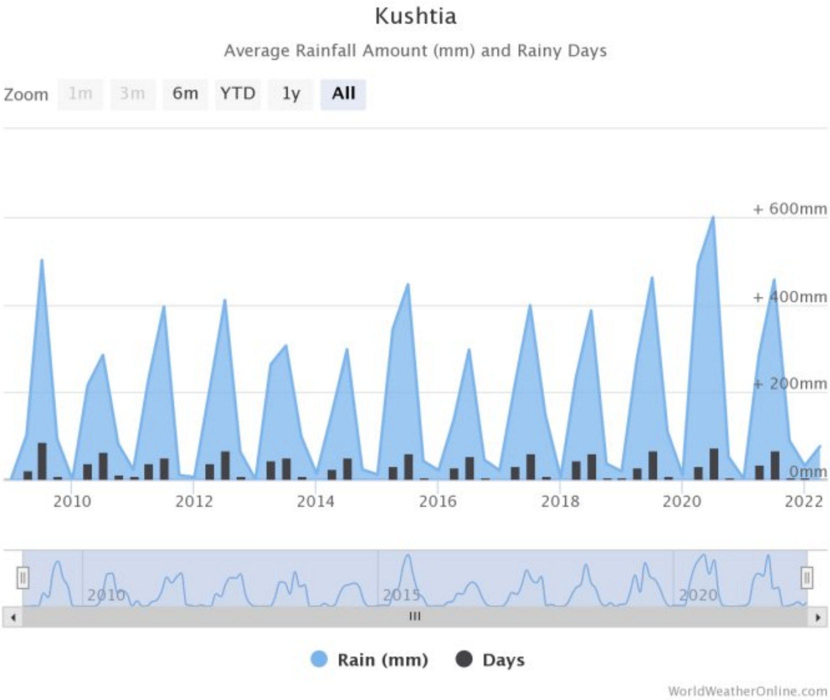

Figure 12: ***Average rainfall amount and rain days in Kushtia (data period 2009 to March, 2022).*** [45]

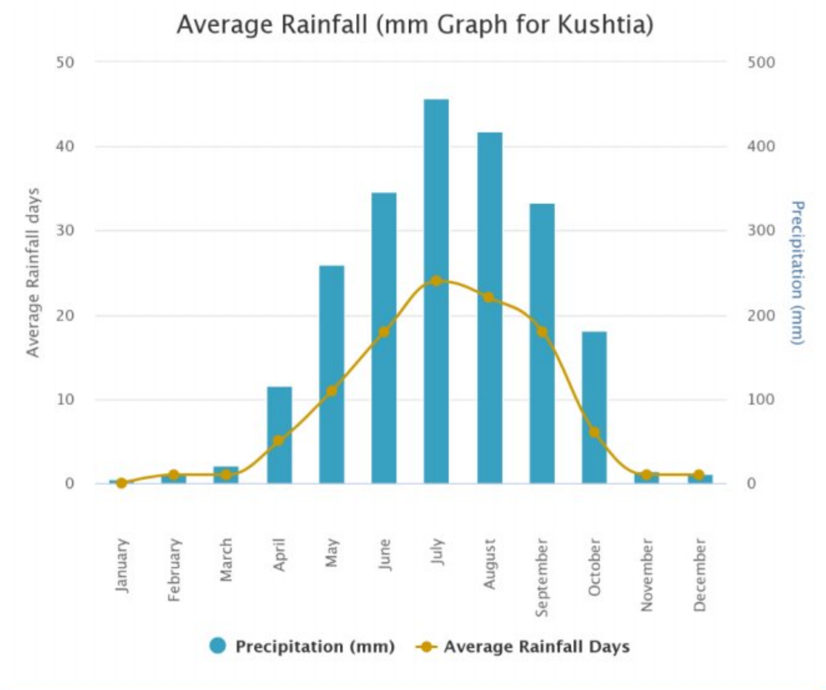

Figure 13: ***Monthly average rainfall in Kushtia (mm Graph for Kushtia).*** [45]

In case of Sylhet, the highest temperature has been recorded of 39°C. Figure 14 shows max, min, and average temperature. And Figure 15 shows Monthly average temperature for selected site. Sylhet has 7377 mm of rainfall annually. "Rainfall reports" in material.

Data of rainfalls in Sylhet all around the years is shown in Figure 16 And the Monthly average rainfall in Sylhet is also shown in Figure 17.

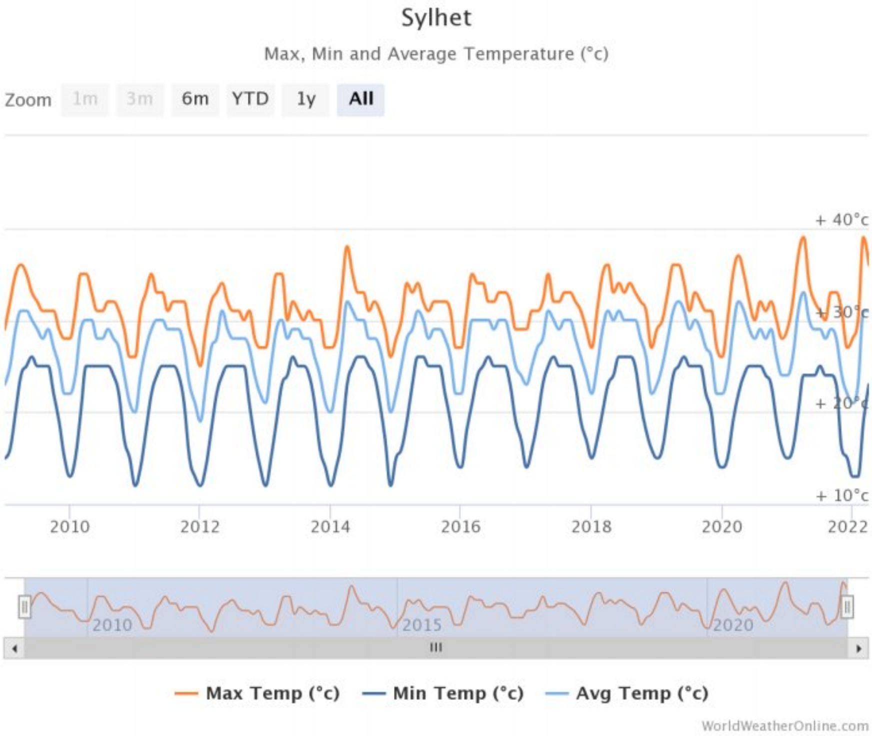

Figure 14: ***Max, min, and avg temp of Sylhet (data period 2009 to 2022).*** [46]

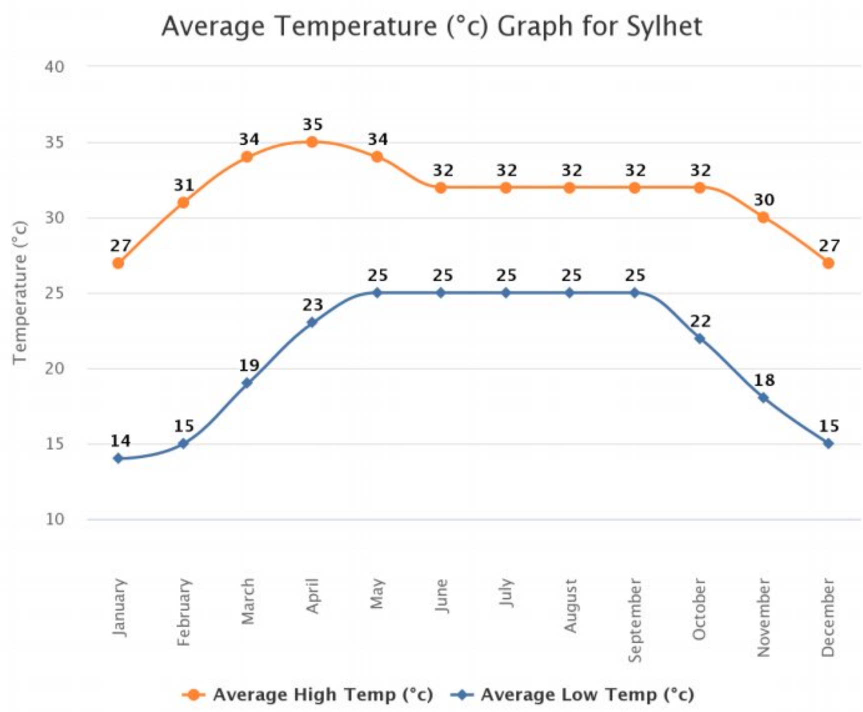

Figure 15: ***Monthly Average Temperature of Sylhet*** [46]

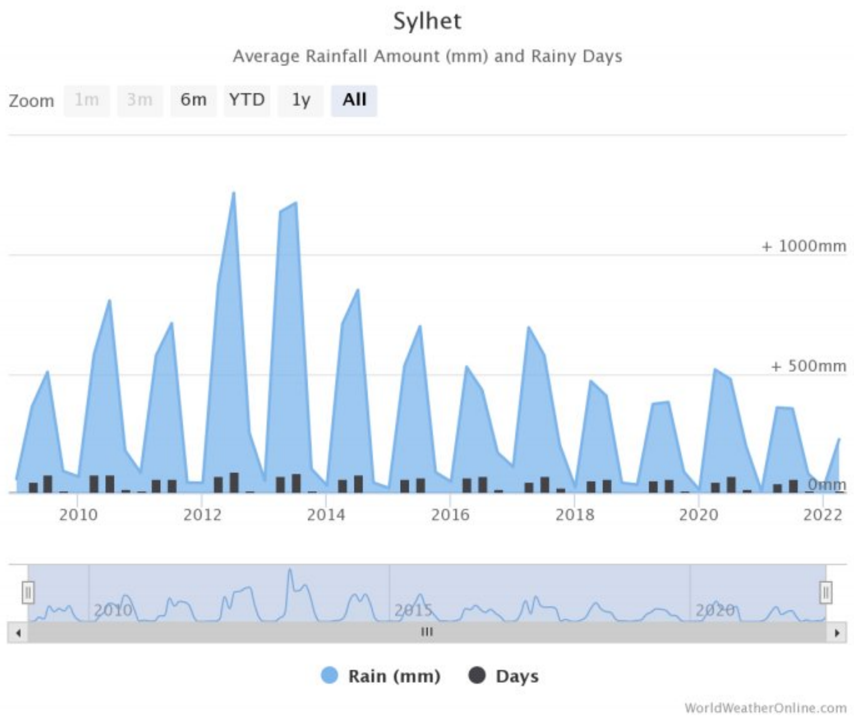

Figure 16: ***Average rainfall amount and rain days in Sylhet (data period 2009 to March, 2022).*** [46]

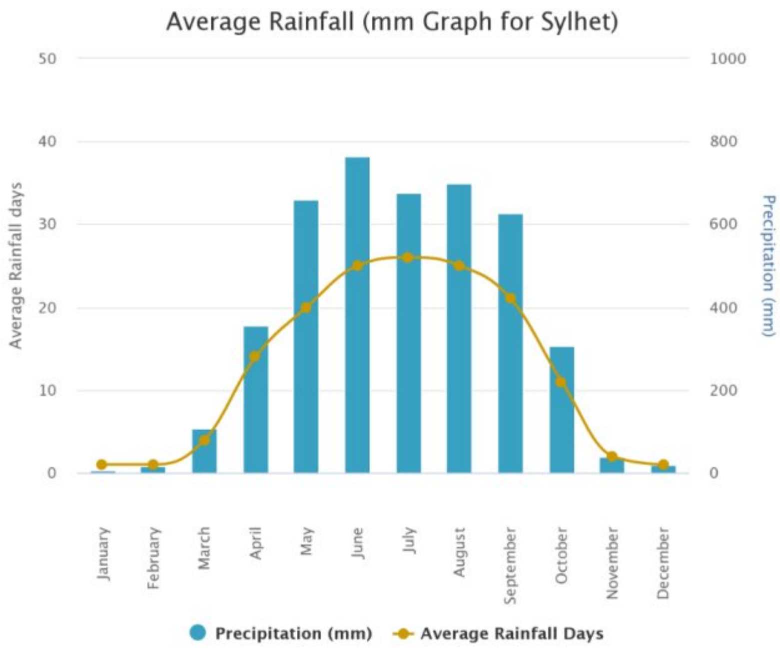

Figure 17: ***Monthly average rainfall in Sylhet (mm Graph for Sylhet).*** [46]

The hottest temperature ever recorded in Gazipur was 37°C. In Figure 18, you can see the highest, lowest, and average temperatures for the specified area. A look at Figure 19 reveals the selected location's yearly average temperature. Additionally, Gazipur is one of Bangladesh's driest towns, receiving just 2317 mm of rain each year. In the material, "Rainfall reports." As can be seen in Figure 20, the quantity of rain that falls on average and the number of wet days in Gazipur throughout time. For Gazipur, see Figure 21 for a month-by-month breakdown of Gazipur's rainfall.

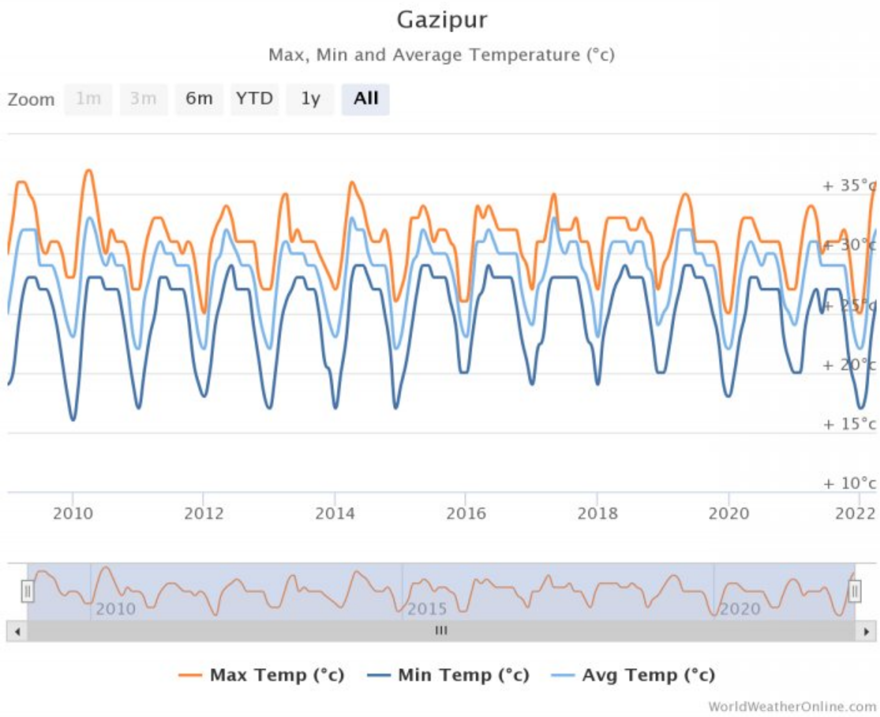

Figure 18: ***Max, min, and avg temp of Gazipur (data period 2009 to 2022)*** [47]

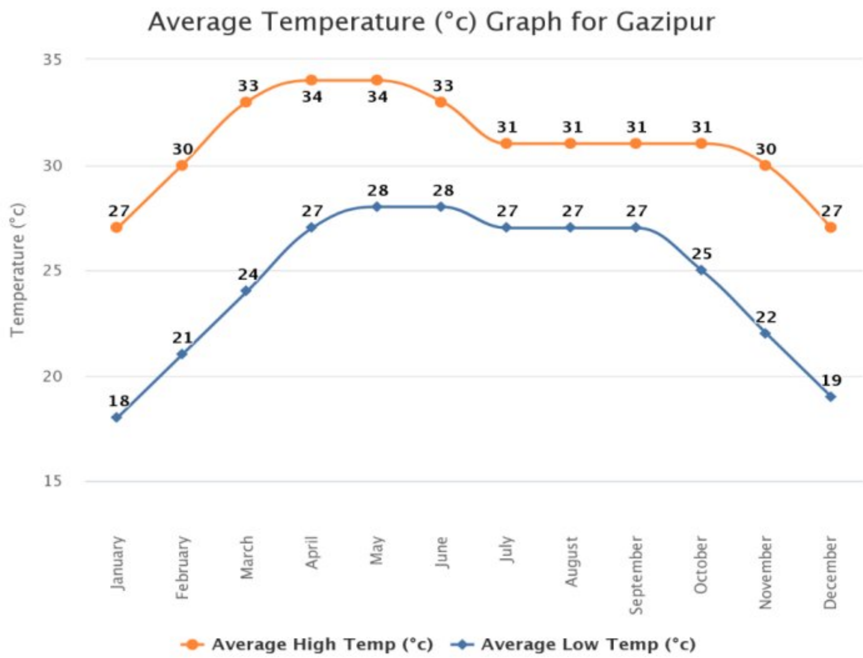

Figure 19: ***Monthly Average Temperature of Gazipur*** [47]

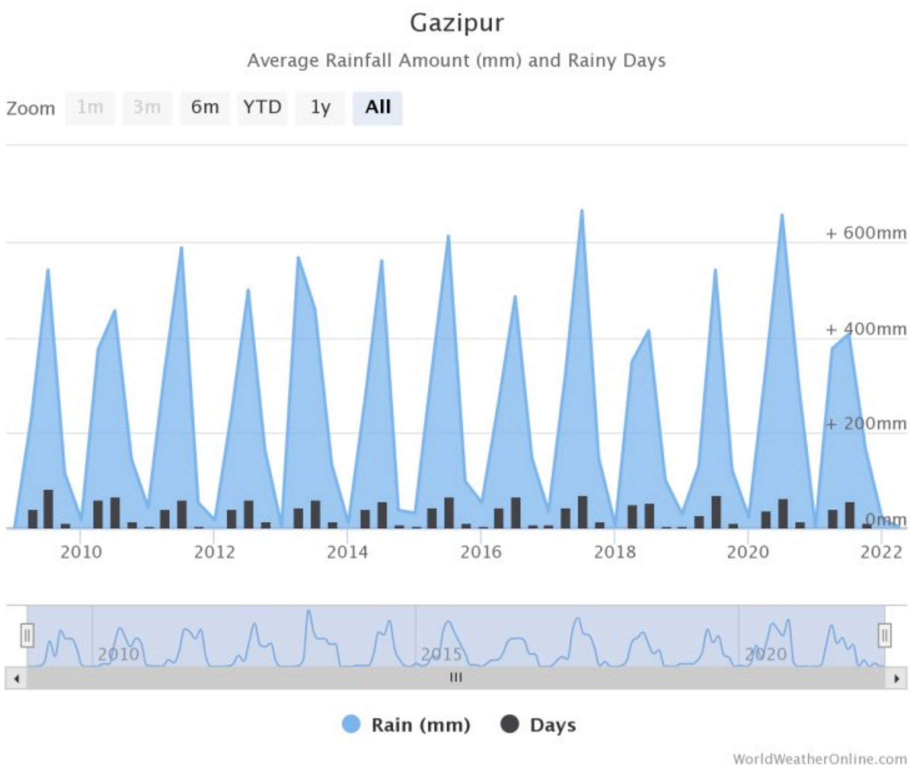

Figure 20: ***Avg rainfall amount(mm) and rain days in Gazipur (data period 2009 to 2022).*** [47]

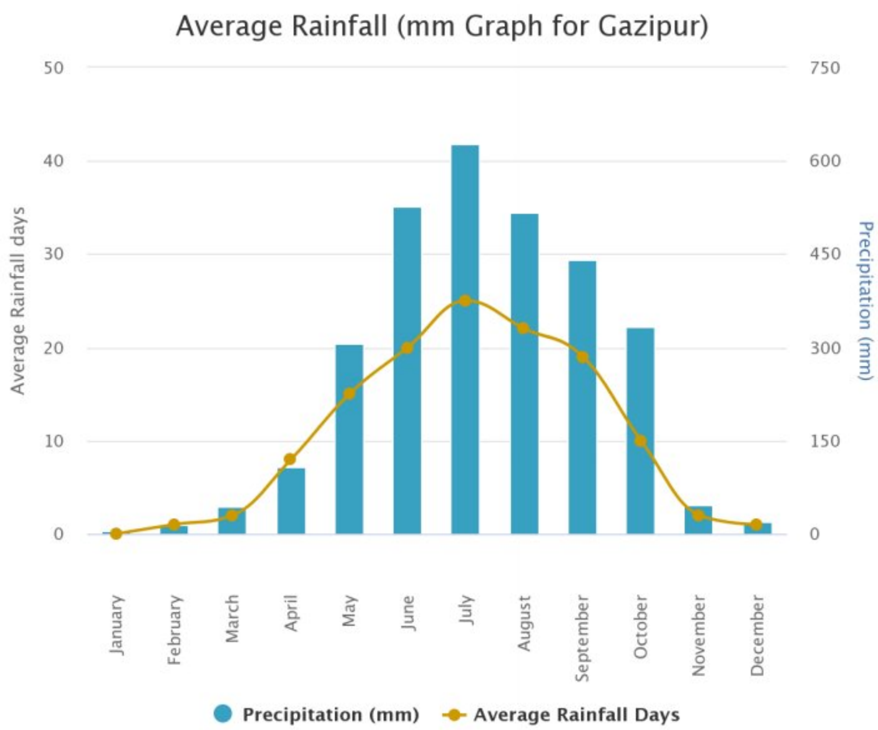

Figure 21: ***Monthly average rainfall in Gazipur (mm Graph for Gazipur).*** [47]

From the above discussion we can see that Sylhet has higher monthly average high temperature but it has a very high annual average rainfall and in case of Gazipur we can see that it has a very good monthly average high temperature and a decent annual average rainfall amount. But among the three selected location Kushtia has really good monthly average high temperature and really low annual average rainfall as well. Kushtia, Bangladesh, is the ideal site for CSP power plant in Bangladesh because of its proximity to the Sun. Once Kushtia, Bangladesh's latitude and longitude coordinates are known, we may download the corresponding data file straight from our website's repository. According to the weather data file, annual averages which we get are summarized in Table 3 in this manner.

Table 3: ***Annual Averages Summary (data from 2020).***

Global horizontal	4.92	kWh/m²/day
Direct normal (beam)	3.75	kWh/m²/day
Diffuse horizontal	2.44	kWh/m²/day
Average temperature	25.0	°C
Average wind speed	1.8	m/s

3.2 SYSTEM DESIGN

The desired plant specification description was designed using SAM. The design we followed had the following features:

Table 4: ***Specification of the plant.***

Plant capacity	10 MW (sent out)
Storage	12 hours
Plant Location	Chandra, Gazipur
Solar Field	Heliostats: 621, each 12.2m*12.2m Total field area: 89,657 m^2 aperture
Working Fluid (HTF)	Molten Salt Max Temperature: 474 ºC Min Temperature: 190 ºC

Receiver	Cylindrical, 20 panels Height: 6.747 Diameter: 4.425
Tower	61.611 m high
Cooling System	Shell and Tube Heat Exchanger
Land Area	155 acres
Expected annual Produced Energy	**11.24 GWh/year**

From Table 3.3, we can see the detailed specification of our potential Concentrated Solar Powerplant. Here it could be seen that the Plant capacity is 10 MW. In this CSP, the solar field storage hours are 6 hours, and the Solar Multiple is 2. This results in a full load storage hour of 12 hours. The required land area is 155 acres of land. And the expected annual produced energy is 11.24 GWh/year.

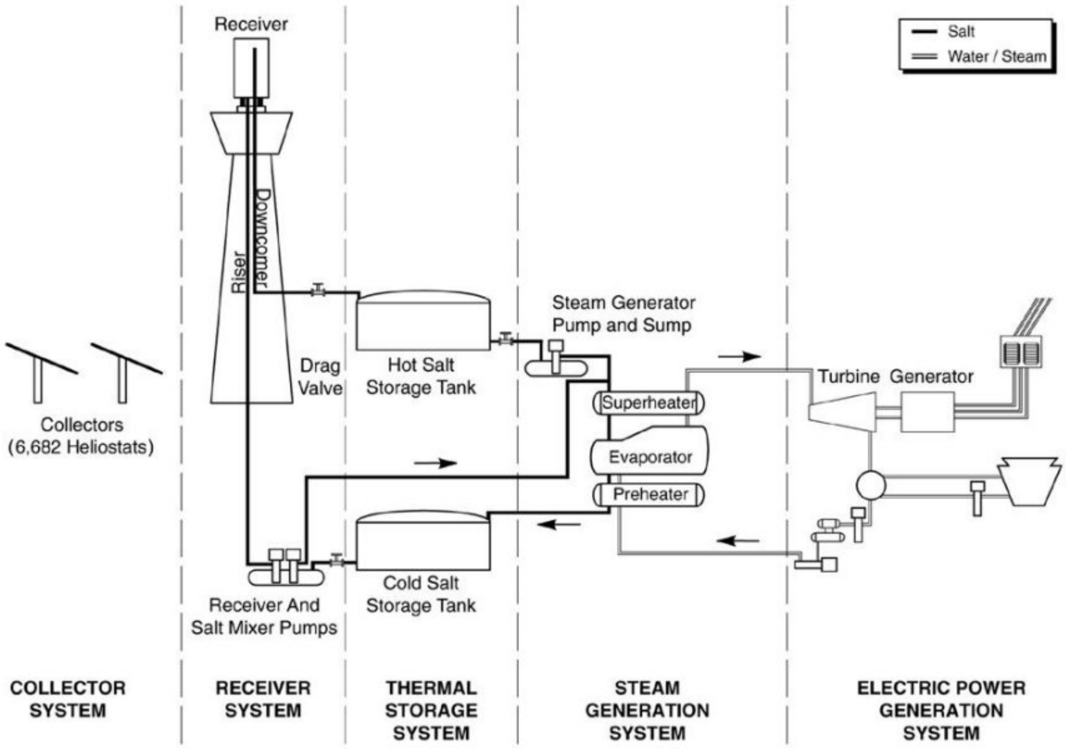

Figure 22: ***Schematic of the Concentrated Solar Powerplant*** [48]

Figure 22 illustrates the Concentrated Solar Powerplant with a molten salt power tower's primary subsystem. Clearly, there are two distinct cycles at work here. There are two types of cycles: one that uses salt, and the other that uses steam. Several subsystems make up the total system. All the heliostats in the field are part of the

Collector System. The tower and receiver make up the Receiver System. Hot and cold salt storage tanks are part of the Thermal Storage System. Heat Exchanger, Evaporator, Preheater, etc. make up the Steam Generation System. Electric power generation systems include a turbine and the associated transmission and distribution infrastructure. Concentrated Solar Powerplant schematics are summarized in this way.

3.3 HELIOSTAT FIELD

In terms of concentrated solar power, the heliostat field holds great promise. An array of applications can benefit from the high working temperature of the heliostat field collector. [49] SAM software was used to calculate the number of heliostats needed for this project depending on the plant location and capacity. Later, by adjusting these factors, it is established how SM and TES hour impact the projected plant's ability to generate electricity. There are 621 heliostats arranged in a ring around the power tower, according to the study's findings. Software also generates the heliostat arrangement, which is based on the optimal solar field geometry. Figure 23 depicts the final placement of the heliostats in the sun's rays. Several of the heliostat's characteristics are listed in Table 5. Heliostat placement is constrained by the tower's 57.63-meter height and the heliostats' 43.22 meter to 547.501-meter distances from the tower, respectively. A computer program calculates the optimal tower height, taking into account the 621 heliostats in use.

Table 5: ***Heliostat properties we got from SAM***

No. of Heliostat, (unit)	621
Heliostat (in Width), m	12.2 m
Heliostat (in Height), m	12.2 m
Heliostat Reflective Area, m^2	144.375 m^2
Heliostat Reflective Area (Total), m^2	89,657 m^2
Ratio of Max. Heliostat Range to Height of Tower	9.5
Ratio of Min. Heliostat Range to Height of Tower	0.75
Heliostat Stow (Deploy Angle)	8°

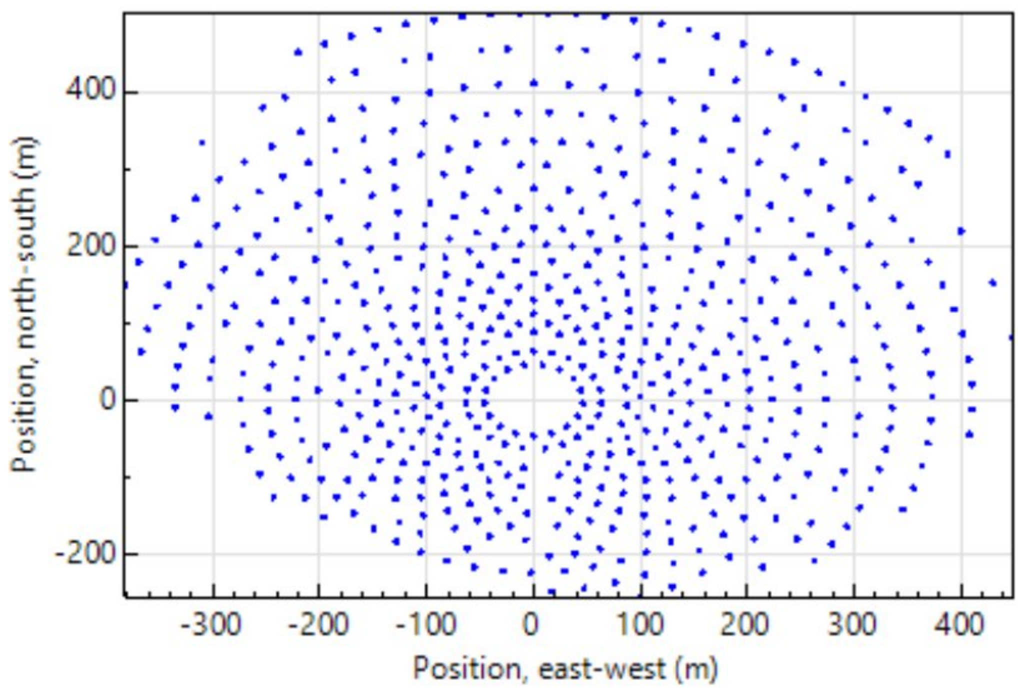

Figure 23: ***field lay out of heliostats from SAM (base design)***

3.4 TOWER AND RECEIVER

The number of heliostats in the system dictates the size of the power tower and receiver. It starts by calculating dimensions, then optimizes the actual dimensions and the geometry of a solar field. The height and diameter of the tower and receiver are determined by the number of heliostats that are used. This value is determined by optimizing the heliostat field arrangement. First, the dimensions and then the optimized dimensions are listed in Table 6. These dimensions are maintained throughout the project's examination.

Table 6: ***Power Tower Receiver input differences***

Dimension	**Initial Input (In m)**	**Optimized Value (In m)**
Height of the Receiver, m	21.60	6.44
Diameter of the Receiver, m	17.65	4.15
Height of the Tower, m	193.46	57.63

When designing the receiver, keep in mind the various heat transfer fluids' properties. For this project, the following molten nitrate salts were used: Solar Salt is one example of a salt that has been discussed in the literature. As it passes through the receiver at the summit of the transmission tower, the heat transfer fluid (HTF) absorbs energy. To function successfully, a receiver must be able to take in and expel salt at the right temperature.

The SAM program contains a Solar salt property table accessible via the menu bar. As a result, while analyzing new salts, the user must manually enter the physical properties.

3.5 POWER CYCLE

Power losses of 10 percent can be accommodated by the project's design turbine gross output of 10 MWe. In its most basic design, the plant has a net output of 9 megawatts (MW). Parasite losses frequently lower net output to 90% of the intended gross power. [50] Annual power losses are expected to be 4%, and there will be no hourly or typical period losses. Tables 7 and 8 list various software parameters for a solar thermal power plant's power block design point and plant control. [51]

Table 7: ***Power block design-point parameters.***

Conversion Efficiency of Cycle (Rated)	0.458
Design of the Thermal Power, MWt	10 MWt
Design of the Inlet Temperature of HTF (Solar-Salt), °C	474°C
Design of the Outlet Temperature of HTF (Solar-Salt), °C	190°C

Table 8: ***Plant control design parameters.***

Min. Needed Temperature to Start-up, °C	500°C
Fractional Thermal Energy Required for Stand-by	0.2
Startup Time of Power Block, hours	0.5 hours
Fractional Thermal Power Required for Start-up	0.5
Min. Turbine Operation	0.2
Max. Turbine Over Design Operation	1.05
Cycle design of HTF (in mass flow-rate), kg/s	51.5 kg/s
Through power block Pumping power for HTF, kW/kg/s	0.55 kW/kg/s

3.6 THERMAL STORAGE

Only the two-tank type of thermal storage system was studied in this project. Each TES hour and tank height specify a specific set of storage tank parameters that are unique to that tank (discussed more in the result and discussion part). The same is true for the amount of storage available. During the simulation analysis, the software estimates these parameters on the fly for convenience. As a result, certain qualities must be included in two-tank storage systems that hold both hot and cold water. Other parameters are only applicable to hot water tanks.

3.7 SYSTEM COST

Both the Direct Initial Cost and Indirect Initial Cost were analyzed using SAM. So, the detailed Total Installed Cost can be seen from the Table 9.

Table 9: ***Detailed Total Installed Cost of the CSP Plant***

Direct Capital Cost	
Heliostat Field	
Heliostat Reflective area, m^2	82,582 m^2
Improvement cost of Site, $\$/m^2$	15 $\$/m^2$
Heliostat field cost, $\$/m^2$	124 $\$/m^2$
Heliostat field cost fixed, $	$ 0
Total Site Improvement cost, $	**$ 1,238,736**
Total Heliostat field cost, $	**$ 10,240,215**
Tower	
Tower-height, m	57.6316 m
Receiver-height, m	6.44008 m
Heliostat-height, m	12.2 m
Fixed Tower cost, $	$ 3,000,000
Tower cost of the scaling exponent	0.0103
Total Tower Cost, $	**$ 5,944,066**
Receiver	
Receiver area, m^2	1320.15 m^2

Reference cost of the Receiver, $	**$** 103,000,000
Reference area of the Receiver, m^2	1571 m^2
Cost scaling exponent of the Receiver	0.7
Total Receiver Cost, $	**$ 12,258,722**
Thermal Energy Storage	
Capacity of Storage, MWht	2753.71 MWht
Storage cost for Thermal Energy, $/kWht	22 $/kWht
Total Thermal energy storage cost, $	**$ 5,764,192**
Power Cycle	
Gross capacity of cycle, MWe	111.25 MWe
Backup cost of Fossil, $/kWe	0 $/kWe
Backup cost of Fossil (Total, $	$ 0
Balance plant cost, $/kWe	290 $/kWe
Total Balance plant cost, $	$ 2,900,000
Power cycle cost, $/kWe	1040 $/kWe
Total Power cycle cost, $	$ 10,400,000
Subtotal, $	**$ 49,745,932**
Contigency	
Contigency cost	7% of subtotal
Total Contigency cost, $	$ 3,482,215
Total Direct Cost, $	**$ 53,228,148**

Indirect Capital Cost	
Land Cost	
Total land area, acres	155 acres
Net capacity of Cycle, MWe	9 MWe
EPS and owner cost	13% of direct cost
Total EPS and owner cost, $	$6,919,659
Land cost, $/acre	9,000 $/acre
Total land cost, $	$1,395,195
Sales Tax	
Sales tax basis	50% of direct cost
Tax rate of Sales, %	5%
Total Sales Tax, $	$1,330,703.00
Total indirect cost, $	**$9.645.558**

Total Installed Costs	
Total installed cost, $	**$62,873,704**
Estimated per net capacity of total installed cost ($/kW)	**$6,985.97**

3.8 STEAM GENERATOR:

A stream of steam from the High-Pressure Turbine (state 9) at 540°C and 9 MPa enters the Boiler for additional Reheating after the steam has been converted from water to steam by combustion of the fuel in the Boiler (state 10). HPT outlet (state 10) is used to extract steam for bleeding, and a percentage of the steam enters the CFWH (y amount). The steam (state 11) that has been reheated enters the LPT at a temperature of 540°C. The remaining fraction (1-y) of steam enters the LPT and undergoes a second stage of expansion. When the pressure of the steam in LPT reaches 0.3 MPa, a fraction of the steam (z amount) is removed and delivered to the OFWH for further expansion (state 12). 1-1-y-1-z has finished expanding at the LPT outlet and then flows through a condenser (state 13) where it is transformed into liquid water by a constant pressure heat rejection (state 14). (State 1).

Although mixing happens in the OFWH, the two streams must be at the same pressure at the input of OFWH in order to be mixed. State 1 has a stream pressure of 7 kPa, whereas state 12 has a pressure of 0.3 MPa. A Pump-I is needed to raise the pressure of the stream at the condenser's output (state 1) to 0.3 MPa since the LPT's outlet (state 12) is at a lower pressure. A pressure of 0.3 MPa is maintained in the OFWH after the two streams have been pumped into it, and the result is the mixture stream at state 3. The stream (at state 3) must now be pumped up to a boiler pressure of 9 MPa using a second Pump-II (state 4).

Furthermore, there is no requirement for the streams entering CFWH to be at the same pressure because no mixing will occur. At state 10, which was 2 MPa, both the streams from states 4 and 10 were entering the CFWH. A heat transfer occurs in the CFWH between the steam and the feed water, resulting in the state 4 stream being heated and becoming state 5 and the 10 streams being cold and becoming state 6 in the CFWH. State 7 at the pump output is achieved by using a third Pump-III to boost pressure from state 6 (CFWH) to the Boiler pressure of 9 MPa (state 7). Because the pressures of the two streams have equalized to 9 MPa, they are now ready to be combined in the mixing chamber. This is the same mass flow rate that was used in the first stage of mixing (state 9) and again in the second stage (state 8). [40]

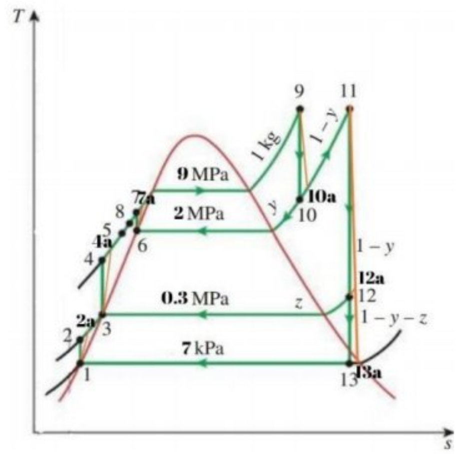

Figure 24: Schematic diagram for designed cycle [40]

3.8.1 Assumptions:

- There are stable operational conditions.
- At the feedwater heater pressure, feedwater is heated to saturation temperature in both open and closed heat exchangers.
- Reheat–regenerative operation does not take place in the power plant. Pumps and turbines in our power plant were anticipated to be 87% isentropically efficient because of the Rankine cycle, but they were not.
- The heat generated by the burning of coal in the boiler furnace is entirely absorbed by the boiler's water.
- The power source's temperature is 1023.15 Kelvin, or 750 degrees Celsius.
- It's 20 degrees Celsius (293.15 Kelvin) in the sink.
- Electrical motors are estimated to have a 98 percent or 0.98 efficiency.
- This power plant's components have been tested to ensure that they can operate under the harsh circumstances of a power plant.
- For some reason, we failed to account for the real vapor power cycle variance.

3.8.2 Operation Parameters:

Using MATLAB and Cool-Prop, the modeling of the thermodynamic power cycle has been done according to the operating conditions that has been described above. The code will be provided later in the Appendix of this report.

Process: (9-10)- (isentropic expansion in High Pressure Turbine):

State 9: Superheated vapor, Pressure = 9 MPa, Temperature = 540°C

$P_9 = (9 \times 10^6)$ Pa

$T_9 = (540+273.15)$ Kelvin

$H_9 = 3487290.04$ J/kg (Using MATLAB and Cool-prop)

$S_9 = 6786.25$ J/kg/Kelvin (Using MATLAB and Cool-prop)

Process: (10-11)- (Reheating in the boiler):

State 10: Superheated vapor, entropy same as state 9, Pressure = 2 MPa

$S_{10} = S_9$

$P_{10} = (2 \times 10^6)$ Pa

$H_{10} = 3034441.31$ J/kg

Process: (11-13)- (isentropic expansion in Low Pressure Turbine):

State 11: Superheated vapor, temp same as state 9, Pressure same as state 10

P11 = P10

$T_{11} = T_9$

$H_{11} = 3556749.38$ J/kg (Using MATLAB and Cool-prop)

$S_{11} = 7545.33$ J/kg/Kelvin (Using MATLAB and Cool-prop)

State 12: Superheated vapor, entropy same as state 11, Pressure = 0.3 MPa

S12 = S11

$P_{12} = (0.3 \times 10^6)$ Pa

$H_{12} = 2982248.69$ J/kg (Using MATLAB and Cool-prop)

Process: (13-1)- (Constant Pressure Heat rejection in the Condenser):

State 13: liquid - vapor mixture with high percentage of dryness fraction, Pressure = 7

KPa, entropy same as state 11

S13 = S11

$P_{13} = (7 \times 10^6)$ Pa

H_{13} = 2344122.79 J/kg (Using MATLAB and Cool-prop)

Quality of steam,

Q_{13} = 0.9054 or 90.54% (Using MATLAB and Cool-prop)

<u>Process: (1-2)- (isentropic compression in pump 1):</u>

State 1: Saturated liquid, Pressure same as state 13

$P_1 = P_{13}$

$Q_1 = 0$

H_1 = 163351.27 J/kg (Using MATLAB and Cool-prop)

S_1 = 559.028 J/kg/Kelvin (Using MATLAB and Cool-prop)

<u>State 2: Subcooled liquid, entropy same as state 1, pressure same as state 12</u>

$S_2 = S_1$

$P_2 = P_{12}$

H_2 = 163646.45 J/kg (Using MATLAB and Cool-prop)

Process: (3-4)- (isentropic compression in pump 2):

State 3: Saturated liquid, pressure same as state 2

P3 = P2

$Q_3 = 0$

H_3 = 561426.68 J/kg (Using MATLAB and Cool-prop)

S_3 = 1671.72 J/kg/K (Using MATLAB and Cool-prop)

<u>State 4: Subcooled liquid, entropy same as state 3, Pressure same as state 9</u>

$P_4 = P_9$

$S_4 = S_3$

H_4 = 570744.07 J/kg (Using MATLAB and Cool-prop)

Process: (6-7)- (isentropic compression in pump 3):

State 6: Saturated liquid, pressure same as state 10

P6 = P10

$Q_6 = 0$

H_6 = 908498.08 J/kg (Using MATLAB and Cool-prop)

S_6 = 2446.75 J/kg/K (Using MATLAB and Cool-prop)

State 5: Enthalpy same as state 6 according to TS diagram

$H_5 = H_6$

State 7: Subcooled liquid, entropy same as state 6, Pressure same as state 9

$S_7 = S_6$

$P_7 = P_9$

H_7 = 916715.28 J/kg (Using MATLAB and Cool-prop)

Energy Balance in Closed Feedwater Regenerative Heater ($E_{in} = E_{out}$)

$yH_{10} + (1-y) H_4 = (1-y) H_5 + yH_6$;

$y(H_{10}-H_4) + H_4 = y (H_6-H_5) + H_5$;

Therefore,

$$y = \frac{(H_5 - H_4)}{(H10 - H6)} + (H_5 - H_4)$$

y = 0.14 (Using MATLAB and Cool-prop)

Energy Balance in Open Feedwater Regenerative Heater ($E_{in} = E_{out}$)

$zH_{12} + (1-y-z) H_2 = (1-y) H_3$; $z (H_{12}-H_2) + H_2 - yH_2 = H_3 - yH_3$;

Therefore,

$$z = \frac{(1 - y)\,(H_3 - H_2)}{(H12 - H2)}$$

z = 0.12 (Using MATLAB and Cool-prop)

Energy balance in the Mixing chamber, ($E_{in} = E_{out}$):

State 8: Enthalpy from energy balance

$H_8 = (1 - y)\,H_5 + (yH_7)$

H_8 = 909624.59 J/kg (Using MATLAB and Cool-prop)

S_8 = 2432.16 J/kg/K (Using MATLAB and Cool-prop)

Determination of Actual enthalpies considering isentropic efficiency for each turbine and pump as 87%: In the boiler and condenser, as well as in the Pumps and Turbines, the real vapor power cycle is deviated from the ideal one because of pressure drop. This irreversibility in pumps and turbines must be taken into consideration in order to compute the real enthalpies at their outputs following the deviation.

Tena, 12a, and 13a are the real outlets or deviated states of the turbines and two and four and seven are the actual outlets or deviated states of the pumps.

In the MATLAB code, those points were also calculated.

Let us assume each turbine and pump in our power generation cycle to have isentropic efficiency of 87 %.

η_turbine_1 = η_turbine_2 = 0.87, η_pump_1 = η_pump_2 = η_pump_3 = 0.87,

η_turbine_1 = (H9 -H10a)/(H9-H10);

$H_{10}a = H_9 - \eta\_turbine\_1(H_9 - H_{10})$

H_{10a} = 3093311.64351604 J/kg (Using MATLAB)

S_{10a} = 6885.96880168941 J/kg/K (Using MATLAB and Cool-prop)

$H12a = H11 - \eta\_turbine\_2(H11 - H12)$

H_{12a} = 3056933.78 J/kg (Using MATLAB)

S_{12a} = 7681.52 J/kg/K (Using MATLAB and Cool-prop)

$H13a = H12a - \eta\_turbine\_2\ (H12 - H13)$

H_{13a} = 2501764.24 J/kg (Using MATLAB)

S_{13a} = 8050.35 J/kg/K (Using MATLAB and Cool-prop)

η _pump_1 = (H2-H1)/(H2a-H1)

$$H2a = \frac{H2 - H1}{\eta pump\_1} + H1$$

H_{2a} = 163690.55 J/kg (Using MATLAB)

S_{2a} = 559.17 J/kg/K (Using MATLAB and Cool-prop)

$$H_{4a} = \frac{H4 - H3}{\eta pump\_2} + H_3$$

H_{4a} = 572136.32 J/kg (Using MATLAB)

S_{4a} = 1675.13 J/kg/K (Using MATLAB and Cool-prop)

$$H7a = \frac{H7 - H6}{\eta pump\_3} + H6$$

H_{7a} = 917943.14 J/kg (Using MATLAB)

S_{7a} = 2449.27 J/kg/K (Using MATLAB and Cool-prop)

3.8.3 Cost Estimation

The ultimate aim of power plant design is to produce electrical energy at minimum cost and maximum efficiency. The generation cost per unit kWh depends upon the cost of creating design, erection, commissioning and operation of power plant. [52]

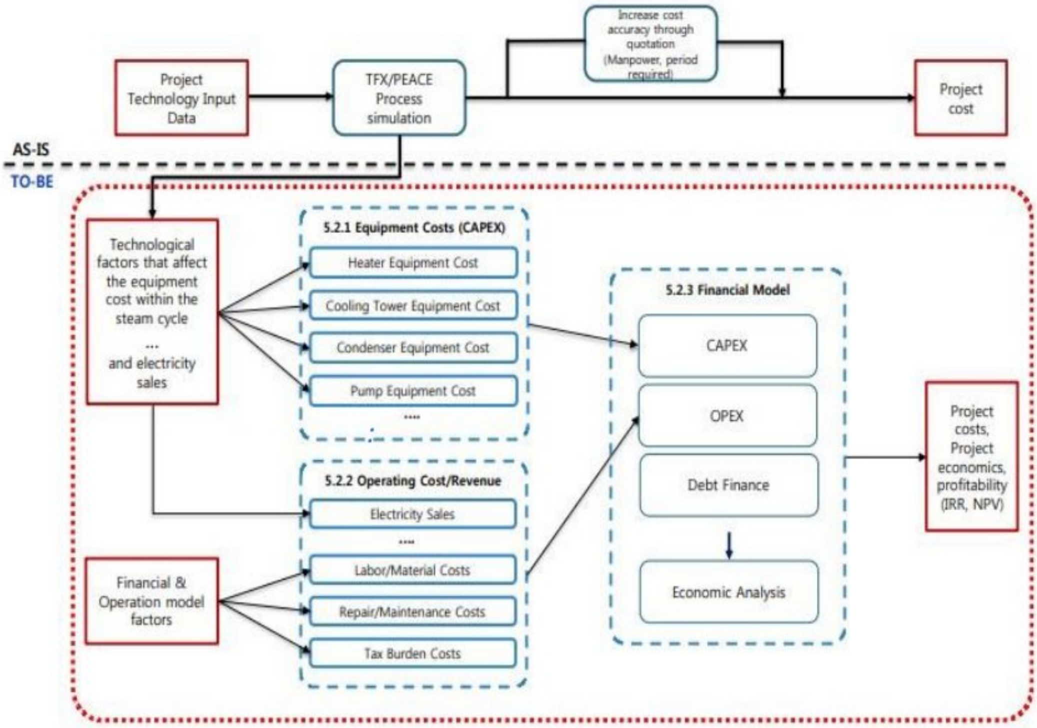

Figure 25: Cost analysis model structure [52]

3.6.3.1 CAPEX (Capital Expenditure)

During the plant building phase, the overall investment cost of a project is typically referred to as CAPEX, which includes both equipment and installation expenses. To put it another way, the financial model of the power plant's CAPEX includes the expenses of building, operation, and plant decommissioning. Equipment placed in the power plant accounts for the supply cost element of the direct cost. Because the costs of equipment are very variable and influenced by technical aspects, a proposed model states that the formula for equipment cost should look like the following. [52]

$$Equipment\ Cost = Ref.Cost \times \left(\frac{Technical\ factor_1}{ref.factor_1}\right) \times \left(\frac{Technical\ factor_2}{ref.factor_2}\right)$$

CAPEX is the summation of Net increase in PPE (property, plants and equipment) and depreciation expense. It calculates the total purchase of the assets by the Power plant in the given year. The formula for Capex is given below:

CAPEX = Net increase in PPE in a given year + Depreciation expense of the same year

All kinds of fixed cost for the power plant falls under the CAPEX.

Fixed cost: Fixed cost is usually incurred only once during the life of plant. Fixed cost has following components:

Capital cost of power plant:

Purchase of land, Land development, purchase of machinery and equipment and their installation, engineering and architectural fee of that project.

Interest on capital cost:

most of the times the. Capital cost or part of it is usually borrowed and the borrower has to pay the interest. This payment is called as interest on capital cost.

Taxes:

The management also has to pay various taxes to town and state authorities such as property tax, land tax, etc.

Insurance:

The heavy investment made has to be protected from the risk of fire, explosion, storms, earthquake, flood etc.

Depreciation cost:

Every equipment depreciates due to corrosion, erosion, wear and tear with use. Therefore, when they equipment failure occurs and it stops working, then this old equipment has to be replaced with new one. According to straight line method,

$\boldsymbol{A} = \frac{n-S}{P}$ [53]

Where, P = initial investment

S = Salvage value at the end of plant life

n = life of plant in years

r = annual rate of interest on invested capital

A = depreciation amount set aside per year

Managerial cost:

It includes salaries and wages of the people working in the plant during construction. [54]

3.6.3.2 OPEX (Operational Expenditure) Estimates

A facility's operating expenses (OPEX) include both direct costs (such as labor and materials) and indirect costs (such as taxes and revenue), such as the cost of managing the facility itself. Profits from power plants are often generated by selling energy (electricity, steam) and water (water). According to the author's assumptions, this paper exclusively deals with electricity. It is usual to split variable costs from fixed costs in power-generation projects since the fuel cost is a significant component of these expenditures, which is why it is typical practice. The cost of fuel for thermal power generation depends on the amount of coal used. Coal usage and plant heat rate are demonstrated to be correlated in the following equation. [52]

$$\text{Coal Yearly Demand (kg)} = \frac{Plant\ Power\ Capacity\ (kW) \times Heat\ Rate\ \left(\frac{kJ}{kWh}\right) \times 0.239\ \left(\frac{kcal}{kj}\right)}{Higer\ Heating\ Value\ \left(\frac{kcal}{kg}\right)} \times Coal\ Efficiency \times \frac{24\ h}{day} \times \frac{365\ days}{year}$$

Operating cost / Variable cost: The expenditure incurred got operating the Power plant to Produce electrical energy. Operating cost includes:

cost of fuel, **cost** of salaries and wages, **cost** of maintenance and repair, **operating** taxes

Overall efficiency = $\eta\_cycle \times \eta\_Boiler \times \eta\_Generator \times \eta\_turbine$ [55]

Let us Assume, $\eta_{\_Boiler} = 90\% = 0.90$

$\eta_{\_overall} = 0.311297266395863$

CHAPTER 4

ANALYSIS AND DISCUSSION

4.1 COST ANALYSIS OF A 10MW STEAM POWER PLANT

The cost per unit electricity or per kWh_{net} electricity is determined by: [56]

- Fuel cost
- CAPEX-Capital Expenditures include the cost of the power production project's investment, which typically comprises equipment supply costs, land costs, installation costs, and so on.
- OPEX-Operational Expenditures encompass the cost of operating a facility and include both direct (such as salaries, wages, materials, repair/maintenance, etc.) and indirect expenditures (such as tax costs and income).
- kWh_{net} of electricity which is sent out per year

The total annual costs (Ct) in a power plant can be calculated from [56]

$$C_t = \left(\left(\frac{I + D + T}{100}\right)^{m-1}\right) C_C + OPEX + \left(\left(\frac{F}{100}\right)^{m-1}\right) C_f$$

Where, I is the interest rate, %

D is the depreciation rate, %

T is the taxes and insurance, %

F is the fuel inflation rate, %

(Other rates can be incorporated)

C_c is the construction/capital cost (CAPEX)

C_f is the fuel cost

m = No. of years

The annual amount of electricity sent out by power plant kWh_{net} is given by [56]

$$kWh_{net} = kW_{installed} \times (load_{total-h} \times 365) \left(\frac{hr}{year}\right) \times (1 - \frac{L_{aux}}{100}) \times n$$

Where,

$kWh_{installed}$ = Installed output

L_{aux} = power consumption by auxiliaries, %

In diesel-based power plants generally the auxiliary power consumption is about 5 to 8 % [57]

For this power plant auxiliary power consumption is assumed 8 %

$Load_{total\text{-}h}$ = Total load hour = 16 h

n = plant capacity factor = $\frac{\text{average load}}{\text{capacity of plant}}$

Average load is determined from load distribution curve which is a curve representing the variation in energy demands with time. Generally, average load is less than the capacity of plant. Therefore, plant capacity factor is less than 1. For this power plant capacity factor is assumed 0.9

4.1.1 Fuel Cost

Assuming a diesel-based power plant, the fuel cost of the power plant depends on diesel consumption.

Energy content of coal

Energy content of diesel is given in terms of kilojoules per kilogram (kJ/kg) of diesel as the Gross calorific value (GCV) or the Higher Heating value (HHV) of diesel. This value can vary from 42000 kJ/kg to 46000 kJ/kg depending on the quality and type of the coal. [58]

The HHV value for coal is taken 42000 kJ/kg for this project.

Conversion efficiency

Two phases are involved in the process of converting energy in a factory. The efficiency of the boiler and the combustion is the first step in the conversion. As a rule of thumb, a well-optimized power plant's boiler conversion efficiency should be in the region of 80% to 90%. The efficiency of the steam cycle is the second portion.

Diesel engines, large capacity industrial engines, deliver efficiencies in the range of 35 to 42 %. [59]

For this case the efficiency is taken as 37%

The overall conversion efficiency then is (37% x 90%) = 33.3%

Heat rate

The heat rate is the amount of heat needed to generate one kilowatt-hour of electricity. 3600 kJ/h is the energy output of a single kilowatt-hour (kW). In order to create one kilowatt-hour of electricity, a 3600 kilojoule (kJ) heat input is needed.

Considering the conversion efficiency in a power plant,

It is required a heat input of = $\frac{3600\ (\frac{kJ}{kWh})}{33.3\%} = 10810.81\ \frac{\text{kJ}}{\text{kWh}}$

Required quantity of coal

Higher heating value of coal 42,000 kJ/kg.

For producing 1 kWh required amount of diesel = $\frac{10810.81\ (\frac{kJ}{kWh})}{42000\ \frac{kJ}{kg}}$ = 0.257 $\frac{\text{kg}}{\text{kWh}}$

Therefore, for producing 10 MW or 10x10^3 kW the required amount of diesel

= 0.257 $\frac{\text{kg}}{\text{kWh}}$ ×10×10^3 kW= 2574.002 kg/h = 2993.03 Litre/h = 790.68 gallon/h

Yearly requirement of diesel = 790.68 (gallon/h) ×16 (h/day) ×365(day/yr) = 4617571.2 gallon

Coal Cost

F = Fuel inflation rate = 15.45% [60]

It is assumed coal price of around = 3.475 $ / gallon [61]

Fuel cost per hour = 835.86 × $3.475= 2904.6135 ($/h)

Fuel cost for first year will be, C_f= $\left(\frac{F}{100}\right)^{1-1}$ × 4617571.2× 3.475$= **16046059.92** ($/yr)

4.1.2 Fixed cost

4.1.2.1 CAPEX or Capital cost [62]

Table 10: ***CAPEX of steam power plant***

Cogeneration System Components	**Specifications**	**Estimated Amount**
1.Heat Exchanger	• Counter-flow • 280 tubes, 2-tube pass, t, in = 0.083 in, diameter, in = 0.834 in • Tube length, m = 4.0, squared pitch layout • Maximum Design velocity, m/s = 0.820648 m/s • Baffle spacing, mm = 533.4 mm • Shell thickness, mm = 5.0 mm • Pressure drop, kPa = 2.109 kPa • Mass flow rate, kg/s = 2.83 kg/s • Exchanger area, sq. m = 89 sq. m	$ 10, 385

2.Exhaust Gas Boiler	• Volume of Boiler cylinder, L = 792L • Thickness, cm = 0.423cm • SCH 40 grade Pipe • NPSI ¼ Size Pipe • Steam pressure, bar = 40 bar • Steam velocity, m/s =120.213 m/s • Provision of: Economizer, Super heater, Pre-heater, and feed-pump	$ 21, 635.66
3. Steam Turbine	• Rotor Speed, rpm = 30,000 rpm • Rotor type = Pelton, single casing geared • Steam pressure, bar = 40 bar • Model = multistage multi-valve • Design = extraction back-pressure	$ 103, 851.15
4.Generatror	• Power output = up to 10MW • Type Synchronous	$ 69, 234.10
5.Other interconnections	• Feed hose, bolts, nuts, pressure gauges, valves etc.	$ 5192.56
6. Land cost	• Land cost taken same as that of CSP plant • Land needed = 10 acre	$ 100,000
Total Capital Cost		**$ 310,298.47**

4.1.2.2 Calculation of fixed cost

Assumptions: [52]

Tax = 20%

Interest rate = 6%

Depreciation = 10%

Fixed cost = $\left(\left(\frac{I+D+T}{100}\right)^{m-1}\right) C_C = \left(\left(\frac{6+10+20}{100}\right)^{1-1}\right) \times \$310,298.47 = \ \$310,298.47$ ($/yr)

4.1.3 OPEX or O&M costs

Annual O&M cost for steam power plant is about $175.2 per kilowatt (kW) [63]

Therefore, O&M cost of 10MW power plant Cc = ($175.2 ×10×10^3) = 17,52,000 ($\$/yr$)

4.1.4 Cost of Electricity of Designed Power Plant

Total annual costs (Ct),

$C_t = \left(\left(\frac{I+D+T}{100}\right)^{m-1}\right) C_C + OPEX + \left(\left(\frac{F}{100}\right)^{m-1}\right) C_f =$ $310,298.47 +$17, 52,000 +$16046059.92 = $18108358.39

The annual amount of electricity sent out by powerplant (kWhnet)

$kWhnet = 10 \times 10^3 \times (16 \times 365) \left(\frac{hr}{year}\right) \times \left(1 - \frac{8}{100}\right) \times 0.9 = 488{,}80{,}200$

Cost for production of 1 unit of electricity = 18108358.39 ($\$/yr$) / 488, 80,200 ($kWh/yr$) = **$0.375**

4.2 OPERATING EXPENSES ANALYSIS OF A 10 MW CSP PLANT

The Total Operating Expenses of the 10 MW Concentrated Solar Power Plant was simulated using the System Advisory Model (SAM) software. Where the initial inputs for a Concentrated Solar Power Plant were given and based on those inputs simulation was done using the integrated system of SAM. And the data of Table 11 was achieved from simulating in SAM. Table 11 indicates us the Total Operating Cost of the 10 MW Concentrated Solar Power Plant that is being designed in this project.

Table 11: ***Operating Expenses Analysis of a 10 MW CSP Plant***

Year	Energy produced (kWh)	O&M production-based expense ($)	O&M capacity-based expense ($)	Insurance expense ($)	Total operating expenses ($)
0	0	0	0	0	0
1	10954710	38341	594000	314919	947260
2	10954710	39108	605880	321217	966206
3	10954710	39890	617998	327642	985530
4	10954710	40688	630358	334194	1005240
5	10954710	41502	642965	340878	1025345

6	10954710	42332	655824	347696	1045852
7	10954710	43179	668940	354650	1066769
8	10954710	44042	682319	361743	1088104
9	10954710	44923	695966	368978	1109866
10	10954710	45822	709885	376357	1132064
11	10954710	46738	724083	383884	1154705
12	10954710	47673	738564	391562	1177799
13	10954710	48626	753336	399393	1201355
14	10954710	49599	768402	407381	1225382
15	10954710	50591	783770	415529	1249890
16	10954710	51603	799446	423839	1274888
17	10954710	52635	815435	432316	1300385
18	10954710	53687	831743	440962	1326393
19	10954710	54761	848378	449782	1352921
20	10954710	55856	865346	458777	1379979
21	10954710	56973	882653	467953	1407579
22	10954710	58113	900306	477312	1435731
23	10954710	59275	918312	486858	1464445
24	10954710	60461	936678	496595	1493734
25	10954710	61670	955412	506527	1523609
26	10954710	62903	974520	516658	1554081
27	10954710	64161	994010	526991	1585163
28	10954710	65445	1013891	537531	1616866
29	10954710	66753	1034168	548281	1649203
30	10954710	68089	1054852	559247	1682187
31	10954710	69450	1075949	570432	1715831
32	10954710	70839	1097468	581840	1750148
33	10954710	72256	1119417	593477	1785150
34	10954710	73701	1141806	605347	1820854
35	10954710	75175	1164642	617454	1857271

4.3 BREAK-EVEN POINT ANALYSIS OF A 10 MW CSP PLANT

From the Figure 4.1, A clear picture of the Break-even Point Analysis, Net Cost Analysis, Total Revenue Analysis, Total Operating Expenses Analysis of a 10 Mega-watt Concentrated Solar Power Plant can be seen. Here, the Total Installation Cost and the Total Operating Expenses were achieved using SAM. Using SAM, the expenses were simulated based on each year of operation of the Concentrated Solar Power Plant. And for the Total Revenue Analysis was done using the same per unit electricity selling rate which is previously calculated in the section 4.1.4. Here the total revenue was calculated using the assumption that electricity produced in the 10 MW Power Plant were to sell in the same price as that of per unit selling cost of Steam power plant calculated in the section 4.1.4. In the Figure 26, The Total Installation Cost is scaled down by 10 times and the Total Revenue is scaled down by 2 times. These were done for achieving a better-looking Graph. And from the Figure 26, It can also be seen that the Break-even Point was achieved in the **18th year** of operation for the 10 MW Concentrated Solar Power Plant.

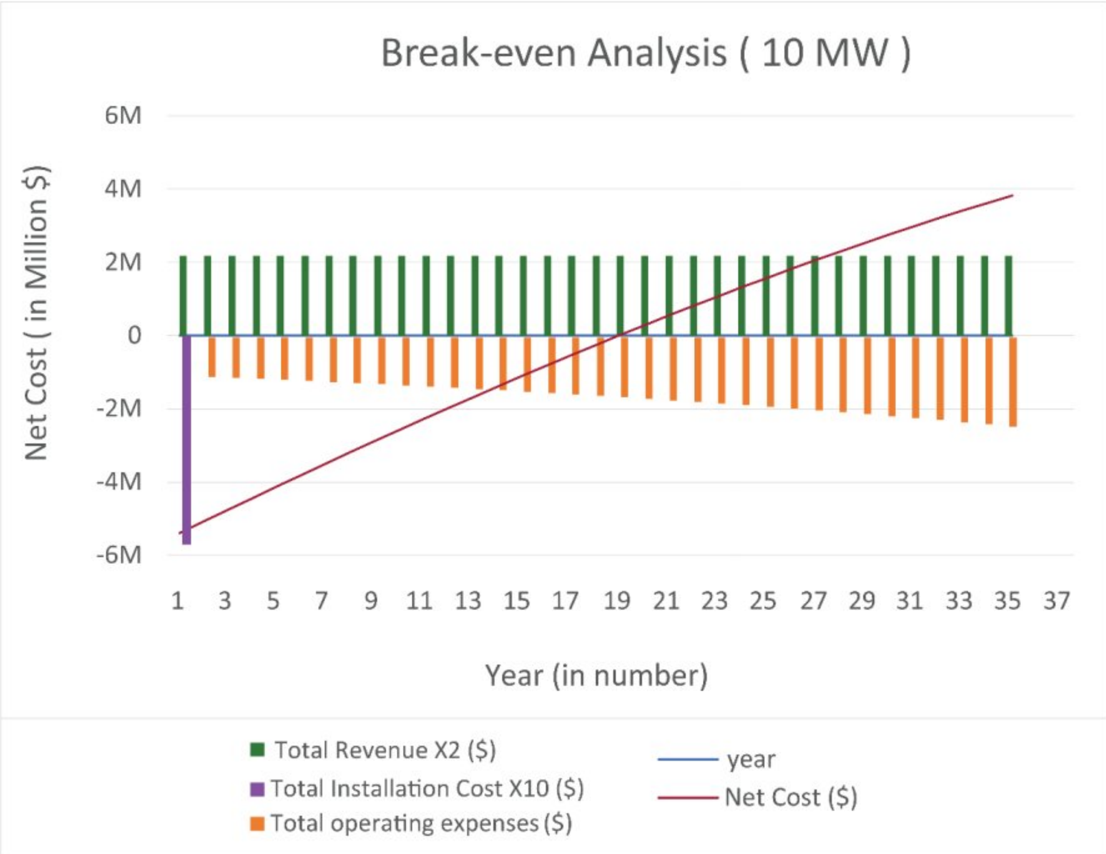

Figure 26: ***Break-even Point Analysis of a 10 MW CSP Plant***

4.4 BREAK-EVEN POINT ANALYSIS OF A 50 MW & 100 MW CSP PLANT

From the Figure 4.2, A clear picture of the Break-even Point Analysis, Net Cost Analysis, Total Revenue Analysis, Total Operating Expenses Analysis of a 50 Mega-watt Concentrated Solar Power Plant can be seen. Here, the Total Installation Cost and the Total Operating Expenses were achieved using SAM. Using SAM, the expenses were simulated based on each year of operation of the Concentrated Solar Power Plant. And for the Total Revenue Analysis was done using the same per unit electricity selling rate which is previously calculated in the section 4.1.4. Here the total revenue was calculated using the assumption that electricity produced in the 50 MW Power Plant were to sell in the same price as that of per unit selling cost of Steam power plant calculated in the section 4.1.4. In the Figure 27, The Total Installation Cost is scaled down by 10 times and the Total Revenue is scaled down by 2 times. These were done for achieving a better-looking Graph. And from the Figure 27, It can also be seen that the Break-even Point was achieved in the **12th year** of operation for the 50 MW Concentrated Solar Power Plant.

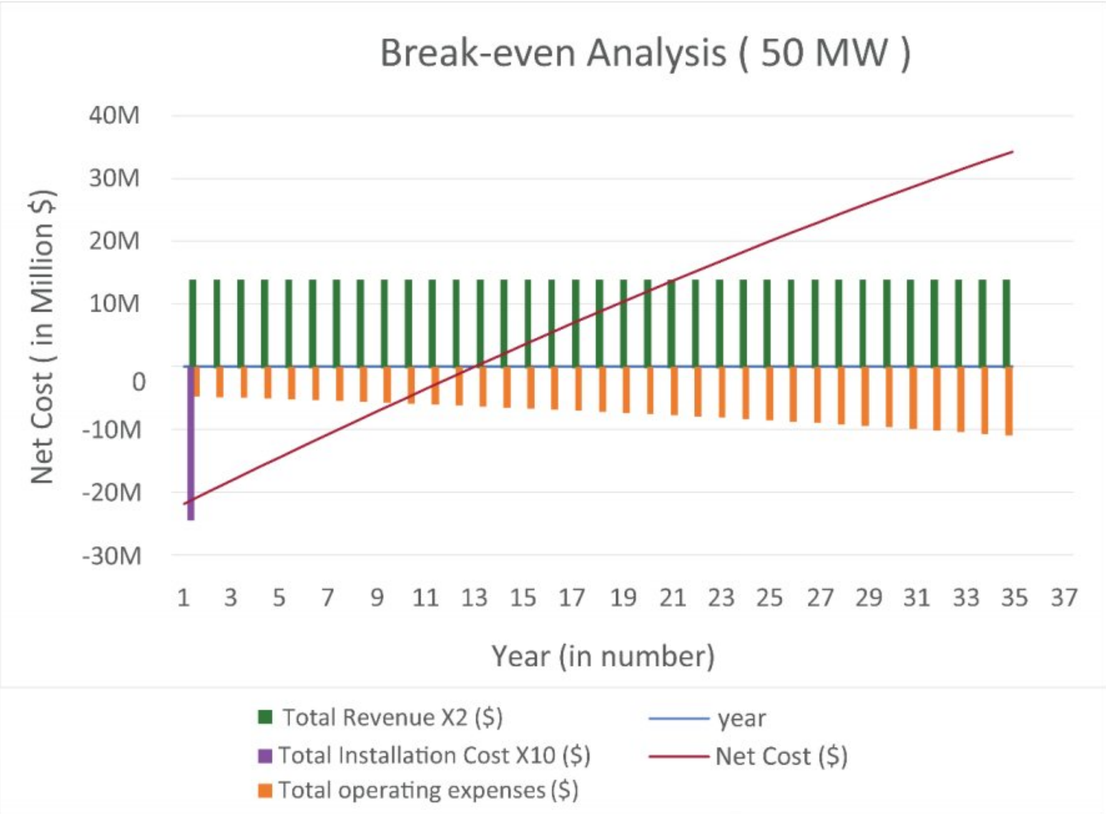

Figure 27: ***Break-even Point Analysis of a 50 MW CSP Plant***

From the Figure 4.3, A clear picture of the Break-even Point Analysis, Net Cost Analysis, Total Revenue Analysis, Total Operating Expenses Analysis of a 100 Mega-watt Concentrated Solar Power Plant can be seen. Here, the Total Installation Cost and the Total Operating Expenses were achieved using SAM. Using SAM, the expenses were simulated based on each year of operation of the Concentrated Solar Power Plant. And for the Total Revenue Analysis was done using the same per unit electricity selling rate which is previously calculated in the section 4.1.4. Here the total revenue was calculated using the assumption that electricity produced in the 100 MW Power Plant were to sell in the same price as that of per unit selling cost of Steam power plant calculated in the section 4.1.4. In the Figure 28, The Total Installation Cost is scaled down by 10 times and the Total Revenue is scaled down by 2 times. These were done for achieving a better-looking Graph. And from the Figure 28, It can also be seen that the Break-even Point was achieved in the **8th year** of operation for the 100 MW Concentrated Solar Power Plant.

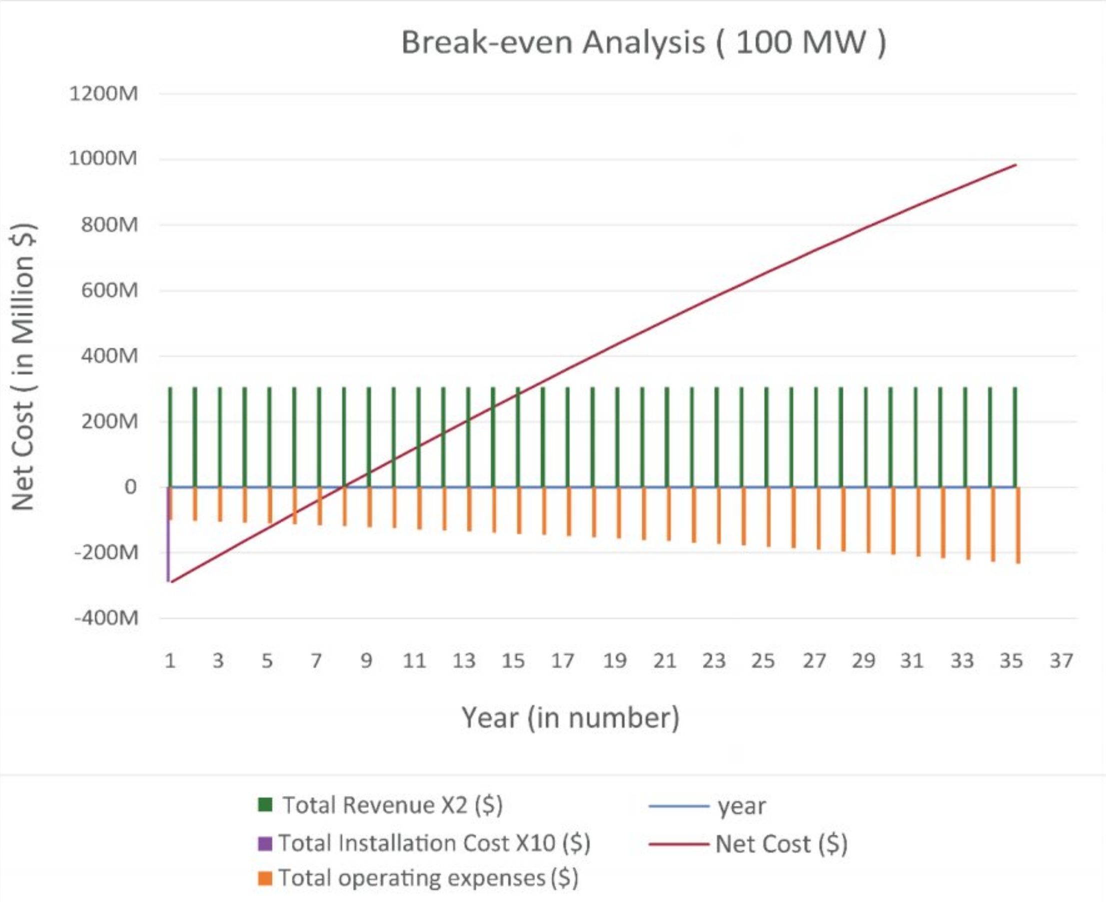

Figure 28: ***Break-even Point Analysis of a 100 MW CSP Plant***

4.5 WHY 10 MW CSP PLANT?

Even though it is seen that The Break-even Point could be achieved much faster in 50 MW and 100 MW Power Plant than that of 10 MW Power Plant, the reason 10 MW Power Plant is designed in case of Bangladesh because of land are and higher cost. In case of 10 MW Power Plant the required land area and the installation cost is much lesser than that of 50 MW and 100 MW Power Plant. From the section 4.3 and 4.4, a clearer picture of cost could be seen. And in case of required land area, it is known that Bangladesh is an agricultural country and the people here love their land more than anything. That's why considering all these 10 MW Concentrated Solar Power Plant was designed in this Project.

4.6 BREAK-EVEN POINT ANALYSIS OF A 10 MW PLANT WITH GOVERNMENT SUBSIDY

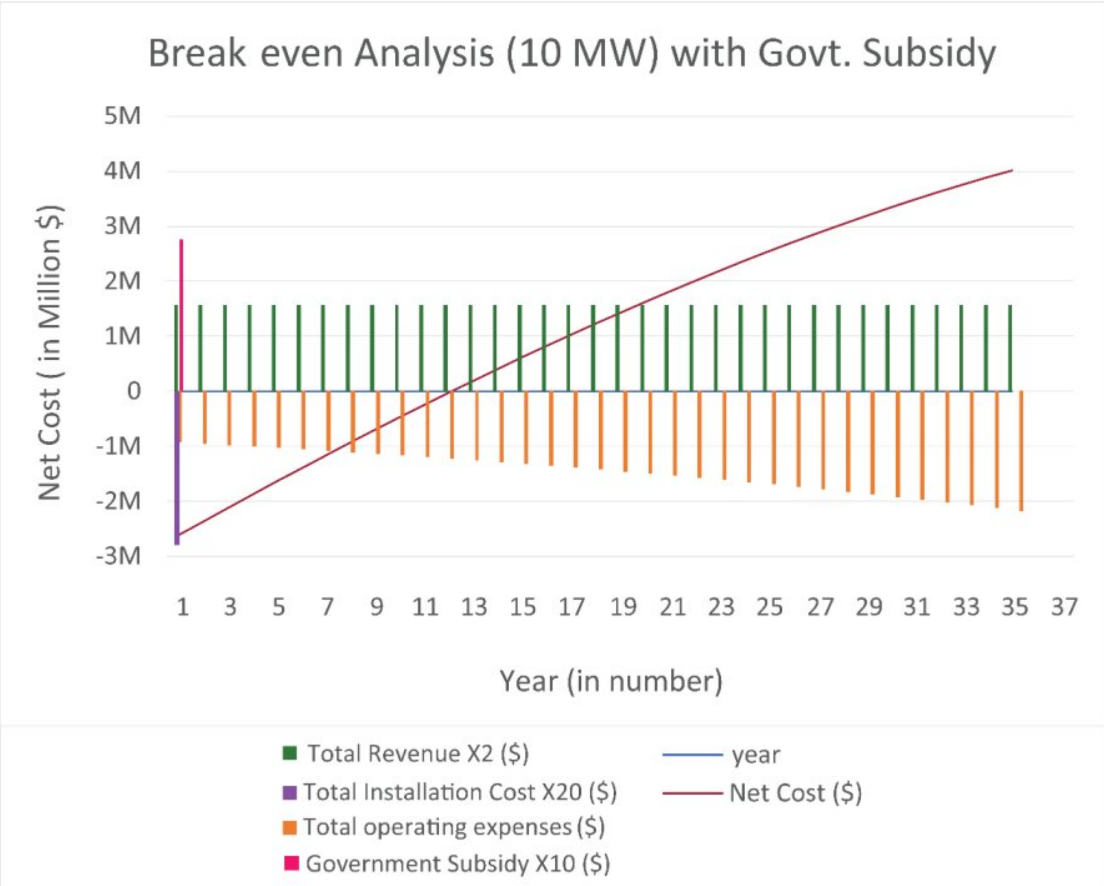

Figure 29: ***Break-even Point Analysis of a 10 MW CSP Plant with Gov. Subsidy***

From the Figure 29, A clear picture of the Break-even Point Analysis, Net Cost Analysis, Total Revenue Analysis, Total Operating Expenses Analysis of a 10 Megawatt Concentrated Solar Power Plant with Government Subsidy can be seen. Here, the

Total Installation Cost and the Total Operating Expenses were achieved using SAM. Using SAM, the expenses were simulated based on each year of operation of the Concentrated Solar Power Plant. And for the Total Revenue Analysis was done using the same per unit electricity selling rate which is previously calculated in the section 4.1.4. Here the total revenue was calculated using the assumption that electricity produced in the 10 MW Power Plant with Government Subsidy were to sell in the same price as that of per unit selling cost of Steam power plant calculated in the section 4.1.4. In this case, we assumed that the government subsidized almost 50% of total installation cost. In the Figure 29, The Total Installation Cost is scaled down by 20 times, Government Subsidy amount is scaled down by 10 times and the Total Revenue is scaled down by 2 times. These were done for achieving a better-looking Graph. And from the Figure 29, It can also be seen that the Break-even Point was achieved in the **12^{th} year** of operation for the 10 MW Concentrated Solar Power Plant with Government Subsidy.

4.7 EMISSION FROM NON-RENEWABLE POWER PLANTS TO PRODUCE THE SAME AMOUNT OF ENERGY AS THE 10 MW POWER PLANT

From the Figure 4.5, the annual emission from Coal, Petroleum, Natural Gas and Concentrated Solar Power of harmful gases (CO_2, SO_2, NO_X, CO) can be seen. Here It could be seen that how much harmful gases would be emitted in the environment if we wanted to produce the same amount of energy that we will generate from our 10 MW Concentrated Solar Power Plant from Non-renewable sources (Coal, Petroleum, Natural Gas). From the Table 4.2 and 4.3 we can actually see the data that were used to plot Figure 30. In Figure 30, the amount of CO_2 is scaled down by 100 times for a better-looking graph. So, from this analysis It can be said that by using Concentrated Solar Power Plant, nature is saved from a tremendous amount of emission. And this also shows that how much cleaner Concentrated Solar Power Plant is.

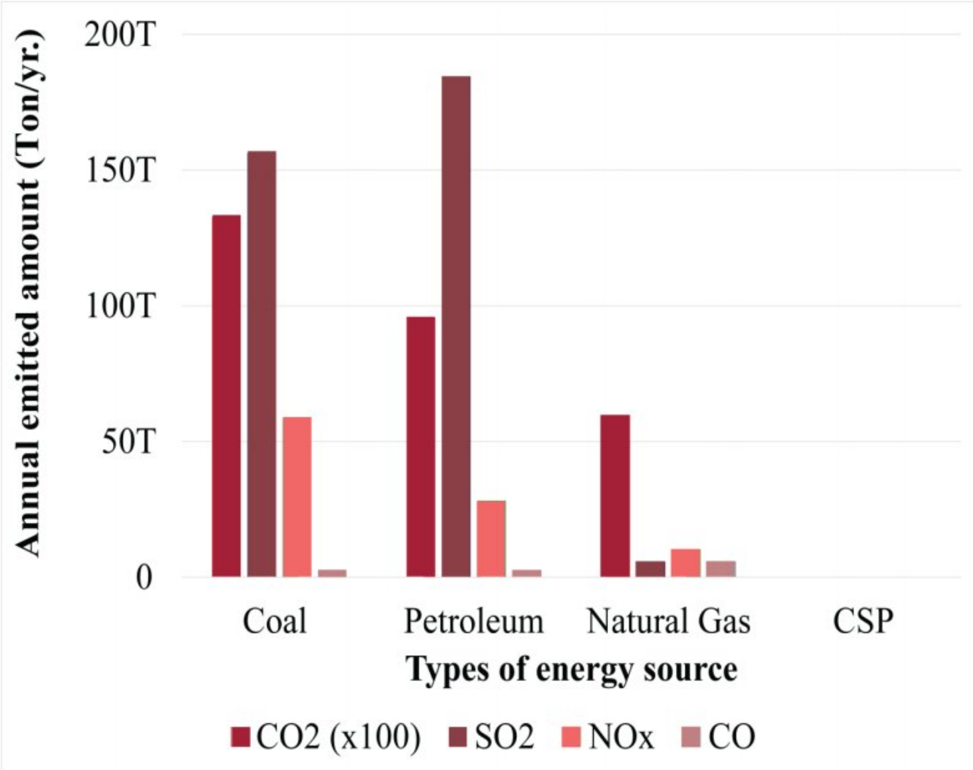

Figure 30: ***Annual Emission from different types of Power Plants***

Table 12: ***Emission factor of different type of Power Plant*** [64]

	Emission factor (kg/kWh)			
	CO2	SO2	NOx	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Natural Gas	0.53	0.0005	0.0009	0.0005
CSP	0	0	0	0

Table 13: ***Annual Emitted Amount of different type of Power Plant*** [64]

	Annual Emitted Amount (kg/year)			
	CO2 (x100)	SO2	NOx	CO
Coal	132617.1202	156218.5	58441.44	2247.748
Petroleum	95529.2815	184315.3	28096.85	2247.748
Natural Gas	59565.3167	5619.37	10114.87	5619.37
CSP	0	0	0	0

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 CONCLUSION:

This study examines the performance of several TES systems in a CSP power facility. All parameter combinations' energy production performances are examined to derive conclusions.

The molten-salt power tower model by SAM has established a cost model based on components.

The Spreadsheet Transfer function is used to connect the cost estimation worksheet to SAM. A notional 10-MWe (net) benchmark plant using a nitrates salt heat transfer fluid is used to calculate costs (HTF). HTF is stored in a 2-tank system with dry cooling, and the layout implies direct storage. The spreadsheet may be used to calculate the cost of different-sized plants and to consider the importance price fluctuations and workers' wages for different construction projects.

We looked at the viability of constructing a CSP plant in Bangladesh as part of this study. As part of this effort, we attempted to explain how a CSP power plant in Bangladesh might work out in terms of a precise calculation. It's high time the government of Bangladesh came up with a vision for a long-term energy source that benefits the environment and the economy. We're eager to watch how these initiatives go in the coming future.

5.1.1 Limitations:

- The poor efficiency of converting solar power to electricity.
- Solar energy collecting is only possible on broad tracts of land.
- Power outages that occur at night and on overcast days.

5.1.2 Sources of Errors:

- Assumed average values for the components
- Safety factors for natural calamities not included
- Assumed tax but it may vary annually
- Vendor system in Bangladesh may be a big problem

5.1.3 Future Prospects:

- The unused lands maybe used for cultivation in future.
- To minimize carbon dioxide emissions by combining with fossil fuel facilities.
- Decrease CSP conversion efficiency discrepancies from theoretical design values.

The LCOE and the plant's efficiency can be further improved by further effort, such as:

1. The first step is to design and optimize various setups.
2. Increase the number of hours the tank may be stored.
3. The tank's functioning may be improved by three steps.
4. The sunlight field should be optimized as well

5.2 RECOMMENDATION:

- Nitrate salts in molten form are researched in this study for their compatibility with the specified TES system for the plant's operation. The TES system can employ molten fluoride salt as the HTF in the same assessment. This information might be used to identify a superior molten salt variety.
- Additional heat transfer fluids and storage media can be utilized in the TES system of solar tower power plants other than molten salts. Direct Steam Generation (DSG) facilities frequently make use of this system. [65]While enhancing total plant efficiency and becoming a more environmentally friendly technology, DSG removes the requirement for intermediate HTFs all at the same time. The plant's performance might be examined using two radically different heat transfer and storage medium in the TES system using water as the HTF (molten salt and water).
- Only a few essential factors are examined in this study to find the ideal combination for the TES system. To identify which TES system design is most suited for the plant, an economic study must be conducted to establish which system is most cost-effective for maximum yearly energy output.

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APPENDIX:

A1: Code for steam power plant

```
format long g
```

```
% Process: 9-10 - (isentropic expansion in High Pressure Turbine)

% State 9: Superheated vapour, Pressure = 9 MPa, Temperature = 540°C

P9 = 9* 10^6 % Pa

T9 = (540+273.15) % Kelvin

H9 = py. CoolProp.CoolProp. PropsSI ('H','P', P9, 'T', T9, 'water') % J/kg

S9 = py. CoolProp.CoolProp. PropsSI ('S','P', P9, 'T', T9, 'water’) % J/kg/Kelvin

% State 10: Superheated vapour, entropy same as state 9, Pressure = 2 MPa

S10 = S9 % J/kg/Kelvin

P10 = 2 * 10^6 % Pa

H10 = py. CoolProp.CoolProp. PropsSI ('H','P', P10, 'S', S10, 'water') % J/kg

% State 11: Superheated vapour, temp same as state 9, pressure same as state 10

P11 = P10 % Pa

T11 = T9 % kelvin

H11 = py. CoolProp.CoolProp. PropsSI ('H','P', P11, 'T', T11, 'water') % J/kg

S11 = py. CoolProp.CoolProp. PropsSI ('S','P', P11, 'T', T11, 'water') %
J/kg/Kelvin

% State 12: Superheated vapour, entropy same as state 11, Pressure = 0.3 MPa

S12 = S11 % J/kg/Kelvin

P12 = 0.3 * 10^6 % Pa
```

```
H12 = py. CoolProp.CoolProp. PropsSI ('H','P', P12, 'S', S12, 'water') % J/kg

% State 13: liquid - vapour mixture with high percentage of dryness fraction,
Pressure = 7 KPa, entropy same as state 11

S13 = S11 % J/kg/Kelvin

P13 = 7* 10^3 % Pa

H13 = py. CoolProp.CoolProp. PropsSI ('H','P', P13, 'S', S13, 'water') % J/kg

Q13 = py. CoolProp.CoolProp. PropsSI ('Q','P', P13, 'S', S13, 'water') % Quality of
steam

% State 1: Saturated liquid, Pressure same as state 13

P1 = P13 % Pa

H1 = py. CoolProp.CoolProp. PropsSI ('H','P', P1, 'Q', 0, 'water') % J/kg

S1 = py. CoolProp.CoolProp. PropsSI ('S','P', P1, 'Q', 0, 'water') % J/kg/Kelvin

% State 2: Subcooled liquid, entropy same as state 1, pressure same as state 12

S2 = S1 %J/kg/Kelvin

P2 = P12 % Pa

H2 = py. CoolProp.CoolProp. PropsSI ('H','P', P2, 'S', S2, 'water') % J/kg

% State 3: Saturated liquid, pressure same as state 2

P3 = P2 % Pa

H3 = py. CoolProp.CoolProp. PropsSI ('H','P', P3, 'Q', 0, 'water') % J/kg

S3 = py. CoolProp.CoolProp. PropsSI ('S','P', P3, 'Q', 0, 'water') % J/kg/K

% State 4: Subcooled liquid, entropy same as state 3, pressure same as state 9

P4 = P9 % Pa

S4 =S3 %J/kg/Kelvin

H4 = py. CoolProp.CoolProp. PropsSI ('H','P', P4, 'S', S4, 'water') % J/kg

% State 6: Saturated liquid, pressure same as state 10
```

P6 = P10 % Pa

H6 = py. CoolProp.CoolProp. PropsSI ('H','P', P6, 'Q', 0, 'water') % J/kg

S6 = py. CoolProp.CoolProp. PropsSI ('S','P', P6, 'Q', 0, 'water') % J/kg/K

% State 5: Enthalpy same as state 6 according to TS diagram

H5 = H6

% State 7: Subcooled liquid, entropy same as state 6, pressure same as state 9

S7 = S6 %J/kg/Kelvin

P7 = P9 % Pa

H7 = py. CoolProp.CoolProp. PropsSI ('H','P', P7, 'S', S7, 'water') % J/kg % Energy Balance in Closed Feedwater Regenerative Heater (Ein = Eout)

% yH10 + (1-y) H4 = (1-y) H5 + yH6;

% y(H10-H4) +H4 = y (H6-H5) + H5; Therefore y = (H5-H4) / ((H10-H6) + (H5-H4))

% Energy Balance in Open Feedwater Regenerative Heater (Ein = Eout)

% zH12 + (1-y-z) H2 = (1-y) H3;

% z (H12-H2) + H2 -yH2 = H3-yH3;
Therefore z = ((1-y) * (H3-H2)) / (H12-H2)

% Energy balance in the Mixing chamber, (Ein = Eout)

% State 8: Enthalpy from energy balance

H8 = ((1-y) * H5) + (y * H7) % J/kg

S8 = py. CoolProp.CoolProp. PropsSI ('S','P', P9, 'H', H8, 'water') % J/kg/K

A2: SAM simulation data

Optimizing...

Beginning Simulation

Iter tht|rec_height|rec_diameter|| Obj. | Flux | Plant cost

----

[1] 193.458 | 21.6029 | 17.65 || 2128.7 | 284.779 | $1.46414e+08

[2] 205.065 | 21.6029 | 17.65 || 2185.92 | 284.143 | $1.50531e+08

[3] 193.458 | 22.8991 | 17.65 || 2194.56 | 281.978 | $1.50938e+08

[4] 193.458 | 21.6029 | 18.709 || 2193.78 | 278.046 | $1.50938e+08

[5] 187.356 | 20.8186 | 17.0168 || 2021.8 | 295.881 | $1.39049e+08

[6] 174.933 | 19.3 | 15.7276 || 1815.85 | 329.099 | $1.25029e+08

[7] 161.22 | 18.1197 | 14.3167 || 1628.59 | 347.247 | $1.12228e+08

[8] 149.768 | 15.8913 | 14.0344 || 1473.17 | 394.18 | $1.0165e+08

[9] 156.983 | 14.2698 | 12.5186 || 1344.76 | 460.381 | $9.25909e+07

[10] 145.643 | 12.7884 | 11.122 || 1181.03 | 515.485 | $8.11575e+07

[11] 137.557 | 10.7701 | 10.0164 || 1027.99 | 635.121 | $7.04509e+07

[12] 129.395 | 9.55537 | 8.29984 || 894.69 | 739.748 | $6.07492e+07

[13] 131.823 | 7.35034 | 7.2084 || 785.95 | 1181.06 | $5.27139e+07

[14] 115.936 | 5.62643 | 6.57504 || 685.461 | 1478.89 | $4.48668e+07

[15] 109.028 | 6.82879 | 4.80764 || 655.137 | 1387.95 | $4.23549e+07

[16] 99.023 | 9.1556 | 4.6107 || 691.421 | 933.285 | $4.49797e+07

[17] 78.5681 | 8.73095 | 3.67108 || 643.478 | 982.435 | $4.04683e+07

[18] 63.9141 | 9.01548 | 2.0449 || 715.639 | 1379.51 | $4.29117e+07

[19] 66.0216 | 7.84816 | 5.30064 || 661.132 | 810.762 | $4.2762e+07

[20] 68.8647 | 8.67009 | 3.09204 || 638.079 | 1047.04 | $3.93193e+07

[21] 68.8163 | 9.19997 | 3.18324 || 648.61 | 983.267 | $4.00809e+07

[22] 72.3492 | 8.00422 | 3.94319 || 631.725 | 1005.67 | $3.98263e+07

[23] 69.985 | 7.06715 | 4.64234 || 624.026 | 982.554 | $3.97727e+07

[24] 73.1876 | 6.0939 | 5.27781 || 616.115 | 1132.11 | $3.95437e+07

```
[25] 67.9473 | 6.08114 | 5.30412 || 616.726 | 1062.73 | $3.93895e+07

[26] 69.6144 | 5.30645 | 6.13942 || 617.691 | 1114.78 | $3.9657e+07

[27] 68.0415 | 6.38261 | 5.33612 || 623.759 | 994.886 | $4.00525e+07

[28] 57.2045 | 6.01118 | 4.90713 || 612.756 | 1057.35 | $3.8485e+07

[29] 46.8771 | 6.24283 | 4.46227 || 756.873 | 808.825 | $3.65408e+07

[30] 58.1846 | 5.98923 | 4.52238 || 603.989 | 1119.44 | $3.76723e+07

[31] 62.1126 | 6.32151 | 5.48121 || 626.676 | 963.433 | $4.01305e+07

[32] 62.6589 | 6.15177 | 5.98979 || 636.142 | 918.564 | $4.09066e+07

[33] 60.8051 | 6.50533 | 4.98766 || 620.009 | 963.71 | $3.94354e+07

[34] 59.9676 | 6.57655 | 4.46695 || 614.561 | 1007.98 | $3.85045e+07

[35] 65.3166 | 6.8224 | 4.42373 || 614.202 | 999.454 | $3.87234e+07

[36] 69.0558 | 7.12923 | 4.1057 || 614.852 | 1021.95 | $3.85852e+07

[37] 66.5893 | 6.67629 | 4.62954 || 614.97 | 997.171 | $3.89432e+07

[38] 64.5309 | 7.09506 | 4.54754 || 623.412 | 954.748 | $3.94524e+07

[39]   66.391 | 6.90141 | 4.36251 || 615.167 | 1006.8 | $3.87252e+07

[40] 64.1494 | 6.72618 | 4.42581 || 612.865 | 1034.73 | $3.86183e+07

[41] 65.5846 | 6.74712 | 4.42435 || 612.326 | 1010.87 | $3.86161e+07

[42] 65.8745 | 6.68349 | 4.45563 || 611.37 | 1021.21 | $3.85795e+07

[43] 66.1622 | 6.68519 | 4.45252 || 611.144 | 1025.14 | $3.85913e+07

[44] 65.0409 | 6.78186 | 4.37224 || 612.194 | 1025.1 | $3.85775e+07

[45] 65.5526 | 6.82498 | 4.42353 || 614.048 | 1007.39 | $3.87382e+07

[46] 65.0415 | 6.74747 | 4.42541 || 612.723 | 1036.36 | $3.8605e+07

-------------------------------------------------------------------------------------------

Algorithm converged:

tht= 65.0415   rec_height= 6.74747   rec_diameter= 4.42541

Objective: 612.723
```