Department of Mechanical and Aerospace Engineering

Masterplan to reduce the carbon emission in the Industrial site, Irvine which includes GSK, I3 and Shewalton landfill site

Author: Manishankar Thirunavukkarasu

Supervisor: Dr Paul Tuohy

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Signed: Manishankar Thirunavukkarasu Date: 17/8/2021

Abstract

As the UK moving towards the mission of achieving net-zero by 2050. As part of this mission, the Northern Ayrshire council decided to make an industrial site a zero-carbon zone that comprises GSK, I3, Shewalton. Also, NAC and Nethermains landfill site included in this thesis. This can be achieved by implementing renewable sources to cover the electrical and thermal demand of the industrial site. The annual electrical demand of the site and NAC together is 250 GWh. The annual thermal demand of GSK and I3 is 162 GWh and 97 MWh respectively. The thesis underwent a detailed study about different renewable sources to determine the best renewable source for onsite electricity production.

The analysis is done in a scenario-based approach using Energy Pro software to determine a better combination scenario to achieve the electrical and heat demand of the site. The result generated using the software is validated using the old data or from older thesis.

The software's output is being examined, and the electrical requirement of the site is being met by wind and solar energy. Total electricity produced by all the component is 240 GWh. As the overall demand is calculated solely by taking GSK's peak demand into account, the demand is quite low during the months of June to August, so any excess electricity produced is stored in a battery and can be used when there is a shortage, eliminating the need to import electricity from the grid. CHP, a hydrogen boiler, and a water source heat pump meet the heat needs. The I3 hydrogen CHP is sufficient to meet both the electrical and thermal demands of the I3. Even if I3 intends to expand in the future, this single CHP is sufficient to suit both demands. According to the thesis's goal or motivation, the plan can reduce a significant quantity of carbon emissions in the site and NAC. According to the strategy, NAC does not need to rely on non-renewable sources to supply their electrical needs, which reduces carbon emissions and makes NAC a sustainable place. The limitation faced is as the electrolyser has low efficiency, The demand for hydrogen fuel is around 6360 Metric Tons, whereas the total amount of hydrogen generated is 1576 Metric tons. So, the hydrogen produced from the electrolyser is not enough to meet the fuel requirement by CHP and three boilers.

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List of Acronyms

UK	United Kingdom
CO_2	Carbon di oxide
GSK	Glaxo Smith Kline
NAC	The North Ayrshire Council
CHP	The Combine Heat and Power
MW	Mega watts
KW	Kilowatts
GW	Giga watts
PV	Photovoltaic
DH	Diffuse Heating
FF	Fill Factor
ASHP	Air source Heat Pump
WSHP	Water Source Heat pump
GSHP	Ground Source Heat Pump
COP	Coefficient of performance
DHW	Domestic Hot Water
IEA	International Energy Agency
H_2	Hydrogen
MJ	Mega Joule
Kg	Kilo gram
AWE	Alkaline water electrolysis
PME	Polymer electrolyte membrane
SOE	Solid oxide electrolyte
CAES	Compressed Air energy Storage
SMES	Superconducting Magnetic energy storage
HFTO	The office for the technology and fuel cells
PyLESA	Python for local energy system
NASA	The National Aeronautics and space administration
MERAA 2	Modern era Retrospective analysis for research and application version 2
GES	Goddard Earth Science
MWh	Megawatt hour

IRENA	International renewable energy Agency
FES	Flywheel Energy storage

Nomenclature

P	Power
ρ	Density
A	Area of Rotor
C_p	Betz coefficient
v	Wind speed
C_{max}	Maximum vule of beltz coefficient
I_{Bx}	Direct Beam intensity
I_{Dx}	Diffuse Intensity
I_{Grx}	Ground reflected Intensity
I_B	Measured and Calculated beam radiation
α_s	Solar angle
B	Slope
γ_s	Solar azimuth
D_B	Diffuse beam radiation
P_m	Maximum Power
V_m	Maximum Voltage
I_m	Maximum current
V_{oc}	Open circuit voltage
I_{sc}	Short circuit current
H	Efficiency
E_u	Useful Thermal energy
E_D	Drive energy
Q_{HP}	Thermal power of heat pump
η_g	Global efficiency
η_t	Transportation efficiency
Hp	Electricity production efficiency
Hem	Electromatic efficiency
ηCHP	Efficiency of CHP
ηelectrical	Electrical efficiency of CHP
Hcell	Efficiency of Fuel cell

1.Introduction

United Kingdom (UK) is more environmentally concerned and deep in thought about the health of the planet compared to other countries. Always the UK is ahead of other counties when it comes to tackling problems related to climate change and pollution. Especially Scotland is more concerned about environment among the UK. The UK is on the mission of achieving a net-zero carbon target by 2050 to tackle the problems like climate change etc. As part of this mission, the UK government established a new target of reducing carbon emissions by 78% compared to 1990 levels in the UK, which is expected to be a three-quarter reduction of the 2050 mission [1]. UK's Royal Commission on environmental pollution suggested reducing 60% of the UK's CO_2 level by 2050 to the British government but the government took a tougher target of reducing 80% of CO_2 level by 2050 in comparison to the CO_2 baseline of 1990. From Studies, Comes to know that 30% of carbon is being emitted in the UK due to electricity generation [2]. As part of the goal, the UK undertook many initiatives to meet the aim, including lowering 44 percent of carbon emissions from 1990 to 2019, and covering 50 percent of the UK's electrical consumption with renewable sources since 2010 [1].

Scotland is ahead of UK in achieving the net-zero target. From the climate change, Scotland act 2019 gotten to know that Scotland set a target of achieving net-zero by 2045 which is 5 years ahead of the target set by the UK. Scotland planned to cut CO2 levels by 56 percent from 1990 levels as part of the mission by 2020, whilst the UK set a target of roughly 26 to 32 percent by 2020, 75 percent and 90 percent CO2 reductions by 2030 and 2040, respectively [7].

As the world approaches net zero, Developing an Industrial estate present near Irvine, Scotland planned to make the place a zero-carbon place or site. The place mainly consists of GlaxoSmithKline (GSK), Shewalton landfill site, and I3 business centre which is under The North Ayrshire council. GSK is a British multinational pharmaceutical business with roughly 18 sites across the UK [4], including the Irvine factory, which was established in 1973 and is one of Scotland's largest enterprise zones. The expansion of GSK began in 2013 and was completed in 2016 [3]. The North Ayrshire Council (NAC) is the place located southwest coast of Scotland which is a beautiful place to reside and work. It is home to 135 thousand occupants, and it is a total area of around 340 square miles. The North Ayrshire council came out with 8 sites in the council as a development zone in that one of the areas is I3 in Irvine. I3 is in the southwest of Scotland which innovation and investment location for many types of Industries like automotive, chemicals, and medical industries. NAC developed a principle of making 8 sites a low carbon zone to reduce and tackle the problems and impact created by climate change etc. This shift can only take place if mitigation and adaptation strategies are encouraged [5]. NAC mostly consists of 32 community centres. 2 care homes, 13 high schools in that 5 large, 4 medium, and 4 are small, 55 primary schools among 55 schools 15 are large,4 medium, and 20 small schools. 17 libraries, 6 offices are immense area and 6 small offices. Also, this thesis considers Nethermains is a landfill site to attain the electrical demand of NAC. Nethermains is located near Kilwinning. NAC planned to invest around £ 6.7 million to transfer the landfill site into a solar farm. The figure 1 is the map view of the whole industrial estate.

Figure 1:The map of the Industrial site (source: Google Map)

1.1 Aim

The aim of this thesis is to create a master plan for the industrial complex, which includes GSK, I3, and the Shewalton dump, to meet the electrical and heat demand using purely renewable sources. The aim of this thesis is to create many scenarios of renewable energy sources such as solar and wind energy and then analyse all of them using energy modelling or analytic software to identify the optimum scenario that can be executed to meet the industrial site's electrical and heat demand.

1.2 Objectives of The Thesis

The objective of the thesis is to determine the best scenario by evaluating and analysing to meet the electrical and heat demand of the industrial estate.

- Significant reduction of carbon emissions compared to the current carbon emissions in the site
- To determine the total electrical and heat demand of the whole site.
- To comprehend and investigate various renewable sources, as well as to assess the benefits, dependability, and efficiency of each source.
- To analysis, all the cases using energy analysis software and determine the electricity or heat generated from each case
- Evaluate and discuss the results of the energy analysis programme to establish the best-case scenario for implementation on the job site.

1.3 Methodology

According to the motivation required to reduce carbon emissions from the site and NAC. So, the first step of the thesis to achieve the motive is the Literature review, which is a detailed study of various renewable sources such as solar, wind, heat pumps for heating, and so on... with the help of the study, determine which source is feasible for the site based on various factors such as air temperature, wind speed, sunlight radiation, any river nearby the site, and the nature of the site.

Following the assessment of the literature, many scenarios are created by merging various renewable sources. To determine the best scenario for meeting the site's electrical and thermal demands. Among the countless software on the market, a section of the software is to be used for modeling and simulation. There are a total of five scenarios figured out to meet the electrical and Thermal demand of the site and NAC.

Scenario 1: The GSK planned to install on-site renewable sources, so they installed two renewable sources of each 2.5 MW which is unable to meet the electrical demand of the GSK, but it reduced the carbon emission from GSK. In Scenario 1, it is intended to install two more Enercon E126 EP3 wind turbines with a capacity of about 7 MW to meet the GSK's power requirement.

Scenario 2: Scenario 1 is unable to meet the electrical demand of the GSK. So, GSK planned to install a solar photovoltaic plant of 20 MW to reduce carbon emission and meet the electrical demand. Also, GSK has 4 MW natural gas CHP and two biogas CHP plants of each 500KW capacity. The burning of natural gas releases 0.185 kg CO per kWh. Even though Biogas is considered a renewable source it has little carbon emission. As a result, all the CHP have been converted to Green H2 CHP, lowering GSK's carbon footprint.

Scenario 3: The North Ayrshire Council planned to convert all their old landfills into a solar farm, one of the old landfills is the Shewalton landfill which can accommodate around 5 MW PV plant. This helps to meet the electrical demand of the NAC which is around 22000 MWh also it could help to meet GSK electrical demand when there is a shortage of electricity.

Scenario 4: The total electrical demand of the site is from 198 to 228 GWh. So Scenario 3 is unable to meet the electrical demand of the site so NAC planned to install an additional five wind turbines of each 4.2 MW. To meet the electrical demand of the site. The excess electricity produced by the wind turbines could be used to produce green hydrogen by electrolyzer or it can be used to meet the electrical demand of the NAC.

Scenario 5: Scenario 5 is a master plan for the whole industrial site and NAC. Is a combination of all energy-producing units in GSK and NAC to meet the electrical and thermal demand of the site and NAC. NAC consists mainly of two landfills in that one is Shewalton and the other is Nethermains landfill. The Nethermains capacity is around 7MW. Which can cover 35% of the annual electrical demand of NAC. The I3 is built as per the Passivhaus standard so the electrical demand and thermal demand of I3 is covered by the green hydrogen CHP in I3. The heating demand of GSK is planned to be met by the existing retrofitted CHP and three hydrogen boilers of each 5 MW and 90% efficiency is planned to install. The excess electricity is being stored in a battery or used to produce hydrogen by electrolysis.

After selecting the appropriate software modeling and simulation carried out for the different scenarios and how much electricity and heat produced from each scenario is collected.

The next stage is to assess the software output and provide a comprehensive explanation of the recommended solution. How could it be applied in industrial sites, and what challenges can arise while installing or running the system? Futures work could be done in that industry location.

1.4 Thesis Structure

This Thesis mainly consists of seven sections or chapters. The first chapter is the introduction to the thesis which gives a brief idea about the project and what is the cause for doing this project. The second chapter is the Literature review where the information or data is collected and studied from the different sources to do the modelling and simulation. The third chapter talks about the current site and existing renewable technology in that location. Then the fourth chapter is basically about Modelling and why this software is selected for the stimulation. Then the fifth chapter discusses results gathered from the software. The sixth chapter is about the scope for future works. Then finally is the conclusion of the thesis.

2. Literature Review

2.1 Wind

Among the various renewable sources wind power is the fast-growing technology. IRENA's latest data mentions that there is a drastic increase in the installation of the windmill from 7.5 GW in 1997 to around 564 GW in 2018. Wind power accounted for 16% of the power created by renewable sources. A wind turbine or wind conversion system is used to produce electricity from the air in motion which creates kinetic energy so here the kinetic energy is converted into electrical energy. When the turbine blade meets the wind, it gets rotated which leads to turning the turbine, so their kinetic energy is being converted into rotational energy and then the shaft gets moved which is connected to the generator. By the electromagnetism principle, electric energy is being produced [19]. Mostly windmills are installed in the place where there is strong wind speed. Nowadays offshore wind turbine installation is increased because the wind speed is faster offshore than land. The below figure 2 talks about the growth in the installation of the wind turbine in the last decade.

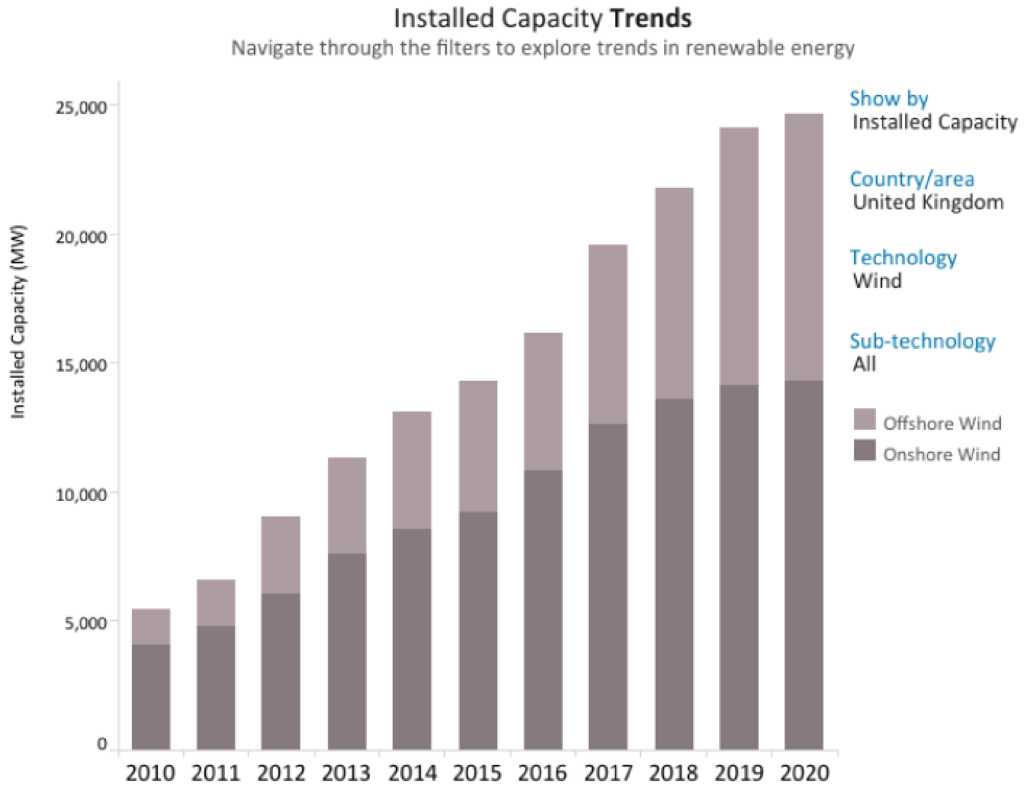


Figure 2 Rise in Onshore and offshore wind turbine in last decade (source: [19])

2.1.1 Wind Power

The power generated from the wind turbine depends on various factors like rotor area, wind speed, the height of the tower, size of turbine and length of a wind turbine, etc. The power output of a wind turbine can be computed using the formula below.

$$P = \frac{1}{2} * \rho * A * \mathrm{Cp} * v^3 \qquad \textit{Equation 1}$$

The power generated from the wind turbine is being calculated from air density (ρ), area of the rotor (A), Betz coefficient (Cp) and the wind speed (v). In most cases, the wind speed is taken in hourly time series to calculate the power [20]. Albert Betz, a German physicist, concluded that the highest kinetic energy that can be transformed into mechanical energy is (16/27) which is around 59 percent, resulting in a maximum power efficiency of 0.59 regardless of wind turbine design. The maximum value for the Betz coefficient (Cmax) is 0.59. But in the real world, the Betz coefficient is less than the Betz limit. In most cases, the coefficient lies between 0.35 to 0.45 however is the design of the wind turbine [21]. Air density is a constant value of 0.15 so wind power is mostly influenced by the rotor Area (A) and wind speed (v). Wind speed is directly proportional to hub height, but increasing the hub height raises the investment cost, hence optimal hub height is always chosen to lower generation costs [20].

2.2 Solar energy

Solar energy is the energy from the sun that is bring converted into electrical or thermal energy. Every technology in the world has its own pros and cons. Solar energy has numerous advantages however there are some disadvantages with solar power. The advantages are low maintenance cost, eco-friendly, reduction of electric bills, and low carbon reduction. Even though it has numerous advantages there are some challenges like energy storage is expensive, depends on the weather, Investment is high and large space required but space is no problem in this case study there is huge empty land which can be used for installation of PV cells. Solar energy can be generated in numerous ways like using photovoltaic (PV) and Solar thermal energy etc. Solar energy can be generated in numerous ways like using photovoltaic (PV) and Solar thermal energy etc. In this thesis, the only photovoltaic cell is considered because only the photovoltaic cell being is planned to be installed by GSK. Photovoltaic cells, which are built of semiconductor materials, are a non-mechanical technology that turns sunlight into electrical energy. The semiconductors convert the photon energy from sunlight into electrons. These electrons are absorbed by electrical conductors on the cell, and the conductor subsequently generates the electrical current stored in batteries [22].

2.2.1 Solar energy in UK

Installation of solar energy is increased in the UK after planning to achieve net-zero by 2050. PV is mostly used in domestic and commercial buildings. Mostly used in domestic buildings where the solar PV is placed in the roof of the domestic building especially in urban areas. Solar capacity in the United Kingdom has increased rapidly, from 5,488.6 MW in 2014 to 13,259 MW in 2018. The UK is in 3rd position among the European countries. The survey tells that one in one in twenty-five buildings has solar technology more than one million rooftop PV placed in the UK. The figure 3 tells an increase in the percentage of solar energy sharing total energy generation in the UK.

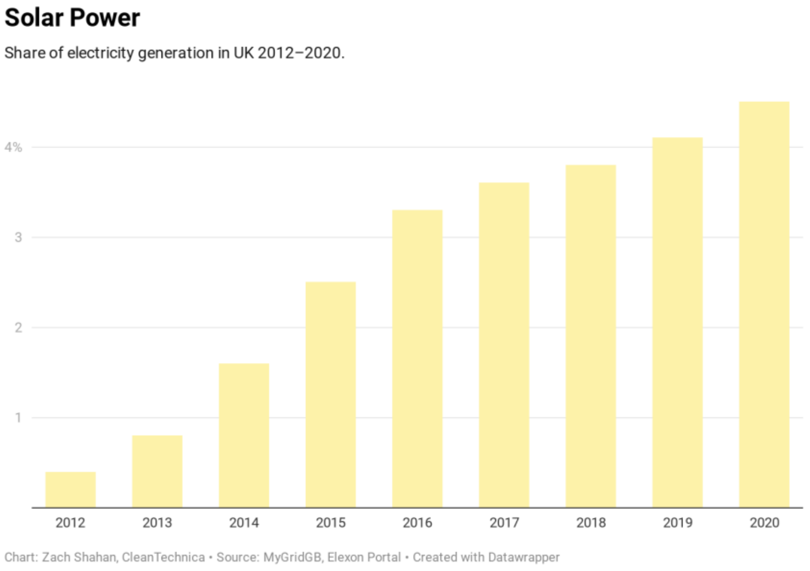


Figure 3 Increase in solar energy contribution in UK (Source: [53])

2.2.2 Solar Radiation (Direct and Diffuse Ration)

Solar radiation falling on a particular location is in two forms Direct and Diffuse radiation. Direct ration means light that directly comes from the solar disc to the earth's surface whereas Diffuse radiation is the light that comes to the surface by scattering one or more events in the atmosphere. When it is a clear day around 90% of radiation hitting the surface is Direct radiation but if it is a cloudy day 100 % of rays hitting the surface going to be diffuse radiation. When calculating total radiation in a certain region, you must consider all three types of radiation: direct, diffuse, and ground radiation. The figure 4 talks about how different radiation hits the surface.

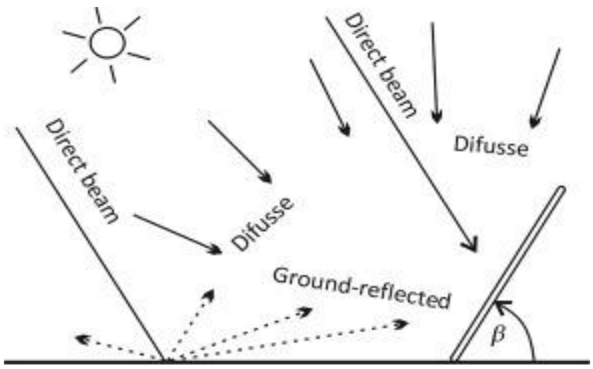


Figure 4 Different types of radiation (source: [54])

$$I_{totx} = I_{Bx} + I_{Dx} + I_{GRx} \quad \textit{Equation 2}$$

I_{Bx} = Direct Beam Intensity

I_{Dx} = Diffuse intensity

I_{GRx} = Ground reflected Intensity

Direct Beam Radiation

By use of geometry and solar angle can be determine the beam intensity. The following formula is used to calculate the intensity of the beam.

$$I_{Bx} = I_B cos\theta_x \quad \textit{Equation 3}$$

Where I_B is measured or calculated Beam radiation and θ_x is the angle of incidence beam radiation on any surface. θ_x is calculated using the below formula

$$cos\,\theta x = \sin \alpha_s \cos \beta + \cos \alpha_s \sin \beta \cos \omega \quad \textit{Equation 4}$$

Angle of incidence depends on solar angle (α_s), slope (β), solar azimuth (γs).

Diffuse Beam Radiation

If the diffuse radiation will be equal to the calculated or measured value of horizontal diffuse intensity (DH) if it falls horizontal to the surface. But in some cases, the diffuse radiation falls slanted at an angle of from horizontal. The Diffuse beam radiation (D_β) is calculated by using the following formula.

$$I_{D_\beta} = I_{D_H} \frac{1+\cos\beta}{2} \quad \textit{Equation 5}$$

However, the previous Diffuse Radiation equation is formed by assuming that the sky has uniform brightness (isotropic sky), but the reality is that the sky is anisotropic, which means that the sky does not have uniform brightness, in which case the following equation is used to calculate the diffuse radiation.

$$I_{D_\beta} = I_{D_H}\left(\frac{1+\cos\beta}{2}\right)\times\left(1+\left[1-\left(\frac{I_{D_H}}{I_{G_H}}\right)^2\right]\sin^3\left(\frac{\beta}{2}\right)\right)\times\left(1+\left[1-\left(\frac{I_{D_H}}{I_{G_H}}\right)^2\right]\cos^2\theta_x\sin^3(90-\alpha_s)\right) \quad \textit{Equation 6}$$

Ground reflected Radiation

The Ground beam radiation is that radiation hit the surface which makes angle of β from horizontal by getting reflected from the ground.

$$I_{GR_\beta} = I_{G_H}\frac{1-\cos\beta}{2}r \quad \textit{Equation 7}$$

2.2.3 Temperature vs Efficiency

The operating temperature of the PV cell influences its efficiency. Maximum power is generally expressed as a product of voltage and current at the maximum power point.

$$P_m = V_m I_m \quad \textit{Equation 8}$$

By inserting the Fill Factor (FF) into the preceding equation. The Fill factor gets reduced when there is an increase in the temperature. So, the maximum power is the product of fill factor, open-circuit voltage, and short circuit current [23].

$$P_{m=} (FF)V_{oc}Isc\ [23]. \quad \textit{Equation 9}$$

The efficiency of the cell is calculated by following equation

$$\eta = \frac{VocIscFF}{Pin}\ [24] \quad \textit{Equation 10}$$

2.3 Heat pump

Humans will feel comfortable in a narrow range of temperatures. Only when the surrounding temperature is appropriate for the individual can they produce their best production and perform at their best. When the surrounding temperature is discomfort, it leads to health and mental get affected so there couldn't work productively. So is important to maintain comfortable condition in a building or any artificial environment. So, to maintain the temperature at a stable level it is needed to employ heating or cooling. Countries with cold weather conditions, such as the United Kingdom, use heating in buildings to keep the temperature steady. The basic working principle of the heating pump is it removes the heat from the fluid gets circulated in heat pump and transfer the absorbed heat into the building. Many scholars believed that giving heat to a building via a heat pump is a more efficient method than providing heat via the burning or combustion of fossil fuels. Industries like as GSK generate a large amount of recoverable waste heat, which may be absorbed by the heat pump and used as a heat source to heat the building [26]. There are predominantly three types of a heat pump in the market which are Air source heat pumps (ASHP). Water source Heat pump (WSHP) and Ground Source Heat pump (GSHP) [25].

2.3.1 Energy Efficiency and Coefficient of Performance (COP) of heat pump

The operation of any heat pump is described by a term called the coefficient of performance (COP). A heat pump is credited as a good heat pump if the COP value of the heat pump is high. COP is the ratio of useful thermal energy produced by the heat pump to the energy consumed by the heat source pump to produce useful thermal energy.

$$COP = \frac{Useful\ Thermal\ energy\ E_U}{Drive\ energy\ E_D}$$ *Equation 11*

In heating operation COP is defined as

$$COP = \frac{Q_{HP}}{P_E}$$ *Equation 12*

Where Q_{HP} is the Thermal power of the heat pump and P_E is power required to run the heat pump. Both represented in watts (W).

The efficiency of a heat pump depends on various factors like the type of heat pump used (Ground or Water or Air source heat pump), Electricity generation method, Type of refrigerant used, climate, thermostat controls and size of heat pump, etc…[27]

$$\eta_s = \eta_g COP$$ *Equation 13*

$$\eta_g = \eta_P \eta_t \eta_{em}$$ *Equation 14*

Where

η_g is global efficiency

η_t is transportation efficiency

η_P is the electricity production efficiency

η_{em} is the electromotor efficiency [27]

2.3.2 Ground Source Heat pump

The Ground Source heat pump is a new technology to provide heat to building with less or no carbon emissions. GSHP is one of the most energy-efficient methods to heat building [25]. It uses ground heat as a source for heating and cooling the building as well as domestic hot water [27]. One of the major advantages of GSHP is that it can be put in any ground condition, unlike geothermal energy, which requires hot rock. It can be installed in most parts of the earth by just using a borehole or shallow trenches. Electricity is the only energy used by the Ground source heat pump to power the pump. To reduce the emission of carbon dioxide green energy can be used to power the GSHP. It has other benefits like low maintenance cost and has a lifespan of around twenty years [25]. GSHP is very energy-efficient for air conditioning than conventional air conditioners. GSHP is installed in both residential and commercial buildings. Ground Source heat pump has a COP of around 3.0 to 4.0 for oven system application whereas for closed-loop application has COP rating from 2.5 to 4.0 [27].

2.3.3 Water Source Heat pump

The water source heat pump (WSHP) system is a high-efficiency heating and cooling system for commercial buildings. WSHP has low carbon emissions. Groundwater, river water, wastewater, or seawater can be used as a source or sink for the WSHP. It is being used in both commercial and residential buildings. The benefits of WSHP are investment cost is less, operation cost is less and a quick payback time [28]. The COP of the water source heat pump is high compared to other heat pumps. WSHP consists of components like compressor, condenser, expansion valve, and evaporator. Most WSHP use cyclic heating mode because the investment cost is less and at once plenty of water can be supplied to the heat pump [29]. The river water temperature is stable, so the COP of the river water source heat pump is 3 to 21% higher than the air source heat pump. WSHP can be used in both the summer and winter seasons. Another big advantage of a water source heat pump is as the density of water gets increases the system efficiency and heat exchanger performance gets increase. COP of water source heat pump gets varied by the source of water. The minimum COP of the water source heat pump is 3 [30].

2.3.4 Air Source Heat Pump

Heat is absorbed from the outside air by air source heat pumps (ASHPs), which heat your home and provide hot water. Even when the air temperature is as low as -15°C, they can extract heat.

The working principle of Air source heat pump heats from the outside air is absorbed and transferred into the low-temperature fluid. Then the fluid is passed through the compressor whether the temperature is further increased that heat is being transferred to buildings [31]. The major drawback of ASHP is when the outer temperature is low especially during winter seasons then ASHP is unable to attain the required heat demand. The other drawback with ASHP is when the ambient temperature goes below -5°C then COP gets reduced then the system becomes unreliable. There many research going on to increase the COP of ASHP during the winter season. The Technical University of Nova Scotia undertook research on ASHP where they got the result that the COP of ASHP is 1.8 and 1.1 when the outdoor temperature was 4.5 & -15°C respectively. As the temperature of the external air drops below 0 °C, the coefficient of performance (COP) of ASHP systems diminishes. [33].

2.4 District heating

District heating and cooling as an important role to play in the future renewable energy system. The idea behind the district heating system is to utilize the waste heat from industries, from CHP plants, solar collectors, geothermal wells, biomass fuels, and waste to energy to attain the heat demand of local customers with the help of a heat distribution network of pipes. District heating systems offer heat to nearly half of the national building stock in nations with stronger driving forces. only a few systems exist in other countries due to a lack of understanding or competition in district heating. When the international fuel prices are high but by installing district heating system heating costs can be lowered. Also, environmental or climate impacts can be reduced. District heating system is placed in most of the major cities. The overall number of systems is projected to be 80,000, with approximately 6,000 systems in Europe [35]. The district heating grid system is separated into two sections, one for generation and one for distribution. Generation side where the one or more heat-producing components employ water as the medium of heat transfer. With the help of a pipeline is connected to the distribution grid, were eventually consumed by the end-user [36].

As per the Geographical condition, the same district heating system can be used as a cooling system in summer. The following are some examples of traditional heat sources:

CHP: The CHP can be used to produce both electricity and heating but not in the same ratio. In some cases, CHP produces only one of them. The benefits include the ability to make it in a variety of sizes ranging from micro to huge, as well as the use of various fuels such as natural gas, hydrogen, biogas, and ammonia, among others.

Waste heat: The waste heat generated from industries, wastewater treatment plants, etc… can be used to attain the heat demand of local consumers.

Solar and Geothermal Heat: Both are renewable sources with zero or low carbon emissions. There can be implemented on both a large and smaller scale.

Heat Pump: This is implemented on both a larger and smaller scale. The electricity is used to run the pump. If the electricity comes from a renewable source then there is no carbon emission [36].

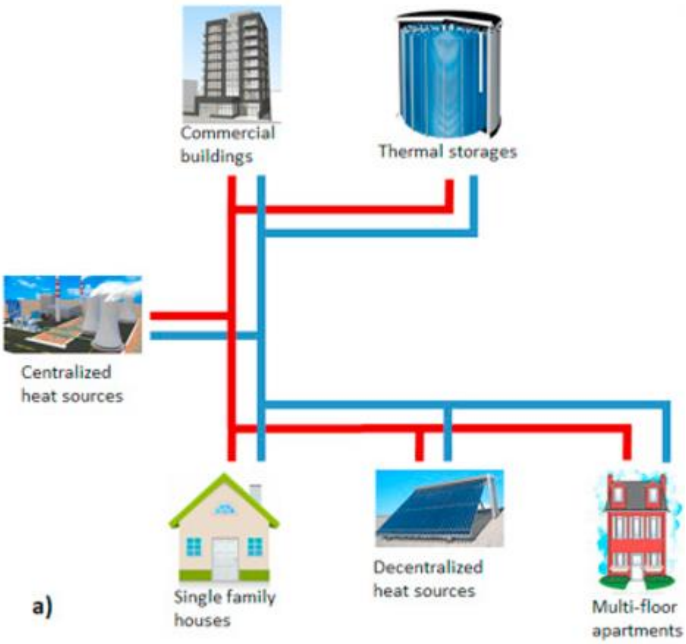


Figure 5 District Heating system (source : [55])

2.4.1 Future District heating

To reduce grid losses, utilize synergies, and thus boost the efficiencies of low-temperature production units in the system, district heating technologies must be further developed. For the distribution of heat, it is also important to concentrate demand for heat so that distribution cost and heat loss are minimized. Low Heat density in smaller areas leads to a relative increase in cost and losses in heat distribution. In addition, district heating must face the following challenges in order to achieve its role in future sustainable energy systems.

- The possibility to provide low- temperature district heating to an existing building, energy renewed existing buildings, and new low energy building for space heating and domestic hot water (DHW).
- The capability of distributing heat network with low grid losses
- Capability for recycling heat from integrate renewable sources like geothermal and solar. Also, from low-temperature heat sources.
- Capability to be an integrated part of smart energy system [38].

2.5 CHP

In consideration of environmental conservation and energy saving CHP (Combined Heat and Power) is considered as the best alternative for the traditional systems [39]. CHP plants generate sixteen percent of global power, with a total usable heat production of 11EJ in 2016, according to the International Energy Agency (IEA,2018b) [44]. CHP produces both heat and power. Also, CHP is available in various sizes from micro to larger size CHP and is mostly used in buildings to produce both power and heat. When compared to conventional power plants and boilers, the fuel consumption of CHP plants is lowered by 20 to 30 percent, resulting in a reduction in overall fossil fuel consumption, which contributes to a reduction in carbon emissions [40]. In CHP 80% of the fuel is used to produce energy. Important components in the CHP system are heat exchanger, absorption chiller, power generator, vapor compressions system. When selecting the component for CHP following things are to be considered individual component efficiency, heating, and electrical demand of the building [41].

2.5.1 Efficiency of CHP

The general formula for efficiency calculation for any energy producing component is the ratio between sum of total energy production to the total fuel or energy input.

$$\eta_{TOT} = \frac{\sum_{m=1}^{M} e(m) + \sum_{n=1}^{N} q(n)}{\sum_{k=1}^{K} f(k)} \qquad \textit{Equation 15}$$

Where

$\sum_{m=1}^{M} e(m)$ Sum of electricity Output

$\sum_{n=1}^{N} q(n)$ sum of heat output

$\sum_{k=1}^{K} f(k)$ Sum of fuel consumed

In case of CHP efficiency calculation is going to be different from the above equation. The CHP overall efficiency is defined as the ratio between output from the CHP to the input CHP [42].

$$\eta_{CHP} = \frac{q_{CHP} + e_{CHP}}{f_{CHP}} \text{ [42]} \qquad \textit{Equation 16}$$

2.5.2 Hydrogen Fuelled CHP

As the world is moving towards zero carbon by 2050 so Hydrogen is preferred as fuel for CHP instead of Natural gas, Biogas, and Biomass. Two major advantages of using hydrogen in the fuel cell are low carbon emission and high efficiency [43]. Electrical efficiency is around 50% in hydrogen fuel cell-based CHP and the overall efficiency is around 95%. The capacity utilization of the H_2 fuel cell CHP is at least 5,000 full load hours. The efficiency calculation of the Hydrogen fuelled CHP is like the above CHP equation. The ratio of converted electrical energy (EFC electrical) to supplied fuel energy (EFC fuel) is the fuel cell's electrical efficiency (ηelectrical).

$$\eta_{electrical} = \frac{E_{FC}\, electrical}{E_{FC} Fuel} \qquad \textit{Equation 17}$$

Thermal efficiency is calculated using the similar electrical efficiency equation. The overall efficiency is calculated using

$$\eta_{total} = \frac{E_{FC}\, electrical + E_{FC}\, Thermal}{E_{FC}\, Fuel} \text{ [45]} \qquad \textit{Equation 18}$$

2.6 Hydrogen (H_2)

Hydrogen (H_2) is quickly becoming a viable alternative source to reduce carbon emissions. It can be used in various sectors like industries, to generate power, mobility, and building. Compared to other fuels like gasoline and coal which have a heating value of 44MJ/kg and 20 MJ/kg respectively hydrogen has a very heating value of around 120 to 142 MJ/kg. Even though Hydrogen is the zero-carbon source if hydrogen is being produced from fossil fuel, then the whole process can't be said a net-zero process. As a result, most governments are promoting or encouraging the extraction of hydrogen from renewable sources, often known as green hydrogen. Hydrogen has been classified into three types are Green, blue, and grey Hydrogen. Blue hydrogen is the hydrogen produced from fossil fuels with carbon capture. Hydrogen produced from fossil fuels is called Grey Hydrogen. In the future renewable sources are used to produce hydrogen by electrolysis and excess power and hydrogen are being stored by using different storage methods [16]. Below figure 6 shows different types of Hydrogen.

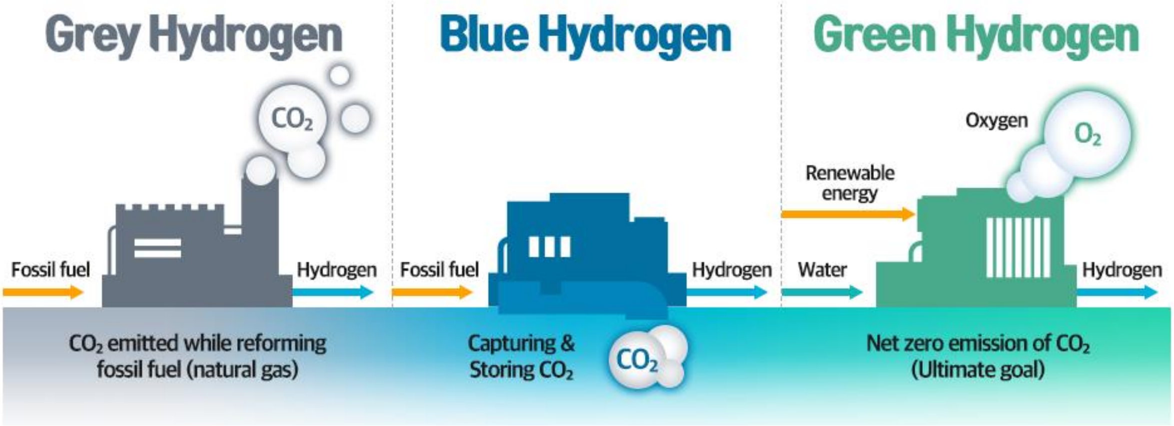


Figure 6 Different types of hydrogen (source: [56])

2.6.1 Electrolysis

Electrolysis is a method of producing pure hydrogen from water. The purity of hydrogen is being estimated at around 99.999%. The major drawback of the electrolysis process is the efficiency which is around 60 percent. The energy consumption is very high, but hydrogen produced is very low so there is a lot of research being done to increase the efficiency of the electrolysis process. In the Electrolysis process water (H2O) is used as a source and there is only oxygen is being produced as the by-product so there is no carbon emission. The water molecule is the reactant in the electrolysis process, and it is dissociated into hydrogen (H2) and oxygen (O2) under the effect of electricity. Electrolysis is classified into three types: alkaline water electrolysis (AWE), polymer electrolyte membrane electrolysis (PEM), and solid oxide electrolysis (SOE). In this thesis only PEM electrolysis is taken into consideration because PEM is mostly used in industries and has numerous benefits compared to other types of electrolysis. A detailed study is not being done because it is out of scope [17].

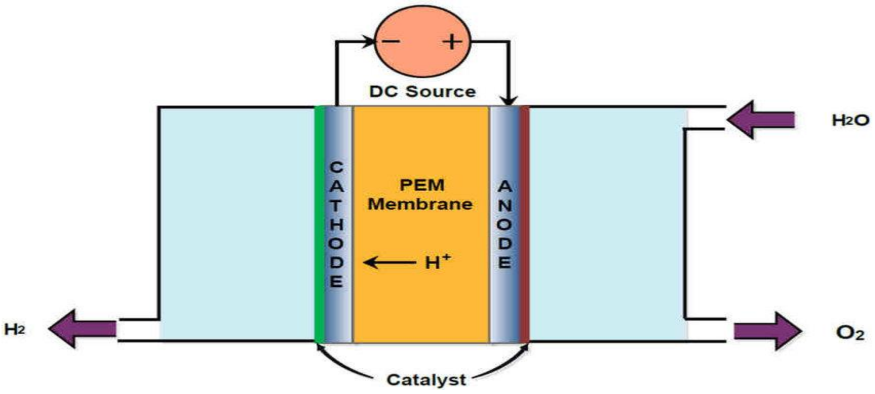


Figure 7 PEM Electrolyser (source:[57])

.

Anode: $H_2O \longrightarrow 2H^+ + \frac{1}{2}O_2 + 2e^-$

Cathode: $2H^+ + 2e^- \longrightarrow H_2$

Overall cell: $2H_2O \longrightarrow H_2 + \frac{1}{2}O_2$ *Equation 19*

2.6.2 Efficiency

Examine the electric work, cooling, and water for the electrochemical reaction as inputs for a PEM electrolyzer. The electrochemical process will produce hydrogen and oxygen gas, which will be the system output [18]. The product of Faraday efficiency and voltage efficiency determines the cell efficiency of a water electrolyser [34]: The electrolyser basically have less efficiency. Efficiency of electrolyser will be from 58 to 75%. In most cases efficiency lies between 60 to 65%,

$$\eta_{cell} = \eta_F \eta_U \text{ [34]}$$ *Equation 20*

2.6.3 Production cost of Hydrogen

Hydrogen is produced in three ways: from fossil fuel, electrolysis (green hydrogen), and from the grid. As this thesis moving towards zero carbon, Thesis not going to study the cost of production from fossil fuel is out of scope.

- The promising new production method is electrolysis with energy generated by a wind turbine (lowest quartile, median quartile, and the upper quartile are 0.095,0.150, 0.201 euros per kilowatt hour respect0ively).
- Total prices have been adjusted to include grid expenses of 0.015 euros per kilowatt hour (cost of transportation from the supplier to the building) [45].

2.6.4 Hydrogen vs Natural gas

Natural gas is a popular fossil fuel that is less polluting than coal and gasoline. Natural gas is abundant, and its use has been steadily growing over the previous fifty years. Natural gas-fired power plant emits much less pollution than other fossil fuel power plants. Currently, there is a lot of interest in hydrogen fuel, and there has been a lot of study done on it, and it is seen as a dominant alternative fuel. Hydrogen technologies aren't quite ready yet, and they're also more expensive [46].

2.7 Energy Storage

Whether it's for electric utilities or industrial uses, energy storage has been the most difficult and complex issue in the industry. As the world moving towards zero carbon, installation, and usage of renewable sources like solar, wind as being increased so this led to constant need of efficient energy storage in future energy system. Energy storage helps balance supply changes and meet the increasing energy demand. Energy storage helps to reduce the operational and investment cost [51].

2.7.1 Types of energy Storage technology

There have been several electric storage devices designed to serve different electrical uses, including:

- Compressed air energy storage (CAES)
- Pumped Hydropower
- Batteries
- Superconducting magnetic energy storage (SMES)
- Flywheel
- Hydrogen Storage
- Super capacitors

Compressed Air Energy Storage (CAES)

This best storage method for bulk and large storage. This method storage is more economically feasible. CARES concept is quite simple. Electrical powered compressed used to charge storage which convert electric energy into potential energy, or more precisely exergy, of pressurised air. The electricity is produced when there is demand by expanding the stored air in CAS volume into gas turbine.

Pumped Hydropower

In comparison to other energy storage methods, pumped hydro energy storage offers the biggest storage capacity. When there is a requirement of electricity in the power grid the stored water in uphill is let to flow downhill to drive the generator which produces electricity. Pumped Hydropower storage accounts for about three percent of global production of around 90 GW. The efficiency of pumped hydropower storage is around 70 to 85 percent. The drawback of this technology is high capital cost, highly reliant on the topography of the area and During construction there more chance of leading to environmental related problems [52].

Battery Energy Storage

Stored chemical energy is converted into electrical energy by chemical reaction which is the basic principle of the battery. Also, voltage is being produced between terminals. For many industrial and household applications, it has become the most common direct current source. There are many types of battery like lead acid, nickel battery, Sodium-sulphur (Na–S) battery, metal air battery, lithium battery etc [52]. Battery storage technology is critical to ensuring that green energy can be used to power homes and businesses even when the sun is not shining, or the wind is not blowing. Each type of battery has its own advantages and disadvantage but, in this thesis, not going to study in detail about different types of battery because it is out of scope of the project.

Flywheel

Flywheel energy storage can be used in alone or it can be used by coupling with another energy storage like battery. The energy stored as inertial energy by speeding the rotor and retaining the energy in the system at a very high speed. Depending on the speed is divided into two types which are high speed flywheel and low speed flywheel. High speed FES has a lengthy storage time but low power capacities, whereas low speed FES has a short storage time but high-power capacities. Flywheel storage depends on the Flywheel geometry, length and material used to manufacturing the flywheel.

Hydrogen Storage

The Office for the Technologies of Hydrogen and Fuel Cells (HFTO) is developing on-board hydrogen storage systems, which provide more than 300 miles of driving time while complying with cost, safety, and performance. Hydrogen can be stored in three ways liquid, solid and gas. In gas form is stored in high pressure from 350 to 700 bar. Liquid storage is not possible or exceedingly difficult because it needed to be stored in –253°C which mostly used only in ferries or ship. Solid storage in the form of metal hydrides. This is developing technology much research is done on hydrogen and Hydrogen storage.

3.Modelling

3.1 Software Selection

Every day there is new ideas and advancements are emerging in the field of energy this made a boost in the importance of energy modeling software. As new ideas emerge, resulting in complicated systems [13], one programme is insufficient to meet everyone's expectations, resulting in the emergence of multiple energy modelling tools on the market. In the current market, there are more than 50 different types of energy modelling software, each with its own set of characteristics and employed in a variety of applications. Some software can be used to analyze all energy-related components like solar, wind and thermal, etc. but there is some specific software that is built only to review and analyze one component in detail.

From the surplus software in the market, only four software is taken into consideration for the software selection or screening process. The four software are Energy pro, Homer pro, Energy plan, and PyLESA. This software is most well known and used in the industries, but each software has its pros and cons. In the upcoming screening process, a detailed study about each software was being done.

EMD International created the modelling software Energy Pro. Software is being created to perform both technical and economic analyses. Energy Pro is simple to use software. It is possible to carry out a project that involves both trigeneration and cogeneration. Energy pro software can also be used to carry out a sophisticated project involving a combination of electric and thermal energy systems. It is quite useful for financial computations and cost analyses [8]. Energy pros consist of many components like biofuel and biogas CHP, Battery storage, Solar thermal, Geothermal, wind, and photovoltaic cell (PV) which can be used to develop complex energy systems [9].

Homer Pro is a microgrid software developed by Homer energy. Homer Pro is quite famous software in the market and is being used in numerous industries for doing energy analysis. The great advantage of using homer pro software is it can use to analyze any complex system and any possible combination of any energy components as per the equipment for example can build a system of combination of a windmill, electrolyzer, fuel cell, and storage or a system combination of solar and wind energy. Can stimulate hundred or thousand of systems at the same time. It has energy components like Hydro, wind, CHP, Biomass, Advanced load and grid, Hydrogen, etc… One of the big advantages of this software is quite cheaper compared to other energy modeling software [10].

Energy Plan is developed and maintained by the Sustainable Energy Planning Research Group at Aalborg University, Denmark [11]. Since1999, the software has been in development [12]. The stimulation is being done on hourly basics. Both technical data like electrical, thermal data, and economic analysis can be done by using Energy Plan. The energy plan is one of the best software for cost analysis can add data like investment cost, maintenance cost each year so by using software can easily calculate the payback of a system [11]. An energy plan is built not to predict how the future systems will be however it is used to evaluate the future partway and give the transparent, conscious result and inform how the energy system works. It will be more helpful for the earth to move towards 100% renewable energy or net-zero carbon. The energy plan comprises components that can be utilised to develop sophisticated systems, such as district heating and cooling, wave energy, concentrated solar power, tidal power, and thermal storage [12].

PyLESA is a modeling tool. The name stands for Python for local energy systems Analysis. It is mainly developed to model smart energy systems and plays an important role in the world moving towards net-zero especially UK moving towards net zero carbon by 2050. PyLESA can stimulate and analyze both electrical and thermal-related components and demand. Stimulation is an hourly time scale which huge advantage for modeling. Good graphical output is generated from PyLESA which makes the evaluator easy to analyze. The inputs are being given through an excel sheet which is similar to energy pro. The reason for choosing Python as a programming language for this modeling tool is python is open source and is being mostly used in many industries and engineering fields [13].

Stimulation In Energy plan is done in hourly time step or time scale whereas in Energy Pro and Homer pro is done in minutes. In all four software's both electrical and thermal analysis can be done. One most important criteria in the screening process are the resource or input data for the modeling.In the case of Energy Pro and PyLESA, the user must provide all input data such as solar radiation and wind speed to the system for stimulation, whereas in the case of Energy Plan and Homer Pro, all input data such as solar radiation and wind speed are inbuilt or in Homer Pro is connected to NASA so all the data required can be generated. Energy Plan has more electric and thermal components compared to all other software. In Electric component homer and energy, pro have same level components which are biomass, coal, CHP, diesel plant, Gas plant, Geothermal, hydro, photovoltaic and wind still energy plan has additional nuclear, wave and tidal. Thermal components in homer pro are the CHP plant and Fuel boiler. Energy pros have an extra electric boiler, heat pump, and solar thermal. Energy Plan has more thermal components compared to Homer Pro, Energy Pro like Geothermal, heat from the waste source, etc... The Output or result generated from Homer pro is better compared to other software's because in homer autonomy output can generate which can't be done in the other two software's and the graph generated from Homer pro are easy to understand compared to other software results. One of the most important components of a smart energy system is storage. The biggest drawback with Homer pro is analysis related to thermal storage can't be carried out. Energy Pro is quite good in terms of Thermal storage whereas Homer is preferable in terms of caring out analysis related to electric storage. When choosing software, the most crucial factor to consider is the cost of the software. Energy Plan and PyLESA is free and open-source software whereas Homer Pro is cheaper for the student but for general use it cost from 500 to 1500 US dollars. Among the Four software, Energy Pro is quite expensive but there has a student discount of sixty pounds for six months while for general use it cost more than 3,000 pounds [14].

PyLESA has few drawbacks like the energy profile databases are basic certain features not working as per expected, Analysis related to water and ground source heat pump can't be carried out properly and cannot examine solar thermal interactions within a microgrid system at this time. PyLESA can't give data related to heating demands into a storage tank that can be executed in software like Energy pro [15].

After studying the positives and negatives of the four software. Energy Pro is being chosen as software for evaluating and analyzing the different cases and seniors in this thesis. The reason for choosing energy pro is in this thesis need to analysis about wind, solar, both electrical and thermal storage, electrolysis, CHP running with Hydrogen as a Fuel, etc… So, to carry out all the above analysis energy pro is the best software and is affordable for students. Both Technical and Financial analysis can be carried out.

3.2 Climate Data of the site

3.2.1 Wind Speed

The below figure 8 talks about wind speed at the site. Wind speed has been represented on an hourly basis for the whole year. The below wind data is being generated from the renewable ninja software by giving the latitude and longitude of the industrial site. The renewable ninja gathers the values from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) which is a database maintained by the NASA Goddard Earth Sciences (GES) Data and Information Services Centre (DISC). Depending on the wind speed the electricity generated by the windmill is being calculated. Using the power formula mentioned in the literature review the electricity produced by the windmill is calculated. Energy pro fully reliant on the below wind speed for producing results of the windmill

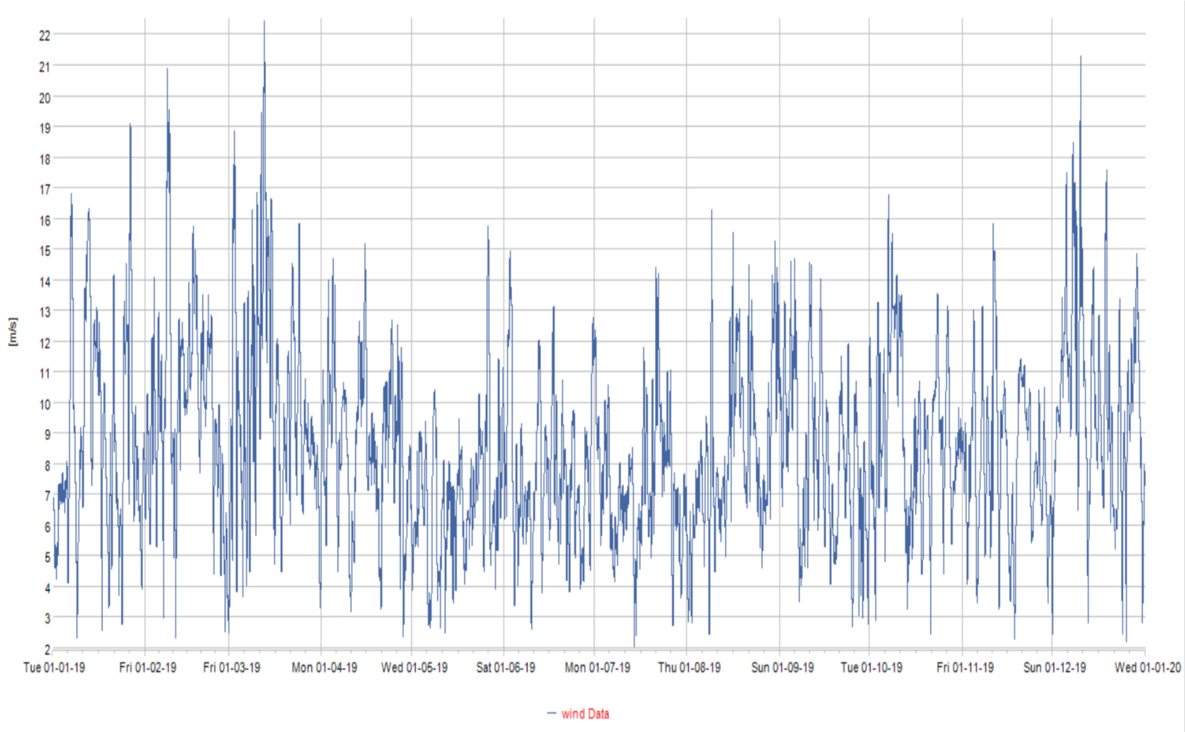


Figure 8 Annual Wind speed

By Interrupting the Above graph, come to know maximum wind speed experienced by the area was 22.468 m/s on 13th March 2019 at midnight and the minimum wind speed experienced by that area was 2.041 m/s on 14th July 2019 at 11 AM. Wind speed is quite high in February and March, so more electricity is being produced during those months yet there are some days with windspeed less than 3 m/s in both months. The below figure shows 10 the wind speed in February and March.

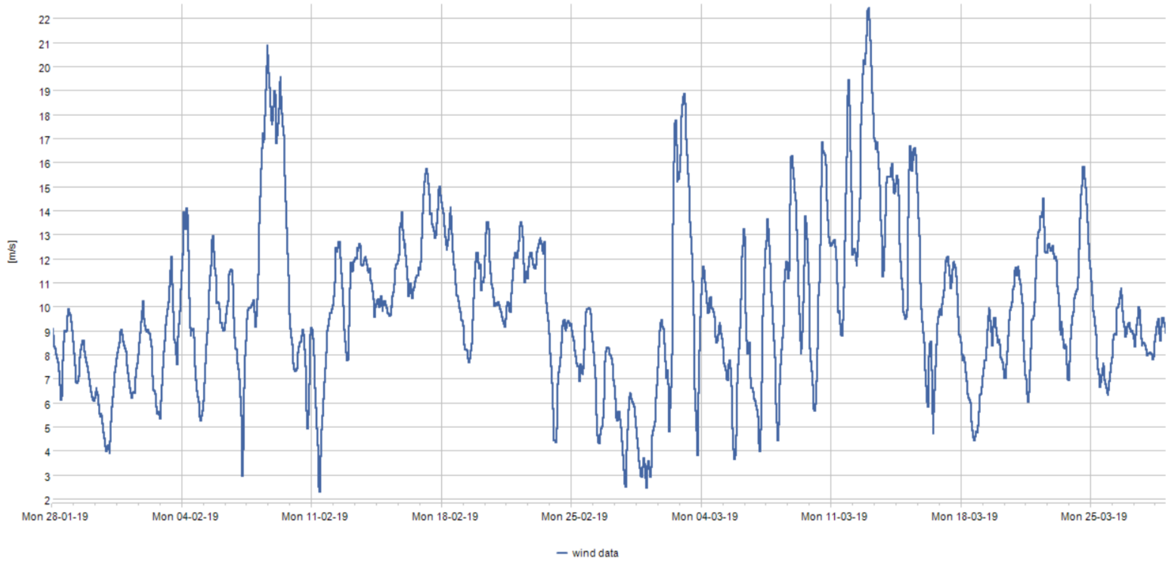


Figure 10 Windspeed in February and March

In the month of June and July the wind is very less automatically generations of electricity gets reduced, so need to depend on the gird or any other sources to attain the electrical demand. The wind speed in June and July is depicted in the graph or figure below. In the month of June and July the wind is very less automatically generations of electricity gets reduced, so need to depend on the gird or any other sources to attain the electrical demand. The wind speed in June and July is depicted in the graph or figure 9 below.

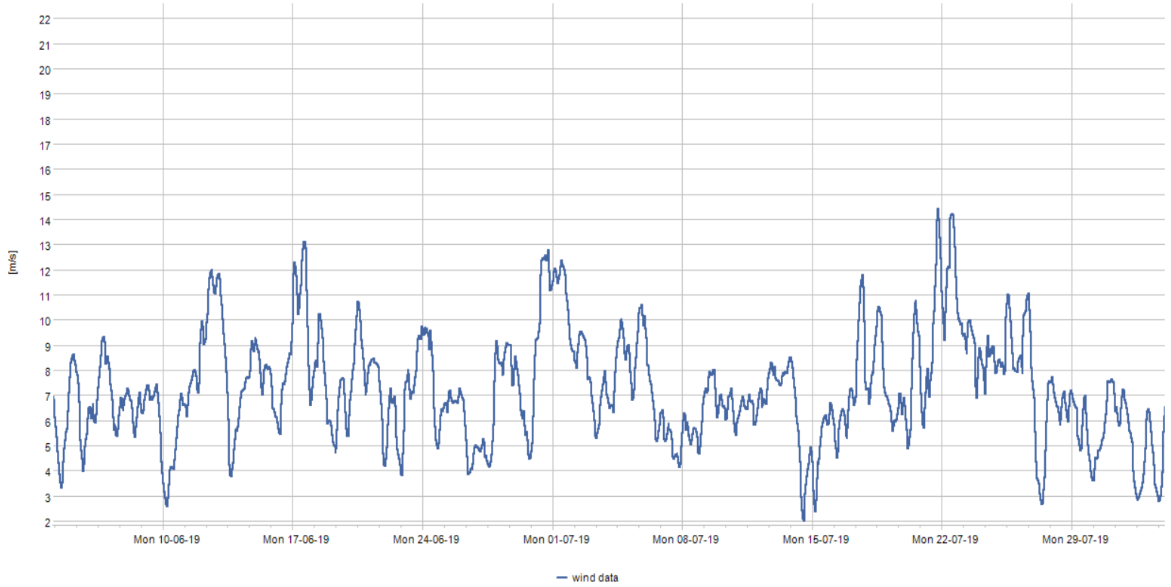


Figure 9 Wind speed June and July

3.2.2 Annual Temperature

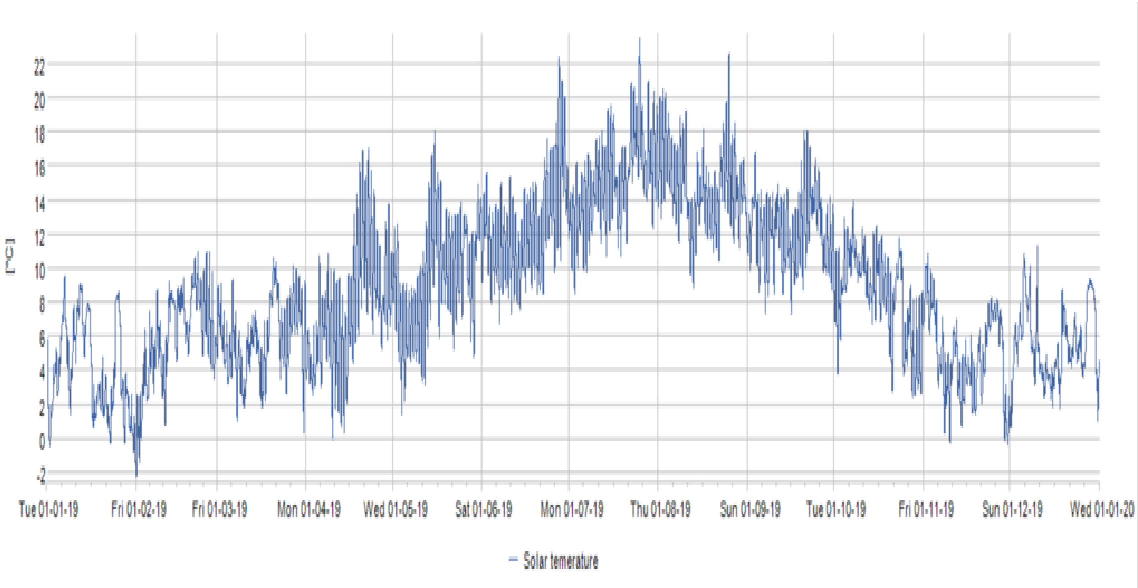


Figure 11 Annual Temperature of the site

The above figure 11 represents the annual temperature of the site. Same as wind speed data is being represented on an hourly basis and data is generated from MERRA-2. The energy pro software calculates the electricity produced by a solar cell using annual temperature data (PV). Temperatures vary according on the season. In the summer, the temperature will be high, however in the winter, the temperature will be low. In the autumn and spring, the weather is pleasant. As a result, more electricity may be generated throughout the summer. However, in the winter, any other renewable sources or electricity imported from the grid were required to meet the electrical demand. The maximum temperature experienced by the site is 23 °C on

25th July 2019 at 2 pm. The minimum temperature experienced in Irvine is -2.225 on 1st February 2019 at 6 am. From June through August, the temperature is quite hot. and Temperature gets reduce from November to December. The maximum temperature experienced during the winter season is around 10°C. The below figure 12a and 12b shows the months where maximum and minimum temperature is being experienced near Irvine.

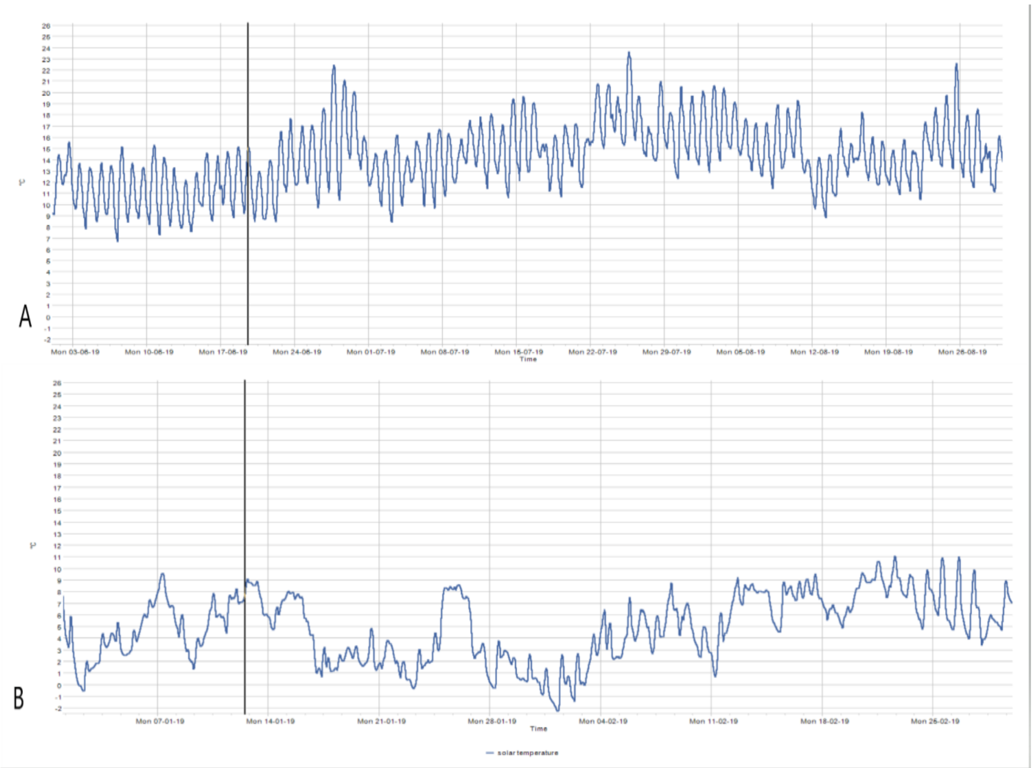


Figure 12 A Solar temperature in July to August

Figure 12b Solar Temperature January and February

3.2.3 Solar Radiation

To compute the energy or electricity produced by photovoltaic cells, Energy Pro requires two crucial inputs: solar radiation and yearly temperature. Solar radiation data are being generated from renewable ninja software for that location which is shown in the below figure 13.

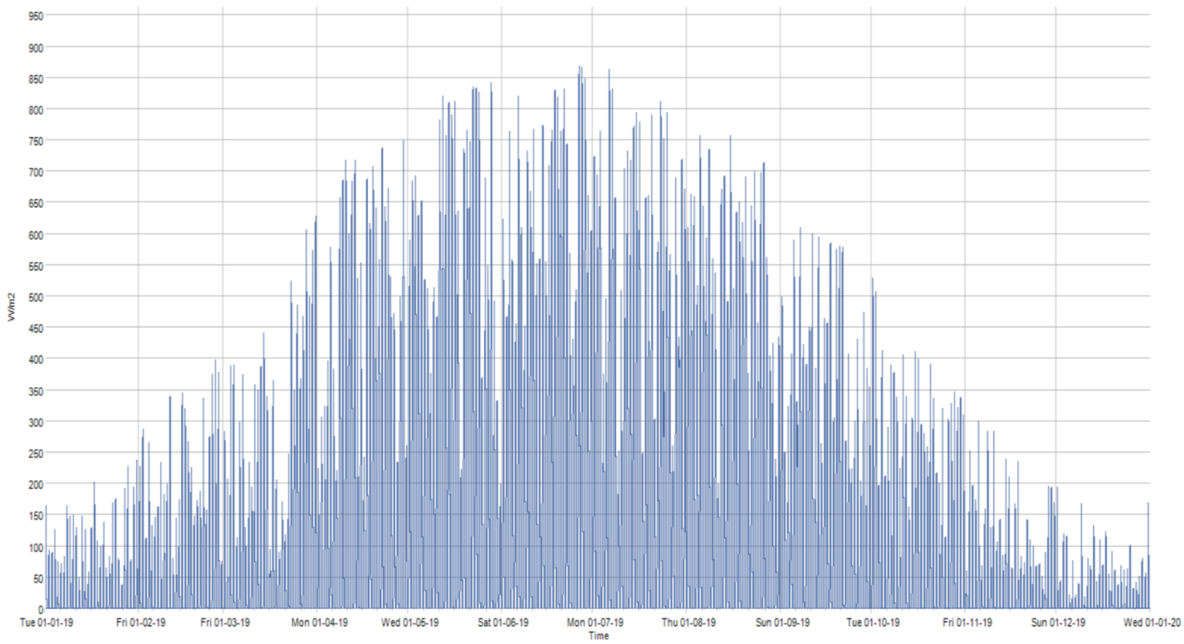


Figure 13 Annual Solar Radiation

Minimum solar radiation falling on the site is 0.001 W/m^2 (excluding zero) on several days. Maximum radiation falling is 870 W/m^2 on 26th June 2019 at 1 pm. This graph explains why storage is an important component in the site or any energy system using solar energy as a source. It fluctuates from time to time and season to season. In winter the radiation falling is very less also sun rises late and sets early so low amount electricity is being produced during winter. In summer is sunrise early around 4 or 5 am and sets around 9 to 11 pm so more amount of electricity can be produced during summer. The below figure 14a and 14b shows a day in summer and winter how radiation gets fluctuated.

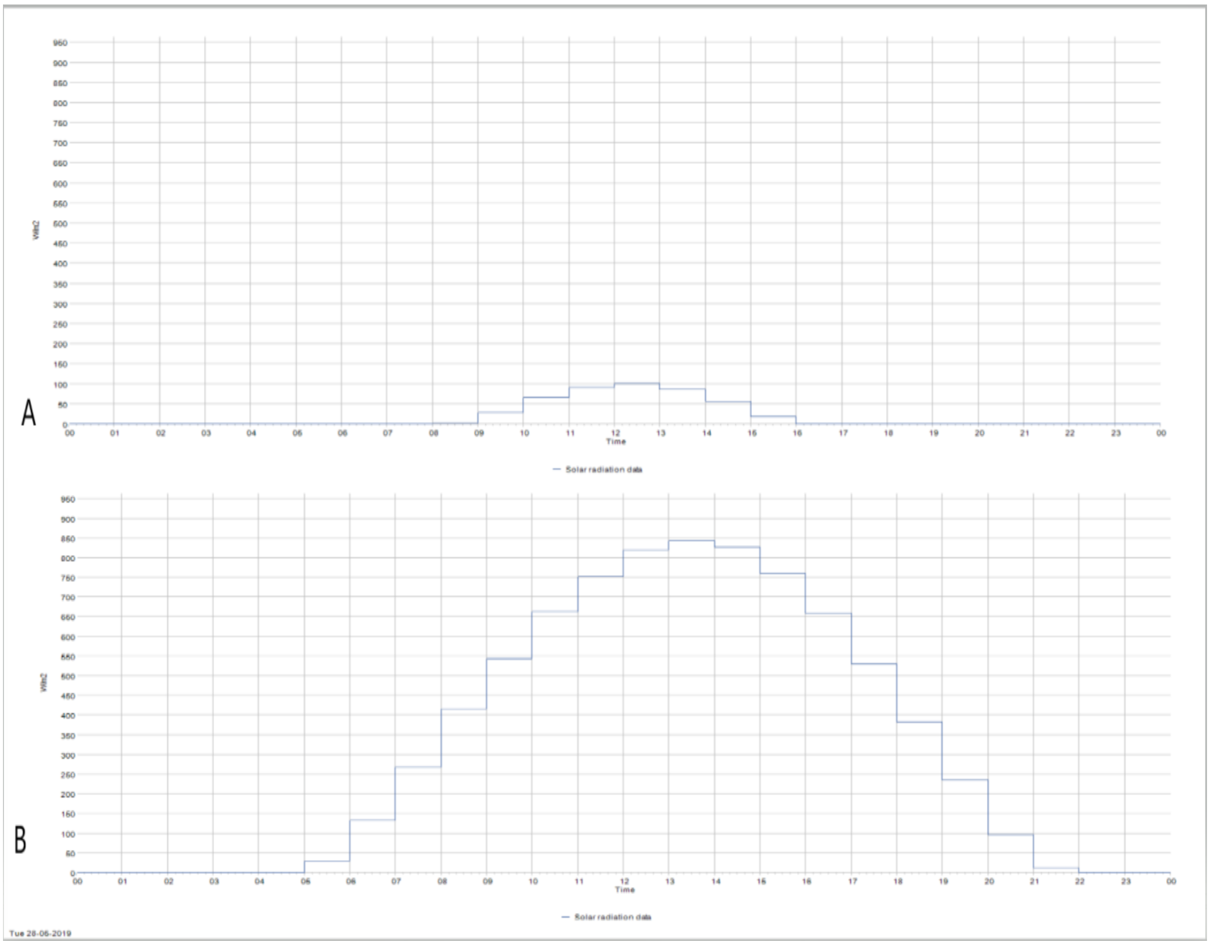


Figure 14 A and B Solar radiation in winter and summer

3.3 Site Demand

3.3.1 Electrical Demand of NAC

The North Ayrshire Council (NAC) which is located southwest of Scotland. NAC is a home to more than 135,900 inhabitants. The total area of NAC is around 340 square miles. The NAC consist of two care homes, thirty-two community centers, thirteen high schools in which comprises five large school, four medium and four small, it consists of fifty-five primary school in that fifty-five are large, twenty medium and twenty smaller, seventy library and six large office and six smaller offices. The total electrical demand of the NAC is 22,316 MWh/year [53]. The Below graph (figure 15) shows the annual demand of NAC.

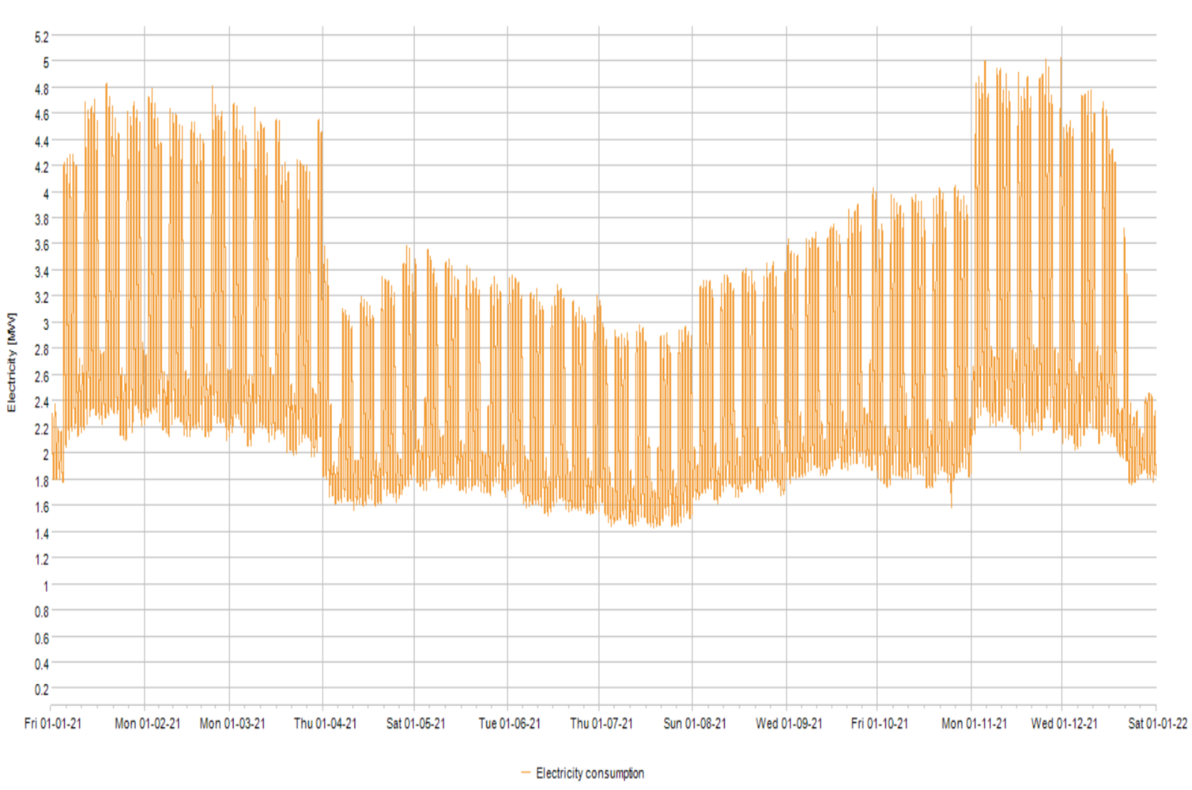


Figure 15 Annual Eletricity Demand of NAC

The maximum electrical demand of NAC is around 5 MWh. The more electricity is required from November to April as is winter season more electricity required for heating purpose. Electricity demand is excessively low from April through October. The maximum electrical demand of April to October is around 3MW. The graph below (figure 16 A and B) depicts NAC's electrical demand during a week in January when demand is quite high and a week in July when demand is quite low.

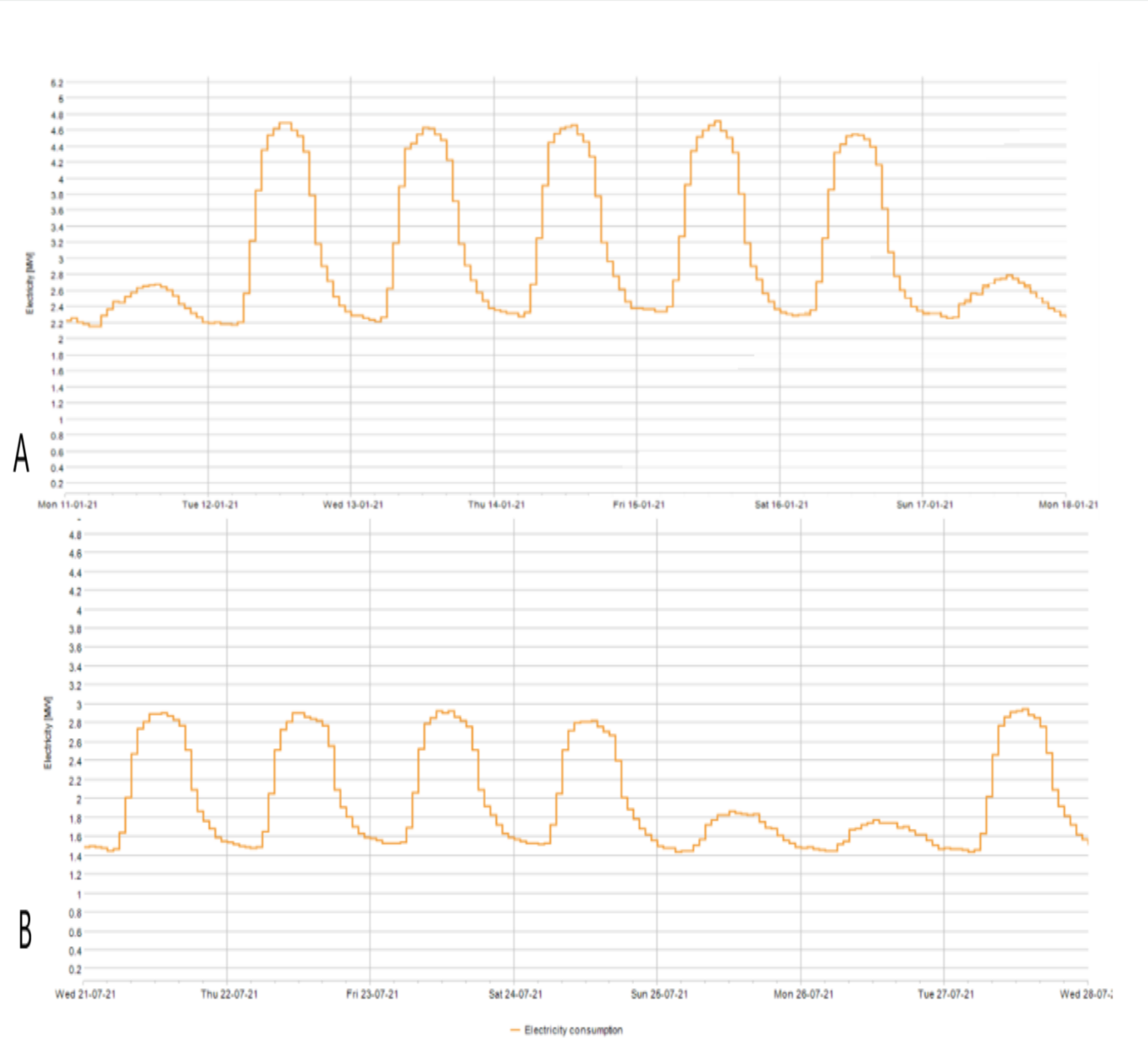


Figure 16 A and B Electrical demand of NAC in January and July

3.3.2 Electrical demand and Heat demand of I3

The I3 is upcoming Scotland's largest enterprise area which is around 132 hectares or 326 acres. The thesis assumes that the whole I3 is constructed as per the passive house and BREEAM standard. The I3 consists of three phases. At present phase 1 is quite bigger than phases 2 and 3.

Phase 1 is in the heart of the I3 campus. According to the current plan phase, 1 consists of three buildings: advanced factory unit, terraced unit, and design manufacturing unit, with areas of 1,858, 230, and 1,100m^2 respectively. Phase 2 is quite smaller compared to phase 1 it consists of two buildings one is the office pavilion which is 825 m^2. The other building is the Advanced Manufacturing unit, which is 1,370m^2. Phase 3 consists of only one building as per the current plan which area is 1,100 m^2.

- Potential future manufacture /supplier park owned by SE which is 1,858 m^2 Potential office pavilion which is 2,550m^2 area.
- Potential future expansion is the 1,858m^2 area.
- Potential manufacturing supplier park which is a 5,5741m^2 area.

Passivhaus standard is maximum heating demand for a year is 15 kWh/m^2. Total energy consumption for heating, lighting, hot water, power not to exceed 120 kWh/m^2 per year.
So, the annual heating demand of I3 as per the current plan is 97.245 **MWh**. The electrical demand is maximum is **777.96MWh**. When factor in the future-plan, the yearly heating demand is **1,026.675MWh**, and the annual electricity demand is **8,213.400 MWh.**

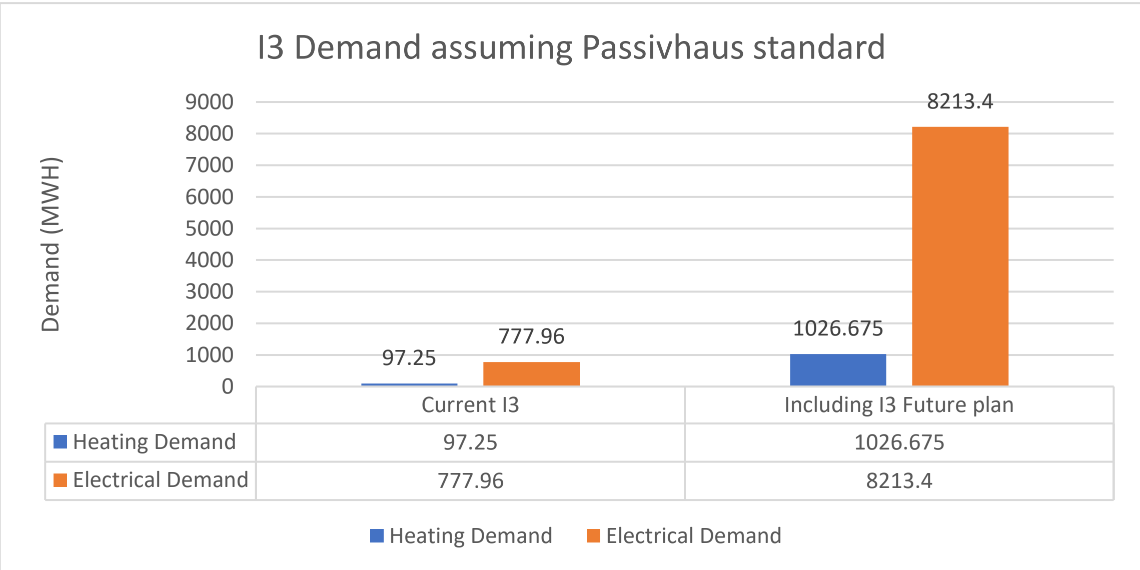


Figure 17 Graph of demand of I3 as per the current and Future plan

3.3.3 Electricity and Heat demand of GSK

For serval years, the GSK Irvine site has been implemented an activity program aimed at enhancing the energy efficiency of its process and utilities. So, GSK did numerous changes such as LED lighting is being used to replace traditional lighting. GSK planned to enhance his renewable sources so installed two 2.5MW windmills and two biogas CHP which contains each 500 KW. Also, GSK has a natural gas CHP which is around 4MW. GSK's total annual electricity demand is 182GWh, with a 20MWh average and a 26MWh peak demand. The annual heat demand is 162GWh and the average demand is 18MWh. The below figure18 shows the annual electrical demand of the site which was taken from Mark Dunn Thesis.

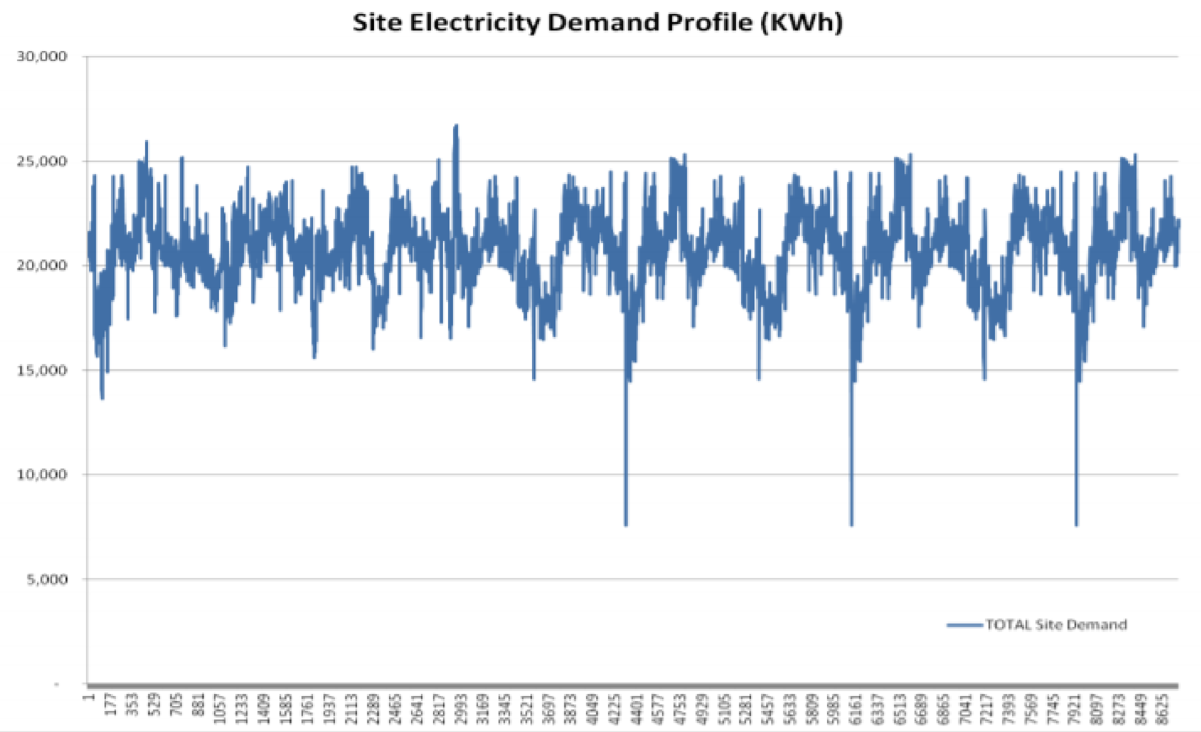


Figure 18 Annual eletric demand of GSK (source: http://www.esru.strath.ac.uk/Documents/MSc_2015/Dunn.pdf)

3.4 Power Curve

Another important piece of data required is the power curve for energy pro to calculate how much electricity is required to be produced. The wind turbine power curve depicts the relationship between wind turbine power and hub height wind speed. Without knowing the technical details of the components of the wind turbine generating system, a power curve can help anticipate wind energy. There are two terms called cut out and cut in speed in a power curve. The cut-out speed is the maximum speed at which the power can be obtained as well as the cut-in speed is the lowest speed at which the turbine can produce power [47]. The power curve, cut-in speed, and cut-out speed differ from one turbine design to the next. Typically, a smaller wind turbine has a cut-in speed of 2 to 3 m/s, whereas a larger turbine has a cut-in speed of 4 m/s. Farm energy company planning to install two turbines of ENERCON-126 EP3 [48]. The cut in and cut out speed of ENERCON-126 EP3 is 3 and 24 respectively [49]. The below figure 19 is the power cover of ENERCON-126 EP3 which is used for modeling and simulation in energy pro software.

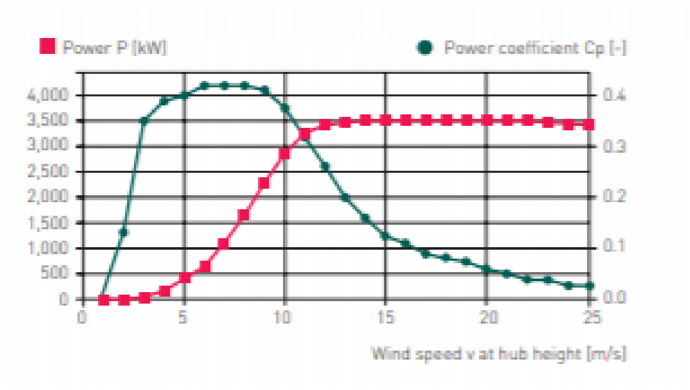


Figure 19 Power curve of Enercon 126 EP 3 (source : 50)

ENERCONE-126 EP4 which is 4200 KW size is being chosen for the five windmills planned to be installed by NAC. Below figure 20 is the power cover of ENERCONE-126 EP4 which is used for modelling and simulation in energy pro software.

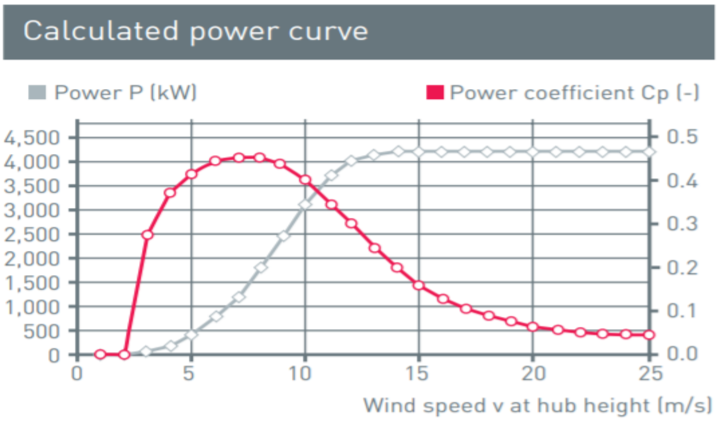


Figure 20 Power Curve of Enercon 126 EP4 (source: [51])

3.5 On site generation

GSK is one of the companies which fight against environmental problems like climate change and pollution etc. As a result, GSK intended to build renewable sources near the industry, reducing the use of non-renewable energy and carbon emissions. GSK installed two windmills of each 2.5 MW. As per Mark Dunn Thesis, The annual electricity produced from the windmill is around 23 GWh in 2016. The same component is modeled in energy pro and validates whether the thesis approach is right or not. In this thesis for 2019 wind speed data modeling of two windmills carried out in energy pro and then validated with Marks Dunn's result. The below figure 21 and 22 shows the energy pro modelling, comparing the energy pro result with Marks Dunn result respectively.

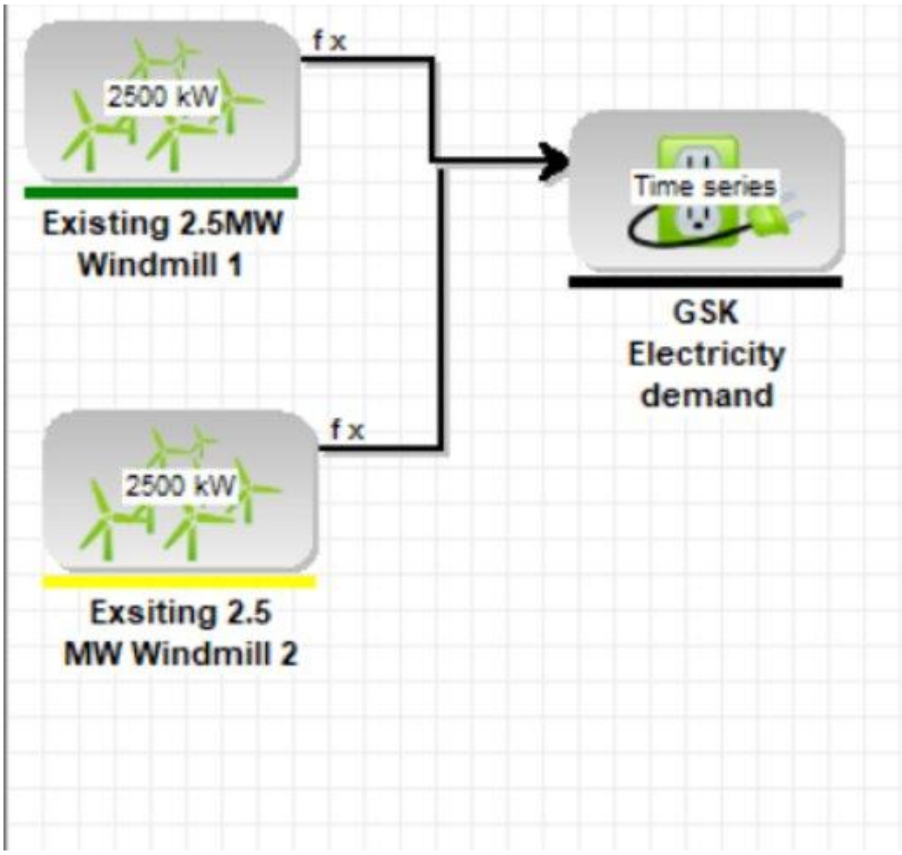
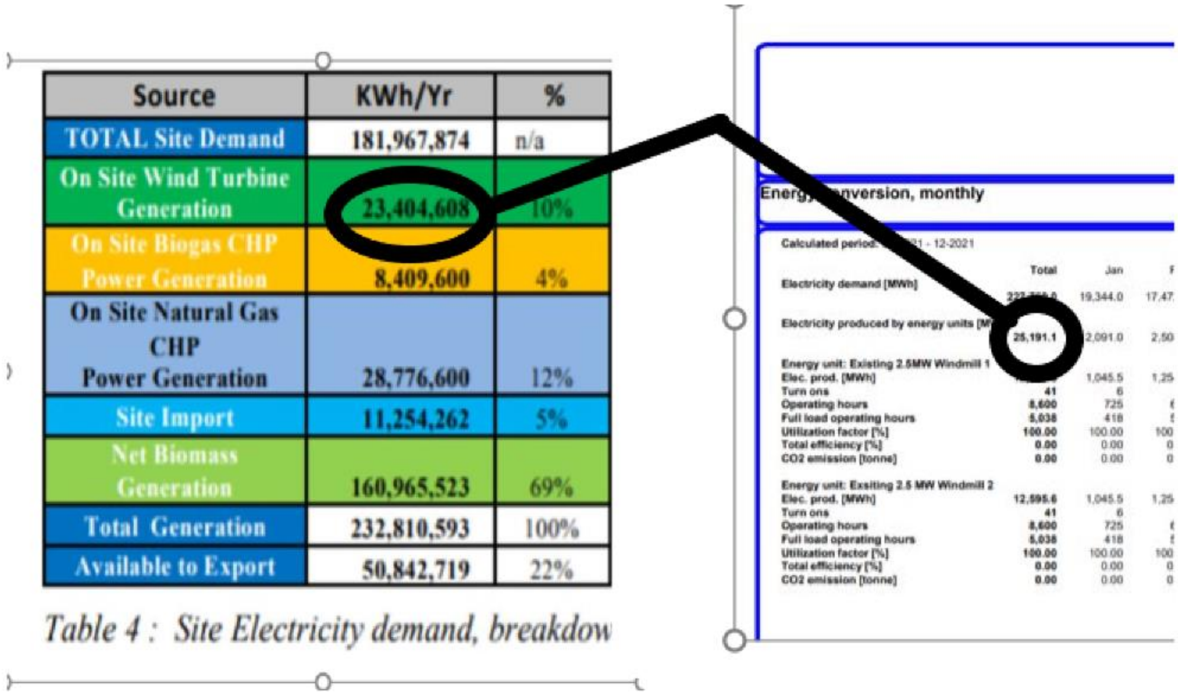


Figure 21 Energy Pro model of existing windmill



Source	KWh/Yr	%
TOTAL Site Demand	181,967,874	n/a
On Site Wind Turbine Generation	23,404,608	10%
On Site Biogas CHP Power Generation	8,409,600	4%
On Site Natural Gas CHP Power Generation	28,776,600	12%
Site Import	11,254,262	5%
Net Biomass Generation	160,965,523	69%
Total Generation	232,810,593	100%
Available to Export	50,842,719	22%

Table 4 : Site Electricity demand, breakdow

Figure 22Comparing energy pro result with Mark dunn result (http://www.esru.strath.ac.uk/Documents/MSc_2015/Dunn.pdf)

The annual production from energy pro is 25,191 MW. The difference between the two data is around 7% The explanation for the divergence is that Mark Dunn used wind speed data from 2016, whereas the thesis uses wind speed data from 2019. Other than windmill GSK has a 4MW CHP plant and two 0.5 KW biogas plant-like windmills even for CHP modelled in energy pro then compared with the Mark Dunn Thesis value to check whether this thesis approach is right or wrong. Below figure 23 and 24 shows the energy pro modelling on CHP and their results respectively.

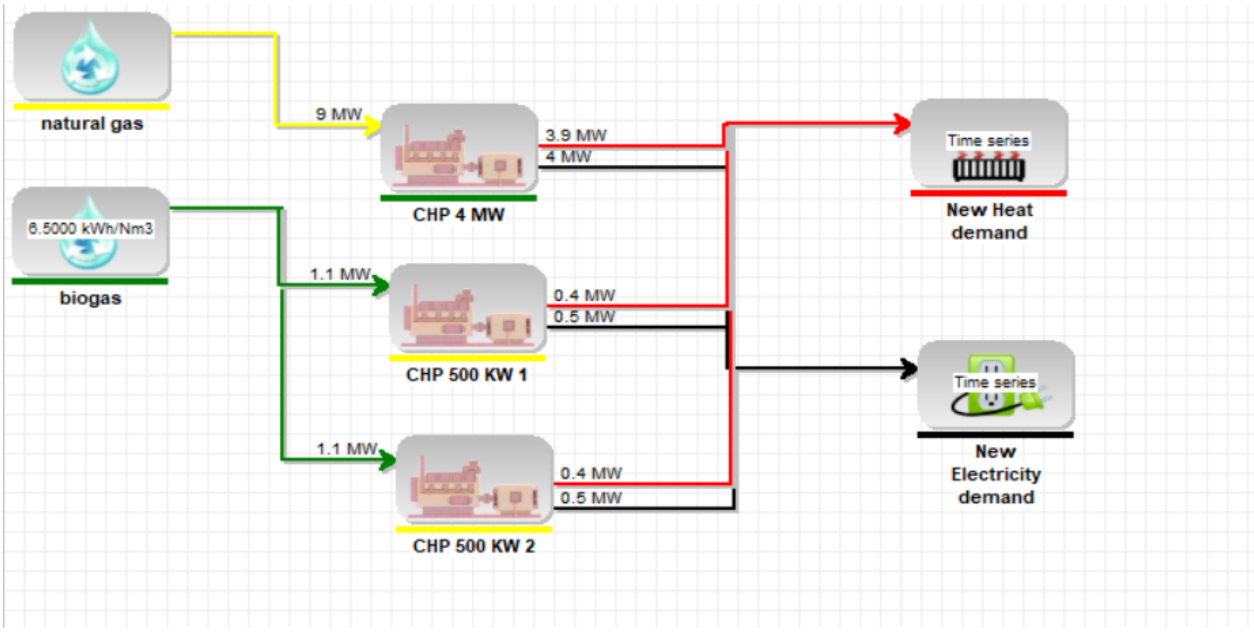
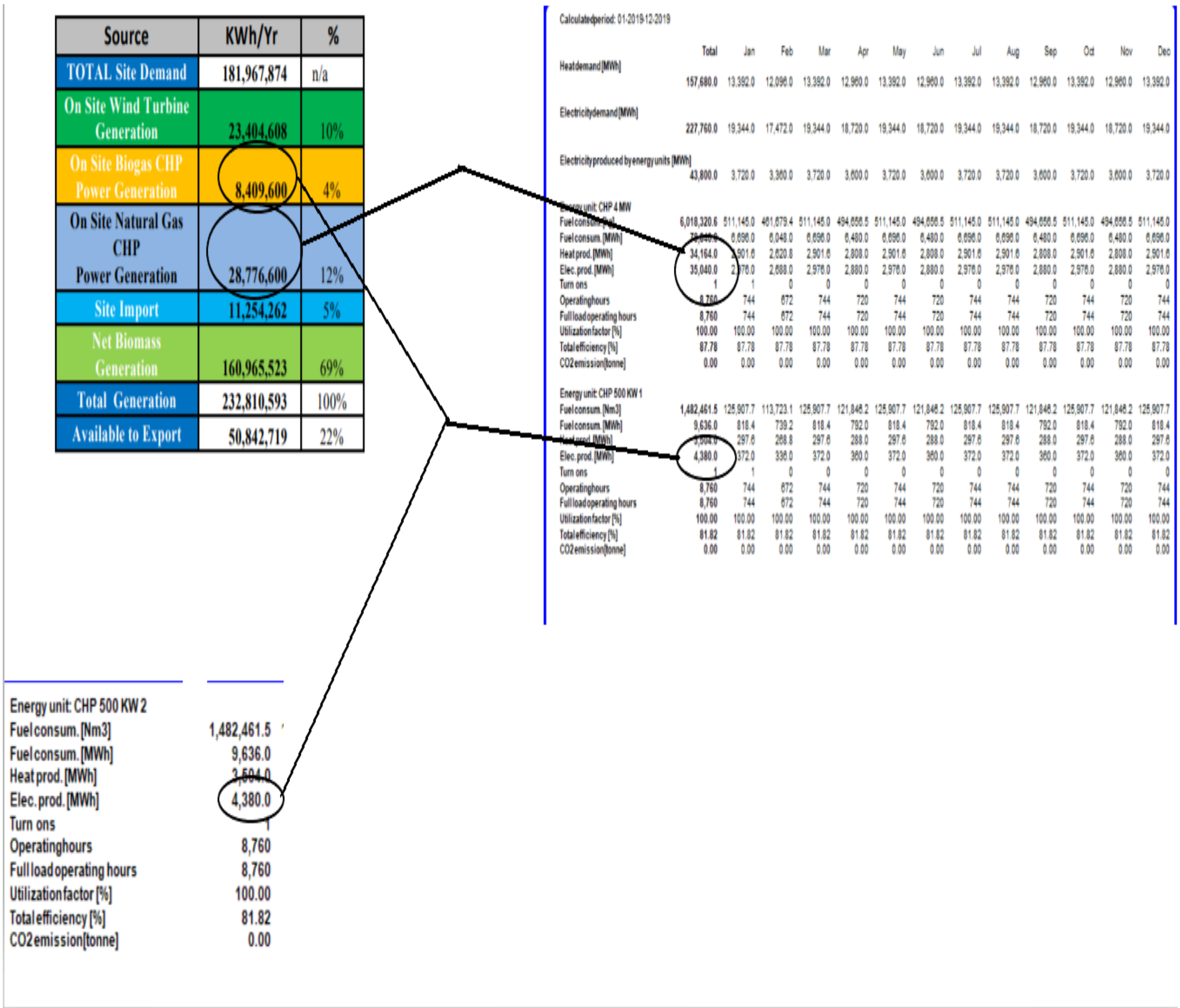


Figure 23 Energy Pro model of existing CHP



Source	KWh/Yr	%
TOTAL Site Demand	181,967,874	n/a
On Site Wind Turbine Generation	23,404,608	10%
On Site Biogas CHP Power Generation	8,409,600	4%
On Site Natural Gas CHP Power Generation	28,776,600	12%
Site Import	11,254,262	5%
Net Biomass Generation	160,965,523	69%
Total Generation	232,810,593	100%
Available to Export	50,842,719	22%

Calculatedperiod: 01-2019-12-2019

	Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heatdemand [MWh]	157,680.0	13,392.0	12,096.0	13,392.0	12,960.0	13,392.0	12,960.0	13,392.0	13,392.0	12,960.0	13,392.0	12,960.0	13,392.0
Electricitydemand [MWh]	227,760.0	19,344.0	17,472.0	19,344.0	18,720.0	19,344.0	18,720.0	19,344.0	19,344.0	18,720.0	19,344.0	18,720.0	19,344.0
Electricity produced by energy units [MWh]	43,800.0	3,720.0	3,360.0	3,720.0	3,600.0	3,720.0	3,600.0	3,720.0	3,720.0	3,600.0	3,720.0	3,600.0	3,720.0
Energy unit: CHP 4 MW													
Fuel consum. [Nm3]	6,018,320.6	511,145.0	461,679.4	511,145.0	494,656.5	511,145.0	494,656.5	511,145.0	511,145.0	494,656.5	511,145.0	494,656.5	511,145.0
Fuel consum. [MWh]	[illegible]	6,696.0	6,048.0	6,696.0	6,480.0	6,696.0	6,480.0	6,696.0	6,696.0	6,480.0	6,696.0	6,480.0	6,696.0
Heat prod. [MWh]	34,164.0	2,901.6	2,620.8	2,901.6	2,808.0	2,901.6	2,808.0	2,901.6	2,901.6	2,808.0	2,901.6	2,808.0	2,901.6
Elec. prod. [MWh]	35,040.0	2,976.0	2,688.0	2,976.0	2,880.0	2,976.0	2,880.0	2,976.0	2,976.0	2,880.0	2,976.0	2,880.0	2,976.0
Turn ons	1	1	0	0	0	0	0	0	0	0	0	0	0
Operatinghours	8,760	744	672	744	720	744	720	744	744	720	744	720	744
Full load operating hours	8,760	744	672	744	720	744	720	744	744	720	744	720	744
Utilization factor [%]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total efficiency [%]	87.78	87.78	87.78	87.78	87.78	87.78	87.78	87.78	87.78	87.78	87.78	87.78	87.78
CO2 emission [tonne]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy unit: CHP 500 KW 1													
Fuel consum. [Nm3]	1,482,461.5	125,907.7	113,723.1	125,907.7	121,846.2	125,907.7	121,846.2	125,907.7	125,907.7	121,846.2	125,907.7	121,846.2	125,907.7
Fuel consum. [MWh]	9,636.0	818.4	739.2	818.4	792.0	818.4	792.0	818.4	818.4	792.0	818.4	792.0	818.4
Heat prod. [MWh]	3,504.0	297.6	268.8	297.6	288.0	297.6	288.0	297.6	297.6	288.0	297.6	288.0	297.6
Elec. prod. [MWh]	4,380.0	372.0	336.0	372.0	360.0	372.0	360.0	372.0	372.0	360.0	372.0	360.0	372.0
Turn ons	1	1	0	0	0	0	0	0	0	0	0	0	0
Operatinghours	8,760	744	672	744	720	744	720	744	744	720	744	720	744
Full load operating hours	8,760	744	672	744	720	744	720	744	744	720	744	720	744
Utilization factor [%]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total efficiency [%]	81.82	81.82	81.82	81.82	81.82	81.82	81.82	81.82	81.82	81.82	81.82	81.82	81.82
CO2 emission [tonne]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Energy unit: CHP 500 KW 2	
Fuel consum. [Nm3]	1,482,461.5
Fuel consum. [MWh]	9,636.0
Heat prod. [MWh]	3,504.0
Elec. prod. [MWh]	4,380.0
Turn ons	1
Operatinghours	8,760
Full load operating hours	8,760
Utilization factor [%]	100.00
Total efficiency [%]	81.82
CO2 emission [tonne]	0.00

Figure 24 Comparing energy pro CHP result with Mark Dunn's Result (sourcehttp://www.esru.strath.ac.uk/Documents/MSc_2015/Dunn.pdf)

4. Stimulation and Analysis

This section discusses about the stimulation, results, and analysis of all the scenarios using the energy pro software.

4.1 Scenario 1: Combining two proposed wind turbines with two existing wind turbine to meet the electrical demand.

GSK, like many other firms, intended to combat environmental issues such as climate change and pollution, among others. Also, to support achieving zero carbon by 2050. So, GSK first planned to install two turbines each of 2.5MW capacity. Which produces annual electricity of 23,000 MW in 2016 as per Mark Dunn Thesis and Using energy pro software annual production for already existing two windmills is around 25,000MW in 2019 However, the existing two windmills are insufficient to meet the site's electrical requirements, thus GSK will need to rely on a grid or import electricity, therefore another two windmills of 3.5 to 4 MW capacity will be installed. The farm energy company decided to install Enercon E-126 EP3 in open land near GSK. The below figure 25 shows the energy pro model of GSK's existing two windmills plus newly proposed two windmills.

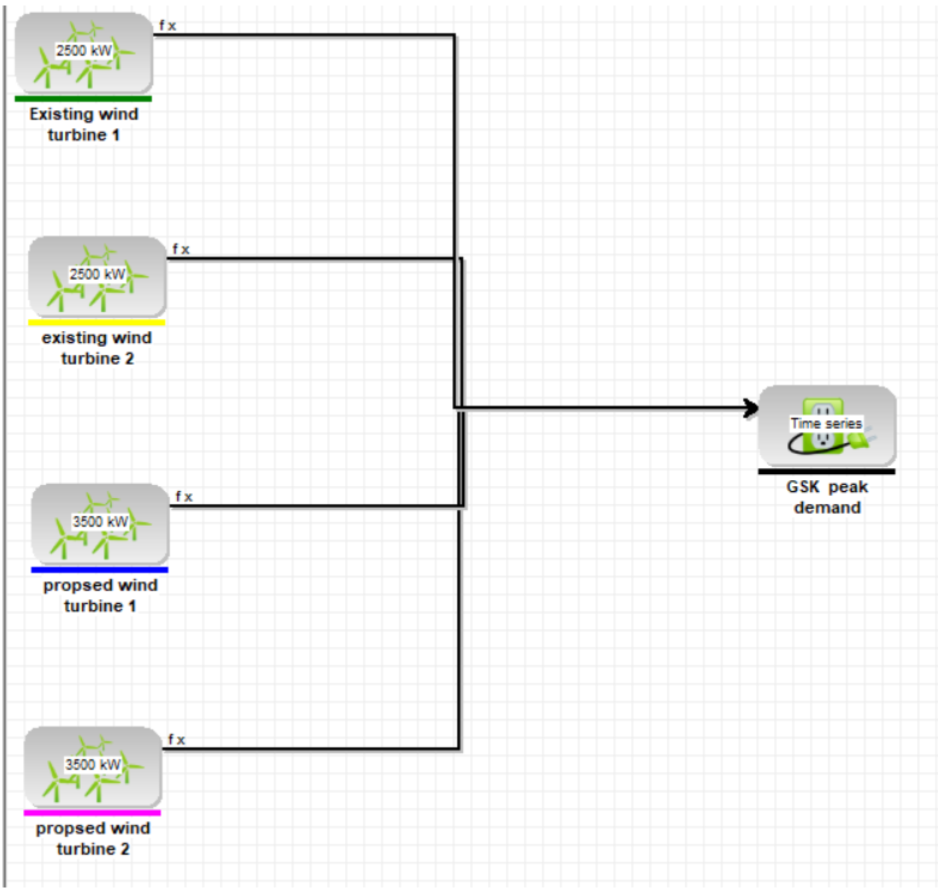


Figure 25 Energy pro model of Scenario 1

The annual electricity produced by these four windmills is around 59,313 MWh. Electricity produced depends on the wind speed which indirectly depends on what season, time, climatic condition. From December to March, the wind speed is relatively high, allowing the windmill to generate its maximum capacity. From June to September the wind speed is quite low so only a low amount of electricity can be produced from the windmill. The bellow figure 26 shows the annual power generation from the four windmills.

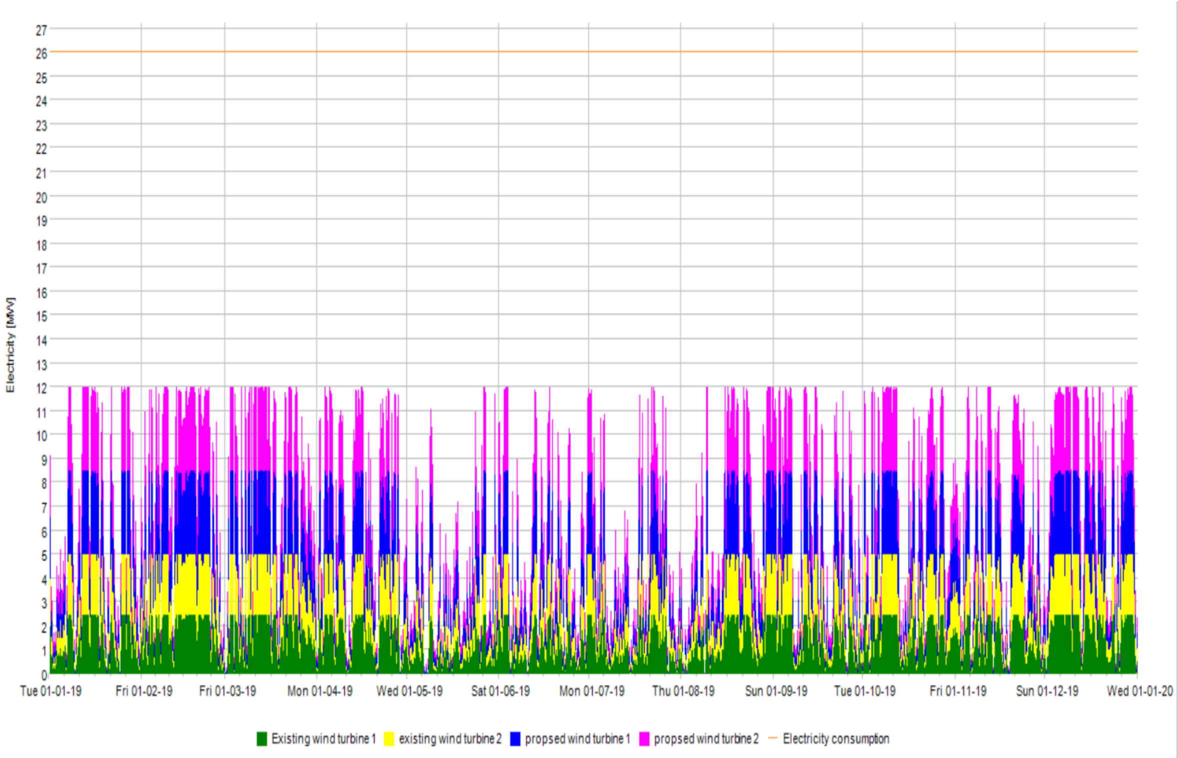


Figure 26Annual eletricity produced by Scenario1

Highest electricity production week is from 9th March to 16 the March. During this week maximum and minimum wind speed is around 22 and 4 m/s respectively. The maximum electricity generated is around 12MWh during that week and lowest is electricity produced during that week is around 2 MWh. when the wind speed is around 4 m/s. Below Figure 28 shows the graph of highest electricity generation week by the four windmills.

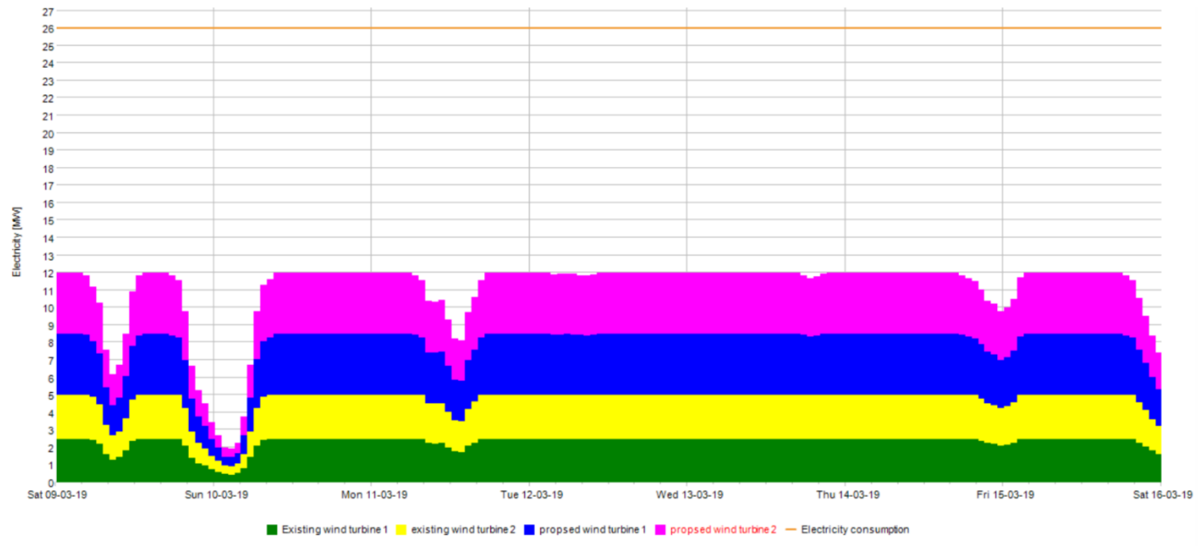


Figure 28 Energy production in a week in March

The Below figure 27 shows the minimum power generation week by the four wind turbines. The minimum power is generated from 10 th July to 17 July which is during the summer season were maximum electricity generated is around 7 MW and minimum of around 1.5 MW during this week. The average electricity production of this week is around 3 MWh. During this time needed to depend on any other renewable source or needed to be imported. So by seeing the output generated from four windmill is not enough to attain the electrical demand of the site even through during the days where wind speed is high.

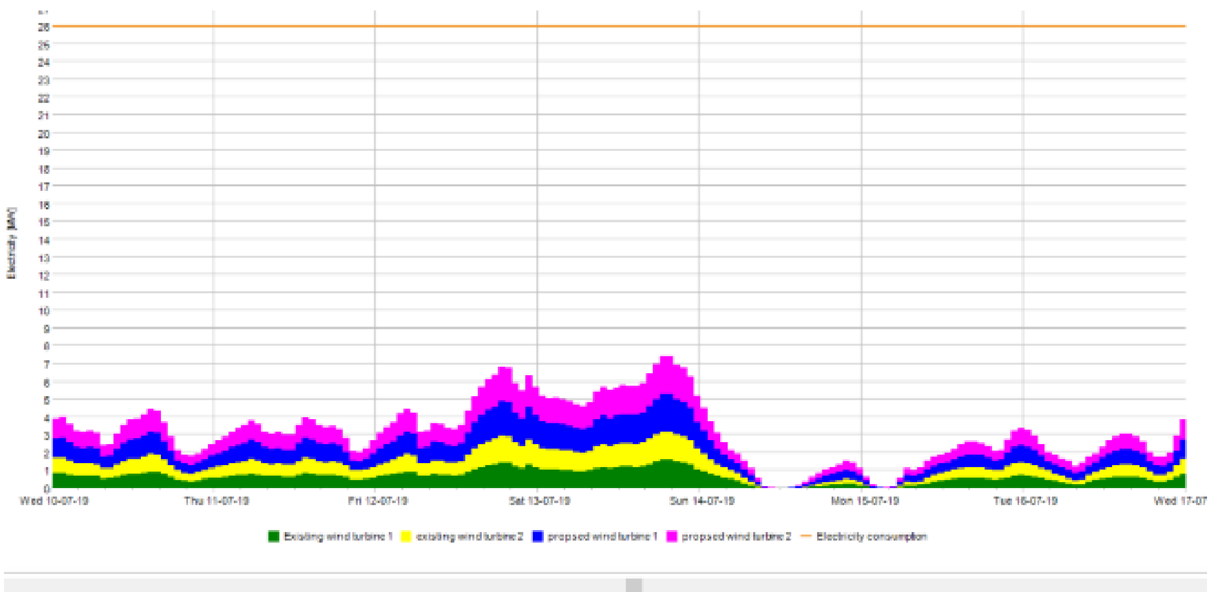


Figure 27 Energy production during a week in July

4.2 Scenario 2: Wind turbine combined with a 20MW solar PV plant and a Green H2 retrofitted 4MW natural gas CHP and a 1MW biogas CHP.

4.2.1 Scenario 2a: GSK 20MW Photovoltaic Plant

Scenario 1 was unable to fulfill the peak electrical demand of GSK so they decided to install another 20 MW photovoltaic plant near to GSK Site. The solar power plants are not more efficient in the UK because of the UK climatic conditions generally the efficiency of a solar panel will be around 10 to 20% but in some types of PV, efficiency can reach up to 25%. The figure 29 below depicts the energy pro modeling for a 20MW photovoltaic project near GSK.

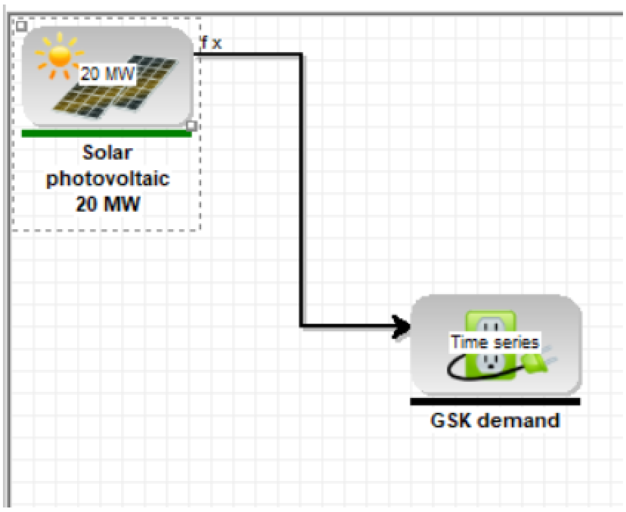


Figure 29 EnergyPro model of Scenario 2a

Energy pro uses solar radiation dropping and temperature to determine the energy produced by the PV plant. In this thesis aggregate of direct and diffuse radiation is considered for calculating the energy produced at the location. From seeing the radiation graph in modelling sections, know that electricity is not produced throughout the day. In winter is produced from 9 am to 5 pm whereas during the summer is electricity is generated from 5 am to 11 pm. So, there is too much fluctuation in electricity production. The annual production from the PV plant is around 22,394 MWh. The month with the most electricity generated is June, with roughly 3,008.9 MW h whereas the lowest month is December with around 374 MWh. But in any month solar PV does not produce a full capacity of 20MW. The figure below 30 depicts the electricity produced by the 20MW photovoltaic project near GSK.

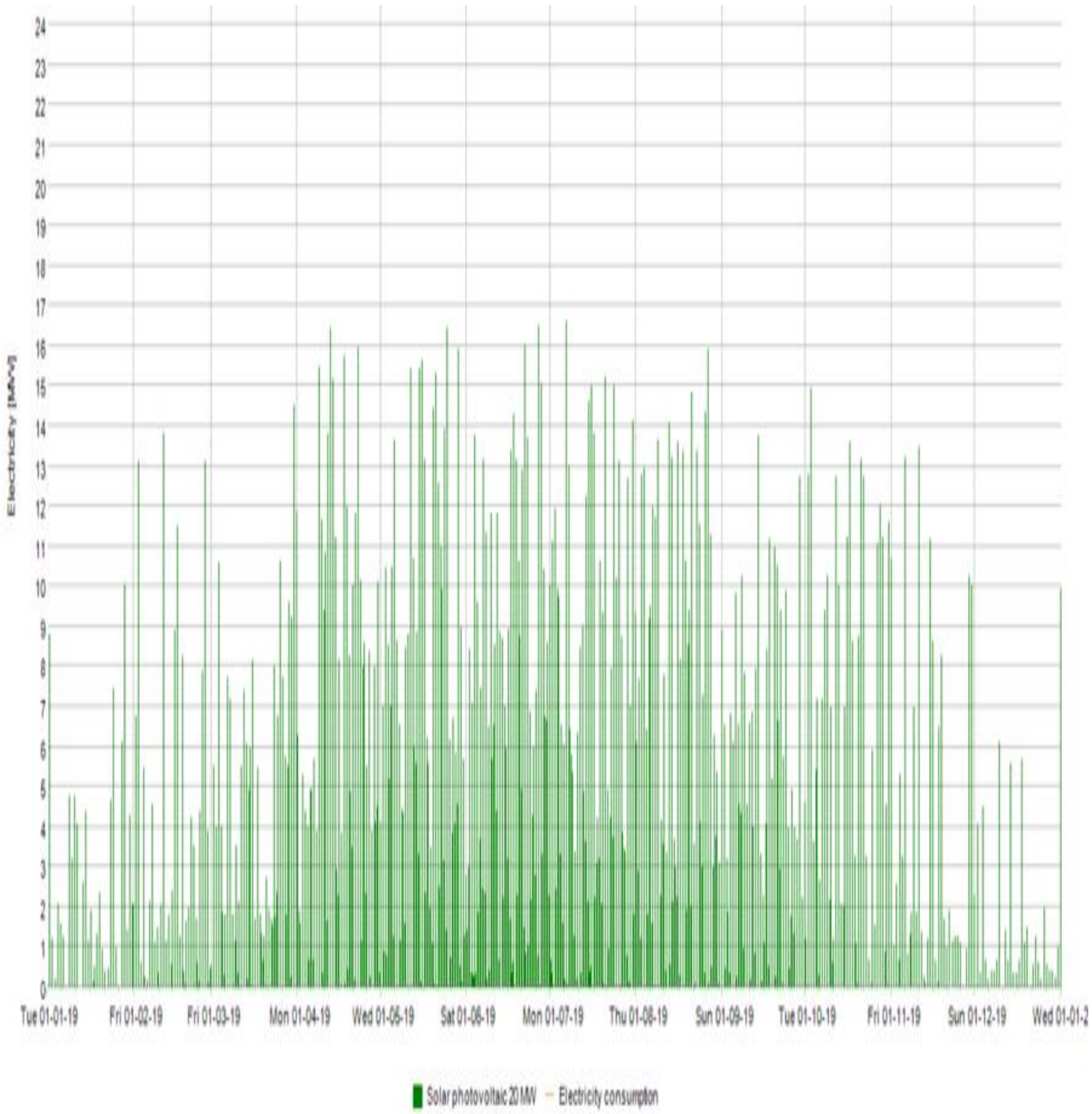


Figure 30 Annual electricity produed by Scenario 2a

The highest electricity production week is from 16 July to 23 July. During this week maximum radiation was around 800 W/m^2. The sun rose at 4 a.m. and set at 9 p.m. this week, thus the radiation fell for a longer period in that place. Maximum electricity produced per hour is around 17 MW on that week. The below figure 31 shows the highest electricity generation week

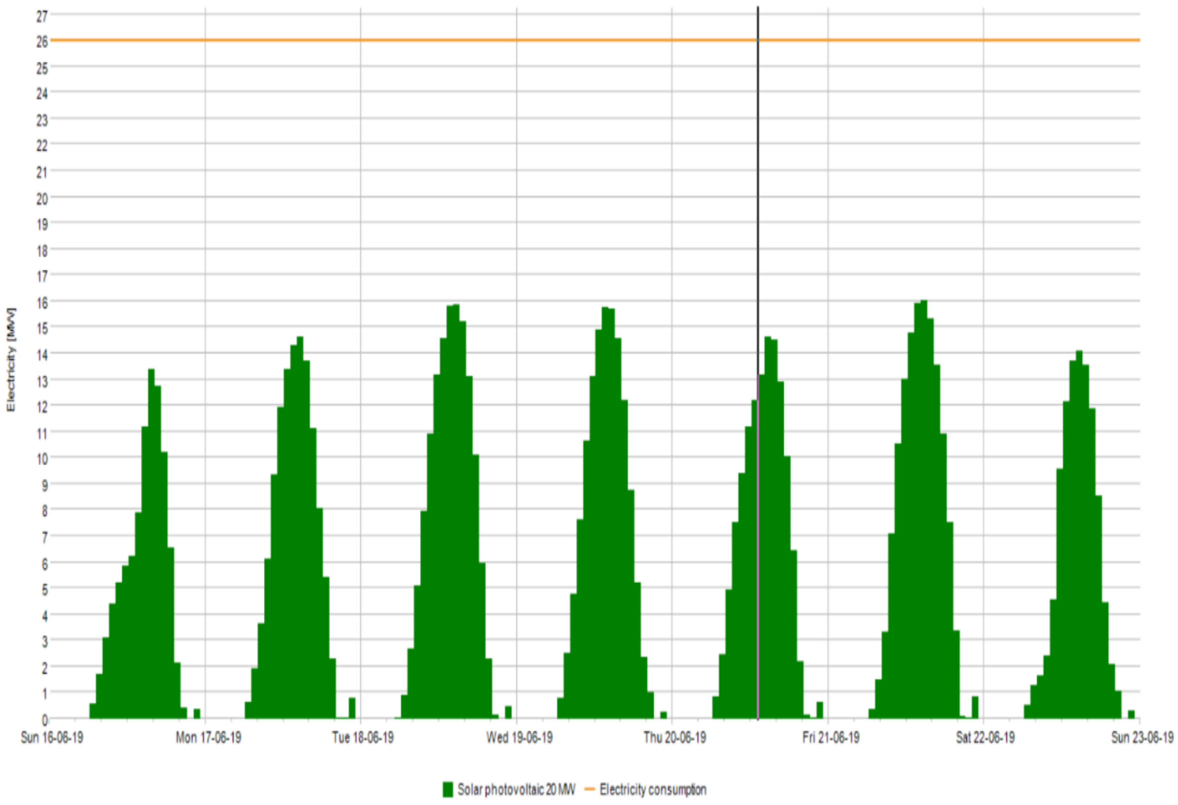


Figure 31Electricity produced in a week july

The lowest electricity production week is from 18 to 25 th December which is the winter season. During this time temperature is from 0 to 8°C and the radiation falling is between 0.031 to 92 W/m^2. The sun rose at 8 a.m. and set at 3 p.m. this week, thus the radiation fell for a shorter period in that place. So, the electricity produced during this period is very little. The maximum electricity produced this week was around 3 MWh so during this week GSK needed to be dependent on the other sources or import energy which could be from the carbon source. Using the stored electricity in the battery when there is a peak in electricity production, especially in July, is the best option during this week. The below figure 32 shows the lowest electricity generation week by 20MW PV plant.

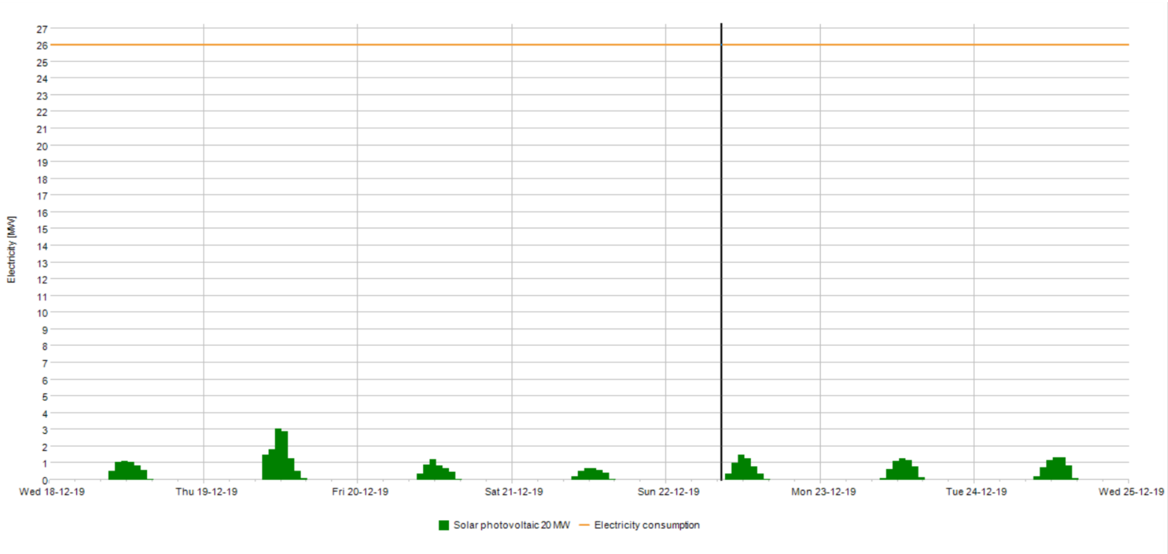


Figure 32Electricity produced in a week in December

4.2.2 Scenario 2b: GSK four windmills combined with 20MW photovoltaic plant and Retrofitted 4MW natural gas CHP and 1MW biogas CHP with Green Hydrogen

Scenario 1 is insufficient to meet the GSK's electricity requirement, hence it is preferable to combine Scenario 1 with Scenario 2a, which also includes outputs from the current CHP plant, which is around 5 MW. The main advantage of a CHP plant is that it uses less fuel than previous techniques. Despite lower fuel usage, natural gas generators emit a significant quantity of CO2. A similar scenario is the University of Strathclyde's CHP plant, which emits approximately 15,000 tonnes of CO2 per year. Biogas is called renewable energy, yet it emits very little carbon dioxide. When the thesis is moving towards the vision of making the industrial site a 100% zero-carbon zone is necessary to retrofit both natural gas and biogas CHP with Hydrogen. Hydrogen is considered as fuel for the future with zero carbon emission. But a detailed study about the retrofitting of hydrogen is not done because is out of scope. Assume that CHP is always running at full capacity in this thesis. The below figure shows 33 an energy pro modeling of Scenario 2b.

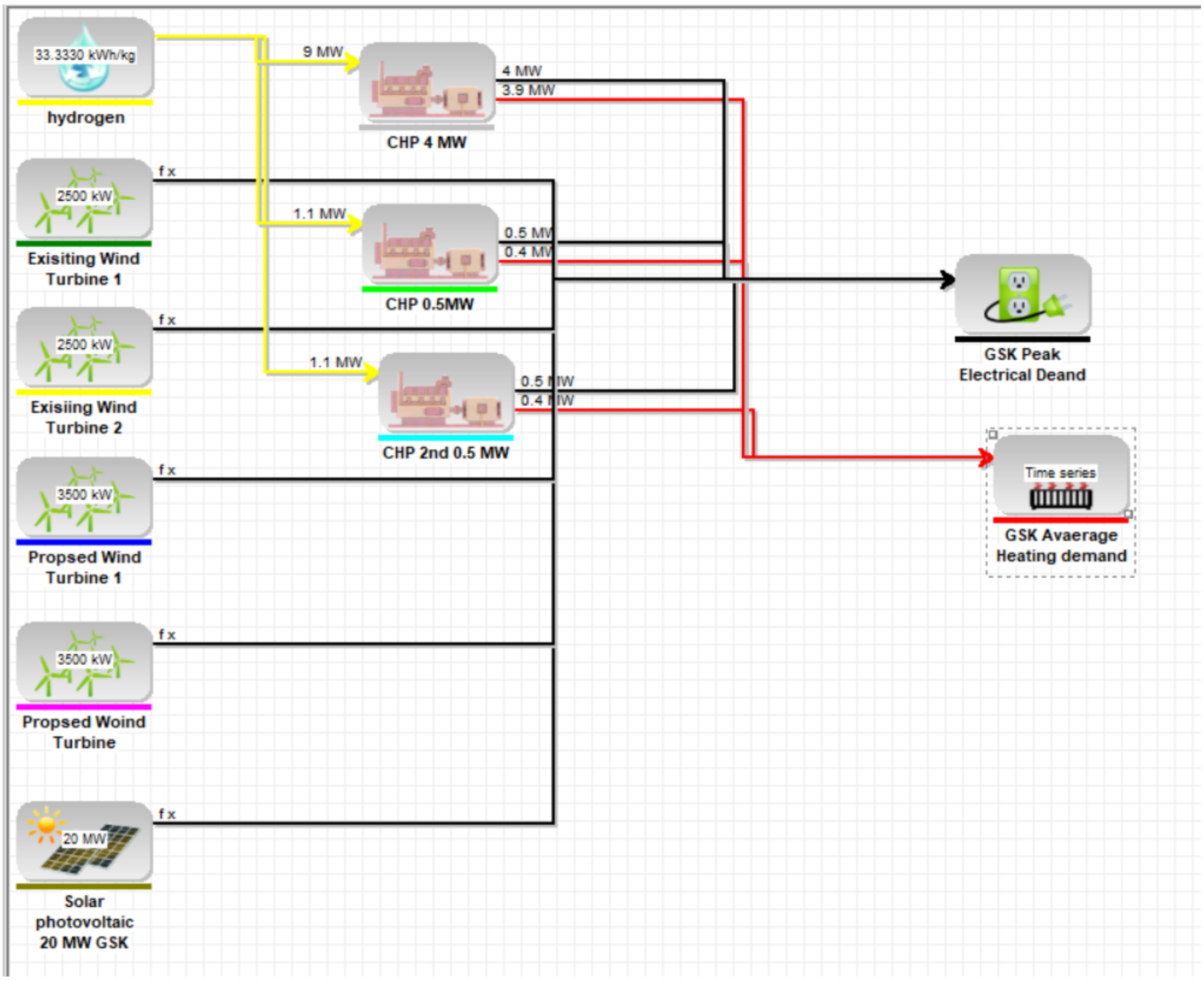


Figure 33 Energy Pro model of Scenario 2b

The total annual electricity produced by all components is 124.5GWh, with the retrofitted 4MW CHP plant producing the most electricity of around 34,192 MWh. In that maximum electricity is being produced in the months of October and April of around 11,054.3MWh. The minimum electricity produced was in month of March and April around 2,1000 MWh. But only some days it could attain the peak electrical demand of GSK other days there need to import the electricity if is unable fulfill that day's demand. In December, wind energy produces a lot of electricity, while solar energy produces a lot less. In July, solar energy produces a lot of electricity, but wind energy produces very little. Below figure 34 shows the annual electricity produced by scenario 2b. The below Table 1 shows the annual electricity produced and the electricity produced by each component.

Table 1 Energy Production by each component in Scenario 2b

Source	Annual Production MWH/Year
GSK existing wind turbine 1 (2500 KW)	12648.8
GSK existing wind turbine 2 (2500 KW)	12549
GSK Proposed wind turbine 1 (3500 KW)	17090
GSK Proposed wind turbine 2 (3500 KW)	17026
Retrofitted Natural GAS CHP (4MW)	34192
Retrofitted Biogas CHP 1 (500 kW)	4358
Retrofitted Biogas CHP 2 (500 kW)	4331.5
GSK 20 MW Solar PV plant	22393.4

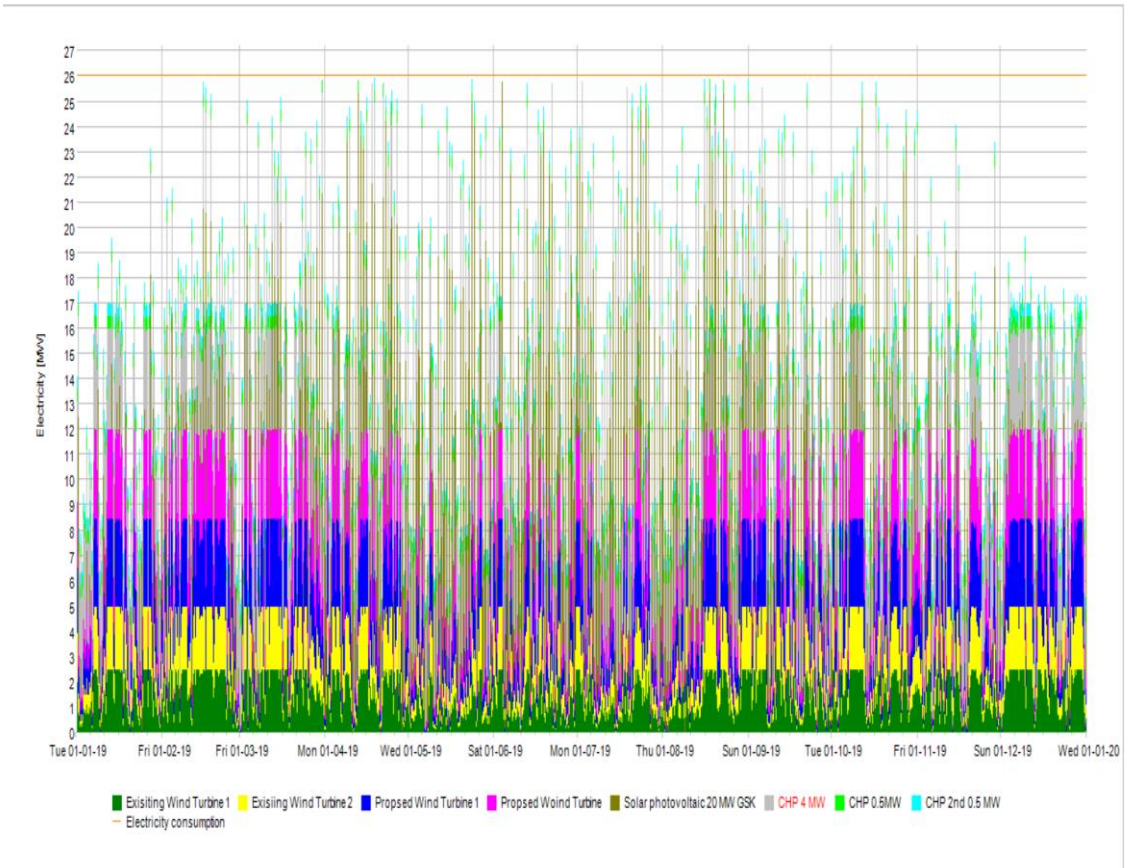


Figure 34Annual electricity produced by scenario 2b

The below figure 35 shows the highest electricity produced per week based on scenario 2b. The maximum electricity produced week is from 21st April to 28th April. The production of CHP going to same for all the months because it doesn't depend on external conditions like wind speed, solar radiation, and solar current. The reason for this week's high production is that the output from four wind turbines is excellent, and the output from solar energy is excellent, so when both are combined, the output during that week is high, and it frequently touches the peak demand of 26 MW.

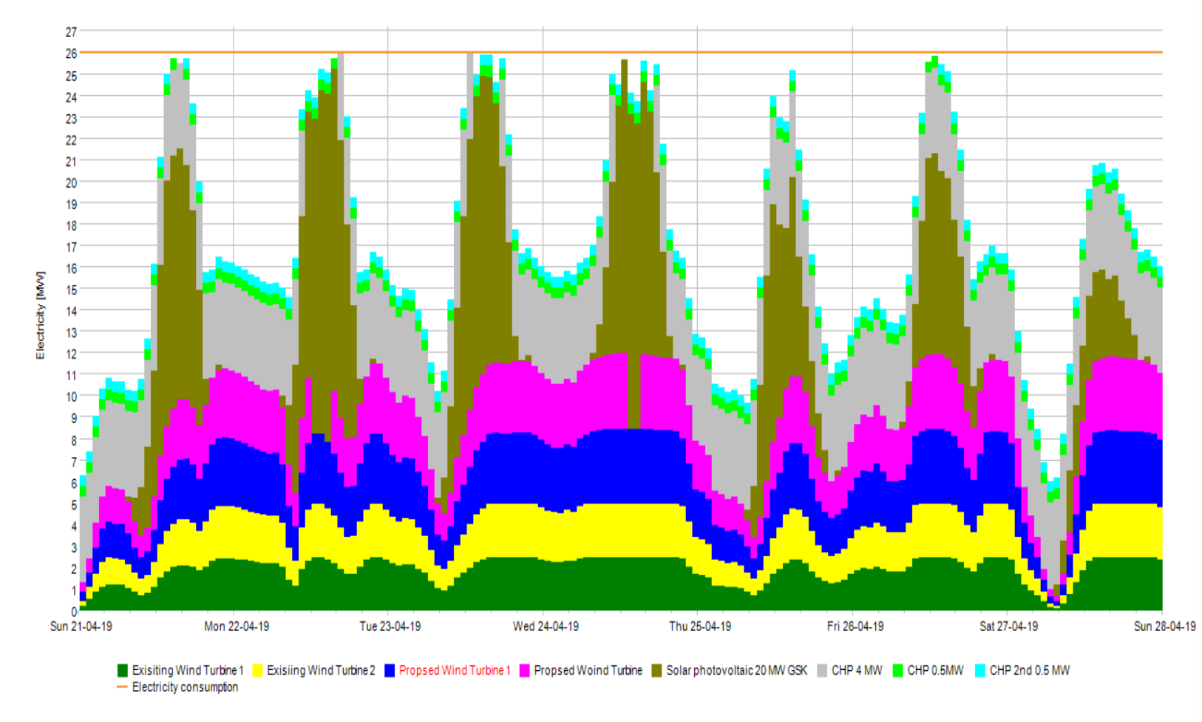


Figure 35 Electricity produced in a week in April by Scenario 2b

The below figure 36 shows the lowest electricity produced week based on scenario 2b. The minimum electricity produced week is from 19th December to 26th December. The reason for the lower electricity production this week is that, except for the 23rd, wind energy production is pretty good, but solar energy production is very low, and at times is equivalent to zero. The maximum electricity produced during this week is 18MW and a minimum of 8 MW.

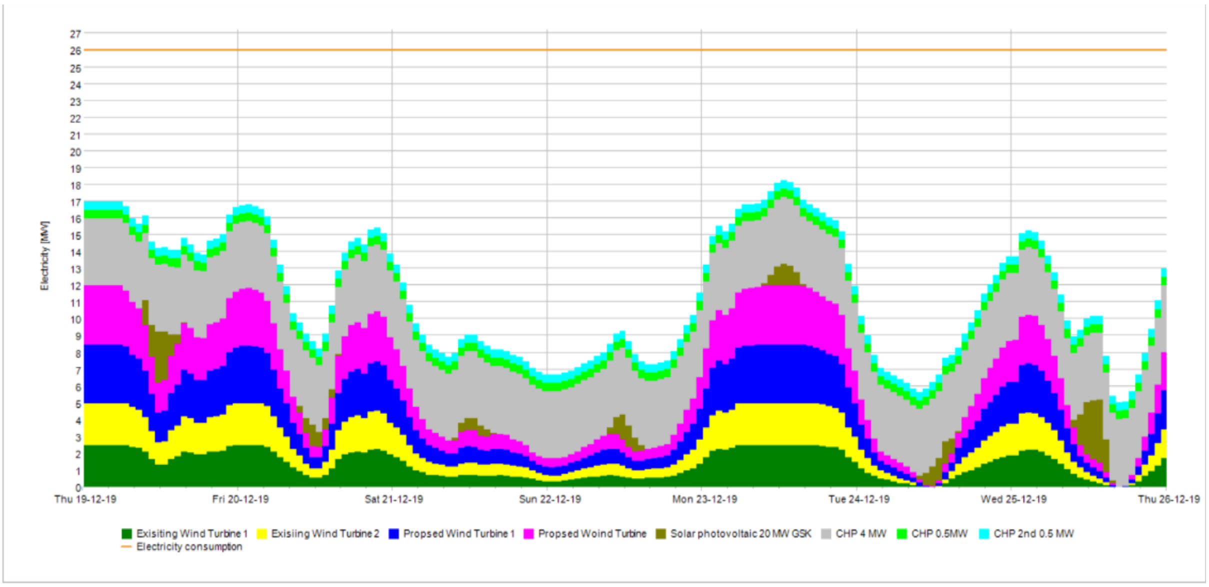


Figure 36 Electricity Production in week in December by Scenario 2b

4.3 Scenario 3: GSK's entire energy-producing plant is combined with the Shewalton solar farm.

Scenario 2 is not enough to attain the electrical demand of the whole industry site. Shewalton is an old landfill or waste dumping site which is planned to be converted into a solar PV plant which is 5.5 MW capacity. The below figure shows the power output only from the Shewalton landfill. The highest amount of electricity is produced from April to August because solar radiation is at its peak during this time. In addition, the sun rose early in the morning and set later in the evening. From December to January, the electricity production is very less because the solar radiation is very less most of the cases is not exceed 100 W/m^2. In addition, the sun rose later and set early in the evening. Usually, sunrise will be around 8 to 9 am during this month. The annual electricity production from the Shewaltan landfill is 5,598.3 MWh. In that maximum production month is July of around 752.2 MWh and the minimum is December of around 93.6MWh. Combined annual electricity production is around130GWh. The graphs below figure 37, 38,39 depict the annual production from Shewalton landfill, the Energy Pro model combining Shewalton and GSK, and the annual output from combining GSK and Shewalton landfill.

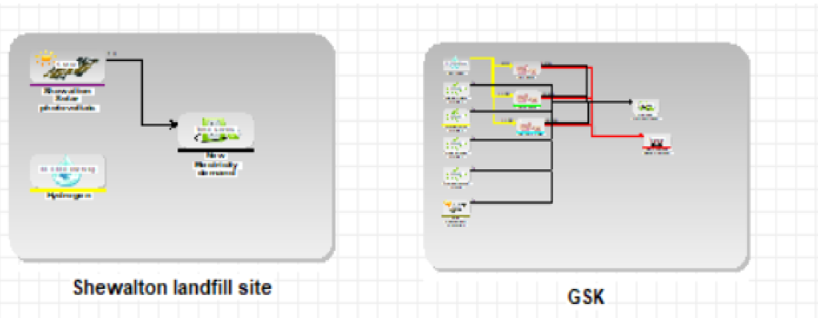


Figure 37Energy Pro model of scenario 3

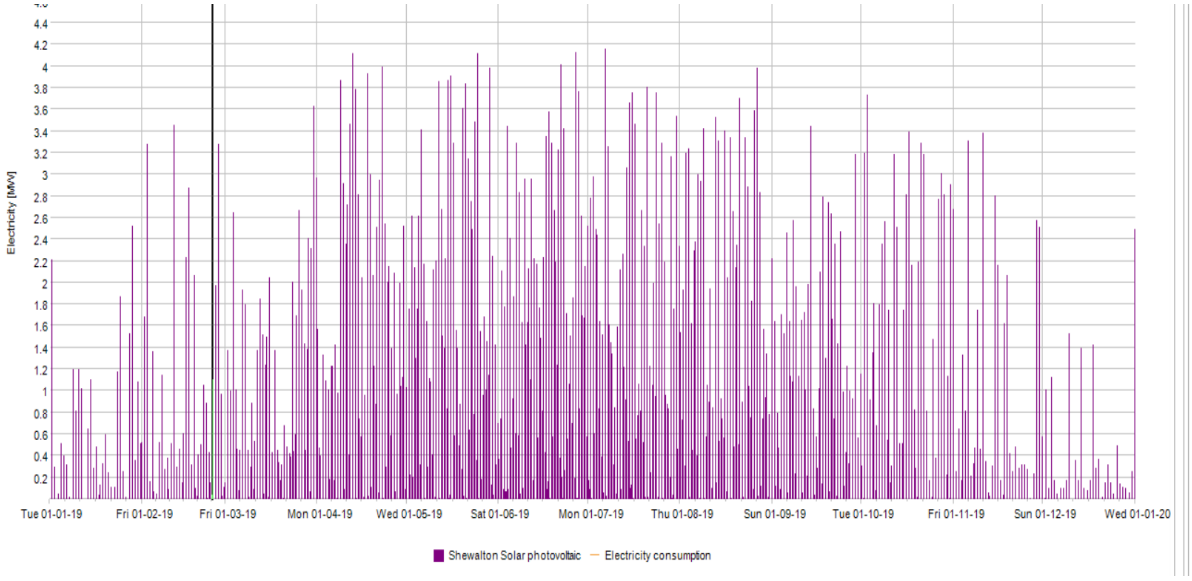


Figure 38 annual production from Shewalton landfill

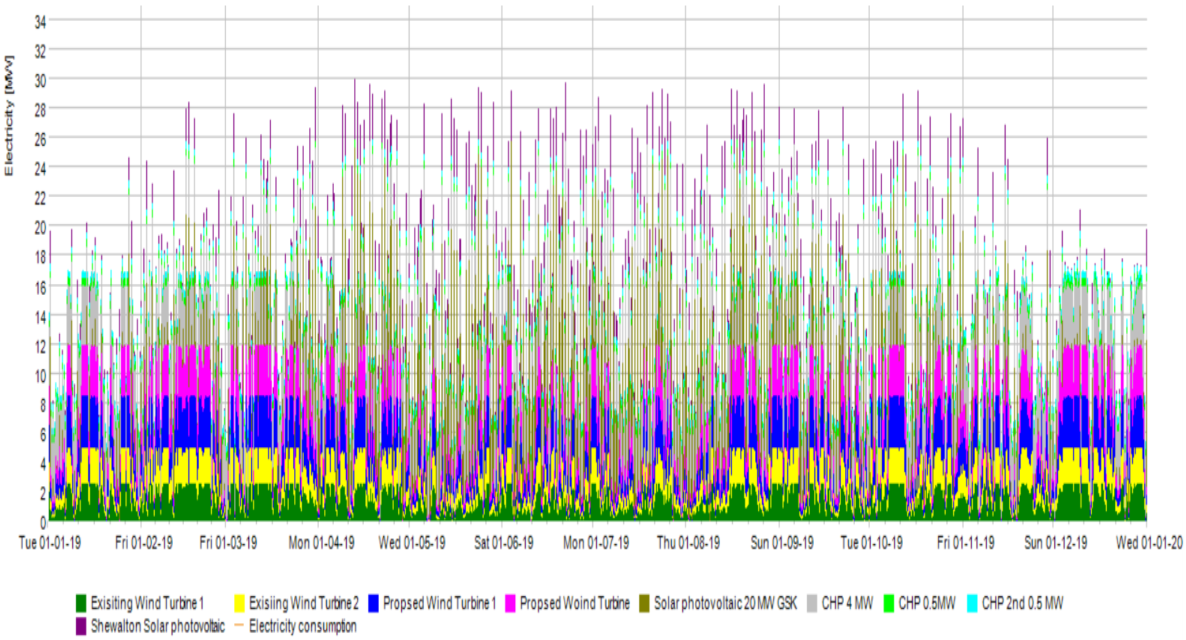


Figure 39 Annual energy Production by Scenario 3

The graph below (figure 40) depicts energy production in June, which is sufficient to meet NAC's peak demand. The maximum electricity produced during this week is around 4.2MWh. The electricity is being produced for longer time in a day so here is maximum production.

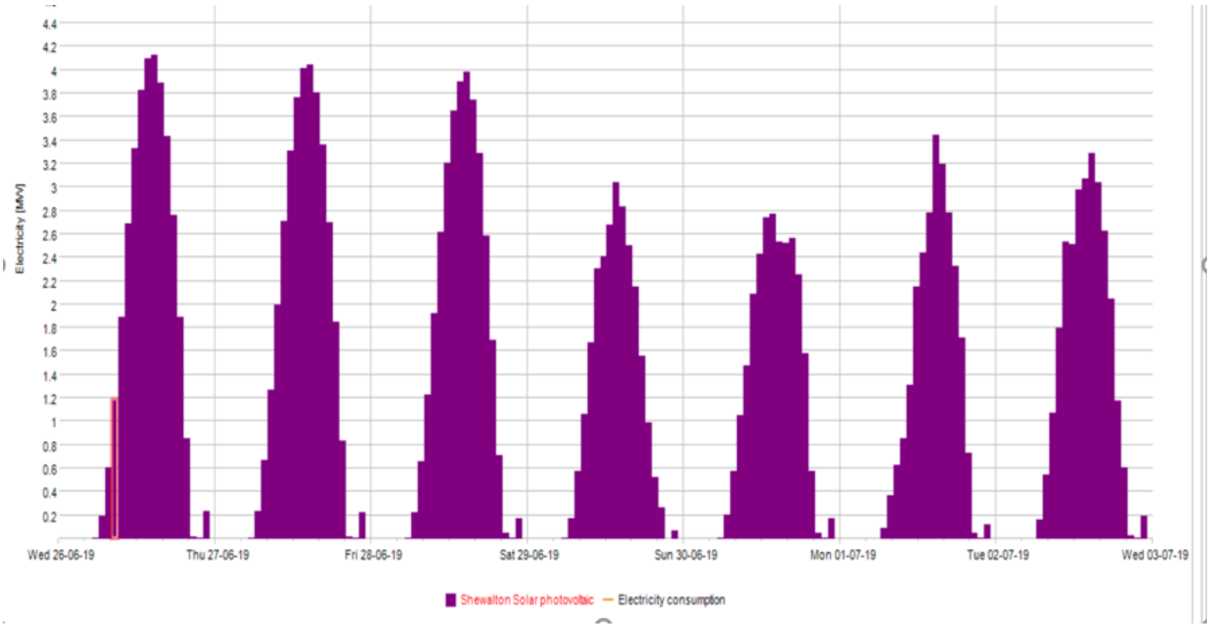


Figure 40 Energy produced in week in July by shewlthan

The below figure shows 41 electricity production in December. Sun rose later and sets early so early. Also, radiation falling is very low during December and January, so the electricity production is very less. The peak electricity production is around 0.9MW in the below week. During this period solar power is unable to match the electrical demand of the NAC

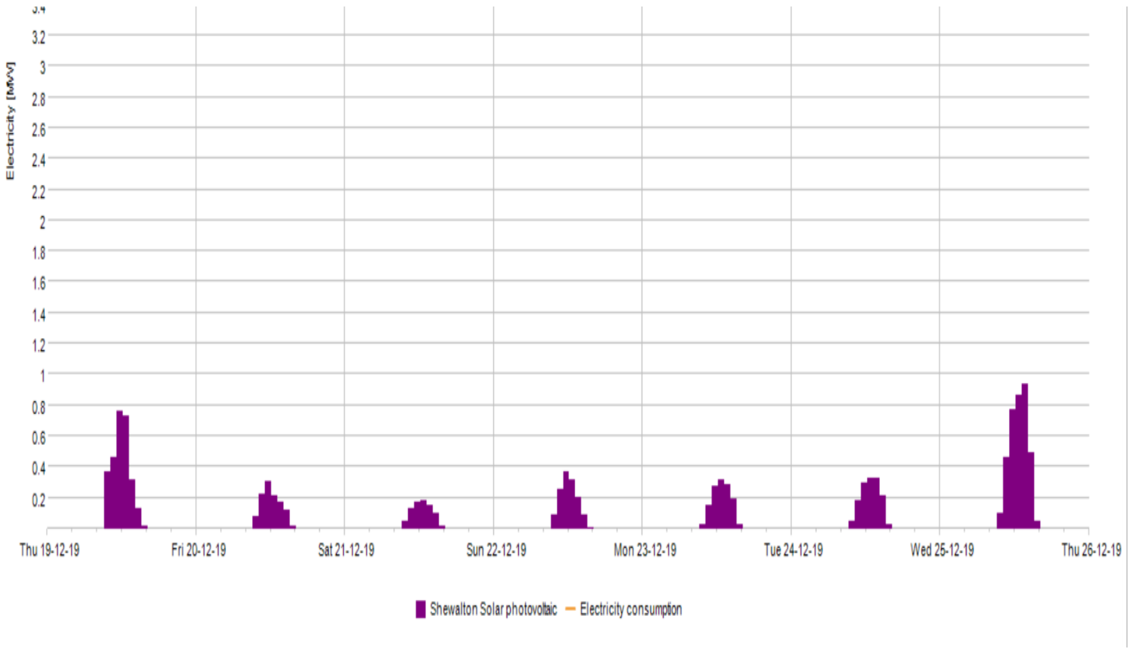


Figure 41Energy production in a week in December by shewalton

4.4 Secnario 4: Combination of all energy producing units in the Industrial site

4.4.1 Secnario 4a: NAC Wind Turbine Alone

Five wind turbine is placed in the site by NAC of each 4.2MW to fulfill electrical demand I3. The limitation faced by this thesis don't know the exact amount of electricity required for the I3 because I3 is still undergoing project and don't know what type of industries going to occupy the I3. The total electricity produced by 4 windmills is 77,160.9MWh. In that maximum electricity is being produced in December which is 2,066.66 and the minimum is in May around 1,007 MWh. Planned to install Enercon E-126 EP4 which is the maximum capacity of 4.2 MW on the site. Around 4,000 hours in 8,760 hours (total hours in a year) operating in a full load. The below figure 42 and 43 shows the energy pro modelling and annual production by the five wind turbines respectively.

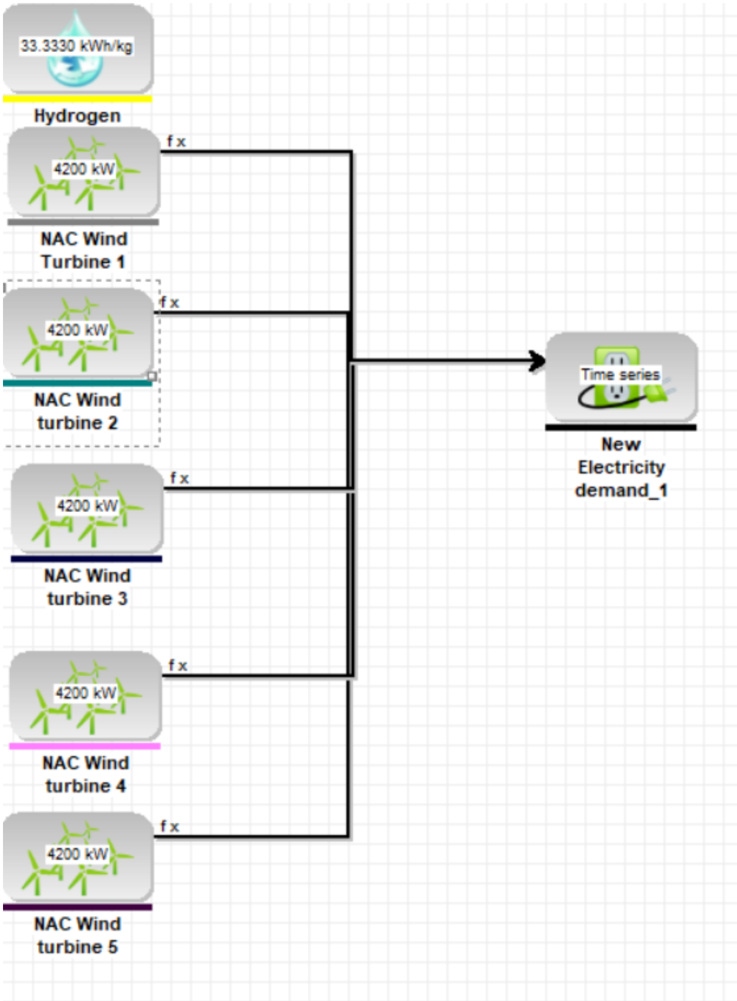


Figure 42 Energy Pro model of Secnario 4a

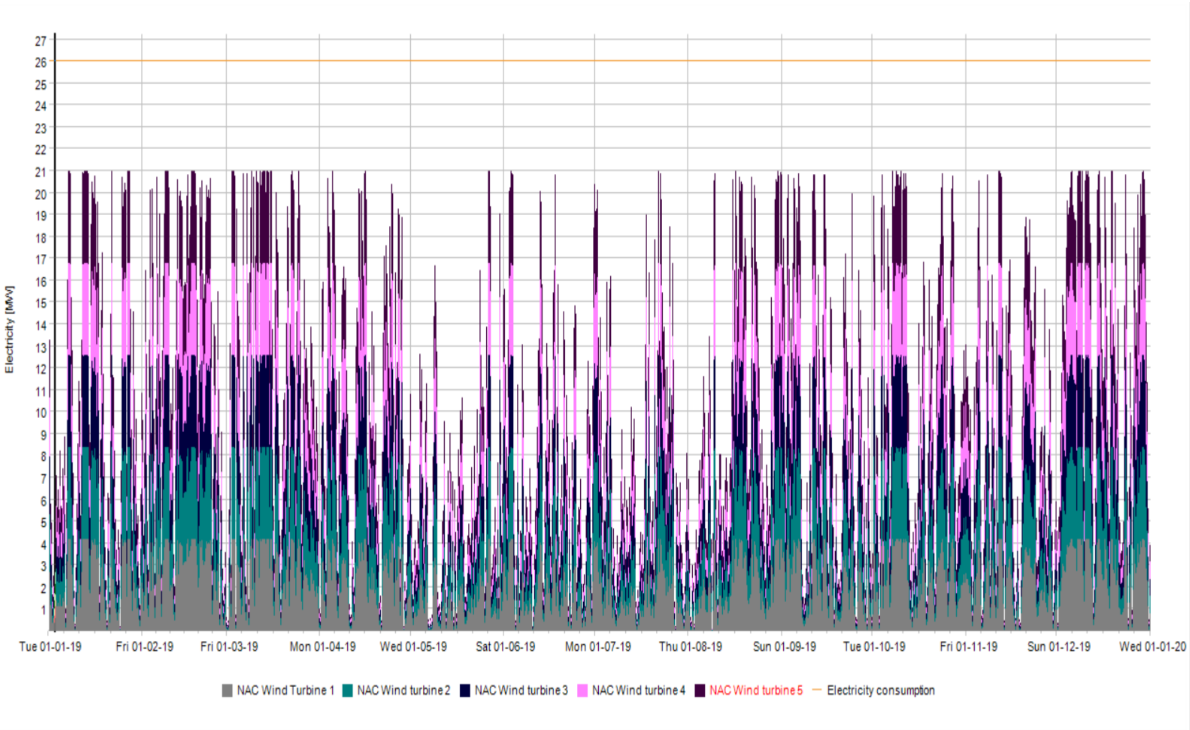


Figure 43Annual production by scenario 4a

The below image 44 A and B shows the weekly production in July and December respectively. The energy production is higher in December compared to July because the wind speed is high in December compared to July. The peak electricity produced in below graph A is 22MW and in graph B maximum electricity produced is around 10 MW. So, During July needs depend on the grid or to be imported to attain the electrical demand of I3.

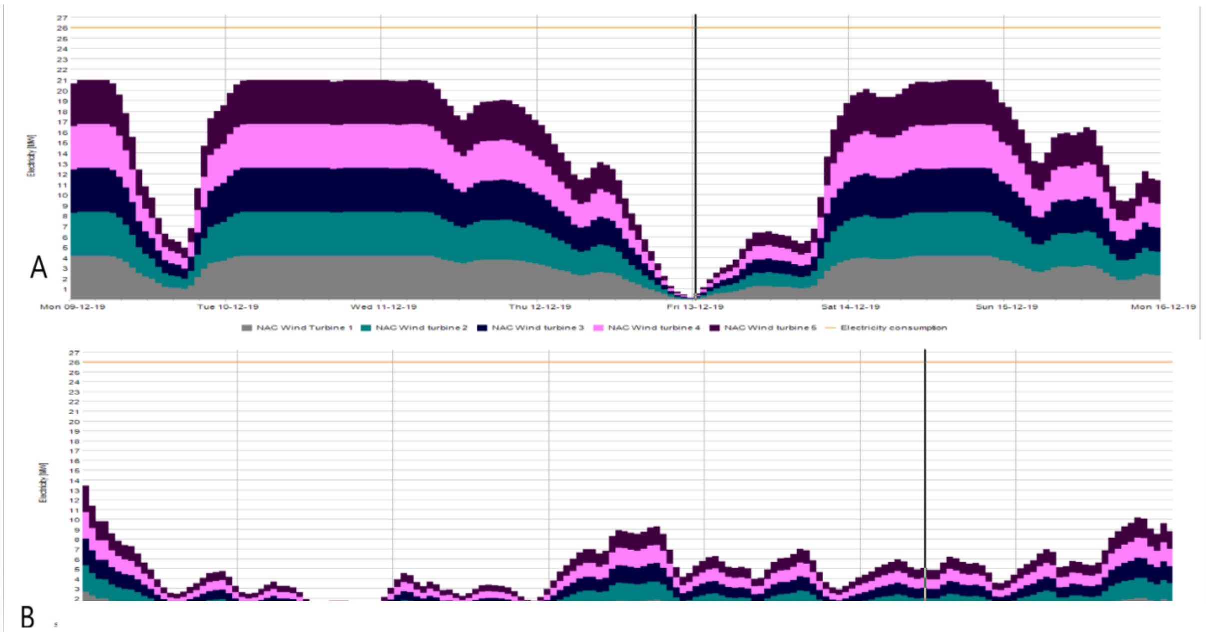


Figure 44 A and B Energy production in a week in December and July by Scenario 4a

4.4.2 Scenario 4b: Combination of all energy producing units in the Industrial site

Scenario 4b is the master plan for the electrical production of the whole site. It comprises GSK, Shewalton landfill, and I3. GSK comprises two existing windmills of each 2.5MW, two proposed windmills of each 3.5MW, 20MW PV Plant, Retrofitted 4MW CHP and two retrofitted CHP of each 500KW, Shewalton comprises of 5MW solar plant and NAC consist of five windmills each of 4.2MW. The below figure 45 shows the modeling of all components in energy pro.

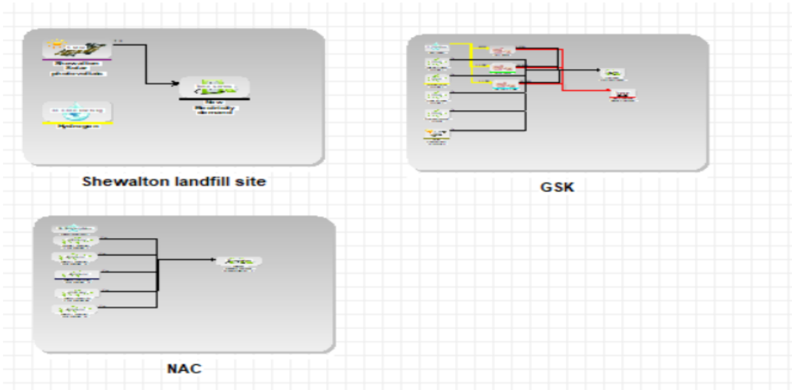


Figure 45 Energy Pro model of Scenario 4b

The annual electricity production by 224 GWh. Even though solar radiation is very less in December is the second maximum month of 20,983.3MWh. The electricity generation month is March of around 21,714MWh. The reason for the march to be high is both wind speed and solar radiation is good and high. The lowest electricity generation is in May at around 15,742.2 MWh. However solar radiation is quite high in May, the wind speed is very low so very low electricity generation from wind energy. Wind turbines generate approximately 60% of total annual electricity production. The peak electricity produced by scenario 4b is around 50MWh. The below image 46 figure and table 2 shows the annual production by scenario 4b.

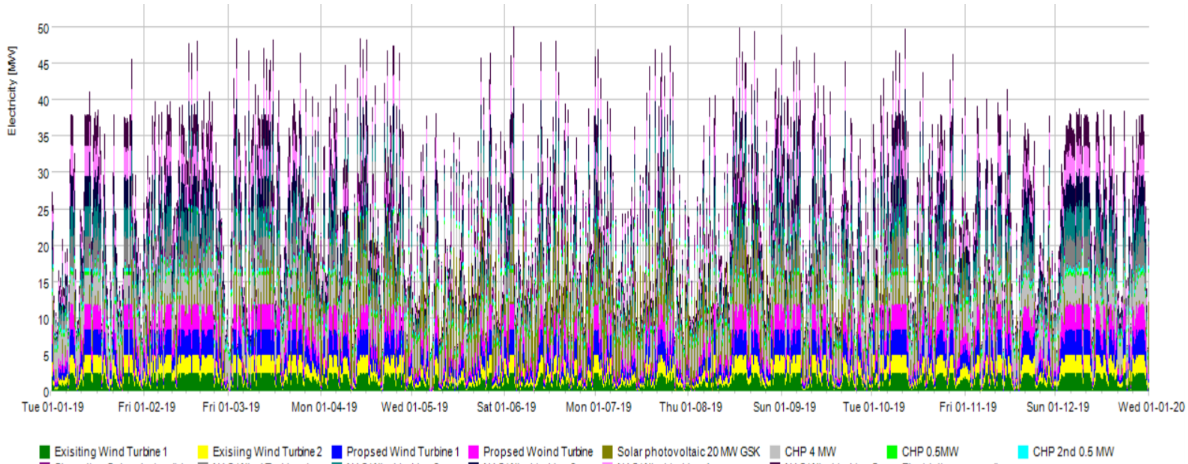


Figure 46 Annual Production by Scenario 4b

Table 2 Annual Energy production by each component in scenario 4b

Source	Annual Production MWh/Year
GSK existing wind turbine 1 (2500 KW)	12648.8
GSK existing wind turbine 2 (2500 KW)	12549
GSK Proposed wind turbine 1 (3500 KW)	17090
GSK Proposed wind turbine 2 (3500 KW)	17026
Retrofitted Natural GAS CHP (4MW)	34192
Retrofitted Biogas CHP 1 (500 kW)	4358
Retrofitted Biogas CHP 2 (500 kW)	4331.5
GSK 20 MW Solar PV plant	22393.4
Shewalton PV Plant	5598.3
NAC five wind turbine (5*4.2MW)	77160.9
Net Annual electricity generation	224 GWh

In January the solar radiation is very less so electricity produced from solar energy is very less. Electricity generation complete depend on wind source. Peak electricity production in January is around 48MW. Total electricity produced by solar energy in January around 800MWh. Each wind turbine produces more than 1,000MW in the January alone. The graph 47 below depicts energy production during a week in January.

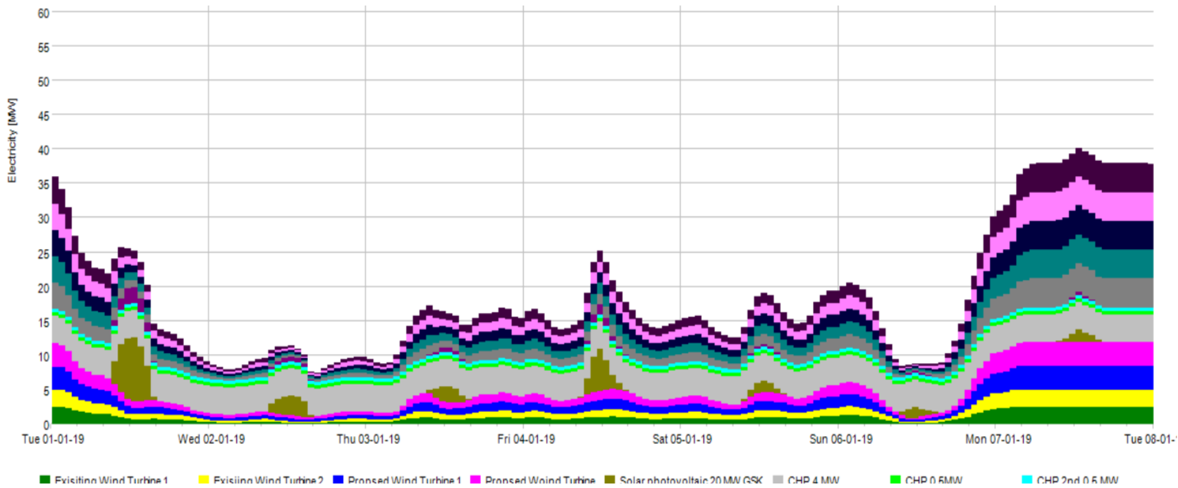


Figure 48 Energy production during a week in january

In July the solar radiation is quite high compared to the January. Also, wind speed is quite fair so quite good amount of electricity is being produced using the wind energy. In July, which is the second highest solar energy production month of the year, approximately 3,655 MW of electricity is produced using solar energy. Each windmill produces from 800 to 1,200 MW depending on its capacity. The graph below figure 48 depicts energy production during a week in July.

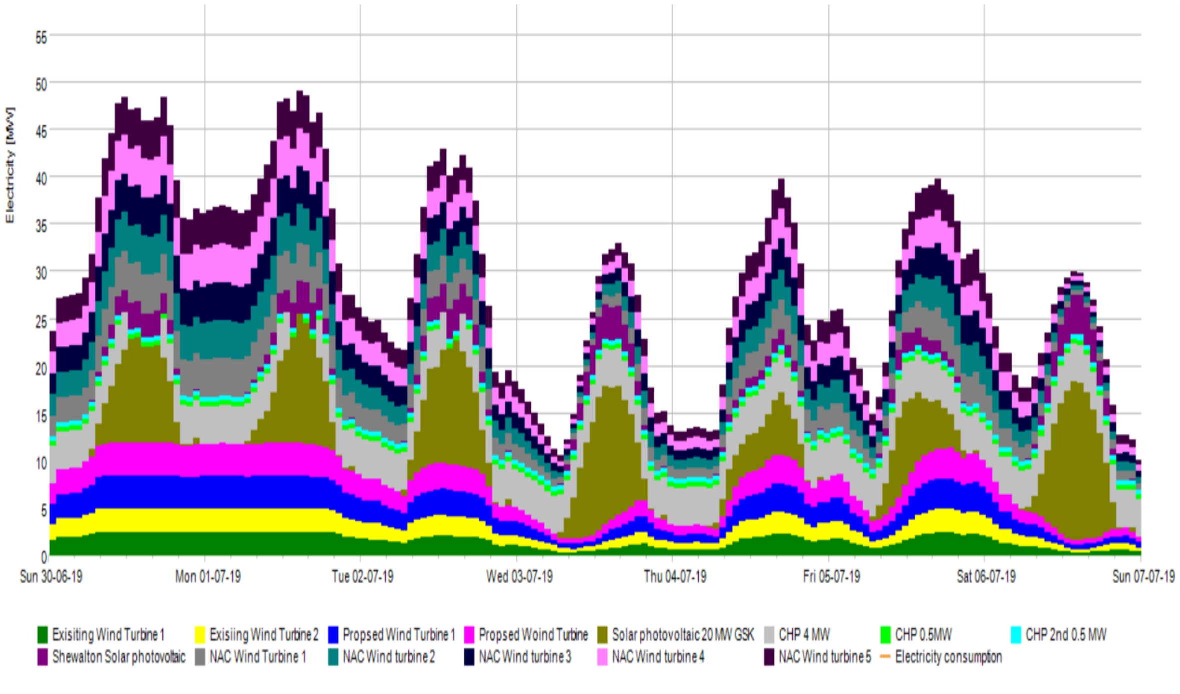


Figure 48 Energy production during a week in January

4.5 Scenario 5: Masterplan to reduce carbon emission in the Industrial site and NAC.

4.5.1 Scenario 5a: Nethermains Only

Nethermains is an old landfill site near Irvine that is being planned to be converted into a solar farm by NAC. This process is done to attain the electrical demand of the NAC. From the result generated using energy PRO can be conclude that is enough to attain the electrical demand of NAC but there are some months where NAC needs to import electricity like December and January due to less solar radiation. Annual energy generated by solar farm is 8,642MWh. The below figure 49 and 50 shows the Energy PRO modelling and annual energy generated by the CHP respectively.

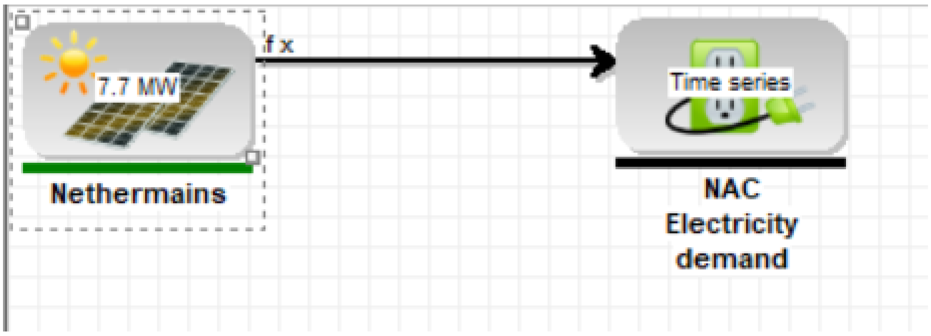


Figure 49 Energy pro model of Nethermains

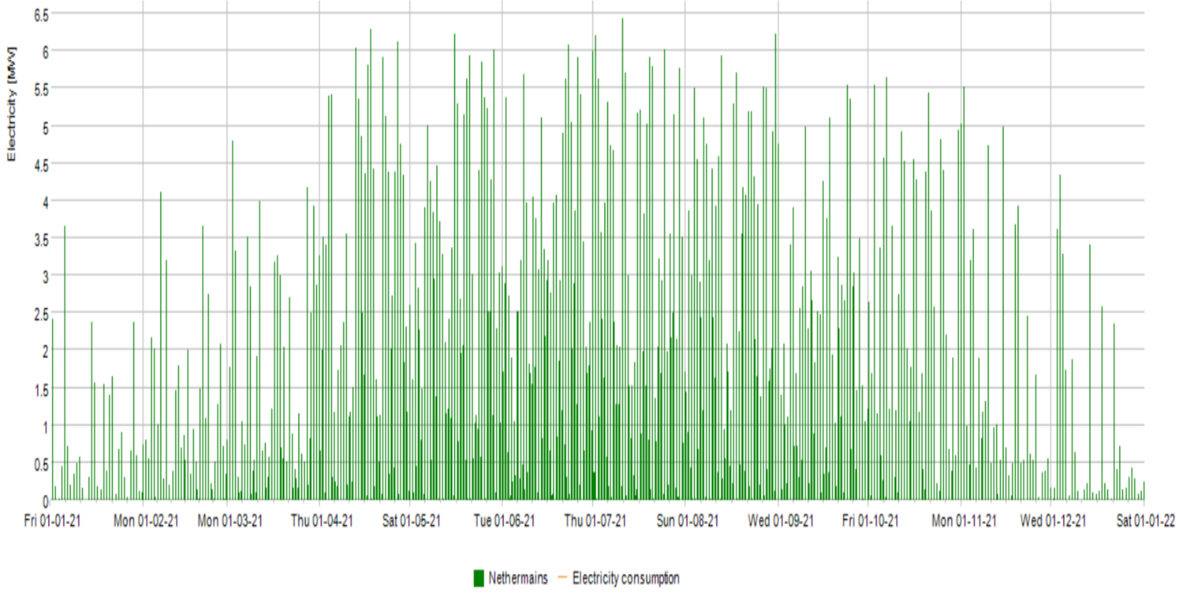


Figure 50 Annual electricity production by scenario 5a

The energy production in June and July is quite high compared to other months. The peak energy produced in July is 6.441MW. Nethermains is enough to cover the electrical demand of NAC in June. The energy produced in December is quite less compared to other months the Electricity produced in December is 188.8MW. Doing this time NAC needs to import electricity from the grid. The below figure 51 A and B shows the energy production of a week in July and January.

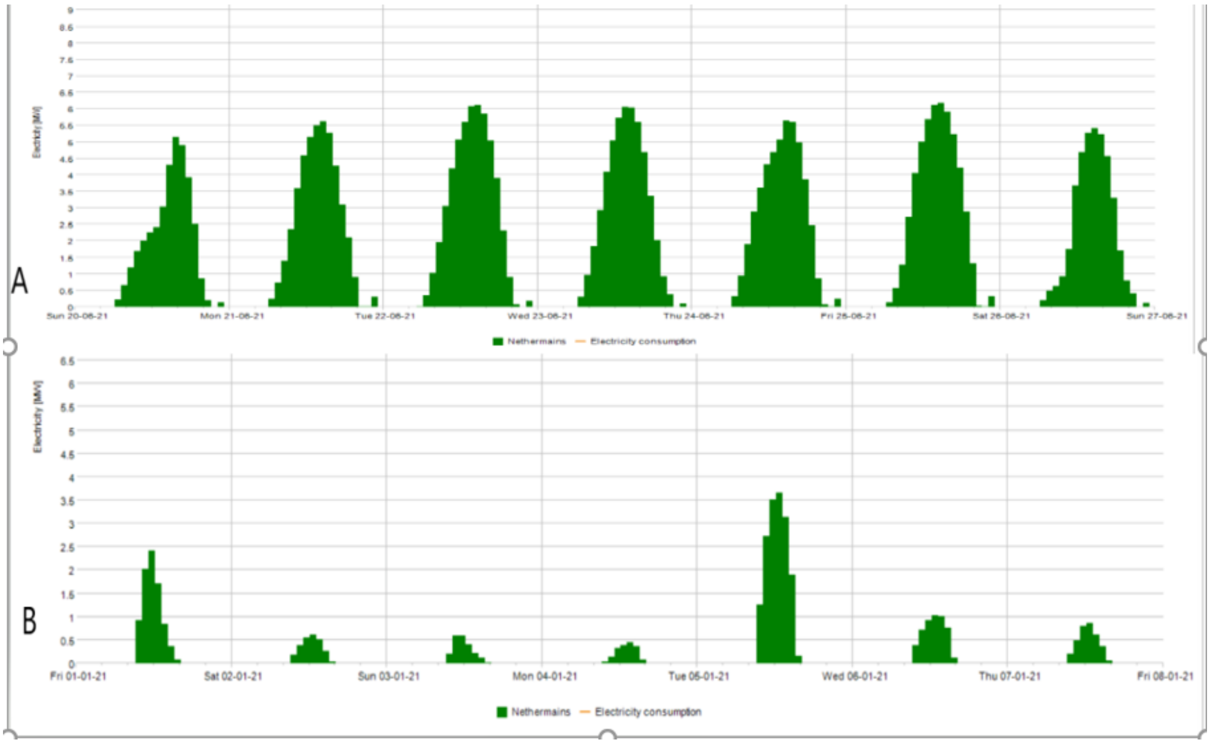


Figure 51A and B Electricity Production during a week in June and Junuvary

4.5.2 Scenario 5b: Meeting the Electrical and Heat Demand of I3

As discussed in section 3.3.2 all the buildings in I3 are assumed to be built in I3 Standard. As per the current plan, the electrical and heat demand of I3 is 777.96MWh and 97.25MWh respectively. When the future growth of I3 is factored in, the demand rises to 8,213.400 and 1,026.675MWh. Planned to install a Green Hydrogen CHP Plant to cover the electrical and heat demand of I3. The Below figure 52 shows the energy pro model of the I3.

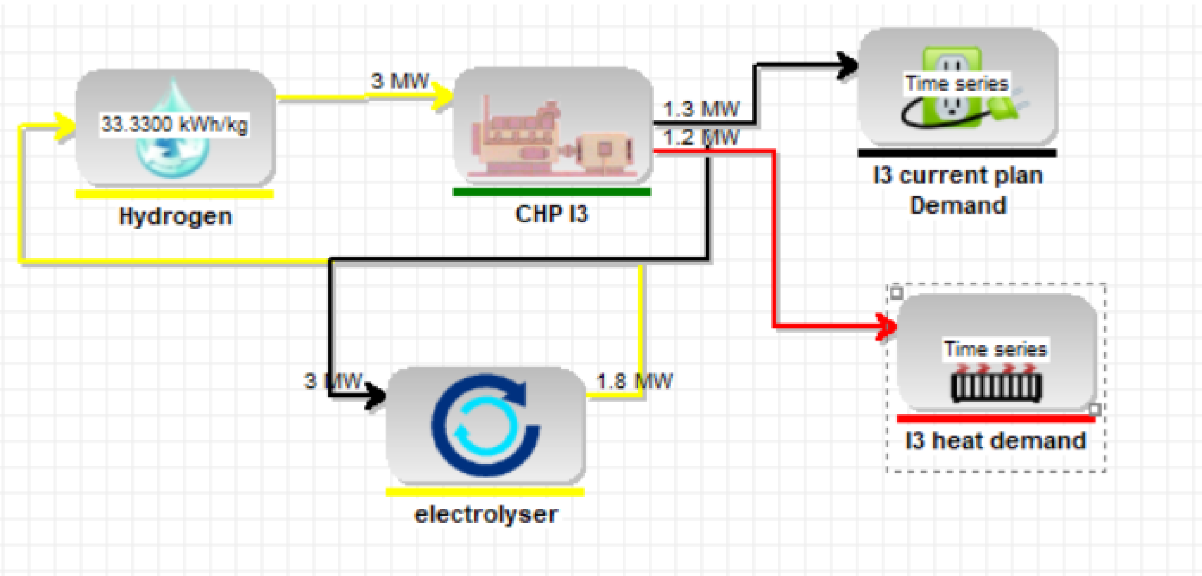


Figure 52 Energy pro model of I3

In this thesis, assume CHP runs in 100% load. The CHP generates 11,388 MWh of total power. CHP generates a total of 10512 MWh of heat. The entire amount of hydrogen required to power the CHP is around 7.8 x 10^5 kg. As per the current plan around 10,000MWh excess hydrogen is being produced 1.5 x 10^5 kg,

4.5.3 Scenario 5c: Masterplan of Combining All the Energy Component

In This scenario, All the energy components of GSK, I3, Shrewton, and NAC are combined. The GSK consist of already existing two windmills which each of 2.5MW power. Also proposed wind turbine of each 3.5MW and 20MW solar PV plant installed to meet the electrical demand of the GSK which is 182GWH as per Mark Dunn thesis. Aside from that, GSK already has three CHP facilities, two of which are 4MW natural gas CHP plants and two of which are 500MW biogas CHP plants. When natural is being bunted it emits around 0.185 kg per kWh. Even though Biogas is considered a renewable source it emits CO2. As per the aim site needed to be changed to a zero-carbon site so is being retrofitted using Hydrogen fuel. NAC planned to convert their two old landfills into a solar farm. The two landfills are Shewthon and Nethermains, the capacity of each landfill is 5.5MW and 7.2MW respectively. Also, NAC planned to install five windmills which each 4.2 MW near I3. To cover the electrical demand of I3 a Green H2 CHP was installed. The excess electricity produced from CHP is used to produce Hydrogen in an electrolyser which is reused as fuel in CHP.

The Heat demand of GSK is covered by existing CHP and three Hydrogen boilers of each 5MW. The efficiency of the boiler is around 90%. Green H2 CHP in I3 meets the I3 heating needs. All the energy components are connected through a private wire from one place to another place. In below picture 53 shows energy pro modelling of all electrical components of the whole site and NAC.

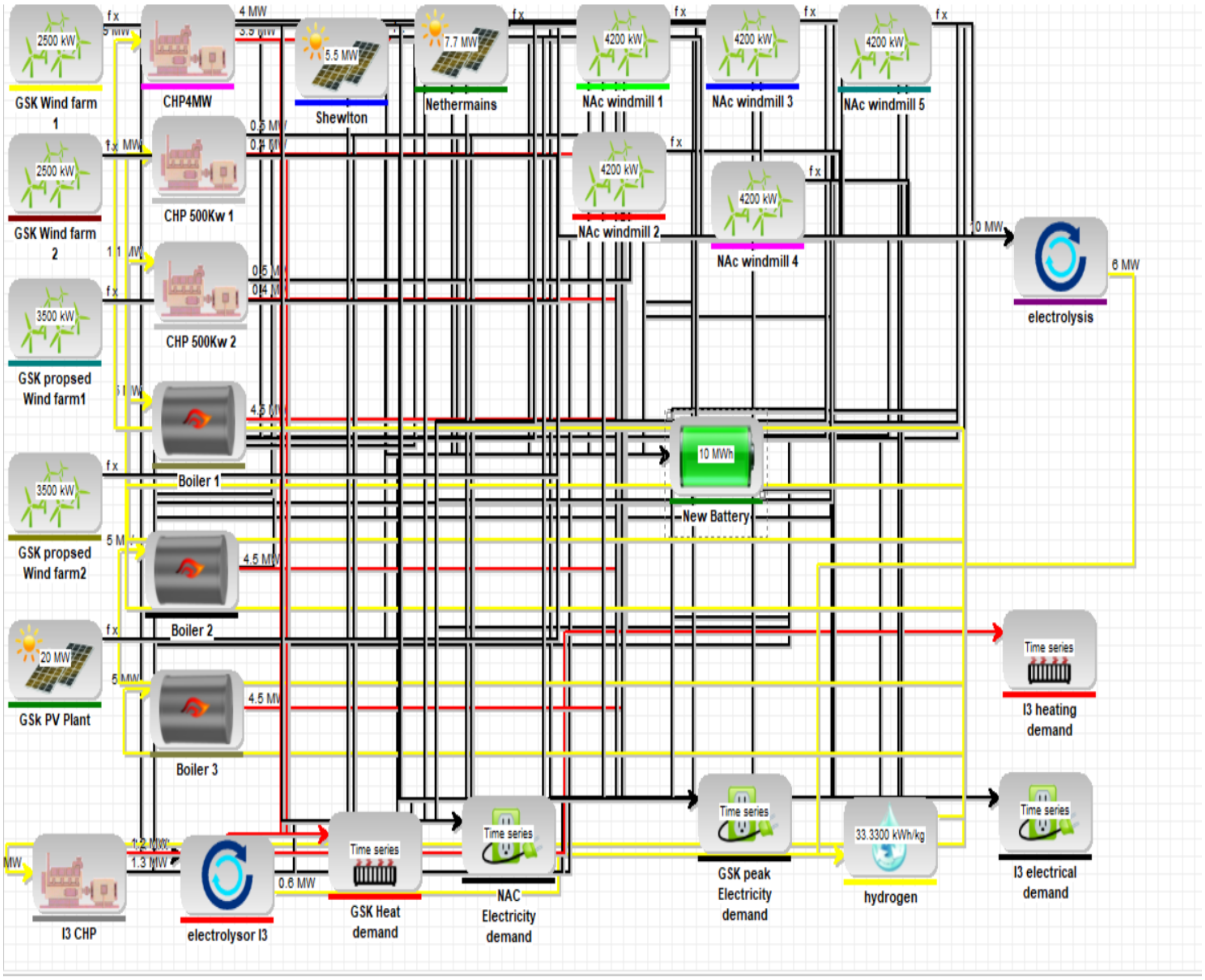


Figure 53 Energy Pro model of Scenario 5c

The total electrical demand of the site and NAC together is 250GWh. The highest amount of power that may be produced is 240GWh. The below figure 54 and 55 shows the maximum amount of electricity that can be produced by all the energy units and the energy produced as per the demand (In energy pro software per the demand production automatically gets regulated) respectively.

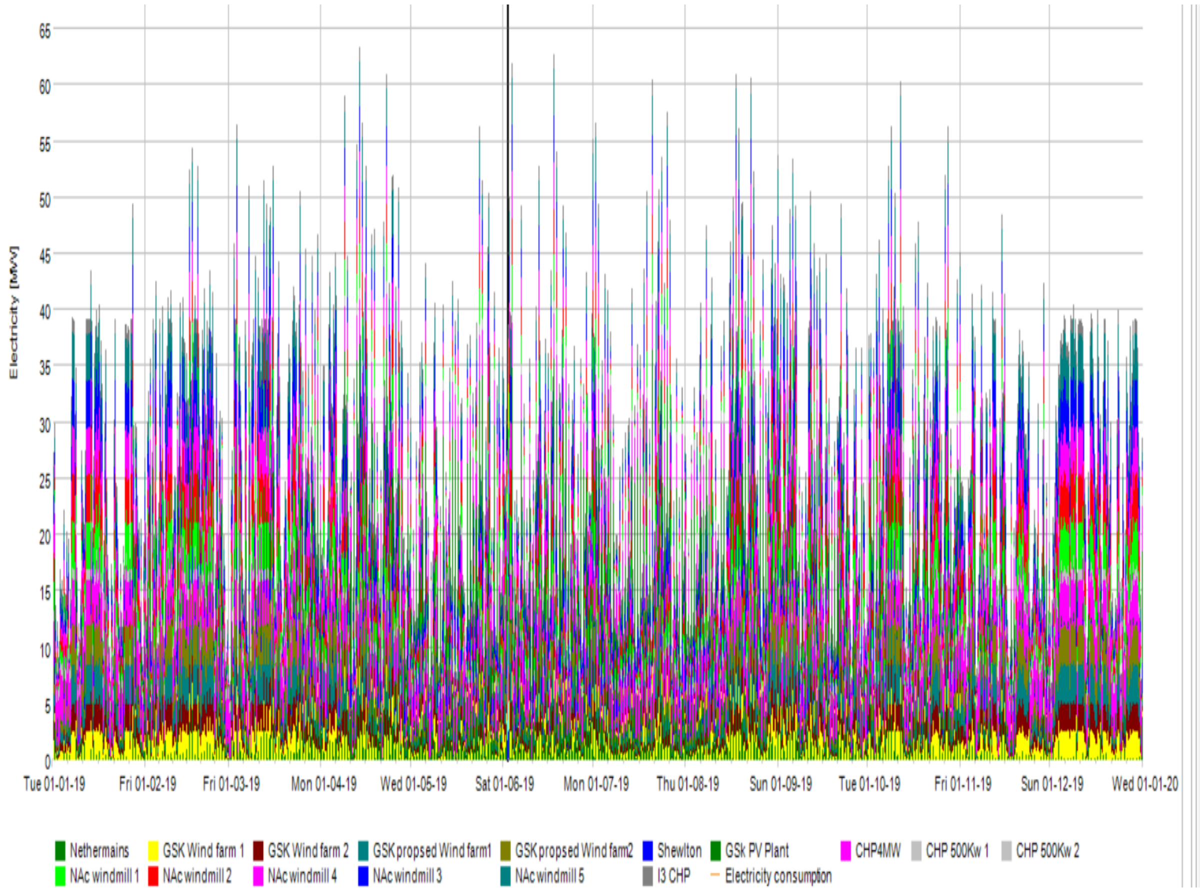


Figure 54 Maximum electricity Production by the Scenario 5c

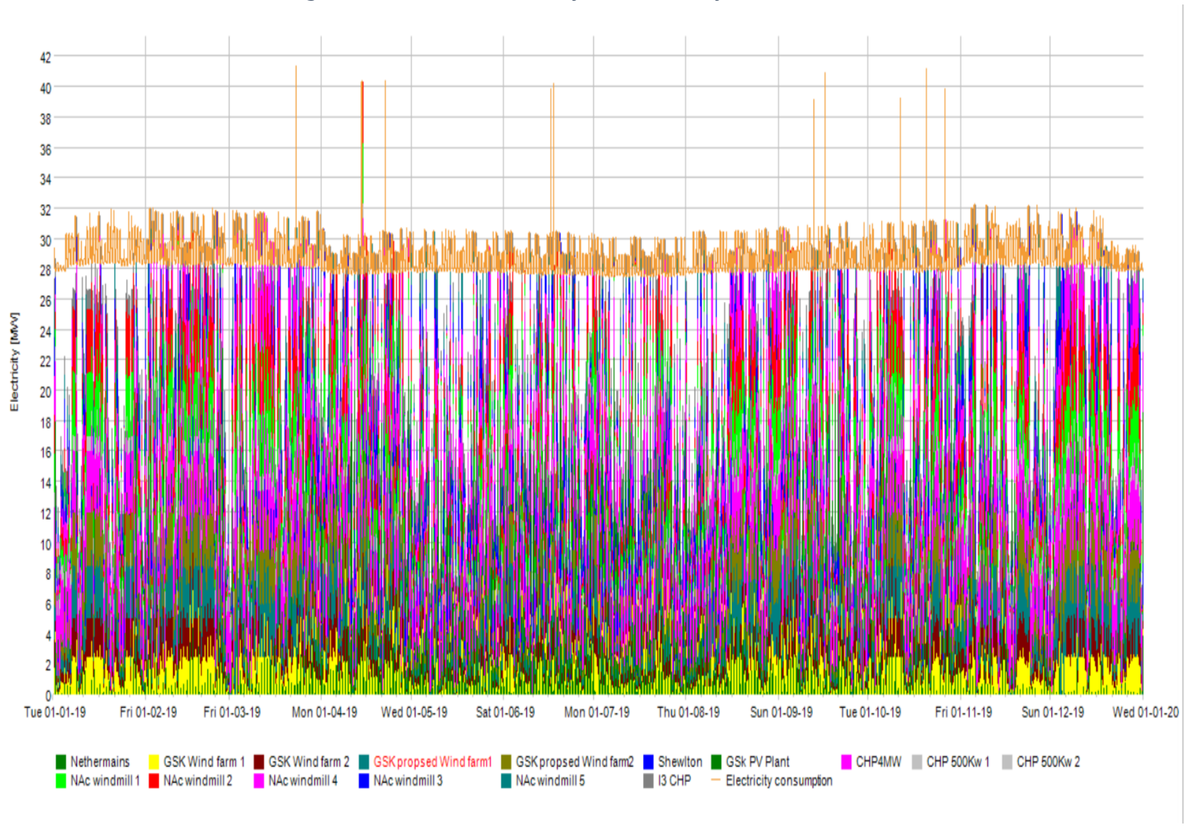


Figure 55 Energy produced as per demand

The most electricity is produced in March, at roughly 22,000 GWh, and the least in November, at around 17,000MWh. The windmill generates 60 percent of the electricity. Because CHP is assumed to run at full capacity, So, energy production varies across months according to wind speed and sun radiation. The graph below 56 depicts the electricity generated by GSK and NAC.

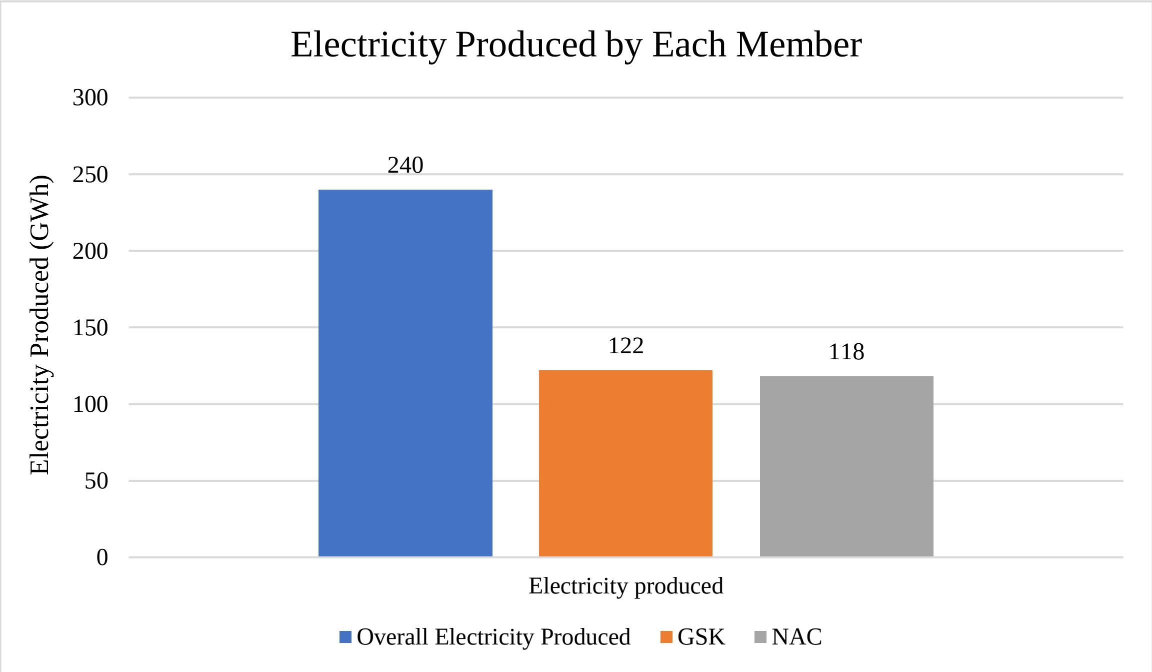


Figure 56 Electricity produced by each organisation

The energy produced in July is around 18,876.4 MWh and In January is around 18,432.4 MWh.As there is no significant variation between the months in terms of overall output, the h ighest amount of energy is produced by wind energy and the lowest amount of energy is prod uced by solar energy, which is approximately 1,080.8MWh when all three solar plants are inc luded. In July maximum electricity is bring produced by solar energy of around 4,891.1MWh. The below figure shows energy production in a week in January and July.

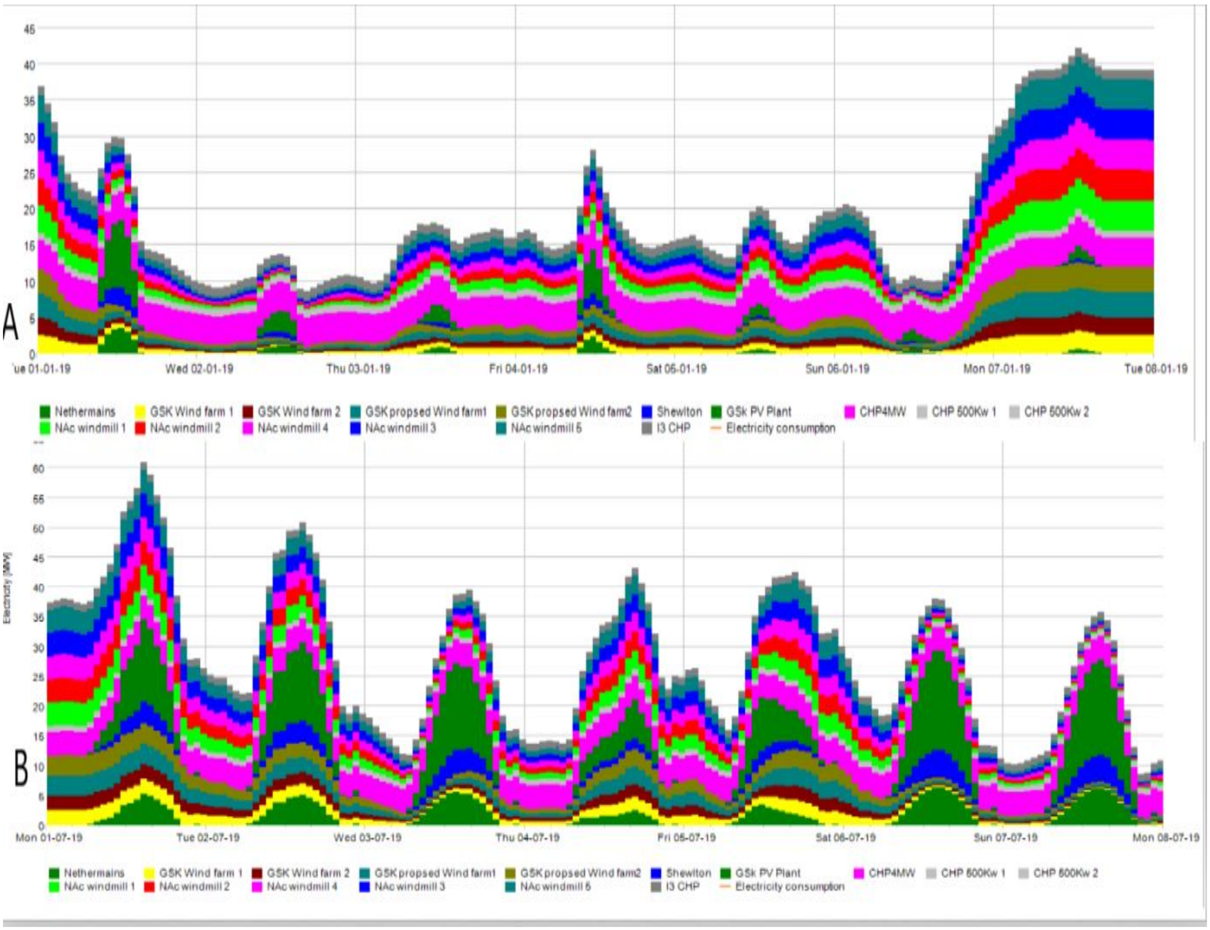


Figure 57 A and B Energy Produced in a week in January and July respectively by Scenario 5c

The annual heating demand of GSK is 162GWh with an average of around 18MWh as per Mark Dunn Thesis. I3 is built as per Passivhaus standard so the maximum heating demand is 97.245MWh for the current plan and after future expansion heating demand changes to 1026.675. Due to lack of data NAC heating demand is not considered in this thesis. In the future, NAC heating demand will be included in this thesis. The below graph (figure 58) shows the heat produced on the site.

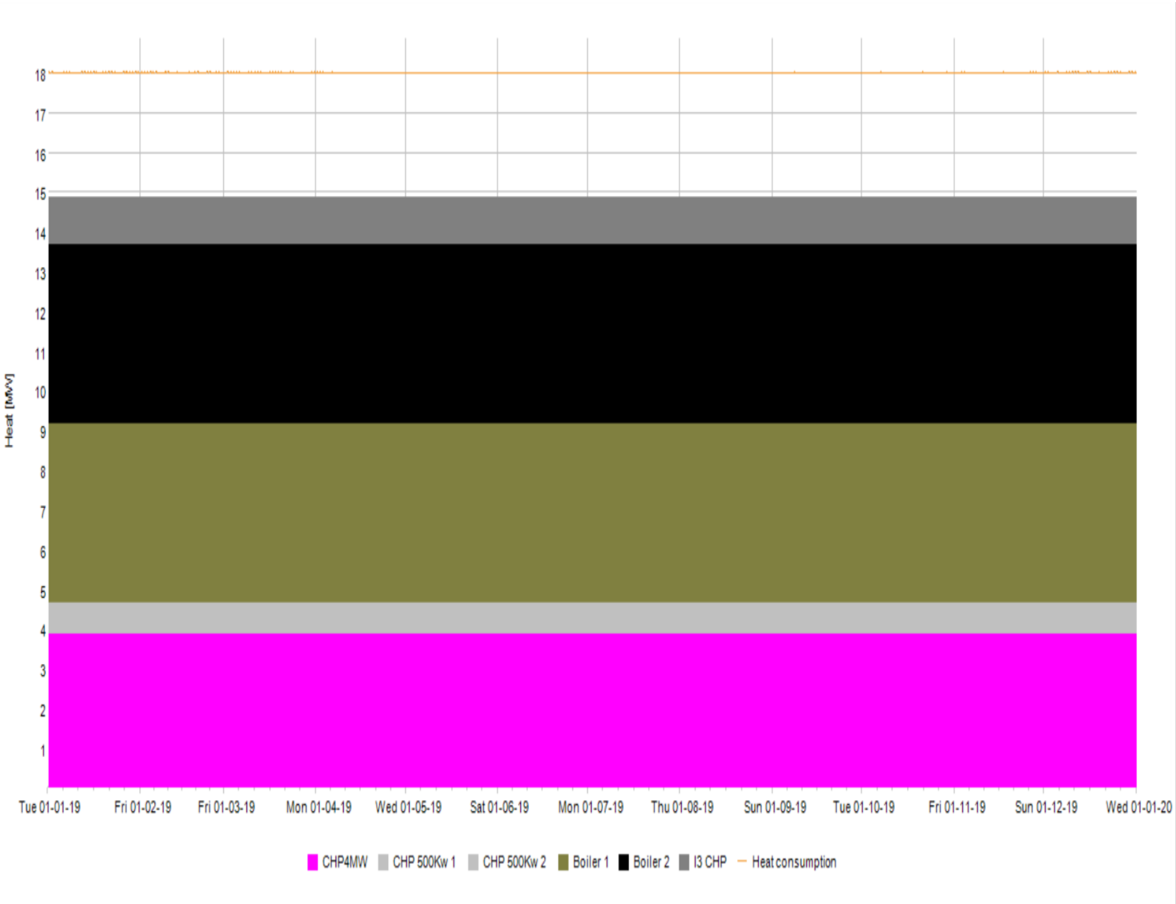


Figure 58Heat produced by the energy components to meet the heating demand

5. Discussion and Future Scope

The aim or main motive of the thesis is to make the industrial site which includes GSK, I3, and Shewalton also NAC is included in the scope to make the whole area a zero-carbon place or at least reduce the carbon emission of the place. This planned to be executed by studying different renewable sources and came up with different scenarios of combining different renewable sources. In the above section, detailed information about different scenarios is being given. The limitations of the thesis are only the average and peak electrical demand of the GSK is known. Because GSK's hourly demand is unknown, the peak demand of 26MWWh of electrical energy and the average heating demand of 18MWh are used in the thesis analysis. Other limitations include the fact that the annual heating demand of NAC is unknown, so only electrical demand is considered in this thesis, and I3 is the upcoming Scotland's largest enterprise area, so what type of industries and offices will be established is unknown, making it impossible to conduct an accurate analysis for I3.

There are mainly two assumptions made in this Theis. As the hourly electrical demand and heating demand of GSK is unknown so assumed that CHP is running 100% load. As what industries going to be installed in I3 is unknown so assumed that all buildings constructed in I3 are constructed in Passivhaus and Breeam standard. The Passivhaus standard is maximum heating demand is 15 kWh/ m^2 per year and primary energy demand which includes heating, hot water and electricity is 120 kwh/m^2 per year.

The total electrical demand is around 250 GWh including both industrial site and NAC. The annual electrical demand of NAC is 22,316 MWh. The annual electricity produced by Nethermains is around 8,000MWh which can cover 35% of the annual electrical demand of the NAC. The total electricity produced is around 240 GWh which is around 10,000 MWh less than the overall demand but considered the peak demand for GSK. During June to August, the demand is quite less so can store the electricity during that time in the battery and can be used when there is a storge of electricity so don’t need to import electricity from the grid. The first water source heat pump is being explored for heating I3 due to its proximity to the Irvine River, but power is required to run the WSHP, necessitating grid importation. So, a Green H2 CHP is placed to meet both the electrical and heat demand of I3. The excess electricity can be used to produce hydrogen by electrolysis which is reused in CHP. All the existing CHP is being retrofitted green H2 CHP so there is no carbon emission in the overall process. The heating demand of GSK is covered by the existing retrofitted CHP and hydrogen boiler of 5MW which has an efficiency of 90%. The GSK produces a large amount of waste heat that waste heat can be used to heat GSK. The excess electricity produced is used to produce Hydrogen by electrolysis for CHP and boiler. Electricity is transported from one place to another place by private wire. A District heating system is placed in the energy system to meet the Heat demand of the site and NAC. According to the goal, renewable sources are employed to meet the electrical and heat demand of CHP, resulting in a reduction in carbon emissions. The only problem faced by the thesis is hydrogen produced by electrolyzing is not enough to meet the fuel demand of the site. So, hydrogen needs to import from gird or other places through a private wire. The oxygen produced from CHP can be sold to medical industries which additional income for NAC.

The project's future objective is to produce an accurate study for I3 after learning which industries and offices would be in I3. In this thesis, another assumption is made that CHP runs in full load but in the future after knowing the hourly demand of GSK then CHP can be regulated as per the demand. There are numerous research is going on to increase the efficiency of the electrolyzer. So, In the future highly efficient electrolyzer could be implemented on the site. Undoubtedly, the world is moving towards electrical vesicles. A company like TESLA who are investing and coming with innovative technologies to more in electrical vehicles. So, in the future planned to set up an electrical charging point near I3.

6.Conclusion

The conclusion of the thesis is by using renewable sources the electrical demand and heating demand of the industrial site and NAC can be met but there are some days were demand unable to be met so needed to be imported from the gird or additional windmills can be installed near Old hall ponds, Irvine to meet the electrical demand. Retrofitted CHP and boilers meet GSK's heat demand.

As many kinds of research are taking place on electrolyzer, a highly effective electrolyzer could perhaps be installed at the site in the future. At present to cover the hydrogen demand is could be done by only importing the excess electricity required for electrolysis from the gird. Otherwise, Hydrogen needed to be transported from the source to the site through Turks. However, Turks have numerous disadvantages like insufficient design, whether it can meet the required Hydrogen demand.

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