University of Twente

Mechanical Engineering

Project Design of an Energy System Green Lanzhou

Group 22

Autors:

Rick Pluimers	s1916246
Ties Loohuis	s2184486
Dennis de Heus	s2180715
Miguel Cacarin Cumbal	s2074311
Sacha Chernyavskii	s2068311
Atilhan Deveci	s2004658
Rik Kok	s2136198
Selim Abdelbakey	s2035537

Tutor:
Iqbal Abdulrasheed

4th of April, 2019

Summary

The aim of this project is to design a new sustainable energy system for the city of Lanzhou. This energy system must replace the existing coal power plant, because it is outdated and very polluting. The new energy system must provide enough electricity throughout the entire year. Moreover, the new energy system also has to provide heat for the Lanzhou district heating system.

In order to design the new energy system, several aspects must be considered such as social, ethical and environmental aspects. Furthermore, research on material selection and efficiencies had to be done. With this information, three concepts are designed. Every concept is based on one of the following renewable energies: geothermal energy, hydroelectricity, wind power and biomass. These concepts are then compared with each other to choose the best concept. From the best concept a detailed design has been made. The parts of the power plant have been analyzed to be able to select the materials that are most applicable in certain conditions. Finally, an analysis of life Cycle Analysis have been included.

Project Group 22

Students Bachelor Mechanical Engineering at the University of Twente.

Contents

1 Introduction

Lanzhou is a city in China which is known as a very polluted city. In order to reduce pollution, the local utilities company is taking a huge step to build a new sustainable energy system. Lanzhou is located near a desert, where a lot of sun energy is available. This makes a concentrated solar power plant a potential alternative energy system. The utilities company thrives for an eco-friendly energy system. The new energy system should also deliver the local district heating system with heat. Hence, the goal of this project is to design a new energy system, which can provide enough electricity during the whole year and which also can deliver heat. To do this, a concentrated solar power plant must be used as the basis.

This report is made for the Lanzhou utilities company and the staff members of the University of Twente who set up the project assignment for Module 3 in the Bachelor Program of Mechanical Engineering. The objective of this report is to provide a solution to the following assignment: ''Design a sustainable energy system, based on concentrated solar power and biomass, that provides Lanzhou with electricity and heat during the whole year. Compare the new installation with the current situation at Lanzhou and give advice on the suitability of your design"

This report is divided in separate chapters which are linked together. In the first chapter, there is a detailed thermodynamic analysis. The aim of this thermodynamic analysis is to have an insight which concept is thermodynamically seen the best. Three concepts will be discussed, and the best concept will be chosen as the final concept. Also, there is a detailed explanation on our final concept. The next chapter describes a detailed analysis of the materials that should be chosen, and the steps taken to reach the final material for each part of the power plant and in this analysis five critical components are taken into consideration and described in detail. The final chapter is about the life cycle assessment of the current Lanzhou coal power plant and our final concept, which then are compared to each other.

2 Thermodynamic design of a new power station in Lanzhou

To fulfill the demand of Lanzhou energy and heat supply, three concepts has been made. In this part, the concepts will be presented and the best concept will be selected. That best concept will be improvement to create a final concept.

2.1 Problem definition

The current power plant of Lanzhou should be replaced. The new power plant has to deliver sufficient power to the city Lanzhou. This is 220 MW during the entire year. Probably, there will be a small fluctuation in the demand of power because during the night, less energy is required. Next to the power, the power plant needs to deliver heat in the form of steam. During wintertime, this has to be 130MW at a temperature of 120 degrees Celsius at 14 bar. In the summer, this requirement is 65 MW of heat in the form of steam. The steam will come back at 90 degrees at 4 bar. All of this energy has to be produced in an environmentally friendly way.(1)

2.2 Estimates

Crescent Dunes power plant
Collector area: 1.2 km^2
Site: 6.76 km^2
Power production: 110MW
Estimates for Lanzhou
Collector area: 2.4 km^2
Site area: 13,52 km^2
Power Production: 220MW
Old power plant location: 143 Jiayuguan Road, Chengguan (2)
Population: 3,616,163 (3)

2.3 Location of he new power plant

The size of the new energy plant would be twice as large as the Crescent Dunes power plant. There is currently not enough space available for a power plant this big, but there are two options available for the location of the power plant.

- The first option is shown *Satellite image option one* in Figure 1 This is an area just north-east of Lanzhou. It is a wide open space surrounded by hills. The area of this location is 3,5 km^2, so a total area of 10 km^2 of hills should be removed. This would cost a lot of money.

- The second option is the farming district just north of the Lanzhou airport and can be seen in figure 2. Because this area is a farming district, it is relatively flat. This means that not a lot of terrain adjustion has to be done.

One of the downsides of this location is that a lot of farming land has to be removed. This land will have to be bought off with money, because it's probably privately owned by the farmers.

Another downside of this location is the airport. If a concentrated solar power plant would be built there, the airplanes and pilots could potentially be hindered by the massive brightness of all the mirrors there. However it probably should be not a big problem, as long as the flight routes are altered in a manner that the pilots are not hindered by the mirrors.
In the end, the second option is chosen to be the location of the power plant, since this location is easier to transform into a power plant.

Figure 1: In the top right corner, the possible location of the new power plant.

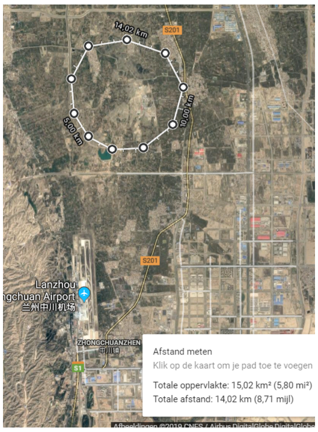

Figure 2: Satelitlie image of the second possible location

2.4 Concepts

There are different sustainable options for energy. The most common ones are listed below:

- Solar energy
- Wind power
- Hydroelectric energy
- Hydrogen and fuel cells
- Geothermal power

2.5 Biomass concept

The first concept we came up with is one with biomass and solar energy. Below the flowchart of the concept with biomass and solar energy can be seen.

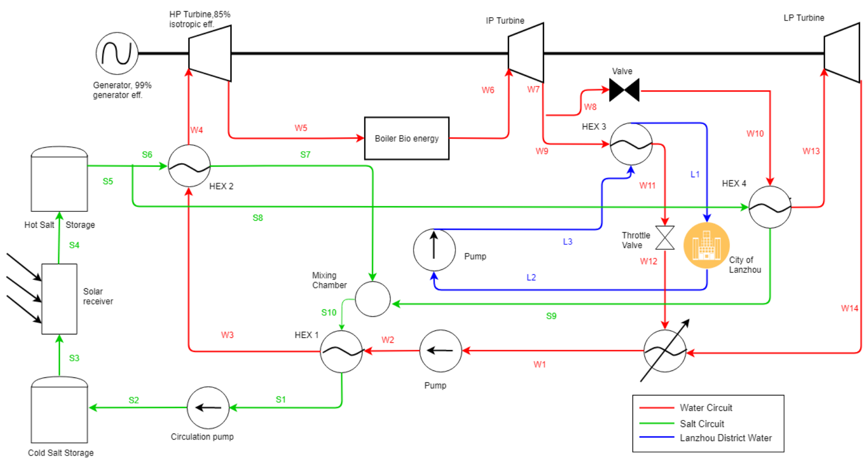

Figure 3: Flow chart of concept with biomass.

The heat which is needed to heat up the water which goes to Lanzhou, is provided with a part of the outcome of the heat from the Intermediate Turbine (IP). The water will be heated from 90 to 120 degrees Celsius. The water (W11) that comes out of HEX 3 is in the ideal situation a saturated liquid, this means that it will cost to much energy to heat this again to 520 degrees Celsius. Thus is decided to use a throttle valve to reduce the pressure of the water. After the throttle valve the water comes out in the condenser.

The valve between W8 and W10 is used because in the summer there is less heat needed in Lanzhou, so with this valve the amount of mass flow to W9 and W8 can be adjusted. This is a regular valve, so it does not have any influence on certain thermodynamic properties.

Further, the plant should provide at least 220 MW of energy, therefore it is decided to use 3 turbines, a High Pressure (HP) turbine, a Intermediate Turbine (IP) and a Low Pressure (LP) turbine. Between the HP and IP the water is heated up with the burning of Biomass. In Heat Exchanger (HEX) 4 the water is again heated up to 520 degrees Celsius but now heat of the salt is used. The water enters the LP with a pressure of 3 bar and a temperature of 520 degrees Celsius. The outcome of the LP is a superheated vapor which is directed to a condenser, where the whole process is repeated again.

2.5.1 Calculations of massflow in the winter

The mass flows needed to supply Lanzhou with heat were calculated as in the following way:

$$130MW = Cpw * Mcity(Tout - Tin) \quad (1)$$

$$130MW = 4.2433 * Mcity * 30 \quad (2)$$

$$Mcity = 10210.2kg/s \quad (3)$$

$$130MW = MwaterW9 * (h9 - h11) \quad (4)$$

$$130MW = Mwater9 * (2751.2 - 561.5) \quad (5)$$

$$MwaterW9 = 59.63kg/s \quad (6)$$

Mcity is the mass flow in the Lanzhou cycle for the summer. MwaterW9 is the mass flow in flow W9, W11 and W12. The other mass flows in our system are calculated as follows:

$$Wnet = m4(h4-h5)+m4(h6-h7)+(m4-m9)(h13-h14)-mWaterW4(h2-h1) \quad (7)$$

$$220\,MW = MwaterW4 * 205.7 + MwaterW4 * 871.9 + ... \quad (8)$$

$$+(MwaterW4 - 59.7) * 736.6 - MwaterW4 * 22.36 = 220\,MW \quad (9)$$

$$MwaterW4 = 165\,kg/s \quad (10)$$

The main mass flow is now 165 kg/s. This is a little over twice as large as the mass flow of the Crescent Dunes power plant. This results in a salt mass flow of 1345.1 kg/s. This is around 93% larger than Crescent Dunes. This means the area of all the mirrors and collector should be 93% larger as well.
During the winter the output of the power plant is 220 MW. These calculations above are the mass flows for in the winter, in the summer there are different mass flows because of the valve. The mass flows for in the summer are calculated in the same way, the main mass flow remains the same but m8 and m9 are different.

$$MwaterW8 = 135.30\,kg/s \quad (11)$$

$$MwaterW9 = 29.68\,kg/s \quad (12)$$

$$Mwater4 = 165\,kg/s \quad (13)$$

Because the mass m9 decreases and m8 increases, the LP Turbine will produce more output. This results in the following a net output of 245.29 MW during the summer. This extra electricity could maybe be stored in batteries, so when there is demand for more electricity then the 220 MW it can be delivered by use of the batteries.

For the biomass boiler an efficiency of 80% was assumed (the calculations made in equation 13,14,15,16 and 17 where made at an earlier stage of the project, the real values can be found in the final design).The amount of biomass burned in the biomass burner is equal to:

$$Qin, bio = m4(h6 - h5) \quad (14)$$

$$Qin, bio = 56694kJ/s \quad (15)$$

$$\frac{EnergyDensity}{Density} = \text{Energy per kg} \tag{16}$$

$$\frac{(4.7GJ/m3)}{(255kgm/m3} = 18.431MJ/kg \tag{17}$$

$$\frac{\frac{(56.7MJ/s}{18.431MJ/kg)}}{0.80} = 3.85kg/s\,[AppendixB] \tag{18}$$

This means that every second 3.85 kg off biomass is burned in the power plant.

2.5.2 Strengths and weaknesses

The main strength of this concept is that it's very easy to adjust the amount of heat that goes to Lanzhou. This is done by simply opening the valve between point 8 and point 10.

The weakness of this concept is that in the summer the mass flow in point 9 is decreased. This means that in W8, W12, W13 and W14 the mass flow is increased. This results in a higher output of the Low Pressure Turbine. This means that in the summer there is a 22 MW electricity surplus. This electricity however, can be used to power other things or charge batteries to keep the electricity stored.

2.5.3 Materials selection

For the materials selection part, almost nothing lot has changed, since mostly the same temperatures and pressures were used as in module 2. The only thing is that the mass flow has increased with a factor of 2. This means that all the pipes and components should be bigger as well.

2.5.4 Environmental impact

The environmental impact of this power plant is probably not a lot, since during the use of the power plant a theoretical amount of 0 kg CO2 is emitted, because biomass turns the CO2 back into O2 during its lifetime. However, a lot of expensive and rare metals are used, so the environmental impact will have to be analyzed in more detail during the Life Cycle Analysis.

2.5.5 Stakeholder consideration

The main aspects of the stakeholder consideration in this concept are one: The total area this concept would occupy. It is twice as large as the power plant in Crescent Dunes and if this power plant is built on farmland a lot of local farmers will probably not agree with that. Second, this design uses a lot of mirrors, so some flight paths may need to be altered in order for a safe flight, since the mirrors could distract pilots. So a possible stakeholder would be the aviation industry in the area. Finally, this design would cost a lot of money. This is why the government is a large stakeholder as well, because they will have to subsidize the building of the power plant.

2.6 Concept of wind and hydroelectric power

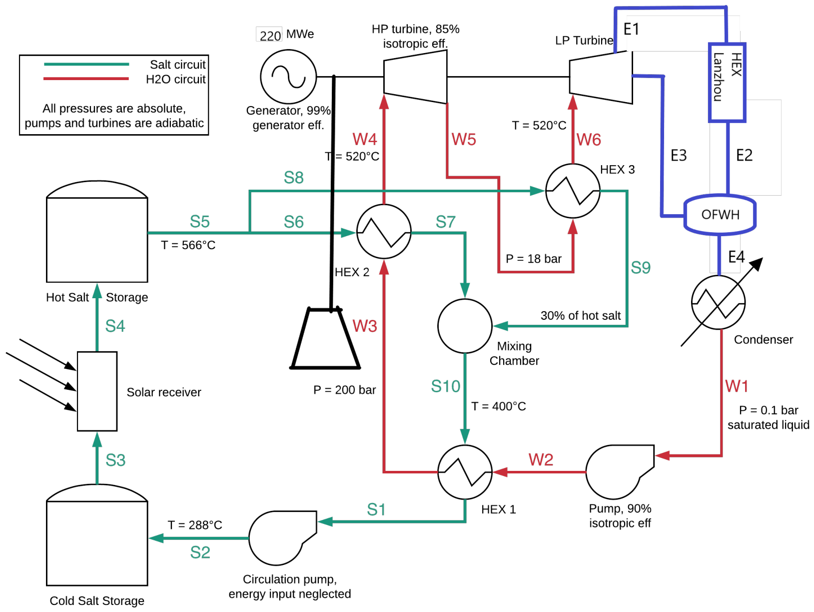

Figure 4: Flow chart of concept with biomass.

The basis of this concept is the power plant in Crescent Dunes. The surface area of the mirrors is increased by one and a half and so is the mass flows but the temperatures will stay the same. To provide the city with heat, there is water-steam tapped off the power plant and used in a heat exchanger. The water is tapped off by the High-pressure turbine at 1 bar, the temperature is around 241 degrees Celsius. After the heat exchanger, the mass flow is mixed in open feed water heater with a mass flow with 0.1 bar which also comes out of the turbine.

There needs to be 130 MW of heat conducted in the heat exchanger for Lanzhou in the winter. Water at an pressure of 14 bar and with 120 degrees Celsius has an enthalpy of 504.63 KJ/Kg (XSteam). With this knowledge it is possible to calculate the mass flow. Following the calculations stated in the appendix, the mass flow which goes to the city has a Temperature of 120 degrees and a pressure of 14 bars and a mass flow rate of 1020 kg/s in the winter. In the summer this is 510 kg/s. The massflow of E3 is 66.8 kg/s. Those water flows come together in the mixing chamber, afterwards they are condensed.
The energy state of heat after the condenser is lower than in the Crescent Dunes one. Therefore needs to be more energy exceeds in HEX 1 to get W3 on the same temperature. This has the result that the temperature of the cold storage is lower so the needs to be more energy given to the salt in the solar receiver so the area of mirrors need to be somewhat increased. The estimated power loss is 28 MW.
By the result of the rough calculations which where above made, the conclusion is that there is a loose of 28 MW. Now the turbines produce will produce 137

MW so there is 83 MW more work necessary. The lack of power could be solved in two different ways. The first option is wind power, the second option is hydraulic power.

2.6.1 Wind power

According to the calculations made before, loss of energy is released by the turbine and it is delivery to Lanzhou to warm it, the lack of energy could be compensated by wind turbines, which help with the lack of energy required to complete the 220 MW also Gansu province to which Lanzhou belong has the biggest wind farm in the whole world.(4) The area close to Lanzhou has a mean wind power density of 330 W/m2, It indicates how much energy is available at the site for conversion by a wind turbine. the average speed is 5.5 to 6,4 m/s.

It means that the area can place wind turbines, however, the production of energy depends on the climate conditions, furthermore, implement wind turbines will mean less money and no destruction of the environment are the main benefits , nevertheless, the main drawback is the efficiency of the whole system is minimal compared with other ways to generate energy , A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor, this is known as the Betz Limit or Betz' Law. The theoretical maximum power efficiency of any design of wind turbine is 0.59 (5) This is called the "power coefficient" and is defined as:

$$C * p = 0.59 \tag{19}$$

The wind energy is describe as the kinetic energy because It is strongly related to wind speed also the power coefficient have to add to guarantee the maximal efficiency get to the wind turbines which can describe as :

$$E = Cp\frac{1}{2}At\rho v^3 \tag{20}$$

$$P = Cp\frac{1}{2}A\rho v^3 \tag{21}$$

where is the density of air, v is the wind speed; Avt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); Avt is, therefore, the mass m passing through "A". The amount of energy produced by one wind turbine is calculated with the formula above(6) . assuming a constant wind speed of 5 m/s , An area of 40114.99 m2 (Using 113 m as rotor length)(7) ;in order to find the air density we used the values given and found this relation :

$$Wind\,power\,density = \frac{1}{2} * \text{air density} * \text{wind speed}^3 \tag{22}$$

$$\rho = \frac{(2 * \text{Wind power density}}{/\text{wind speed}^3} \tag{23}$$

$$\rho = \frac{(2 * 330W/m^2)}{5.8^3} = 3.38\,kg/m^3 \tag{24}$$

The output power with the assumptions which are mades:

$$P = Cp\frac{1}{2}A\rho v^3 \tag{25}$$

$$P = 0.59 * \frac{1}{2} * 40114.99m^2 * 3.38kg/m^3 * 5.8m/s \tag{26}$$

$$P = 7.8MW \tag{27}$$

The power of 7,8 MW was obtained assuming the best possible efficiency (power coefficient) ,however , turbines cannot operate at this maximum limit. The Cp value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular - the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines.

The output power will rise if the length of the Blades increase , however , The length was taken from the actual wind turbines uses in the real projects, The solar power plant needs as minimum 11 wind turbines to reach the desirable work output.

Strength and weaknesses The main strength of this concept is that it's very easy to adjust the amount of heat that goes to Lanzhou. This is done by simply opening the valve between point 8 and point 10.

The weakness of this concept is that in the summer the mass flow in point 9 is decreased. This means that in point 8, 12,13 and 14 the mass flow is increased. This results in a higher output of the Low Pressure Turbine. This means that in the summer there is a 22 MW electricity surplus. This electricity however, can be used to power other things or charge batteries to keep the electricity stored.

Material science For the material science part not a lot has changed, since mostly the same temperatures and pressures were used as in module 2. The only thing is that the mass flow has increased with a factor of 2. This means that all the pipes and components should be bigger as well.

Environmental impact The environmental impact of this power plant is probably not a lot, since during the use of the power plant a theoretical amount of 0 kg CO2 is emitted,because the use of wind power doesn't emit any polluted gas to the environmental and during the possible production of wind turbines a small portion of the land will use to locate it.

Stakeholder consideration The main aspects of the stakeholder consideration in this concept are one: The total area this concept would occupy. It is twice as large as the power plant in Crescent Dunes and if this power plant is built on farmland a lot of local farmers will probably not agree with that. Second, this design uses a lot of mirrors, so some flight paths may need to be altered in order for a safe flight, since the mirrors could distract pilots. So a possible stakeholder would be the aviation industry in the area.later, this design would cost a lot of money. This is why the government is a large stakeholder as well, because they will have to subsidize the building of the power plant. finally located the wind turbines required a specific land , some fields will be affected , destroyed in order to locate those machines.

2.6.2 Hydroelectric power

The basis of this concept is combining the salt circuit from the Crescent Dunes power plant with hydroelectric power. In the salt circuit the water flow which heat the city is warmed and raised in pressure. Still this part of the power plant produces 137 MW. For Lanzhou is 220 MW necessary so. The rest could be received from hydroelectric power.
If the hydroelectric power plant has an efficiency of 90% (8) there needs to be:

$$\frac{\text{power needed}}{efficiency} = \frac{83}{0.9} = 92.2MW \tag{28}$$

The power output could be calculated with:

$$Massa * Gravitatie * height = \text{output} \tag{29}$$

The mass flow of the river is 2110 cubic meters per seconds. (9)

$$2110 * 1000 * 9,81 * high = 20.7\,MW * hight = 92.2\,MW \tag{30}$$

$$Hight = \frac{92.2}{20}.7 = 4.5\,meter \tag{31}$$

There needs to be a drop of 4.5 meters to make sure that enough work can be produced.

Strength and weaknesses Hydroelectric power is a form of sustainable energy. The drawback of hydroelectric power is the big investment that it take. Furthermore, there has to be a good place in the environment for to place a hydroelectric installation.

Material science The dam has to be strong but the weight of it has no influence. Furthermore needs the dam to be resistant to corrosion. The material has to be resistant to erosion, since there will flow a lot of water through the dam. A material which fulfill this requirements is concrete.

Environmental impact The hydroelectric installation will influence the waterflow. When the river changes in speed and in size, this could have an impact on the flora and the fauna.

Stakeholder consideration Building a dam means that there are no possibilities anymore for boots to cross that part of the river. This will decrease the amount of possibilities of transport and can influence the cost of transport. The industry will not be pleasant with this change.

2.7 Concept geothermal power

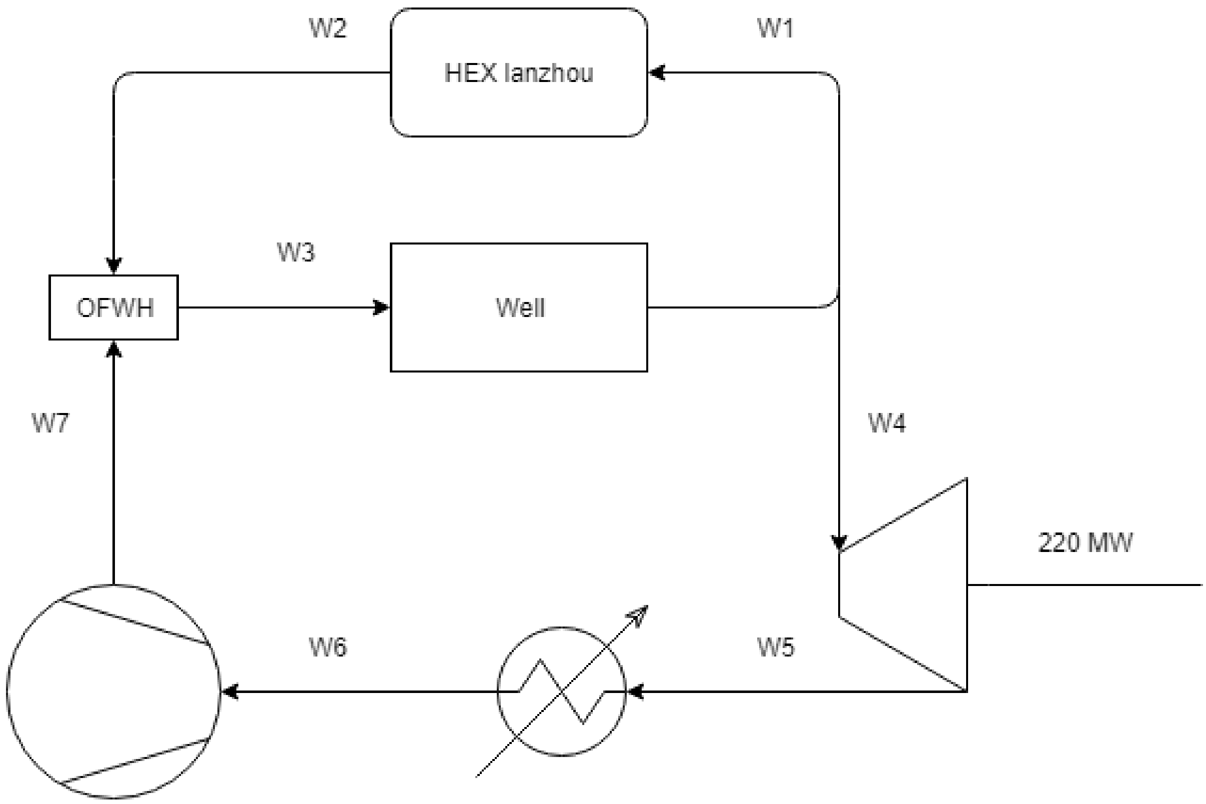

Figure 5: Flow chart of geothermal energy

In the center of the earth is a lot of energy in the form of heat. For Lanzhou, the maximum temperature which can be reached is 120 degrees Celsius. This heat can be used for the heating process of Lanzhou and to get work output from turbines to receive 222 MW.

There are two mass flows in the flowchart. One flow is used in a heat exchanger to heat up the mass flow for Lanzhou. The other mass flow is used to create work in a turbine. In the highest part of the flowchart is the heat exchange process. The inlet W1 has a temperature of 120 degrees and 20 bars. Flow W2 is the outlet of the heat exchanger. When the W2 has a temperature of 95 degrees Celsius and there is no pressure drop, the mass flow of W1 and W2 is 1231 kg/s.

There is 130 MW heat necessary. The enthalpy of W1 is 504 kJ/kg and from W2 is it 399 kJ/kg.

$$\text{mass flow} = \frac{\text{power for lanzhou}}{\text{enthalpy difference}} = \frac{130MW}{504 - 399kJ/kg} = 1231\,kg/s \tag{32}$$

The turbine is in the lower part of the flowchart. The enthalpy of the W4 is the same as W1 and is 504 kJ/kg. The pressure of W5 is 0.1 bar and W5 has an enthalpy of 500 kJ/kg. The turbine has to deliver 222.2 MW when the generator has an efficiency of 99%.

$$\text{necessary work} = \frac{\text{needed electricity}}{\text{efficiency}} \tag{33}$$

$$\text{necessary work} = \frac{220MW}{0.99} = 222.2MW \tag{34}$$

There needs to be a mass flow of 6628.5 kg/s.

$$\text{mass flow} = \frac{\text{power output}}{\text{enthalpy difference}} = \frac{222.2}{504 - 471kJ/kg} = 6628.5kg/s \tag{35}$$

All of this in the ideal case when there is a isotropic efficiency of 100%. The total mass flow will be:

$$\text{total mass flow} = \text{mass flow 1} + \text{mass flow 2} \tag{36}$$

$$1231 + 6628.5 = 7859.4kg/s \tag{37}$$

This is not possible to pump more almost 7860 kg every second through the pipes and therefore is this concept rejected.

2.8 Final choice

After analyzing the power plant from all aspects the concept that fits the most is the concept with the biomass as it is the most simple concept and without any harm to the environment as the other concepts will have impacts on the environment for example the hydro-concept requires a dam with big dimensions and for the wind-powered concept requires a large area for the wind turbines to be installed. For the materials analysis it was less complicated to select material and this has been done by deriving performance indices for all the parts. For this concept the Life Cycle Analysis Midpoints have been calculated and most of them are better in the new biomass concept, this is why the biomass concept was chosen in the end.

2.9 Final design

Eventually concept 1 is chosen as the final design. The flowchart of this concept can be seen in figure 6

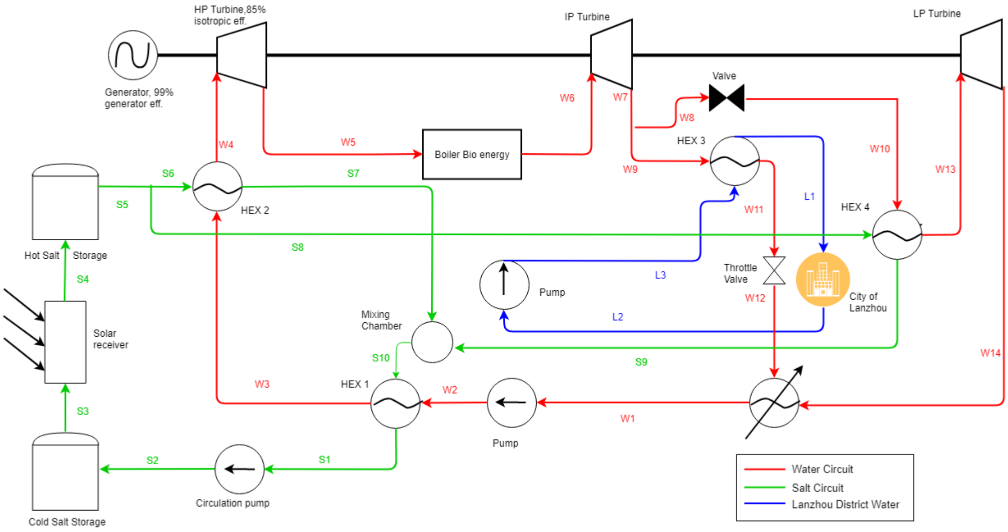

Figure 6: Flow chart of final concept

2.9.1 Assumptions which are made to do the calculations

After the final concept was chosen, for almost every flow in the flowchart the values were calculated. The following assumptions were made in order to make the calculations in matlab.

In the winter the average temperature T0 is taken as: T0= 0.01 degrees Celsius. The real average Temperature in the winter is namely -7.3 degrees Celsius, but matlab only can calculate the entropy with temperatures between 0 and 2000 degree Celsius. So is decided to choose a value near zero. In the summer the average temperature: T0 = 22.4 degrees Celsius. The other assumptions can be shown below:
- All heat exchangers are adiabatic and isobaric.
- All condensers are isobaric.
- The circulation pump in the salt circuit is isothermal.
- T0 winter = 0.01 degrees Celsius (10)
- T0 summer = 22.4 degrees Celsius (10)
- Generator efficiency = 99%
- Temperature of Salt flow S7 = 402.51 degree Celsius
- Temperature of Salt flow S9 = 394.15 degree Celsius
- (The Temperatures of the salt flows S7 and S9 are taken from the project in the second module.)

2.9.2 Biomass

The power plant will be using biomass to heat up the water. There are some kind of biomass resources in Gansu which can be seen in table 1.

Table 1. The spatial distribution of the theoretical energy potential available of agricultural residues in 2003 and 2007 at province level (PJ)

	Rice	Rice husks	Wheat	Corn	Corn cobs	Other grains	Beans	Tubers	Cotto
Gansu	0.42	0.10	32.63	34.09	6.51	13.85	5.12	14.38	7.27

In *table 1* can be seen that there is a lot of corn available as agricultural residues for extra energy production. It is chosen to use the residus of the corn, like the stalks, because of the high availablitity in the area. Furtermore pyrolyis is chosen instead of gasification, because the heat that pyrolysis can generate is high enough to heat up the water. Another disadvantage is that gasification is difficult to store because of the high pressure it need to be stored at.

The amount of biomass to be burned per second in the biomass burner can be determined with use of the Low Heating Value of the corn cobs (11). Considering a efficiency of 75% for the biomass burner 56.69 MW of heat must be added to the water. The mass flow rate of the biomass can be determined using equation 38.

$$\dot{m}_{biomass} = \frac{\dot{Q}_{out}}{(LHV)} = \frac{56.69}{18.4} = 3.08 kg/s \tag{38}$$

By taking the efficiency into account of 75% the total mass input can be calculated with equation 39.

$$\dot{m}_{input} = \frac{\dot{m}_{biomass}}{\eta_{pyrolysis}} = \frac{3.08}{0.75} = 4.11 kg/s \tag{39}$$

2.9.3 Tables with all the values of the water flows

Table 2: flow table of the water in winter.

	Temperature	Pressure	Enthalpy	Entropy	Phase	Mass_flow	Other	Energy	Exergy
W1	45	3	188.44	0.63862	'Saturated liquid'	164.99	'-'	31090	2292.9
W2	47	200	210.77	0.65603	'Compressed liquid'	164.99	'n_iso = 0.90'	34775	5192.9
W3	360	200	1740	3.8786	'Compressed liquid'	164.99	'-'	2.8708e+05	1.1227e+05
W4	520	200	3305.2	6.2263	'Superheated vapor'	164.99	'-'	5.4533e+05	2.6471e+05
W5	389.83	85	3099.5	6.2816	'Superheated vapor'	164.99	'n_iso = 0.85'	5.1139e+05	2.2828e+05
W6	520	85	3443.1	6.756	'Superheated vapor'	164.99	'n_iso = 0.75'	5.6808e+05	2.6359e+05
W7	140	3	2751.2	7.0269	'Superheated vapor'	164.99	'n_iso = 0.85'	4.5392e+05	1.3722e+05
W8	140	3	2751.2	7.0269	'Superheated vapor'	105.62	'-'	2.9059e+05	87847
W9	140	3	2751.2	7.0269	'Superheated vapor'	59.368	'-'	1.6333e+05	49377
W10	140	3	2751.2	7.0269	'Superheated vapor'	105.62	'-'	2.9059e+05	87847
W11	130.62	3	561.46	1.6719	'Saturated liquid'	59.368	'-'	33332	6213.7
W12	45	0.1	188.44	0.63862	'Saturated liquid'	59.368	'-'	11187	825.05
W13	520	3	3529.5	8.3818	'Superheated vapor'	105.62	'-'	3.728e+05	1.3097e+05
W14	155.13	0.1	2792.9	8.7123	'Superheated vapor'	105.62	'n_iso = 0.85'	2.9499e+05	43623

Table 3: Flow table of the water in summer.

	Temperature	Pressure	Enthalpy	Entropy	Phase	Mass_flow	Other	Energy	Exergy
W1	45	3	188.44	0.63862	'Saturated liquid'	164.99	'-'	31090	552.14
W2	47	200	210.77	0.65603	'Compressed liquid'	164.99	'n_iso = 0.90'	34775	3387.8
W3	360	200	1740	3.8786	'Compressed liquid'	164.99	'-'	2.8708e+05	98550
W4	520	200	3305.2	6.2263	'Superheated vapor'	164.99	'-'	5.4533e+05	2.4232e+05
W5	389.83	85	3099.5	6.2816	'Superheated vapor'	164.99	'n_iso = 0.85'	5.1139e+05	2.0568e+05
W6	520	85	3443.1	6.756	'Superheated vapor'	164.99	'n_iso = 0.75'	5.6808e+05	2.3924e+05
W7	140	3	2751.2	7.0269	'Superheated vapor'	164.99	'n_iso = 0.85'	4.5392e+05	1.1187e+05
W8	140	3	2751.2	7.0269	'Superheated vapor'	135.31	'-'	3.7225e+05	91746
W9	140	3	2751.2	7.0269	'Superheated vapor'	29.684	'-'	81666	20128
W10	140	3	2751.2	7.0269	'Superheated vapor'	135.31	'-'	3.7225e+05	91746
W11	130.62	3	561.46	1.6719	'Saturated liquid'	29.684	'-'	16666	2106.6
W12	45	0.1	188.44	0.63862	'Saturated liquid'	29.684	'-'	5593.6	99.349
W13	520	3	3529.5	8.3818	'Superheated vapor'	135.31	'-'	4.7757e+05	1.4288e+05
W14	155.13	0.1	2792.9	8.7123	'Superheated vapor'	135.31	'n_iso = 0.85'	3.7789e+05	29985

2.9.4 Tables with all the values of the salt flows

Table 4: Flow table of the salt in winter

	Temperature	Mass_flow	Energy	Exergy
S1	277.95	1345.1	1.1342e+06	1.7746e+05
S2	277.95	1345.1	1.1342e+06	1.7746e+05
S3	277.95	1345.1	1.1342e+06	1.7746e+05
S4	566	1345.1	1.727e+06	5.339e+05
S5	566	1345.1	1.727e+06	5.339e+05
S6	566	1032.4	1.3255e+06	4.0978e+05
S7	402.51	1032.4	1.0673e+06	2.4503e+05
S8	566	312.67	4.0143e+05	1.241e+05
S9	394.15	312.67	3.1922e+05	71837
S10	400.55	1345.1	1.3865e+06	3.1685e+05

Table 5: Flow table of the salt in summer

	Temperature	Mass_flow	Energy	Exergy
S1	285	1433	1.2237e+06	1.6376e+05
S2	285	1433	1.2237e+06	1.6376e+05
S3	285	1433	1.2237e+06	1.6376e+05
S4	566	1433	1.8398e+06	5.1563e+05
S5	566	1433	1.8398e+06	5.1563e+05
S6	566	1032.4	1.3255e+06	3.7148e+05
S7	402.51	1032.4	1.0673e+06	2.144e+05
S8	566	400.54	5.1425e+05	1.4412e+05
S9	394.15	400.54	4.0894e+05	80313
S10	400.14	1433	1.4762e+06	2.9468e+05

2.9.5 T-s and h-s diagrams

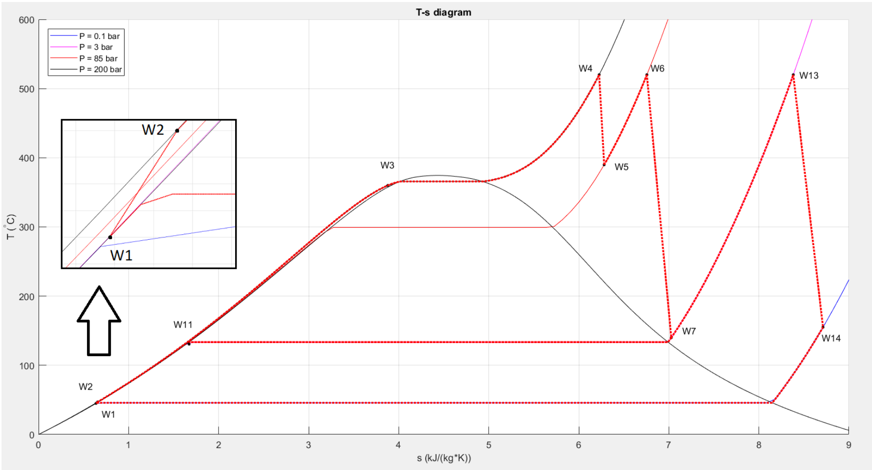

Figure 7: T-s diagram of the water flow

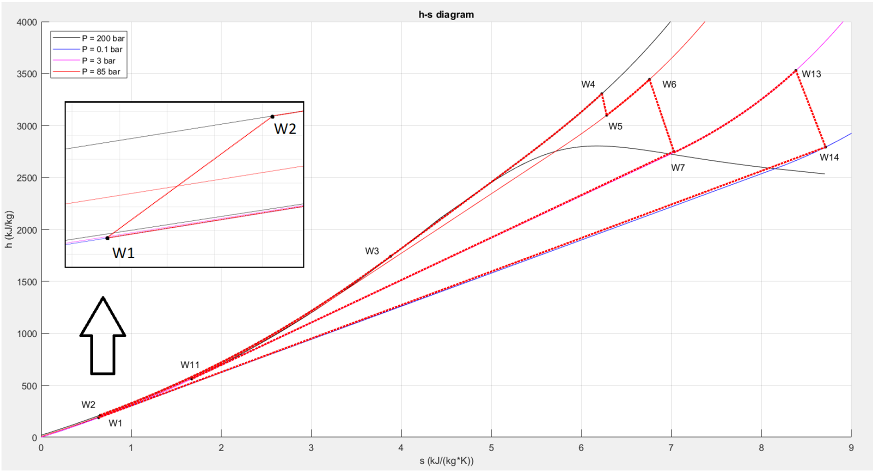

Figure 8: h-s diagram of the water flow

2.9.6 The basic equations which are used in matlab

Below is shown how the different mass flows of the salt are calculated, the results are shown in figure 9 and figure 10.
Equation for calculating the total heat that should be added to the water in Heat Exchanger 2.

$$\text{Q HEX2} = \text{M water W4} * (hW4 - hW3) \tag{40}$$

Equation used for calculating the mass flow through the salt flows S6 and S7.

$$\text{mass flow salt S7} = \frac{QHEX2}{(hS6 - hS7} \tag{41}$$

Equation for calculating the total heat that should be added to the water in Heat Exchanger 4.

$$\text{Q HEX4} = \text{M water W8} * (hW13 - hW10) \tag{42}$$

Equation used for calculating the mass flow through the salt flows S8 and S9.

$$\text{mass flow salt S8} = \frac{QHEX4}{(hS8 - hS9} \tag{43}$$

Equation for calculating the total mass flow of the salt.

$$\text{Total mass flow salt} = \text{mass flow salt S7} + \text{mass flow salt S8} \tag{44}$$

The calculations for the different mass flows of the water are in section 1.5.1

2.9.7 Equations used for calculating energy and exergy

Equation for calculating the enthalpy of a pump.

$$\eta_{input,s} = \frac{h_{out,s} - h_{in}}{h_{out,a} - h_{in}} \tag{45}$$

Equation used for calculating the enthalpy of a turbine.

$$\eta_{output,s} = \frac{h_{in} - h_{out,a}}{h_{in} - h_{out,s}} \tag{46}$$

Equation used for calculating the energy in the water, salt and air cycle.

$$En_{water} = \dot{m}_{water} \cdot h \tag{47}$$

$$En_{salt} = \dot{C}_{salt} \cdot T \tag{48}$$

Equation used for calculating the exergy in the water and salt There are different equations for the exergy because the salt and the water have different mass flows.

$$Ex_{water} = mwaterW4 \cdot ((h - hsur) - ((T_{sur} + 273.15) \cdot (s - s_{sur}))) \tag{49}$$

$$Ex_{water} = mwaterW8 \cdot ((h - hsur) - ((T_{sur} + 273.15) \cdot (s - s_{sur}))) \tag{50}$$

$$Ex_{water} = mwaterW9 \cdot ((h - hsur) - ((T_{sur} + 273.15) \cdot (s - s_{sur}))) \tag{51}$$

$$Ex_{salt} = \dot{m}saltS6 \cdot (Csalt \cdot (T - (T_{sur} + 273.15) - (T_{sur} + 273.15) \cdot C_{salt} \cdot \log(\frac{T}{T_{sur} + 273.15}))) \tag{52}$$

$$Ex_{salt} = \dot{m}saltS8 \cdot (Csalt \cdot (T - (T_{sur} + 273.15) - (T_{sur} + 273.15) \cdot C_{salt} \cdot \log(\frac{T}{T_{sur} + 273.15}))) \tag{53}$$

$$Ex_{salt} = \dot{m}saltS10 \cdot (Csalt \cdot (T - (T_{sur} + 273.15) - (T_{sur} + 273.15) \cdot C_{salt} \cdot \log(\frac{T}{T_{sur} + 273.15}))) \tag{54}$$

2.9.8 Sankey and Grassman diagrams

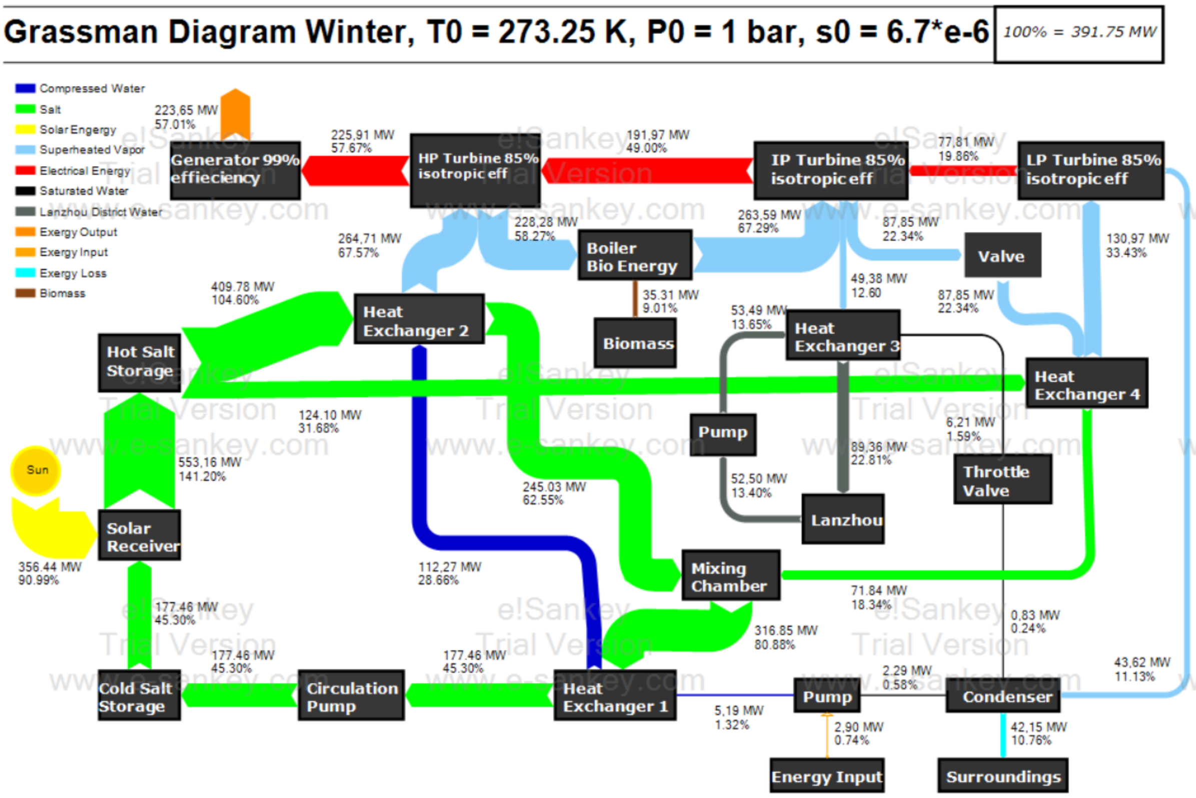

Figure 9: Grassmann diagram for in the winter.

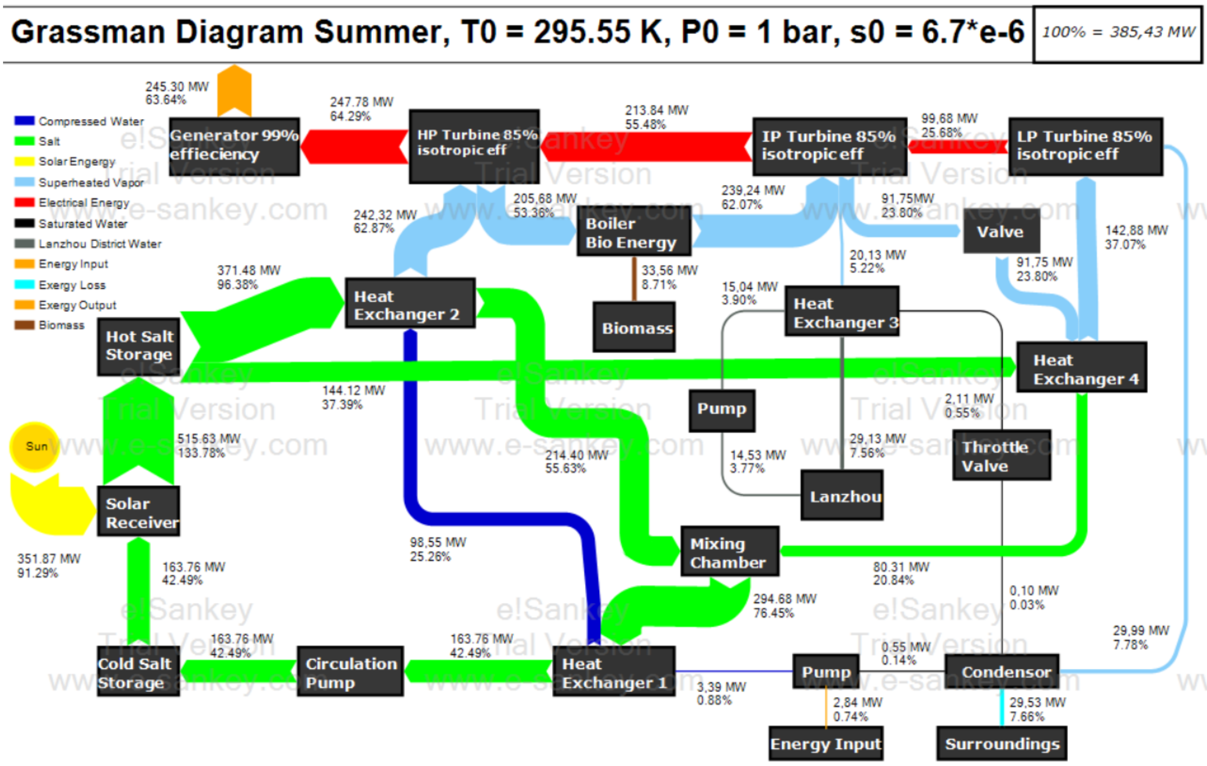

Figure 10: Grassmann diagram for in the summer.

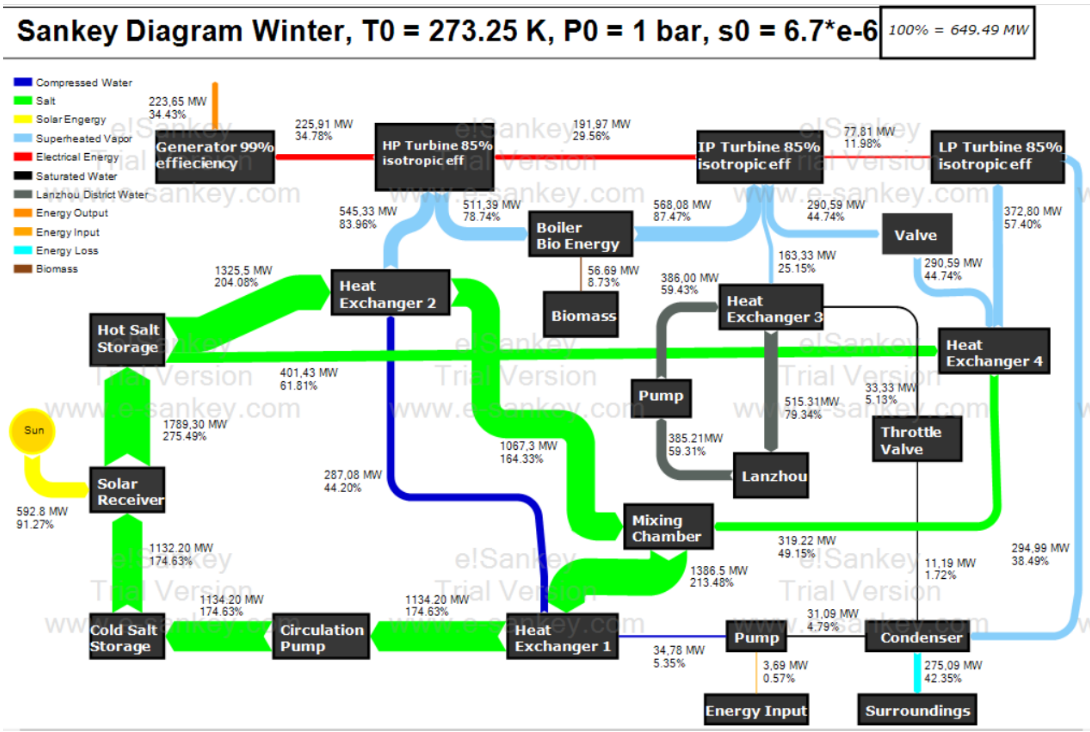

Figure 11: Sankey diagram for in the winter.

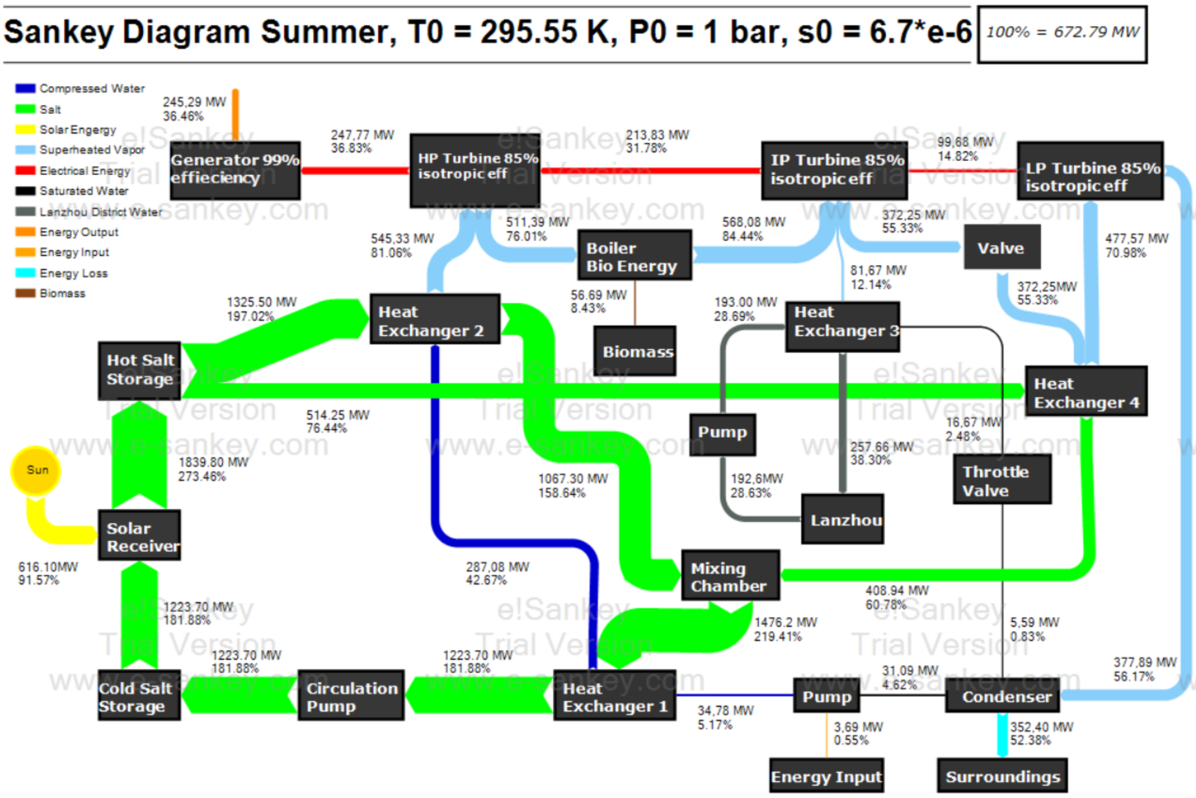

Figure 12: Sankey diagram for in the summer.

2.9.9 Information about the Sankey and Grassmann diagrams

The exergy values of both the water and the salt flow are put into a Grassmann diagram, figure 9 and figure 10, with the program eSankey. It can be seen that over most of the components there is some exergy loss. Only over the hot salt storage, the cold salt storage and the solar receiver, there is no exergy loss. At the solar receiver, it is assumed that there is no exergy loss. At the other 2 points, there is no converting of exergy and there is no transferring of exergy, so there is no exergy loss. The biggest exergy loss occurs in the summer in HEX 1. This is caused, because T0 is relatively high in the summer.In the winter most of the exergy loss is in the condenser. The mean differences between the exergy losses in the winter and in the summer are probably caused by the difference in the average temperature T0.

The energy values of both the water and the salt flow are put into the Sankey diagrams, figure 11 and figure 12, with the program eSankey. It can be seen that all of the energies over almost every component, like the turbines and the heat exchangers, are the same before entering the component and after leaving. The energy difference at the pump will be supplied by an external energy source since this is the energy needed for the pump in order to do work. However, there is a lot of energy loss at the condenser, which will go to the environment.

Equation used for calculating the exergy in the condenser.

$$\text{Exergy condenser} = ((EW14 + EW12 - EW1) * (1 - \frac{T0}{TW1 + 273.15})) \quad (55)$$

The exergy in the condenser in the winter is 38.91 MW and in the summer 25.03 MW. From the Grassmann diagram in the winter it becomes clear that the exergy in the condenser in the winter is 42.15 MW and in the summer 29.53 MW. The difference between the calculated exergy and taken from the Grassmann diagram is the exergy loss, the rest is exergy that could be used someweher else. So the exergy loss in the winter is 42.15-38.91 = 3.24 MW and in the summer 29.03 - 25.03 = 4 MW.

2.9.10 Equations used for calculating the several efficiencies

Thermal Efficiency

$$\eta_{thermal} = \frac{Netto\ power\ output}{Energy\ input} = \frac{W_{net,}}{Q_{in}} \tag{56}$$

Electric Efficiency

$$\eta_{electric} = \eta_{thermal} \cdot \eta_{generator} \tag{57}$$

Carnot Efficiency

$$\eta_{carnot} = 1 - \frac{T_{cold}}{T_{hot}} \tag{58}$$

Second Law Efficiency

$$\eta_{2nd,law} = \frac{\eta_{thermal}}{\eta_{carnot}} \tag{59}$$

Utilization factor

$$\epsilon_u = \frac{W_{net} + Q_{process}}{Q_{in}} \tag{60}$$

The results are shown below:

Efficiencies of the plant in the summer:
Thermal efficiency = 36.60%
Electrical efficiency = 36.23%
Carnot efficiency = 62.74%
2nd law efficiency = 58.34%
Utilization factor = 46.35%

Efficiencies of the plant in the winter:
Thermal efficiency = 34.45%
Electrical efficiency = 34.11%
Carnot efficiency = 65.56%
2nd law efficiency = 52.55%
Utilization factor = 54.60%

Average efficiency of the plant for the whole year:
Thermal efficiency = 35.53%
Electrical efficiency = 35.17%
Carnot efficiency = 64.15%
2nd law efficiency = 55.45%
Utilization factor = 50.48%

2.9.11 Possible improvements and recommendations

The efficiency of the power plant could be improved in different ways. The mentioned flows are according to the flowchart of the final design.

One water mass flow for the whole plant
When calculating the thermal efficiency it became clear that it was not as high as expected. After a small research it became clear that the mean reason for this was splitting the mass flow of the water into 2 separate flows. So a possible solution is to change this into one mass flow. In the current design the water of Lanzhou should then be reheated with maybe the biomass burner. The efficiency of the Low Pressure Turbine will probably increase but The biomass burner should then burn more biomass to heat up the water of the plant and of Lanzhou. So it is doubtable of the efficiency will increase.

Decrease Temperature in W14
The Temperature in flow W14 is very high, so there is still a lot energy in the water. The flow goes from the Low Pressure Turbine to the condenser, in the condenser a lot of energy is lost. This massive energy loss will cause that the Thermal efficiency is low. An solution is to lower the temperature of flow W14, one way to lower the temperature is to raise the efficiency of the low pressure turbine. This can be seen in the Ts-diagram (figure(7)). If the efficiency will be for example 90% instead of 85% the temperature will drop, this temperature drop will cause that the enthalpy drops. When the enthalpy in W14 drops, the energy in that flow will decrease which means that there is less energy going to the condenser.

3 Material Science analysis of the new power station in Lanzhou

In this section the materials selection will discussed for diverse components of the new power plant , based on the fundamental aspect of the working conditions, design requirements and possible failure modes and by looking how the components are produced. With these information a performance index has been made for every component and based on these indices, the most appropriate material has been selected.

3.1 Turbine axle

3.1.1 Working principles

The axle is responsible for the movement of the parts in the turbine, it works at high pressure and temperature environment , the axles operates under higher speeds for a long period of time .

3.1.2 Design requirements

Due to the principles of work, the material that is chosen must support these conditions , it must be work correctly. The highest temperature and pressure are the main aspects to be taken into account at the time of the election, another essential feature is the hardness and finally if the material can be manufactured to get the axle shape.

3.1.3 Failure modes

- **Creep**
  As the axle is present at high temperature environment creep might occur, creep occurs at 40 % of the melting point, also taking the temperature of the environment and dividing it with 0.4 the new melting point is found and This should be the melting point of the chosen material, furthermore, the tube must be thick enough to prevent fractures from happening.

3.1.4 Production process

Due to its shape and size, it would be best to produce this part using a hot forging method. A large shaft will be beaten into shape at temperatures above the material's recrystallization temperatures. The deformations will be plastic, so the shape will remain upon cooling.

3.1.5 Perfomance Index

In order to derive the performance index for turbine axel, important characteristics need to be considered first. Since the turbine axel is a rotating part with varying stress acting upon it, fatigue is a factor to consider, which may cause fractures in the shaft. Hence, fracture toughness and strength need to be considered. Furthermore, mass of the complete shaft should be as low as possible for two reasons: the lighter it is, the cheaper its is to produce and less energy is required to rotate it. Thus, density is an important factor to consider

Fixed	Free
a_c	ρ
L	C (Price per volume)
Y	σ_y
σ	K_{ic}
π	
F	
m	

Table 1: Free and fixed values

From this, equations 1 , 2 and 3 need to be considered. Equation (1) for stress upon the shaft.

$$\sigma = \frac{F}{A} \qquad [Mpa] \tag{1}$$

Equation (2) for the material's fracture toughness

$$K_{ic} = Y\sigma_y\sqrt{\pi a_c} \qquad [\sqrt{MPam}] \tag{2}$$

Equation (3) for mass of the shaft

$$M = A\rho l \qquad [kg] \tag{3}$$

Equation (2) rewritten in terms of yield strength

$$\sigma_y = \frac{K_{ic}}{Y\sqrt{\pi a_c}} \qquad [Mpa] \tag{4}$$

Equation (3) rewritten in terms of area.

$$A = \frac{M}{l\rho} \qquad [m^2] \tag{5}$$

Yield strength in equation (4) is replaced with equation (1).

$$\frac{F}{A} = \frac{K_{ic}}{Y\sqrt{\pi a_c}} \qquad [Mpa] \tag{6}$$

Area in equation (6) is replaced with equation (5).

$$\frac{Fl\rho}{m} = \frac{K_{ic}}{Y\sqrt{\pi a_c}} \qquad [Mpa] \tag{7}$$

Equation (7) rearranged.

$$F = \frac{K_{ic}m}{l\rho Y\sqrt{\pi a_c}} \qquad [N] \tag{8}$$

Fixed variables separated from Free variables in order to determine the performance index

$$F = \frac{m}{lY\sqrt{\pi a_c}}(\frac{K_{ic}}{\rho}) \qquad [N] \tag{9}$$

Hence performance index is:

$$M = \frac{K_{ic}}{\rho} \tag{10}$$

3.1.6 Ranking the materials using CES Edupack and the P.I.

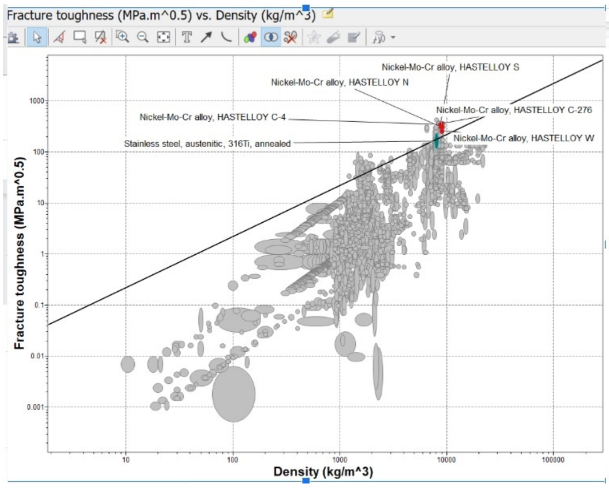

Figure 13: Material selection

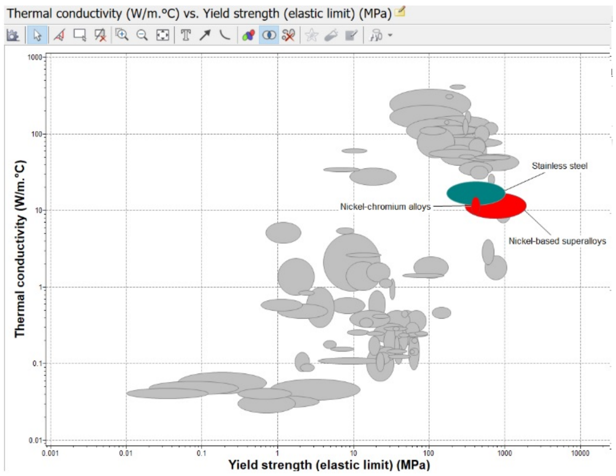

Figure 14: Material selection, Density vs Price

Following the derived performance index, a Fracture Toughness - Density graph of materials was plotted in the CES edupack program. The materials were filtered out based on the following criteria: Elongation at fracture > 10% strain, fracture toughness ¿10 $MPam^{0.5}$, maximum service temperature > 520 ^0C and excellent hot forming ability.

3.1.7 Material Choice

After applying the filters, 14 materials remained: annealed austenitic stainless steel, annealed low alloy steel and a variety of Nickel alloys. Based on the price performance index, the best material was low alloyed steel. However, since low alloy steel has 0.56 - 0.64 % carbon, it is in the austenitic region. This means that the only processes happening during annealing would be recovery and grain growth, thus bringing little to no benefit to increasing fracture toughness. The next best material on the list is hot rolled nickel alloy. The axel cannot be produced by hot rolling because of its shape, hence this material does not suffice. The next material is Nickel-Mo-Cr alloy, HASTELLOY C-4. This material has higher fracture toughness than the aforementioned steels, but has a considerably higher price.

3.1.8 Final Choice

- **HASTELLOY C-4**
  Despite higher pricing, the material conforms to all the requirements and has a higher price performance index, hence it is the most suitable material for the axel.

3.2 Turbine Blades

3.2.1 Working principles

The blades form a fundamental part of the turbine , because these blades converts energy to kinetic energy. The turbine blades have a particular shape, hence when steam is pressed through the blades the turbine blades are set in motion. The turbine blades are attached to a shaft such that the shaft will rotate. Eventually, the rotating movement of the shaft generates electricity. The turbine blades are exposed to high temperatures and high pressures. This means that the turbine blades have to deal with very high stresses. Thus the working conditions are very extreme.

3.2.2 Design Requirements

Since the conditions at the turbine blades are very extreme, it is very important that the blades are made of a material which can withstand these conditions. Moreover, the shape of the turbine blades are very complex. Therefore, the material of choice has to be able to be formed into this shape. Another requirement, which is important, is that the material of the blades has to be very strong and tough enough to withstand impact and fatigue failures. Furthermore, the blades are working with steam, thus water could be present. This means that it should be resistant to erosion.

3.2.3 Failure modes

The turbine blades have to deal with multiple failure modes for instance :

- **Creep.**
  Since the temperature is high, creep occurs at 40 to 50% of the melting point of the material, under a constant load.
- **Erosion.**
  The turbine blades are perpendicular to the flow of the steam, this means that steam particles collides with the blades , which produces the wear of blades (erosion).
- **Corrosion.**
  It might be a problem if the steam is 'polluted' with air
- **Fatigue.**
  Another problem with turbines and especially at the turbine blades, there is a significant amount of turbulence and cyclic loads of stresses.

3.2.4 Production Processes

Turbine blades are made by casting. Copies of the blades are formed by pouring wax into metal molds. Once each wax shape has set, it is removed from the mold and immersed in a ceramic slurry bath. Each cluster is then heated to harden the ceramic and melt the wax. Molten metal is now poured into the hollow left by the melted wax. Now the solidifying process takes place in computer-controlled ovens in which the blades are carefully heated according to precise specifications. With casting, the dimensions are not very precise. Since it is very important for the blades to be extremely precise, the next and final stages in preparing turbine blades are machine-shaping. The final desired shape is honed by means of high performance machining. Next, parallel lines of tiny holes are formed in each blade as a supplement to the interior cooling passageways. The holes are formed by either a small laser beam or by spark erosion, in which carefully controlled sparks are permitted to remove material.(12)

3.2.5 Performance Index

In order to derive an appropriate performance index for the turbine blades, important factors need to be considered. Firstly , since blades are rotating, the load is varying, hence crack development is possible. Hence, fracture toughness is an important factor. Secondly, since blades are rotating - fatigue is possible, hence fatigue is possible, hence, fatigue strength at 10^7 cycles needs to be considered. Lastly, to reduce work input into blade rotation, they need to be as light as possible, hence material density is an important factor.

From this, it is possible to derive two performance indices for the turbine blade, one including fracture toughness and the other including fatigue strength at 10^7 cycles. In order to derive them, two assumptions need to be made: blades are uniformly shaped and they are uniformly loaded, as shown in the figure 3 .
Case 1

$$F = WL \tag{11}$$

where W is the Distribute Load and L is the blade length

$$\frac{F}{A} = \sigma_e \tag{12}$$

In the equation(2) σ_e is the Fatigue strength Equation (3) is the mass

$$M = A\rho L \tag{13}$$

Rewriting in terms of Area

$$A = \frac{M}{\rho L} \tag{14}$$

replacing by the equations.

$$A = \frac{F}{\sigma_e} \tag{15}$$

Using equation(3) to replace area.

$$\frac{M}{\rho t} = \frac{F}{\sigma_e} \tag{16}$$

Rewriting equation (6).

$$M = \frac{F}{\sigma_e}\rho L \tag{17}$$

Rewriting equation (7).

$$M = \frac{\rho}{\sigma_e}FL \tag{18}$$

Hence the performance index is :

$$M = \frac{\rho}{\sigma_e} W L^2 \tag{19}$$

It is wanted to minimize mass $\frac{\sigma_e}{\rho}$, so density needs to be as low as possible

Fixed	Free
σ	A
L	σ_e
F	ρ
A	M

Table 2: Free and fixed values

Case 2 : Blades (Fracture toughness)

$$F = WL \tag{1}$$

where W is the Distribute Load

$$\frac{F}{A} = \sigma_e \tag{2}$$

In the equation(2) σ_e is the Fatigue strength

$$K_{ic} = \sigma_e \sqrt{\pi a_c} \tag{3}$$

Defining the mass equation.

$$M = A\rho L \tag{4}$$

Rearrange(3) for σ

$$\sigma = \frac{K_{ic}}{\sqrt{\pi a_c}} \tag{5}$$

Rearrange (4) for A.

$$A = \frac{M}{\rho L} \tag{6}$$

Substitute (2) in (5):

$$\frac{F}{A} = \frac{K_{ic}}{\sqrt{\pi a_c}} \tag{7}$$

Substitute (6) into(7)

$$\frac{FL\rho}{M} = \frac{K_{ic}}{\sqrt{\pi a_c}} \tag{8}$$

Rearrange:

$$F = \frac{K_{ic}M}{L\rho\sqrt{\pi a_c}} \tag{9}$$

Rearrange (9) for M:

$$M = \frac{FL\rho\sqrt{\pi a_c}}{K_{ic}} \tag{10}$$

Substitute(1) into (10) and separate free from fixed :

$$M = WL^2\sqrt{\pi a_c \frac{\rho}{K_{ic}}} \tag{11}$$

Mass as low as possible , ρ as low as possible $\frac{K_{ic}}{\rho}$ so $\quad m \propto \frac{K_{ic}}{\rho}$

Fixed	Free
σ	ρ
M	K_{ic}
L	
W	
F	
a_c	
π	

Table 3: Free and fixed values

3.2.6 Ranking the materials using CES Edupack and the P.I.

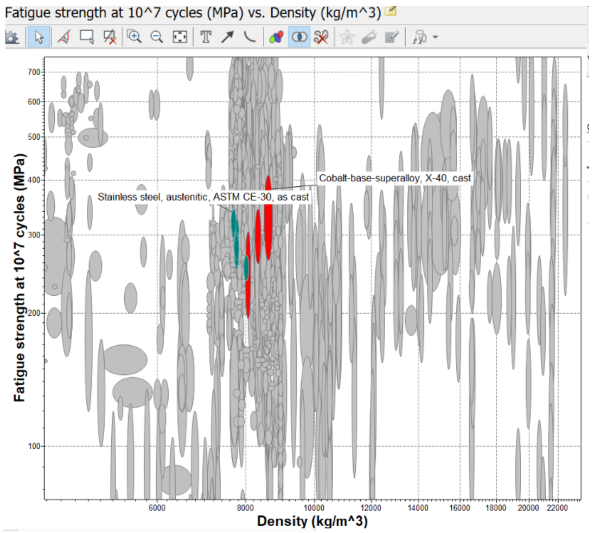

Figure 15: Material selection,Fatigue strength vs Density

Figure 16: Material selection, Fracture toughness vs Density

In order to select an appropriate material for turbine blades, the materials had to conform to the working conditions of a HP turbine. A filter has been set to narrow down the choice of materials: elongation at fracture to be over 10% strain, maximum service temperature to be at least 520 degrees C to prevent creep and lastly excellent casting ability to ensure the blades can be produced. After applying the filter, 24 materials were left: a variety of water quenched stainless steels, a variety of cobalt based superalloys and cast austenitic stainless steel.

3.2.7 Material Choice

Based on both performance indices, austenitic stainless steel had the highest performance out of the 24 materials. It had excellent casting ability, as well as a much lower price than cobalt super alloys, meaning it would be cheap to produce. Moreover, it also had on of the lowest densities, which would reduce mass of the blades, making them cheaper per volume and requiring less energy to rotate in the trubine.

3.2.8 Final Selection

Stainless Steel: Austenitic, ASTM CE-30 , as cast.

3.3 Turbine Housing

3.3.1 Working principles

The turbine housing is an important part of the turbine. The housing goes all around the turbine, so all other components are inside it and is therefore the largest component of the turbine. The housing is also the component that directs the gases through the turbine. That is achieved by the shape of the housing. The housing is made in such a way, that it fits tightly around the turbine blades. This ensures that all the working fluid goes through the turbine blades and is used, instead of flowing around the blades and being useless. [1] The housing is exposed to high pressures and temperatures,200 Bar and 520 ^0C, according to our calculations. The high pressure and temperature mean that the housing is under extremely high mechanical and thermal stresses

3.3.2 Design requirements

The turbine housing is exposed to high temperatures and pressures, as stated in the working principles, therefore ,It is fundamental that the housing should be made out of a material, or an alloy of materials that is able to withstand these extremes conditions . Secondly,The material or an alloy which will be chosen could be formed into the desired housing shape, a cylinder. Furthermore, since heat losses are unwanted, the housing should ideally be adiabatic. This can be achieved by selecting a material, or an alloy, which has a low thermal conductivity.

3.3.3 Failure modes

- **Creep**
  It is a imminent failure mode. Creep will occurs at 40 to 50 % of the melting point of the material, under a constant load. The working fluid is exerting a huge stress on the turbine housing, which acts as a load.

- **Corrosion**
  It is another possible failure mode. This is caused by a polluted working fluid and causes the turbine housing to degenerate and lose strength. Corrosion can be overcome by using a clean, oxygen free, working fluid.

3.3.4 Production Process

Most turbine housings are produced by means of casting. Since the housing is a hollow cylinder, it is very suited to be casted. Casting has the advantage that it can produce a large, continuous components, weighing thousands of kilograms. A mold is made and the material is poured into the opening. After solidification, the mold is removed. The next step is machining. A casted product has the disadvantage that the dimensions are not very precise, which is important for the turbine housing. After machining the dimensions fit the tolerances.(13) (14)

3.3.5 Perfomance Index

In order to derive an appropriate performance index for the turbine housing, its working principle and important factors need to be considered. The housing has two functions: keep working fluid inside and prevent heat loss. This means that the housing needs to both be strong and insulating, which would be impractical to do since most strong-insulating materials are brittle ceramics and strong non-brittle metals are good conductors of heat. This leads to the solution of using a cheap strong material to withstand high heat and high pressure environment to cast the housing and using a different material with as an insulator that has good insulation ability.

First, the performance index for the housing needs to be derived. The housing must be able to withstand high stresses without plastic deformation, hence yield strength is an important factor. Furthermore, wall thickness is an important factor because making it thinner will reduce the housing's volume, hence reducing its price.

Fixed	Free
σ	A
F	P
T	D_0
	L

Table 4: Free and fixed values

Formula for stress

$$\sigma = \frac{F}{A} \tag{1}$$

Formula for Pressure:

$$P = \frac{F}{A} \tag{2}$$

P = Pressure
t = thickness
D_o = Diameter of the inner wall of the housing

Rewriting (2) making F the subject:

$$F = P * A \tag{3}$$

where

$$A = L * D_0 \tag{4}$$

then

$$F = P * L * D_0 \tag{5}$$

For (1) A is equal to:

$$A = 2(L * t) \tag{6}$$

Combining the formulas

$$\sigma = \frac{(P * t * D_0)}{2(L * t)} \tag{7}$$

$$\sigma = (P * D_0) \tag{8}$$

$$t = \frac{1}{\sigma} * P * \frac{D_0}{2} \tag{9}$$

Hence the performance index is:

$$t = \frac{1}{\sigma} \tag{10}$$

Hence, yield strength needs to be as high as possible in order to reduce thickness as much as possible.

Secondly, the performance index for insulation needs to be derived. The insulator needs to be able to withstand the high heat from the housing's surface, hence maximum service temperature is an important factor. Moreover, heat flow and thermal conductivity need to be minimized to increase insulation, hence they are important factors. Thermal conductivity

Fixed	Free
A	Q
ΔT	λ
t	

Table 5: Free and fixed values

$$\lambda = \frac{Qt}{A\Delta T} \tag{11}$$

Rearrange equation (1)

$$Q = \frac{\Delta T \lambda A}{t} \tag{12}$$

separate free from fixed

$$Q = \lambda \frac{A\Delta T}{t} \tag{13}$$

where λ is thermal conductivity
Q is heat flow
A is Surface area of cylinder
t is thickness of the insulator
ΔT is the temperature difference between inside heat exchanger and outside

$$Q \propto \lambda \tag{14}$$

Q needs to be minimized to reduce heat loss to the environment hence λ need to be minimized

3.3.6 Ranking the materials using CES Edupack and the P.I.

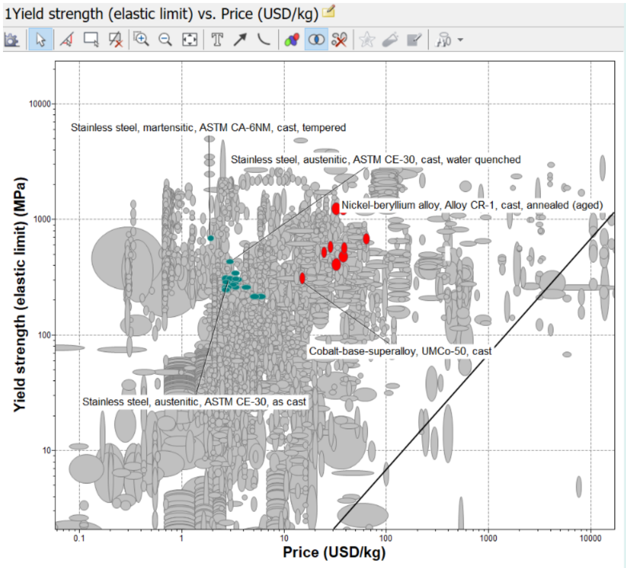

Figure 17: Material selection

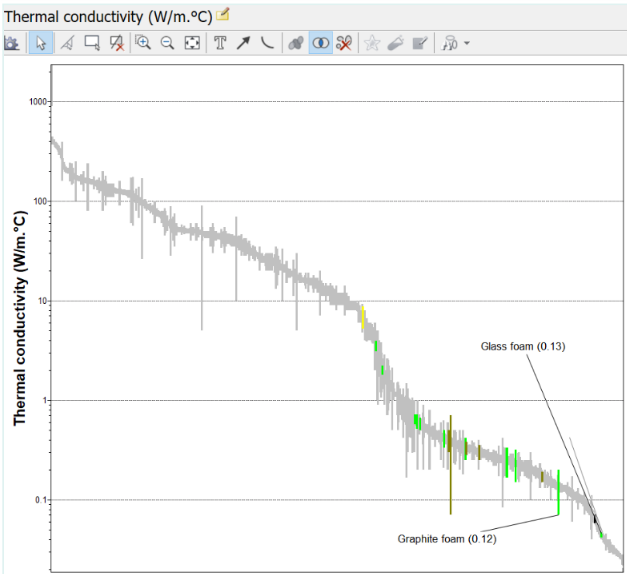

Figure 18: Material selection

3.3.7 Material Choice

In order to choose an appropriate material for turbine housing, the materials needed to be plotted on a yield strength - price graph in CES. A filter has been set to narrow down the choice of materials: yield strength to be over 20 MPa , elongation at fracture of over 10% strain, maximum service temperature of at least 520 degrees C and lastly excellent casting ability.

From this, 24 materials remained: martensitic stainless steel, a variety of austenitic water quenched stainless steels, austenitic stainless steel, cobalt based superalloys and nickel beryllium alloy. From these materials, martensitic stainless steel had the highest performance index. It conformed to all the filter requirements, however, martensitic stainless steels are brittle. This is because the structure undergoes a transformation from BCC to BC Tetragonal structure, which causes a large amount of stress on the structure, making the steel brittle. Using brittle materials in high pressure environments carries a large amount of risk of housing bursting, thus, making martensitic stainless steel not suitable. The next best performing material is water quenched austenitic stainless steel. Water quenching does not give the material enough time to disperse structural stresses, making the material hard but brittle, so water quenched steels are not suitable. The next material on the list is austenitic stainless steel. Unlike water quenched austenitic steels, this type of austenitic steel is let to slowly cool to room temperature after casting, which allows stresses to disperse, making it less brittle. Since the material conformed to other requirements set by the filter, the material is suitable to make the housing out of.

In order to choose an appropriate material for the insulation, the materials were plotted on CES in a Thermal conductivity graph to have an overview of which material has the lowest thermal conductivity. The materials were subject to filters, to narrow down the choice: density to be lower than 1300 kg/m^3 in order to reduce mass per volume and hence total price and maximum service temperature of at least 520 degrees C. From this, 20 materials remained, with the best performing being glass foam (0.13).

3.3.8 Final Choice

- **Stainless steel(case 1):** austenitic, ASTM CE-30, as cast

- **Glass foam(case 2):** had the lowest thermal conductivity and was relatively cheaply priced compared to other foams. Concrete was priced cheaper, but due it its high density, price per volume was a 100 times higher, hence making glass foam the material of choice

3.4 Heat Exchanger Housing

3.4.1 Working Principles

The housing is the component of the heat exchanger that covers the tubes inside, where the heat is exchanged. The housing's main purpose is to isolate the tubes from the outside world and keep the other working fluid inside, so that no heat is lost to the environment and all heat is exchanged.
The housing needs two large openings for the working fluid that does not flow through the tubes. This fluid enters the heat exchanger at one hole and leaves at the other. These openings are situated at both ends of the heat exchanger, perpendicular to the tubes. In the direction of the tubes, at both ends of the heat exchanger, two plates with holes are located. When the other working fluid enters, it is split here en flows through the tubes. At the end of the heat exchanger the working fluid gathers again and continuous through one pipe again.
The housing operates under a high pressure of 200 bar. There is pressure from the working fluid, since only one fluid is in the tubes, the other one flows past the tubes and the inside wall. The outside of the housing is exposed to atmospheric temperatures. However, the inside of the housing is exposed to high temperatures of 566 Degrees Celsius, according to the calculations. This is because the inside of the housing is next to the hot tubes. So the housing has to deal with a high temperature difference.
The housing of the heat exchanger is also the part that has to carry the weight of the tubes and the working fluid flowing through it. Most commonly, the tubes are attached to the inside of the housing, by means of a small plate. This plate has holes inside, where a tube can fit through. This means that the housing is exposed to a considerably large load, in case it is not installed on the ground, but hangs above ground. (15)

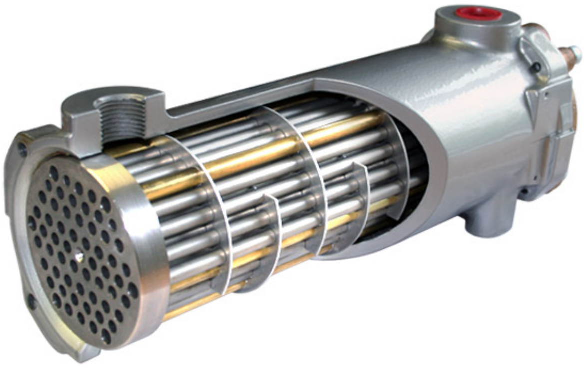

Figure 19: Heat exchanger
(16)

3.4.2 Design Requirements

It is required that the thermal conductivity of the material will be minimal because it influences the efficiency of the heat exchanger. Since the inside of the housing is exposed to high temperatures, a material with a high melting point is desired. The housing is not exposed to very high pressures, but, in case the heat exchanger is installed above solid ground, a large load, in the form of weight, acts on it. It is therefore important to consider the yield strength of the materials, to prevent deformation and/or buckling of the housing. A strong material is preferred. It is important to consider erosion, as one of the working fluids flows past the housing, which could lead to degradation of the housing material.

3.4.3 Failures Modes

- **Creep.**
  Creep occurs at 40 to 50% of the melting point of the material, under a constant load. The load, in case of the heat exchanger, is the weight of the tubes and working fluid inside. This, in combination with the high temperatures could lead to creep. It has to be noted that if the heat exchanger is installed on solid ground, the chance of creep to occur is much less than if it were to be installed above ground.

- **Stress erosion.**
  Since one of the working fluids flows past the inside housing and has a high temperature and pressure, erosion of the material could lead to failure of the housing. (17)

3.5 Production Process

Since finding specific information on the production of heat exchanger housings is quite difficult, a number of assumptions was made. Firstly, it is assumed that the plate with the holes at both ends of the heat exchanger is casted. After casting, the holes are drilled inside the plate and it is then checked if the holes fit with the tubes. Then the plates are polished, creating a smooth surface. When this is done, the plates are secured to the tubes, by means of brazing, so that no fluid can leak through.(18)

Secondly, it is assumed that the rest of the housing is casted. As can be seen from the figure, there stick some components out, which could be fit into a mold. After casting, machining will take place, to create a smoother surface.

Lastly, it is assumed that with the help of special designed tools the plates and rest of the housing are put together, either by bolting, screwing, or welding, so that no leaking can take place. (19) (20)

3.5.1 Performance Index

Since heat exchanger housing operates at the conditions as the turbine housing, performance indices for housing and housing insulation remained the same.

3.5.2 Ranking Materials using CES Edupack and the P.I.

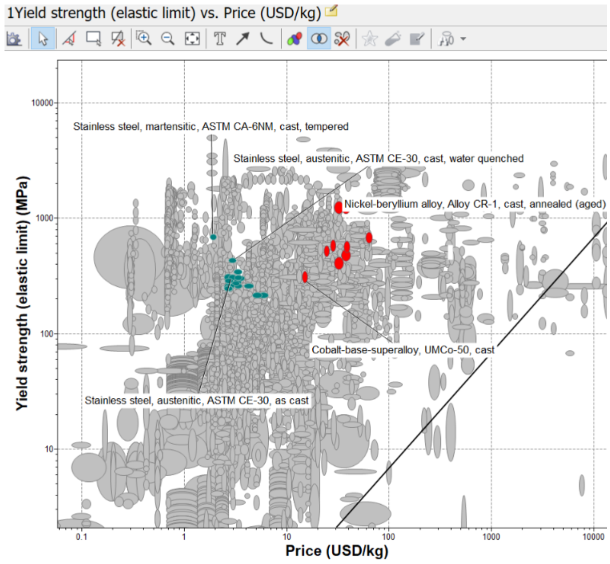

Figure 20: Material Selection heat exchanger housing

3.5.3 Material Choice

Comparing heat exchanger housing to turbine housing, the only difference that can impact material choice is maximum service temperature, since heat exchanger operates at 46 degrees higher than the turbine. All other conditions, such as pressure remained the same. By changing the maximum service temperature from 520 degrees C to 566 degrees C, there was no change in the materials given out for both insulation and housing. Therefore, it can be concluded that heat exchanger housing and housing insulation will be made out of the same materials as for the turbine.

3.6 Final Choice

Stainless Steel: austenitic, ASTM CE-30, as cast. for housing and Glass Foam (0.13) for the insulation.

3.7 Heat Exchanger Tubes

3.7.1 Working Principles

Heat exchanger tubes are responsible for heat exchange between the salt and water in the power cycle. The tubes carry hot salt and cooler water in liquid state. The hot salt conducts heat to the tube which then transfers it to water, heating up the water. In the end, cooler salt(still in liquid phase) and heated water leave the heat exchanger back into the cycle.The tubes are exposed to high pressures and temperatures, highest being at 200 Bar and 566 ^{o}C in HEX 2.

3.7.2 Design Requirements

Since the tubing is exposed to high temperatures and pressures, high thermal and mechanical stresses are applied onto the material. To withstand high mechanical stresses, the material needs to either be strong enough or thick enough to withstand the high pressure. Additionally, the material has to be able to withstand high temperatures. The chosen material has to also be producible in the desirable tube shape. Furthermore, since tubing is responsible in exchange of heat between two fluids, the material should be able to conduct heat well.

3.7.3 Failure Modes

- **Creep.**
  It is an important factor when it comes to high temperature environments. Creep occurs at temperatures around 40 and 50 % of the material's melting point under constant load, hence, the material's melting point should be around 1.5 times higher than the highest fluid temperature (566 ^{o}C)

- **Corrosion.**
  Since the tubing comes in contact with water and salt, corrosion is a possibility. Additionally, corrosion rate is increased at higher temperatures, therefore the material should have an appropriate level of corrosion resistance.(21)

- **Erosion**
  It should also be considered due to high pressure and salt's and water's ability to erode and ware the material surface off. Finally, since the tubes operate at high pressures, fractures may occur, so the material should be strong enough or thick enough to avoid fractures.

3.7.4 Production Processes

The method of extrusion can be used to produce tubes. By pushing a material through a die, the tube of any size or thickness can be produced. This method is also advantageous since the products come out with excellent surface finish, which is good against erosion and crack development. After extruding, the tube is cut to desirable lengths. It would also be possible to manufacture the tubes using the method of rolling and welding sheet metal. The metal sheet is passed through rollers to make them round. Then, the two ends are welded together to form tubes. These methods are dependant on formability and weldability of the material. The material needs to be formable enough to be extruded, if not, then the material would have to be rolled and welded, which in turn requires sufficient weldability.

3.7.5 Performance Index

(22)

Fixed	Free
t	σ
ΔT	$\sigma_{elastic}$
r	q
Δp	h
	U

Table 6: Free and fixed values

In order to obtain the performance index for heat exchanger tubing, equations (1) , (2), (3), (4) and (7) would have to be combined and rearranged.

$$q = h_1 \Delta T_1 \qquad [Wm^{-2}] \tag{1}$$

The first equation shows heat flux , which describes energy flow rate per area, where q is heat flux, h1 is heat transfer coefficient and ΔT_1 is the change in temperature between tube wall and fluid 1.

$$q = \lambda \frac{\Delta T_{1,2}}{t} \qquad [Wm^{-2}] \tag{2}$$

The second equation also shows heat flux but in terms of material's thermal conductivity, wall thickness and temperature difference across the tube wall, where λ is thermal conductivity of the tubing material, $\Delta T_{1,2}$ is the temperature difference across tube surface and t is wall thickness.

$$\frac{1}{U} = \frac{1}{h_1} + \frac{t}{\lambda} + \frac{1}{h_2} \qquad [m^{2o}CW^{-}1] \tag{3}$$

The third equation shows how resistive a material is to heat transfer, where 1/U is total thermal resistance, t/λ is the thermal resistance of the wall and 1/h is the thermal resistance of wall surfaces.

$$q = U\Delta T \qquad [Wm^{-2}] \tag{4}$$

The fourth equation shows heat flux in terms of heat transfer and temperature difference between two working fluids. Where U is the heat transfer coefficient and This the temperature difference between salt and water.

$$q = \frac{\lambda}{t} \Delta T \qquad [Wm^{-2}] \tag{5}$$

Since 1/h values at the two surfaces are rather small in comparison to t/λ so they can be neglected. By combining (4) with (3), which gives equation (5).

$$\sigma = \frac{\Delta pr}{t} < \sigma_{elastic} \qquad [MPa] \tag{6}$$

The sixth equation shows the maximum stress the material can withstand before plastically deforming, which should be below its elastic stress limit, where σ is the stress,Δp is the pressure difference between the inside and the outside of the tube and r the tube radius.

$$t = \frac{\Delta pr}{\sigma} \qquad [m] \tag{7}$$

Rearrange equation (6) to make t the subject.

$$q = \frac{\Delta T}{r\Delta p}(\lambda\sigma_{elastic}) \qquad [Wm^{-2}] \tag{8}$$

Finally combine (5) and (7) to eliminate t and achieve the final equation for total heat flux, q. q can be maximised by maximising the performance index $\lambda\sigma_{elastic}$ since these are the only values that are material dependant and therefore free. Therefore, heat flow rate per unit area is proportional to the product of the material's thermal conductivity and its elastic stress limit $q \propto \sigma_{elastic}$ so the better the material's thermal conductivity and the higher its elastic limit are, the better its performance.

3.7.6 Ranking Materials using CES Edupack and the P.I.

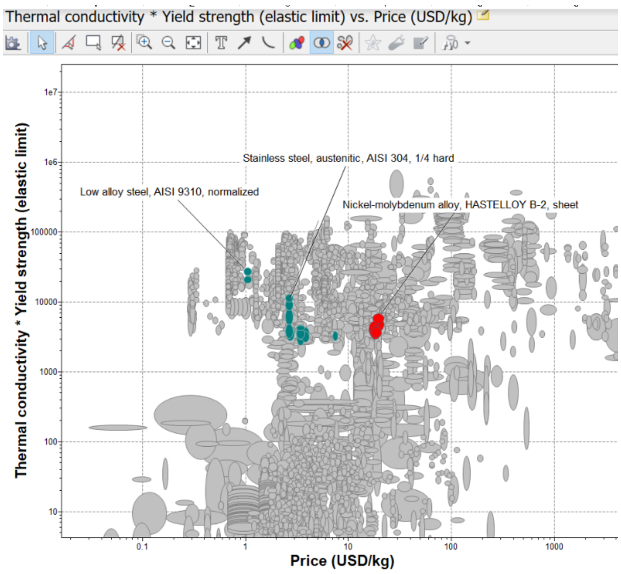

Figure 21: Material Selection heat exchanger

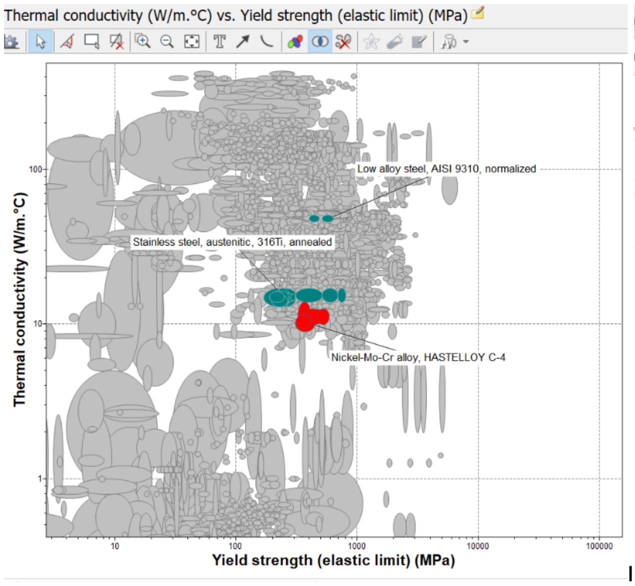

Figure 22: Material Selection heat exchanger , Thermal conductivity vs Yield strength

In order to choose an appropriate material for the heat exchanger tubing, the materials had to be plotted on the Thermal Conductivity - Yield strength axes, based on the performance index derived above. Then, the material choice would have to be narrowed down to choose a material that could withstand high temperature and pressure environments. To do this, a filter was added that filtered out the materials would fail in such conditions. The filter included: Yield strength to be over 20 MPa to prevent plastic deformation, maximum service temperature to be at least 566 to prevent creep, excellent weldability and lastly excellent cold forming ability to ensure it can be produced.

3.7.7 Material Selection

As the result, 19 materials were left to choose from: nickel-based alloys, annealed austenitic stainless steel and low alloy steel. Low alloy steel had the highest performance index out of the 19 materials. It has excellent weldability and cold forming ability, meaning it would be easy and cheap to produce.

3.7.8 Final selection

Low alloy steel: was also the cheapest, Therefore, it would be the best material to make heat exchanger tubing out of. Moreover, when comparing prices, low alloy steel was also the cheapest.

4 Life cycle assessment of the current and new situations

4.1 LCA Goal definition

For the Life Cycle Analysis of both the old coal power plant and the new sustainable power plant, the goals should be defined.

The goal of this LCA is to determine the best sustainable power plant for Lanzhou. This is done to provide the best sustainable environment for the residents of Lanzhou and the wildlife. The initiator of this study is the government of China in the form of the local utilities company.

For the depth of the study, it is chosen to only include 1st order inventorisation. This means that only the construction of the several parts are included and the building of factories to produce these parts and other sub-processes are excluded. The use and disposal phases are included as well. This is done to keep the depth of the study limited, and because the costs of other sub-processes for the two power plants would be about the same. It was also chosen to only model the parts of the power plant that contribute to the core working of the cycle, so the models do not include office buildings and other buildings on the site of the power plant. Furthermore, it was chosen to model the several parts of the Rankine cycle to be made of steel, this also keeps the model simple.

It was chosen to compare both power plants on the basis of ReCiPe, since this gives a good overview of several environmental effects. This study is only meant to be valid for the region of China (or places with similar climate) for the coming 10 years, since the values for the processes were chosen based on the values in China. The temporal validity of 10 years was chosen to be 10 years, because at this moment, the world find itself in a transition period from fossil fuels to sustainable energy. Although fossil fuels will be used less in the future, at the moment fossil fuels are still of critical importance to society. Sustainable energy will be used ever more, but cannot suffice today. In 10 years time, it may be assumed that sustainable energy has taken a large portion of the total fuel consumption and technical aspects have been improved drastically, so that a new life cycle analysis should be performed. The reason not a shorter period was chosen is because the development of and the transition to sustainable energy takes time, so the assumption was made that in e.g. 5 years time, the difference in results are not too large.

4.2 Functional Unit

The functional unit contains 3 recognizable parts:

1. What should be done?
   In this case, the 200MW which have to be produced by the new power plant in Lanzhou.

2. A specification of the function, main limitation or clarification?
   The main function has been eradicated the emissions produced by the old power plant and provide hat to Lanzhou.

3. A unit, the calculation amount of function?
   Per Year, Possible first F.U.

With the above information we came up with four different functional units to the project in Lanzhou:

- To produce constantly 1752000 MW per hour of Electrical power to delivery to citizens and provide 1182600 MJ of heat for one year in Lanzhou and considering that in summer the heat requirement is halved.
- Supply 5280 MW per hour of electrical power to the population in Lanzhou in one day.
- Produce 5280 MW per hour electrical power to fulfil the demand of energy that Lanzhou needs in one year.
- To produce 220 MW of constant power and 130 MW of water during the winter and 65 MW during the summer for the population of Lanzhou for 1 year.

The functional unit for the coal power plant is chosen to be 'to produce 220 MW of constant power for the population of Lanzhou for 1 year.' For the new sustainable power plant it is chosen to be 'to produce 220 MW of constant power and 130 MW of water during the winter and 65 MW during the summer for the population of Lanzhou for 1 year.

We decided to opt the first three functional units out, as the first one is unclear, the second one is in days, which gives 10000+ functional units in a lifespan and the third one does not take heat into consideration.

4.3 LCA coal power plant

4.3.1 Inventory analysis

The life cycle assessment of the current situation in Lanzhou is based on the Gabi model created by the staff members of the University of Twente. This model consists of 3 components, named: production, use and disposal. The fourth component is the total of the power plant.

The production model shows the components taken into account when producing a coal power plant. There is a pump, boiler, steam turbine, condenser, pipe, generator, cooling pump, cooling pipe, cooling tower, power plant structure, conveyor belt, coal bunker and a chimney. This model clearly shows that the production to the structure of the power plant has the most impact of all aspects. The coal bunker has a large influence as well. These make sense, as they are the largest components of the power plant. Striking is the amount of the cooling tower and chimney. These components are large, but it was not assumed that these components has such a large infplan only consists of thermal energy from coal, which makes sense, as that is the only thing this power plant does. In the disposal plan consists of a wide variety of aspects. Some waste ends on landfill, as a direct result of wear and tear of the power plant. Compare this to a rubber bicycle tire, this wears and leaves rubber particles in the environment, landfill. All the rest goes to the plant dismantling, where the largest part goes to the concrete crushing and is then moved by a truck for possible recovery and recycling. The non-concrete components separated into material types and moved by truck after which most materials are recycled. Not all can be recycled, some materials end up on landfill and other components are incinerated. Which makes sense, as not everything can be recycled. For a better understanding, it is recommended to take a look at the process trees.

4.3.2 Profiling

When calculating the impact of the coal power plant with recipe in Gabi, it was striking to see that the use phase of the power plant has by far the largest impact on the 18 midpoints than the construction and dismantling phase. The difference is so large, that these phases are hardly shown in the graphs. It is therefore recommended to read appendixes .... and ... as these include spreadsheets with the impact and normalized impact values. We have scaled these values to fulfilling one functional unit. As the results show, this coal power plant has a large impact on the environment during its 30 years of operation. The only questionable result is that the use-result for ozone depletion negative is. This would mean that the ozone layer increases when burning coal, which seems unlikely to us. Natural land transformation has impact 0 m^2 , which seems logical in the use phase, but when constructing and demolishing the plant, nature got lost and will be given back. The other effects all make sense and show clearly that the use of this power plant leaves the largest environmental footprint. Notable is the fact that the production of the power plant causes the most water depletion. This is due to the fact that producing concrete involves a large water usage. The normalized results show the impact over the lifecycle of this power plant, per person equivalent. Here are some more question marks, as it is strange that water depletion per person equals 0, which is not the case in the total impact. Again, there is a negative ozone depletion, but now during the production phase, which means that building a power plant thickens the ozone layer. That does not make sense. When considering the production phase, the production of the power plant's structure has by far the largest impact on the environment. This makes sense, as the structure is huge, considering the power plant. The condenser comes in second place. The rest of the components do have an impact, but far less than these two components. During the disposal phase, the two processes with the largest environmental impact are the concrete crushing and the supply of the diesel. Since concrete is used for the power plant's structure and that is the largest component, it makes sense that disposing the concrete has a large impact on the environment. It is logical that diesel has the second largest impact, since all separate components need to be transported to their final place before recycling, incineration or landfill. Considering that lots of trucks are needed to transport the disposed power plant, a huge amount of diesel is required for this task. The normalized values again show that the use phase is responsible for the largest impact, per person equivalent. Again there are some questionable results concerning ozone depletion, water depletion and natural land transformation.

.

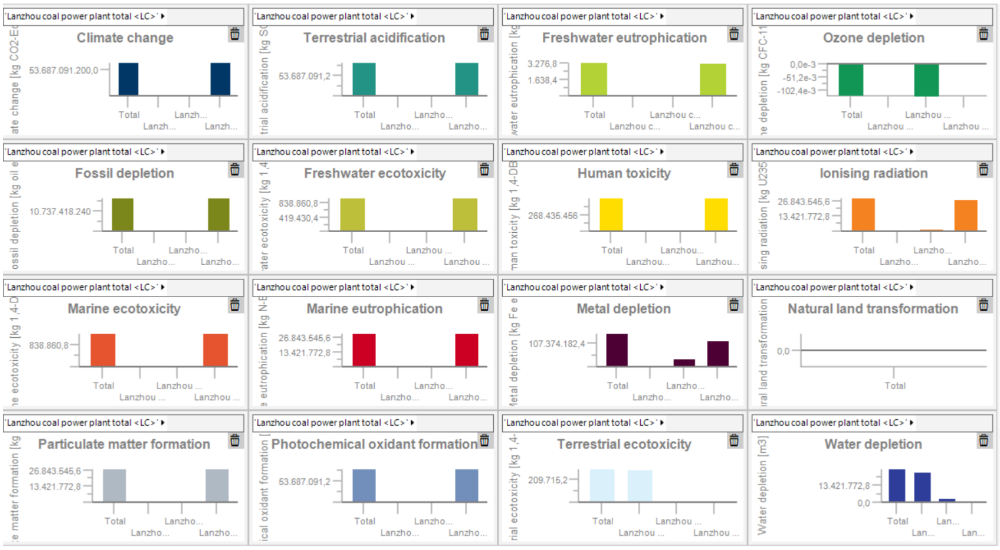

Figure 23: Absolute graphs

4.4 LCA new power plant

4.4.1 Inventory analysis

In this section the modelling of the new power plant is explained, as well as the assumptions that were made during the modelling phase in GaBi.

The new sustainable power plant with solar power and biomass is based on the old coal power plant. The same database has been used, but some components have been added and other comparable components have been scaled down, or scaled up, depending on the mass flow rate or power output of these components.

4.4.2 Production phase

The condenser size was increased by a factor of two, since in the new power plant there is also a mixing chamber. This way the mixing chamber and condenser were modelled as one thing, as these components are relatively similar in function and size.

The generator size was kept the same, as both power plants produce roughly the same amount of power output, so the generator would probably be the same size.

The turbine size was kept the same, because both the old and new power plant are producing the same amount of power, so the turbine sizes would probably be the same. However in the new model three turbines are used, but these together would be roughly the same size as the old one.

The pump size has been increased by a factor of six, because in the new model we also have salt pumps and a pump for the water line to Lanzhou. It was estimated the total mass of all these pumps would be a factor of six times larger than the pump used in the coal power plant.

The pipelines to and from Lanzhou aren't modelled in our power plant, since

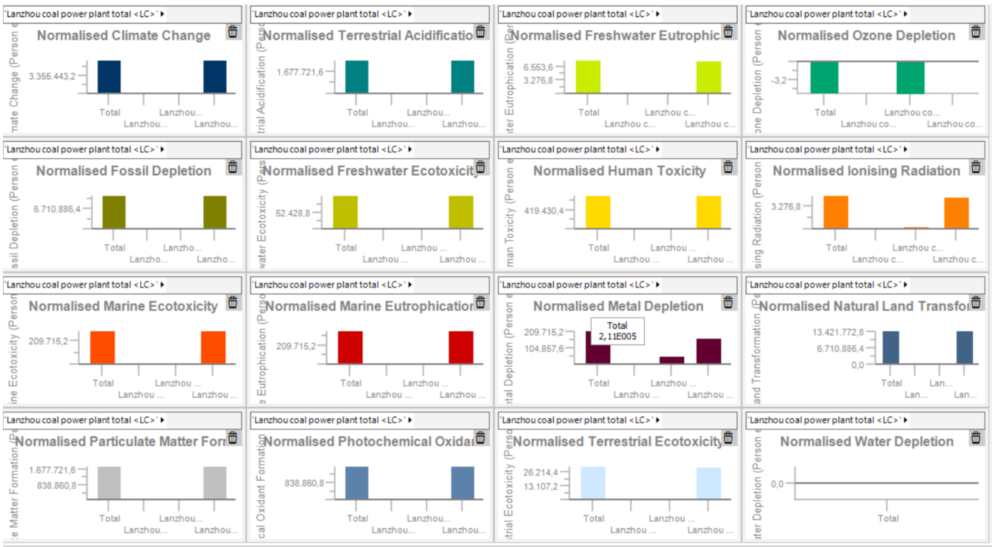

Figure 24: Normalized graphs

there is possibly an already existing pipeline in the Lanzhou pipeline network. However it was also particularly hard to model this pipeline, since it's hard to estimate what length of pipe is needed to bridge the distance to Lanzhou.

For the biomass burner the old coal burner model was used, however it was downsized by a factor of five because in the new power plant about five times less mass is burned.

In the new power plant there are two valves. One is an expansion valve and the other is a regular open/closed valve. It was decided to model these as one type of valve with each a mass of 1000 kg of stainless steel.

For the rest of the pipes in the power plant it was decided to triple the mass of the pipes in the coal power plant, because there is also a salt circuit and pipes going in the solar tower.

The structure was multiplied with a factor of two times the old power plant, since it was estimated that this power plant would be about two times large as the old one.

The conveyor belt was also reused, but with five times less mass, since we burn less biomass per second than coal in the old power plant.

The chimney was kept the same as the old power plant.

The hot and cold salt storages 7,14 million kg of stainless steel, according to information found in the Crescent Dunes brochure.(23)

The solar receiver is modelled as 147 million kg of concrete, 1,82 million kg of stainless steel and 781000 kg of reinforcement steel for the concrete tower. These values were estimated using the information of the Crescent Dunes power plant.(23)

The mirrors are modelled as 3860 kg of glass per heliostat, with 27 kg of aluminium and 100 kg of steel for the framing. In total there are 20688 heliostats. These values were estimated using the information of the Crescent Dunes power plant.(23)

The heat exchangers are modelled as 100.000 kg of steel for the heat exchanger housing and 100.000 kg steel for the tubing. Also 2000 kg of glass wool as insulation was modelled. In the new power plant there are four heat exchangers.

4.4.3 Use phase

The use phase of the new power plant is modelled with biomass and solar energy as input and as output only electricity and thermal energy for the city of Lanzhou. This results in no emissions of CO2, this is because biomass is regarded as CO2-neutral, meaning that all the CO2 it emits is regained during the lifetime of the biomass. This explains also the lack of a use phase in the diagrams, since in theory it doesn't have any emissions.

4.4.4 Disposal phase

The disposal phase was kept mostly the same, but all the values of waste were update to the increased size of all the components in the new power plant. Also some new waste materials were added, for example the glass of the heliostats.

4.4.5 Profiling

The use phase of the solar power plant has an environmental impact of 0 units in all midpoints. This is because solar energy does not have any effect on the environment and the materials released into the environment when burning the biomass, have been taken from the environment when the biomass were living plants.

From the graphs in Gabi, it is obvious to see that the new power plant has the largest ecological footprint in the construction phase. In all categories the production 'beats' the disposal. This makes sense, since the power plant is enormous and requires lots of resources to be built. Disposing however can largely be done by a concrete crusher, because concrete is the most widely used material in the power plant. Other materials are separated and most of it can be recycled, which means that the environmental impact is less than the construction phase.

There are two questionable results. The first one is about ozone layer depletion. This value is negative in total and in production, which would mean an increasing ozone layer when building, but a decrease when dismantling it. That does not make sense to us, building the power plant leaves an ecological mark and should therefore decrease the thickness of the ozone layer. The second questionable result lies in the natural land transformation aspect. Again this value is negative in total and in production. This should mean that, when building this power plant, nature profits from it. This seems very unlikely, because the materials need to be taken from nature, which cannot be beneficial.

The normalized values reaffirm that the largest impact lies in the production phase. Again, the same questionable values occur.

In the production phase, the solar receiver has the largest impact by far. This makes sense, since around 20500 mirrors are put in place, covering multiple square kilometres. These mirrors are huge and should be able to withstand the weather. Therefore the value is very high. The power plant structure comes in second place. This covers the whole body of the power plant and is therefore a large component, which leaves a large footprint. The heliostat has a large impact as well, since it is a huge tower made of concrete.

During the dismantling phase, the largest environmental impact can be written to the concrete crusher. This is logical, since concrete is the material that is most used in the solar power plant and dismantling all of it is an enormous job.

.

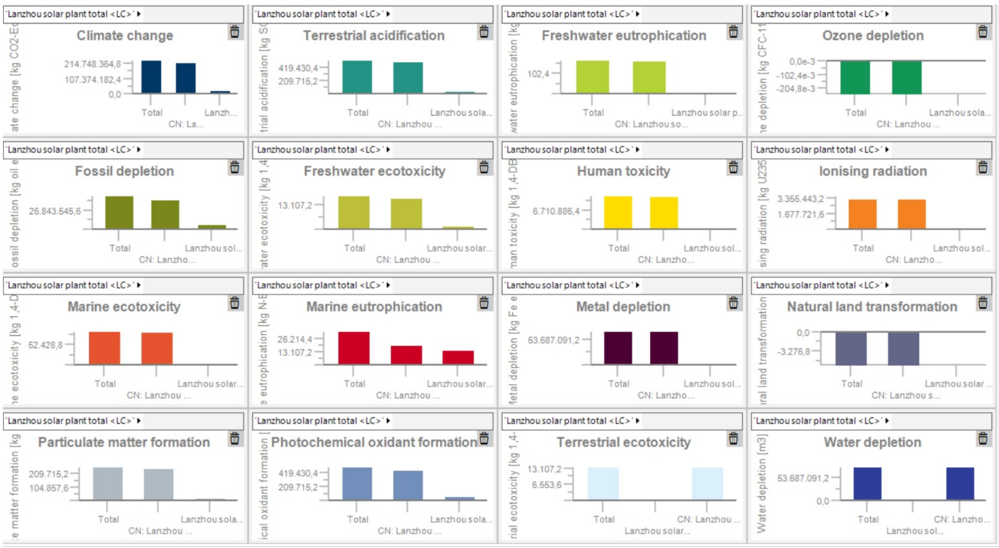

Figure 25: Absolute graphs

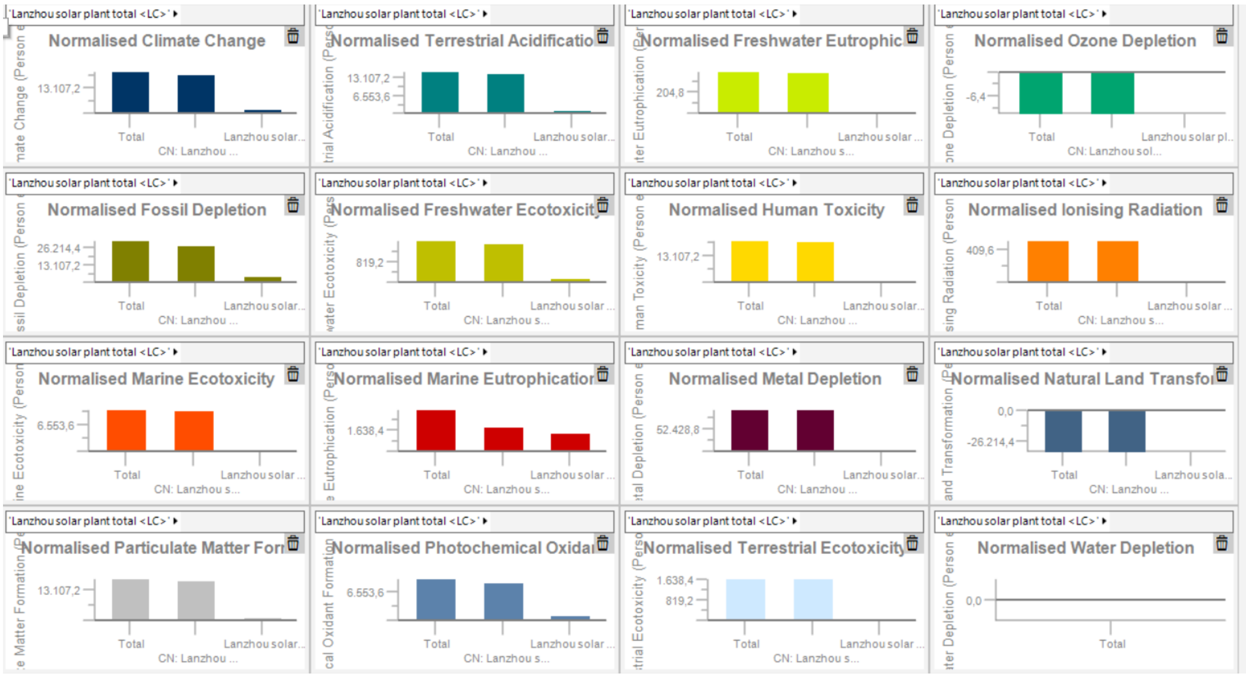

Figure 26: Normalized graphs

4.5 Comparinsion coal power plant versus the new power plant

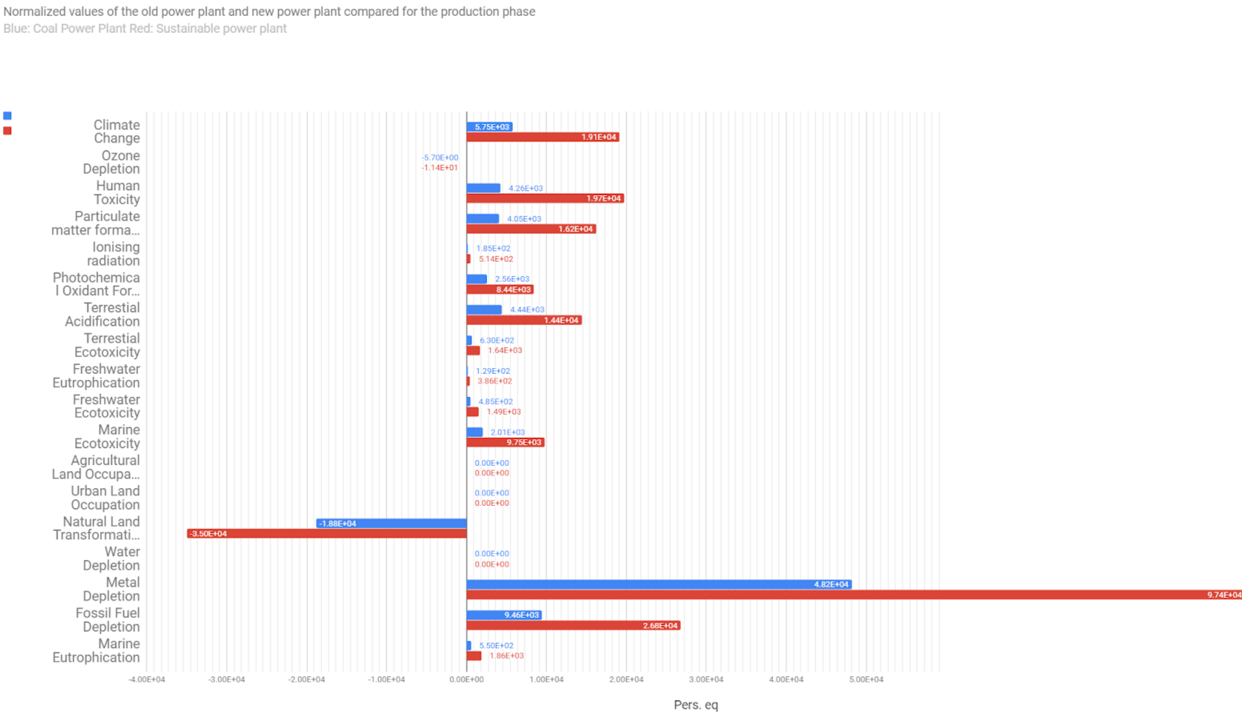

Figure 27: Comparison of both power plants, production phase, normalized values

4.5.1 Production phase, normalized

Figure (27) shows both power plant's production phases plotted against each other. It is interesting to see that the solar power plant has a larger impact on every midpoint than the coal power plant, where some differences are notably larger than others. All differences can be related to the fact that many more materials are being used in the solar power plant.

The solar power plant scores three times worse on Climate Change and Marine Eutrophication.

Ozone Depletion is questionable, but the solar power plant has a double impact.

Human Toxicity and Particulate Matter Formation both are around 4 times larger for the solar power plant values.

Ionising Radiation goes up a little bit, as more concrete means more radiation.

Photochemical Oxidant Formation, Terrestrial Acidification, Terrestrial Ecotoxicity, Fossil Fuel Depletion and Freshwater Ecotoxicity are all about 2.5 times higher for the solar power plant than the coal power plant.

Freshwater Eutrophication of the solar power plant doubles in comparison with the coal power plant.

Agricultural Land Occupation and Urban Land Occupation both have an impact of $0m^2$, in both scenarios. No in the area of the power plant is being used for agricultural purposes, nor urban purposes.

Natural Land Transformation and Metal Depletion for the solar power plant doubles negatively in comparison with the solar power plant.

Water Depletion is $0m^3$, for both scenarios, which is questionable.

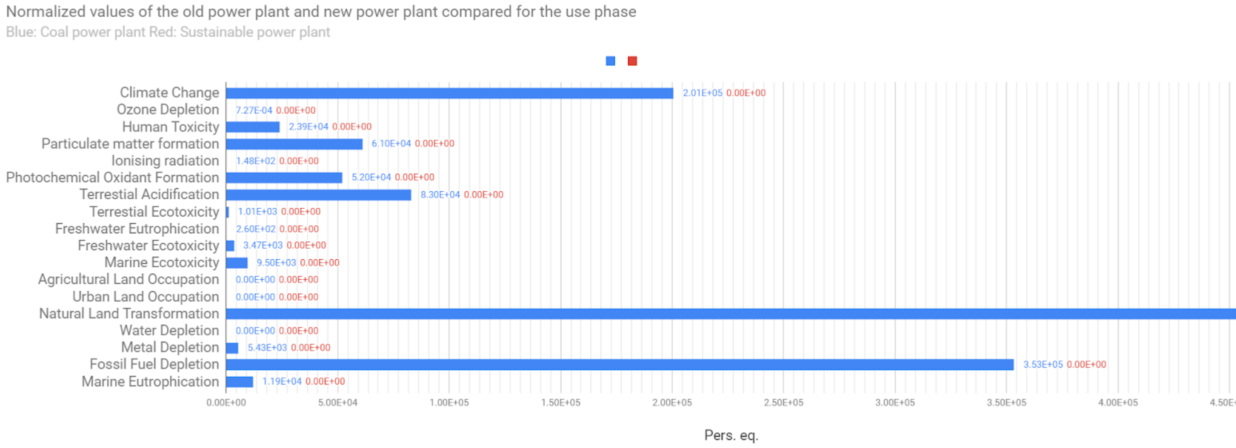

Figure 28: Comparison of both power plants, use phase, normalized values

Use phase, normalized

As indicated before, the solar power plant has a neutral environmental footprint during it's use phase. A comparison of use phases from the coal power plant and the solar power plant is therefore very simple. In all aspects the coal power plant performs an infinite amount of times worse than the solar power plant.

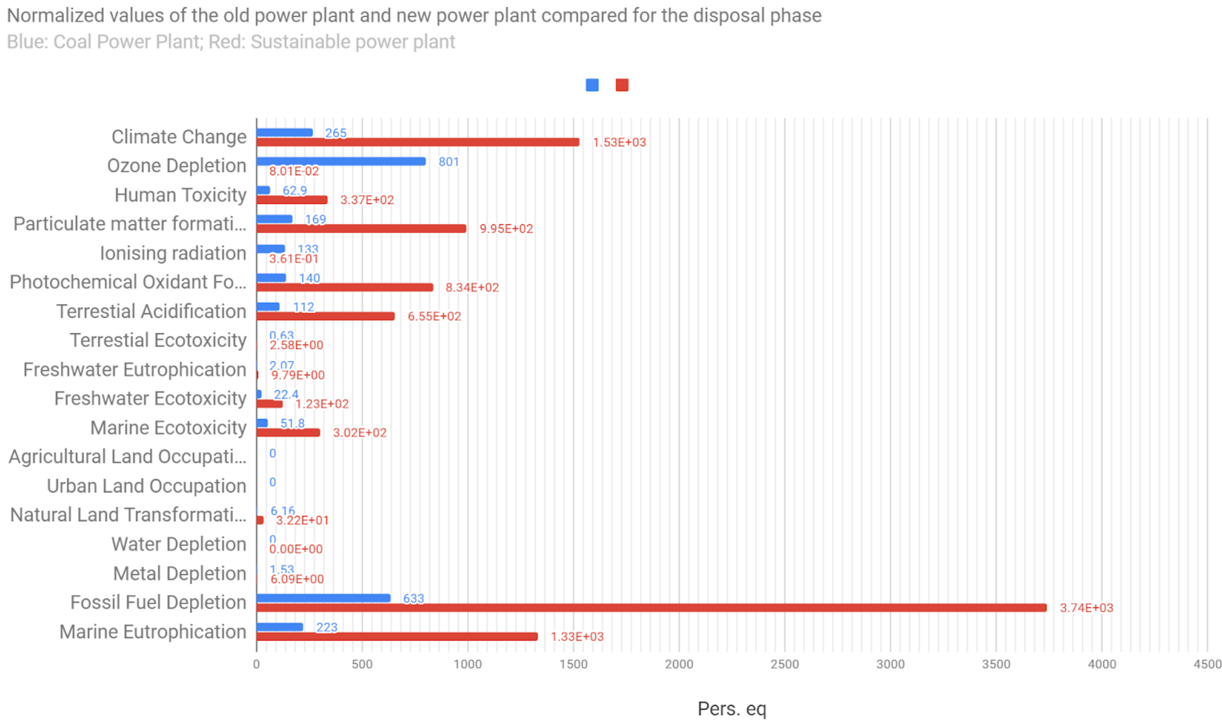

Figure 29: Comparison of both power plants, disposal phase, normalized values

4.5.2 Disposal phase, normalized

From figure (29) can be seen that the disposal phase of the new power plant is for almost all midpoints worse than the coal power plant. This is because of the large amount of extra materials needed to build a concentrated solar power plant.

Climate change is another largely increased midpoint, which is also attributed to the transport of all the materials.

Ozone depletion is actually decreased in the new power plant. It is not known how this is caused, we decided this could be an error somewhere in the model.

Human toxicity has increased with a factor of 6, this is attributed to the large amount of diesel used in transportation.

Particulate matter formation has also greatly increased. This is attributed to the increased transport and the increased amount of concrete crushed in the disposal phase.

Ionising radiation has decreased. It is unknown why this was decreased in the new model.

Photochemical Oxidant Formation has also increased, which is caused by the increased amount of concrete to be crushed.

Terrestrial Acidification has also been greatly increased by the increased amount of concrete and transport.

Terrestrial Ecotoxicity has increased by a factor of five, caused by the increased amount of diesel used.

Freshwater Eutrophication has increased by a factor of five, attributed to the increased amount of diesel used.

Freshwater Ecotoxicity has increased by a factor of six, caused by the increased amount of diesel.

Marine Ecotoxicity has also greatly increased, and is as well caused by the increased amount of diesel.

Both agricultural and urban land occupation haven't changed, but this is because GaBi has no information on the amount of area the power plant takes up. However, the new power plant is much larger in area than the coal power plant, so both of these midpoints will be larger as well. For the disposal phase this would actually mean negative values for these midpoints, since when the power plant is destroyed you get a large area of land back.

Natural land transformation is slightly larger for the new power plant, because of the large amount of diesel used.

Water depletion is for both power plants 0, we believe this is an error in the models.

Metal depletion has also increased for the new power plant, due to the increased amount of materials.

Fossil fuel depletion is the most increased midpoint. This is because of large amount of diesel needed to transport the large amount of concrete and other materials needed for the power plant.

Marine Eutrophication has also increased due to the increased amount of concrete crushing.

It seems that almost all the midpoints have increased by a factor of approximately six, because this is also the amount of increased material used for the new power plant.

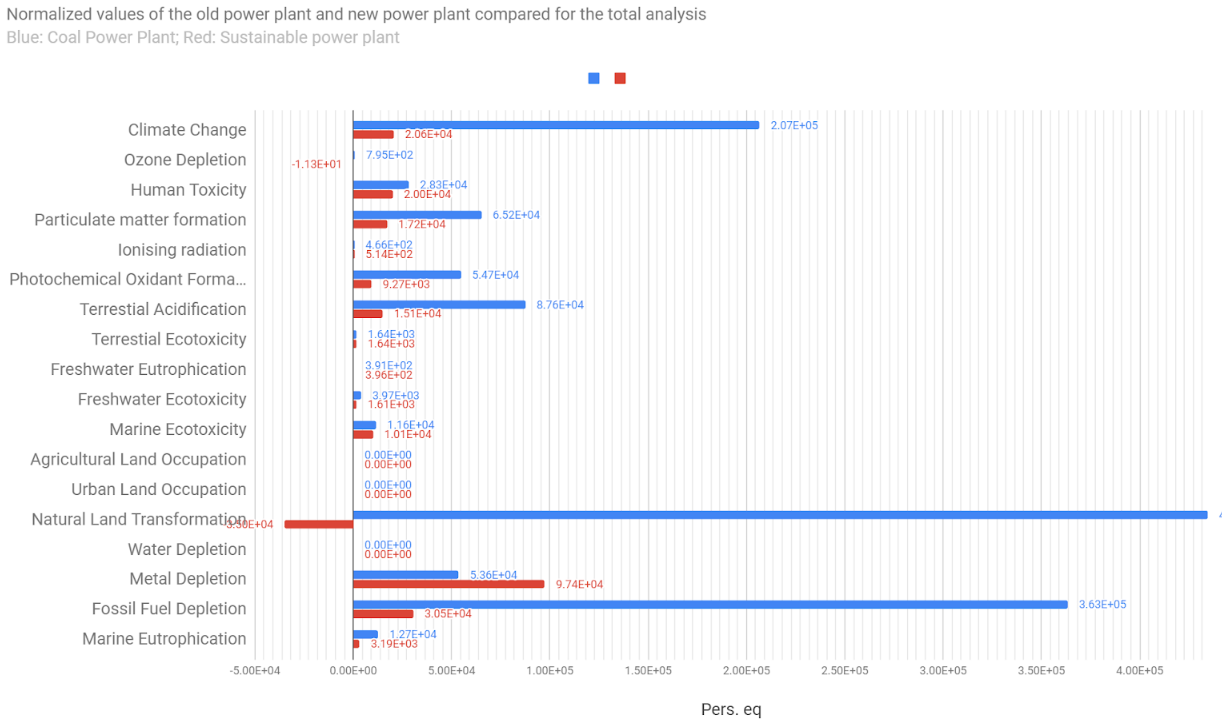

Figure 30: Comparison of both power plants, total values, normalized values

4.5.3 Total

The total figure (30) is the sum of the disposal phase, use phase and production phase. The use phase is 1 functional unit, so 1 year of producing 220 MW of electricity. Since this is a accumulation of all the phases, the conclusions mentioned for the disposal, use and production phase also count for this figure.

It can be seen that after 1 functional unit all the midpoints effects are larger, except metal depletion, for the coal power plant. This is because the use phase is very large. This means that after one year the new sustainable power plant is already better for the environment. This is the same for the entire lifespan, since all ReCiPe midpoints effects are 0 for all effects. So during the entire lifespan of the new power plant it will be better than the coal power plant.

The fact that metal depletion is greater for the new power plant is because of the larger amount of metals used, but after a couple years the new power plant will have less metal depletion, because the coal power plant does cause metal depletion during the use phase, while the new power plant doesn't.

4.5.4 Conclusion and Evaluation

The solar power plant has a moderate ecological footprint when it is being constructed. This is mostly due to the 20500 mirrors, the heliostat and the power plant's structure. This is also valid for the dismantling phase. The use phase does not have any impact, because of the solar energy. Biomass is neutral in totality so it is not added up in this phase. During dismantling most materials are recycled, so it is very difficult to find any improvements here. For the production holds, since huge amounts of concrete are used, it might be useful to try to optimize material use. For instance, to what extent would it be possible to hollow out the heliostat to save concrete but still ensure the structure's strength? The expected life of this power plant is 30 years, so it can fulfil 30 functional units

4.6 Conclusion and Evaluation

The current coal power plant has a large impact on all midpoints in ReCiPe, leaving questionable results for what they are. The production and dismantling phase leave a moderate footprint in the environment, but the use phase has by far the largest impact. This is due to the constant burning of the coal in this phase, which contributes solely to the large impact values. From this model it also follows that the environment is taken into account when dismantling the power plant, most of the materials are recycled. Due to the nature of the coal power plant and the fact that the dismantling phase is as environmentally as possible, it is very hard trying to improve the coal power plant's environmental impact. This power plant has a lifespan of 30 years and can therefore fulfil 30 functional units.

5 Conclusion

The final that have been created in the thermodynamic analysis, is a great idea and meets most of the thermodynamic requirements and also the environment requirements for the new power plant. There are still some improvements that can be added to the system for higher thermal efficiency and higher net power output. Moreover, the selected materials for all the parts of the power plant meet the requirements, this will make it possible to build the power plant. The results from the GaBi model shows that the new system has improved in most of the Midpoints. The overall effect of the new system on the ReCiPe Midpoints is less than the effect of the old system which concludes that the new system has more improvements than the old system.

References

[1] U. of Twente, “Project description,” 2019.

[2] G. Y. power station. Location of Guodian Yuzhong, year = 2019, url = https://www.sourcewatch.org/index.php/Guodian$_{Y}uzhong_{p}ower_{s}tation, urldate =$ $2019-04-04$.

[3] Wikipedia. Lanzhou, year = 2019, url = https://en.wikipedia.org/wiki/Lanzhou , urldate = 2019-04-04.

[4] N. I. for Public Health and the Environment. Lcia: the recipe model. [Online]. Available: https://www.rivm.nl/en/life-cycle-assessment-lca/recipe

[5] S. technology. Power coefficient. [Online]. Available: http://www.ftexploring.com/wind-energy/wind-power-coefficient.htm

[6] F. Macros. Power coefficient. [Online]. Available: https://www.qimacros.com/process-capability-analysis/cp-cpk-formula/

[7] Wikipedia. Wind turbine design. [Online]. Available: https://en.wikipedia.org/wiki/Wind$_{t}urbine_{d}esign$

[8] Electropaedia. Hydroelectric power. [Online]. Available: https://en.wikipedia.org/wiki/Yellow$_{R}iver, sd$

[9] Wikipedia. Yellow river. [Online]. Available: https://en.wikipedia.org/wiki/Yellow$_{R}iver, sd$

[10] T. C. Guide. Lanzhou wether. [Online]. Available: https://www.travelchinaguide.com/climate/lanzhou.htm

[11] Extension. Corn cobs for biofuel production. [Online]. Available: https://articles.extension.org/pages/26619/corn-cobs-for-biofuel-productioncite$_{n}ote-0$

[12] A. K. Kar. Manufacturing process of steam turbine blades. [Online]. Available: https://www.scribd.com/presentation/339826525/Manufacturing-Process-of-steam-turbine-blades

[13] A. chemicals. Turbocharger casting. [Online]. Available: http://www.ask-chemicals.com/foundry-products/applications/turbocharger-casting.html

[14] metals China. Nodular casting, sand casting, iron casting. [Online]. Available: http://www.metals-china.com/nodular-casting-sand-casting-iron-casting.html

[15] Aqualogic. Learn how a heat exchanger works. [Online]. Available: https://aqualogicinc.com/learn-how-a-heat-exchanger-works/

[16] Thermex. Titanium heat exchangers. [Online]. Available: http://www.thermex.co.uk/product/shell-and-tube-heat-exchangers/titanium-heat-exchangers

[17] D. ALEXANDER. Four types of heat exchanger failures. [Online]. Available: https://www.deppmann.com/blog/service-tip-of-the-month/four-types-heat-exchanger-failures/

[18] Youtube. Radiator service building heat exchangers. [Online]. Available: https://www.youtube.com/watch?v=LsfRQGm4-Lc

[19] Comco. Heat exchanger manufacturing machinery. [Online]. Available: http://www.comco.com/corpo$_e/products-heat/heat6$

[20] Airtight. Housing heat exchangers. [Online]. Available: http://advancedcoiltechnology.com/housing/

[21] C. Painting. Factors that affect the rate of corrosion. [Online]. Available: http://www.capital-painting.com/factors-that-affect-the-rate-of-corrosion/

[22] Academia. Materials for heat exchanger tubes. [Online]. Available: https://www.academia.edu/9081744/2$_2$9$_1$3$_M aterials_f or_H eat_E xchanger_T ubes_M aterials_f or_H eat_E xchanger_T$

[23] Issuu. (2019) Crescent dunes. [Online]. Available: https://issuu.com/solarreserve/docs/solarreserve$_c rescentdunes-brochure$

[24] N. I. for Public Health and the Environment. Lcia: the recipe model. [Online]. Available: https://www.rivm.nl/en/life-cycle-assessment-lca/recipe

[25]

[26] Takepart. Climate change. [Online]. Available: http://www.takepart.com/flashcards/what-is-climate-change/index.html

[27] N. Geographic. Ozone depletion. [Online]. Available: https://www.nationalgeographic.com/environment/global-warming/ozone-depletion/

[28] G. V. Houten. Terrestral acidification and ecosystem services: effects of acid rain on bunnies, baseball, and christmas trees. [Online]. Available: https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/ecs2.1857

[29] L. B.Azevedo. Global assessment of the effects of terrestrial acidification on plant species richness. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0269749112004782

[30] E. Ward. Gardening: The ph of your soil can affect plant growth and health. [Online]. Available: http://archive.naplesnews.com/community/gardening-the-ph-of-your-soil-can-affect-plant-growth-and-health-ep-1071358042-331319431.html

[31] G. P. Juan Rocha, Reinette (Oonsie) Biggs. Freshwater eutrophication. [Online]. Available: https://regimeshifts.org/item/55-freshwater-eutrophication

[32] Lenntech. Nutrients in freshwater: The problems caused by an excess of dissolved nutrients in freshwater systems. [Online]. Available: https://www.lenntech.com/aquatic/nutrients.htm

[33] LCANZ. Impact category. eutrophication potential. [Online]. Available: http://www.lcanz.org.nz/sites/default/files/imce/eutrophication$_l canz.pdf$

[34] . N. R. Sergio Durante. Human toxicity potential. [Online]. Available: https://www.sciencedirect.com/topics/engineering/human-toxicity-potential

[35] P. W. M. T. Hertwich EG, Mateles SF. Human toxicity potentials for life-cycle assessment and toxics release inventory risk screening. [Online]. Available: https://www.ncbi.nlm.nih.gov/pubmed/11345472

[36] T. E. O. W. P. . H. POTENTIAL. Photochemical oxidant formation. [Online]. Available: http://encyclopedia.uia.org/en/problem/134677

[37] L. Air. How bad is summer smog? [Online]. Available: https://www.londonair.org.uk/LondonAir/guide/SummerSmog.aspx

[38] ——. How bad are winter smogs? [Online]. Available: https://www.londonair.org.uk/LondonAir/guide/WinterSmog.aspx

[39] U. E. P. A. Ville Miettinen. What is pm2.5 and why you should care. [Online]. Available: https://blissair.com/what-is-pm-2-5.htm

[40] S. E. S. Medicine. Assessment of ecotoxicity. [Online]. Available: https://www.nap.edu/read/18872/chapter/9

[41] W. health organization. Ionizing radiation. [Online]. Available: https://www.who.int/ionizing$_{r}adiation/about/what_{i}s_{i}r/en/$

Appendix

Calculations Concept of wind and hydroelectric power

$$massflow_{totaal} = heat_{requirement}/enthalpy - difference. \tag{9}$$

$$massflow_{winter} = (130 * 10^6)/(504.63 - 377.2) * 10^3 = 1020kg/s \tag{10}$$

During the summer the necessay input is halved so also the massflow of the waterstream which enters the heat exchanger for Lanzhou.

$$massflow_{summer} = (65 * 10^6)/(504.63 - 377.2) * 10^3 = 510kg/s \tag{11}$$

In the ideal case, the turbine is isotropic. The enthalpy of water which leaves the turbine at 1 bar is 2956 kJ/kg and the temperature is 241 degrees celsius. The enthalpy of water at 1 bar and 95 degrees Celsius is 398.03 bar.

$$massflow = power/enthalpydifference = 130MW/(2956-398)kJ/s = 50.8kg/s \tag{12}$$

The entire mass flow is 117.6 kg/s. The mass flow of E3 is:

$$massflow_{E3,winter} = 117.6 - 50.8 = 66.8kg/s \tag{13}$$

The enthalpy at the mixing chamber is the average enthalpy weighted by the mass flow.

$$Enthalpy_{E4} = (E3_{enthalpy} * massflow_{E3} + E2_{enthalpy} * massflow_{E2})/massflow_{E4} \tag{14}$$

$$Enthalpy_{E4,winter} = (2536.4 * 66.8 + 398 * 50.8)/117.6 = 1612kJ/kg \tag{15}$$

Those calculations above correspond with the winter period. In the summer is the requirement heat half of the winter so the mass flow is also half of the winter. This means that the mass flow in E3 is 25.4 kg/s in the summer. The mass flow in E2 is:

$$massflow_{E3,summer} = 117.6 - 25.4 = 92.2kg/s \tag{16}$$

The enthalpy in the summer after the open feedwater heater will be:

$$Enthalpy_{E4,summer} = (2536.4 * 92.2 + 398 * 25.4)/117.6 = 1992.2kJ/kg \tag{17}$$

The loss of power in the low pressure turbine is:

$$powerloss = enthalpy_{difference} * massflow \tag{18}$$

$$(2956.6 - 2536.4) * 66.8 = 28MW \tag{19}$$

The 18 Midpoints of ReCiPe explained

The Life Cycle Assessment software used is GABI. GABI uses, amongst other things, the 18 midpoint effects of ReCiPe 1.08. The purpose of this document is to explain what ReCiPe is, determine the 18 definitions, explain the definitions and formulate their importance on LCA.

First of all, what is ReCiPe?
ReCiPe is an LCA-tool developed by RIVM, CML , PRé Consultants, Radboud Universiteit Nijmegen and CE Delft. (24) ReCiPe's first development was in 2008, and the tool was thoroughly revised in 2016. The version used for this project is the 2016 one.(25)

ReCiPe uses 18 midpoint effects and 3 endpoint effects to analyse the environmental impact of a system during its lifecycle.

What are midpoint and endpoint effects?
The aim of a midpoint effect is to show the effect of a single environmental problem. Below is a list of the 18 midpoint effects ReCiPe uses. The advantage of dealing with a single, specific effect is that the effect it has on the environment can be said with a large certainty. The disadvantage is that these effects can be very difficult to interpret.

The endpoint effects are easier to interpret, as these are more general than the midpoint effects. The three endpoint effects are:

- Damage to human health
- Damage to ecosystems
- Damage to resource availability

The 18 midpoint effects can all be classified as part of the endpoint effects, where some midpoint effects can be classified in more than one endpoint effect. The disadvantage of the endpoint effects is that, because they are more general, they are more uncertain than the midpoint effects.

For this project, it is sufficient to use the 18 midpoint effects. The 3 endpoint effects will not be further discussed.

Climate Change
Climate change is the change of weather patterns over extended periods of time, sometimes even millions of years. It is often also called global warming, this is the rise of the average temperature on earth. This is dangerous because too much global warming will cause the ice caps to melt, which will cause a rise of the sea level. This means parts of the world will be flooded with water. Another danger is massive drought, because of the increase in temperature.(26)

The main substances that contribute the most to climate change are greenhouse gases, such as carbon dioxide. These emissions come mainly from the burning of fossil fuels, caused by humans.

The unit of climate change is kg CO2 equivalent. This means this factor is measured by the mass of CO2 that has an equal impact to climate change as the substance you're researching.

Ozone Depletion
Ozone depletion is the depletion of the ozone layer, this is a layer around the earth which protects us against UVB radiation. When this layer depletes, we

slowly lose or protection against the sun's radiation. This means that skin cancer, a disease caused by ozone depletion, will be more common. However, it will also cause harm in other animals and organisms. (27)

The primary cause of ozone depletion are Chlorofluorocarbons (CFC's). These chemicals are mostly present as gasses in things like hairspray, but are also present in other things.

The unit for ozone depletion is kg CFC-11 equivalent. Meaning this factor is measured by the corresponding mass of CFC-11 that is equally destructive to the ozone layer as the substance you're researching.

Terrestrial Acidification

Terrestrial acidification is a term that describes soil acidity and how it impacts global plant variety. The main cause of this is acid rain, which occurs due to nitrogen oxide and sulfur oxide emissions.

As mentioned before, nitrogen oxide and sulfur oxide are the main pollutants that acidify water in the atmosphere, causing acid rains. These emissions mainly come from combustion of fossil fuels (such as coal, oil, gasoline, etc.) in factories , oil refineries and combustion engines in vehicles.

Soil acidity impacts availability of nutrients essential for plant growth and effectiveness of fertilizers, which leads to nutrient deficit. Furthermore, aluminium can be dissolved at low soil pH, which is toxic for plants. Therefore, if the soil pH gets too low due to acid rain, plant growth can worsen.

The unit that measures Terrestrial acidification is pH, which is the concentration of hydrogen ions in moles per liter (mol/l). Higher hydrogen ion concentration is – the more acidic it is. ReCiPe uses the unit [kg SO2 equivalent] to determine the change in pH and therefore the terrestrial acidification. (28) (29) (30)

Freshwater Eutrophication

Freshwater eutrophication is a process which occurs in fresh water. This process refers to excessive growth of water plants, for example, algae, as the result of high nutrient concentration in water.

Freshwater eutrophication can be very harmful on the wildlife inhabiting in the affected waters. This is because when a large amount of plantation dies in the water, it uses up the majority of the oxygen and, in some cases, completely drains the water from oxygen, leaving water oxygen levels low. This therefore causes underwater wildlife to suffocate.

The largest pollutant that causes Freshwater eutrophication is phosphorus and nitrogen. Those two nutrients mostly come from industrial work, farm lands and sewage waste. Those nutrients support plant and algae growth and when they are in excess it can lead to a more rapid and extensive growth, which, as mentioned before, is dangerous for the ecosystem.

The unit of measuring freshwater eutrophication is kg Phosphorus equivalent. So the more nutrients and phosphorus there are in soil, the more severe the impact is. (31) (32) (33)

Marine Eutrophication

The same as Freshwater Eutrophication, Marine Eutrophication is the increase of supply of organic matter in an ecosystem. The case can be deposition of nutrients in rivers or coast. Another cause can be reactive nitrogen emissions from burning fossil fuels.

The main effect is an increase in phytoplankton in coastal areas. This is similar to freshwater eutrophication, where an increase in lower order organisms can be found. Result is that food chains will be disrupted by the increase in food supply for higher order organisms.

The characterization factor of marine eutrophication accounts for the environmental persistence of the emission nutrients containing nitrogen (N). The unit is kg year per N to marine equivalents.

Human Toxicity

The human toxicity potential (HTP) is a calculated index that reflects the potential harm of a unit of chemical released into the environment. It is based on both the inherent toxicity of a compound and its potential dose. Total emissions can be evaluated in terms of benzene equivalence and toluene equivalents. The potential dose is calculated using a generic fate and exposure model, CalTOX, which determines the distribution of a chemical in a model environment and accounts for a number of exposure routes, including inhalation, ingestion of produce, fish, and meat, and dermal contact with water and soil. Toxicity is represented by the cancer potency q1* for carcinogens and the safe dose (RfD, RfC) for non carcinogens.

The unit of 1,4-dichlorobenzene (DB) equivalents/kg emission is used to calculate each toxic substance. Depending on the substance, the geographical scale varies between a local and global indicator. (34) (35)

Photochemical Oxidant Formation

Photochemical oxidant formation is also known as summer smog. It can occur in urban places and the surrounding countryside when there is no to little wind. When there is no wind, exhaust gasses can not defuse. When the density of those gasses increase, the gasses will react with each other under influence of sunlight. That is the reason why photochemical is in the name. In the reactions will ozone and other toxic compounds be formed.

POF has a negative influence on the flora, but also people can suffer from POF.

The most reactive and harmful substances are nitrogen, dioxide and hydrocarbons with reacts to ozone, nitrogen oxides and other toxic compounds. Nitrogen en dioxide comes from the exhaust gasses of cars and industrial pollution.

The unit of photochemical oxidant formation (POF) is kg NOx-eq*kg$\hat{-}$1. By this functional unit is equivalent to the mass of nitrogen oxides calculated/measured of one kilogram air. The more nitrogen oxides, the higher the impact will be. (36) (37)

Particulate Matter Formation

Particulate matter formation (PMF) is better known under the name winter smog. PMF can occur when there is a thin layer of air cooler than above it. Sulfur dioxide and fine dust can not distribute to the air and will form smog.

Sulfur dioxide and fine dust are the emissions which have the most negative influence and result in PMF. Those emissions come from burned coal. That is a reason why PMF is common in industrial places.

PMF has a negative influence to the human health, especially for older people, children and humans with heart and lung diseases.

The unit in which PMF is expressed is kg primary PM2.5-equivalents/kg. PM2.5 are particles that have a diameter less than 2.5 micrometer. Such particles are NOx, SO2,NH3. This unit express how much of those particles exist in one kilogram of air. (38) (39)

Terrestrial Ecotoxicity

Why is it an effect?

Products emitted during the lifecycle of different products and substances may particularly generate damages to the ecosystem especially to the soil, resulting to harmful effects to the ecosystem.

Where do the emissions come from?

Terrestrial ecotoxicity can occur due to different things like: pesticides, disposal of heavy metals(arsenic, mercury, lead, aluminum and cadmium) and dioxins which can be produced as a result of a combustion processes.

What is the unit for this effect?

The unit for this effect is [kg 1,4 - DB eq.]

Freshwater Ecotoxicity

Why is it an effect?

Toxification of freshwater can cause the production of (forming cancerous cells) in animals which can lead to death, also plants can die which will change the ecosystem.

What emissions are important?

Emissions to water that are toxic to animals and vegetation and emissions that harm the environment.

Where do those emissions come from?

Pesticides, disinfectant, deodorant, mothballs, dyes and pigments and the production of some polymers.

What is the unit for this effect?

The unit for this effect is [kg 1,4 - DB eq.]

Marine Ecotoxicity

Marine ecotoxicity is the ability of a chemical or physical agent to have an adverse effect on the marine environment and the organisms living in it, such as fish, plants, fungi, and algae. Ecotoxicologists rely on a small set of indicator organisms and an understanding of how the physicochemical properties of compounds cause them to partition in the environment and organisms. Those model systems and approaches have provided toxicologists with a surprisingly robust ability to predict the relative hazard of different substances. Because the stated goals of most environmental assessments are primarily on the preservation of species and populations and less with individual organisms (with the exception of large charismatic species, such as bears, mountain lions, and most birds), the end points used most often in hazard assessments are survival and reproduction, with growth included as a surrogate for reproductive fitness in many species. The unit in which MET is expressed is kg 1,4-dichlorobenzene (DB) equivalents. This means that MET is equivalent to an amount of 1,4-dichlorobenzene emitted. (40)

Ionising Radiation Ionizing radiation is radiation with enough energy so that during an interaction with an atom, it can remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized. Here we are concerned with only one type of radiation, ionizing radiation, which occurs in two forms - waves or particles. Forms of electromagnetic radiation. These differ only in frequency and wavelength.

- Heat waves
- Radio Waves
- Infrared light
- Visible light
- Ultraviolet light
- X rays
- Gamma rays

Longer wavelength, lower frequency waves (heat and radio) have less energy than shorter wavelength, higher frequency waves (X and gamma rays). Not all electromagnetic (EM) radiation is ionizing. Only the high frequency portion of the electromagnetic spectrum which includes X rays and gamma rays is ionizing.

Only the amount of energy of any type of ionizing radiation that imparted to (or absorbed by) the human body can cause harm to health. To look at biological effects, we must know (estimate) how much energy is deposited per unit mass of the part (or whole) of our body with which the radiation is interacting. The international (SI) unit of measure for absorbed dose is the gray (Gy), which is defined as 1 joule of energy deposited in 1 kilogram of mass. The old unit of measure for this is the rad, which stands for "radiation absorbed dose." - 1 Gy = 100 rad. Equivalent dose – the biological effect depends not only on the amount of the absorbed dose but also on the intensity of ionisation in living cells caused by different type of radiations. Neutron, proton and alpha radiation can cause 5-20 times more harm then the same amount of the absorbed dose of beta or gamma radiation. The unit of equivalent dose is the sievert (Sv). The old unit of measure is the rem. - 1 Sv = 100 rem. ReCiPe uses the unit 'kilogram U-235 equivalent'. Uranium-235 is highly radioactive and well known, so it was a logical choice to compare ionizing radiation the the effects of Uranium-235. (41)

Agricultural Land Occupation

Agricultural land occupation refers to the place that is occupied to perform agricultural work, cultivate food and producing them. In order to place the new solar power plant, specific location was chosen before, It results that a portion of the agricultural land is being occupied by the new project, however, It is not a problem due to the new location is in the mountains , and the climate condition is not the best to cultivate, furthermore ' the activities of Lanzhou are more focus on the industrialization and Tourism, they don't use those places to cultivate anything.

There are no fields to cultivate in the close area of Lanzhou, moreover, There are forest and park, those help with oxygen to the population. In the place where will be located the solar plant, a few trees and plants are going to be affected, however, the main sources of oxygen production will not be affected in any way. The new power plant will not issue any gas, no future emission for Lanzhou. The unit for agricultural land occupation is m^2. This is logical, because it measures an area which is being transformed.

Urban Land Occupation

As the same as the agricultural land occupation , these places are used to build houses and for the settlement of people, however in China they have very strict laws regarding birth rates, maintaining a controlled growth and It guarantees that places to live are sufficient for them , but if necessary , the place where the power plant will be located is not recommended to live because it is in the mountains and it is difficult to access, our plant is very well located, without causing future problems. In case of emission should be produced by building the houses causing pollution and the destruction of the environment The unit for urban land occupation is m^2. This is logical, because it measures an area which is being transformed.

Water Depletion

Water depletion can simply be described as: If more water is taken from an aquifer, then is being replenished in the same time frame, the total amount of water available in the aquifer is less after this period then the amount started with.

Water depletion has far reaching consequences. For a start, if (ground)water is depleted, the (ground)water level drops over time and lakes or other surface water shrinks. Wells fall dry, which is the start of a shortage of drinking water. Furthermore, the agricultural sector gets into trouble as they need to create deeper, more expensive wells to water their crops, making prices go up. Another problem of water depletion is that the ground could subside, as the groundwater pushes the ground above it up. This is especially of great danger to buildings, they could tople, these need to be reinforced, which will have a high price tag.

The substance that has to be taken into account is solely water, since water is the only substance that has any influence on water depletion. If nature is given time to replenish the aquifer, the problem will solve itself.

The unit for water depletion is [m^3]. This means that for every process or life cycle an amount, a volume, of water is depleted.

Natural Land Transformation

Natural Land Transformation describes the amount of land which used to be nature, but after a life cycle or process is no longer nature. For instance, the land has transformed from a forest area into an open mining site. The problem with natural land transformation is that, in this way, nature slowly gets lost and smaller. This has the consequence that wildlife is having to live on an increasingly smaller area. Natural Land Transformation will cause plants and trees to go extinct, since these creatures cannot move themselves and will be lost first. Animal species will follow, if NLT is not being countered for. The unit for natural land transformation is m^2. This is logical, because it measures an area which is being transformed.

Metal Depletion

Metal depletion is the effect that in certain processes metals get used. This wouldn't be an issue if all the metals are completely recycled, but since most of the time this is not the case, metals get stored in landfills, where they are lost.

The result of lost metals is that new metal will be harder to obtain, meaning it will cost more energy to obtain, which is usually obtained from oil/gas/coal. This also results in the decreased availability of those materials. This means it is also related to fossil fuel depletion another midpoint impact in ReCiPe.

The unit of metal depletion is [kg Fe equivalent], this means that when other materials are lost in a process it is converted to the amount of iron that would cause the same amount of metal depletion. (24)

Fossil Fuel Depletion

It has taken earth millions of years to create fossil fuels in the form of e.g. coal and oil. For the past 150 years, humanity has been using these fuels on an ever larger scale. This scale is so large that the earth cannot create new fossil fuels. Hence, fossil fuels are depleted at the moment. The problem with fossil fuels is that, when being used/burned, lots of greenhouse gases are emitted. These gases lead to, amongst other things, climate change and are bad for human health. Other consequences of fossil fuel depletion is that, when wells/mines are getting empty, humanity needs to find new ones, which makes fuel prices go up and could e.g. lead to deforestation. Fossil fuel depletion is measured in [kilograms oil equivalent]. This means that the depletion of fossil fuels is compared to what 1 kilogram of oil would deplete.