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BACHELOR THESIS

DESIGN AND SOURCING STRATEGY OF PV-SYSTEM FOR WATER WELL IN MONGOLIA

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Bachelor's thesis at the Lucerne School of Engineering and Architecture

Title	**Design and sourcing strategy of PV-system for water well in Mongolia**
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Abstract German
Diese Thesis hatte zum Ziel, eine PV-Anlage und den Anschluss an eine Tauchwasserpumpe für einen Wasserbrunnen zu entwickeln, damit die erforderliche Leistung geliefert werden kann. Dies beinhaltete die Evaluation möglicher Speicher- und Absicherungsoptionen unter Berücksichtigung der Umgebungsbedingungen des Standorts. Die Energy Systems Assessment Methodologie wurde angewendet. Sie beinhaltete die Analyse der aktuellen Situation, die Entwicklung alternativer Lösungskonzepte und die Auswahl der Bewertungskriterien. Basierend auf den Bewertungskriterien, wurden die Lösungskonzepte mit einer Lebenszykluskostenrechnung und einer Gefahrenanalyse bewertet. Die Zwischenergebnisse wurden dann in einer Multikriterien-Entscheidungsanalyse verwendet, um die beste Lösung zu ermitteln. Die Ergebnisse der Analyse sprachen für eine 5,28-kW-Photovoltaikanlage mit einer 4-kW-Tauchwasserpumpe und einem 5-kW-Benzingenerator als Absicherungsoption. Nach der Auswahl des geeignetsten Systems für einen zuverlässigen Betrieb der Pumpe wurde eine Bewertung möglicher Beschaffungsstrategien nach lokalen Möglichkeiten vorgenommen. Den Ergebnissen zufolge sollte das System in Deutschland bezogen und dann in die Mongolei transportiert werden.

Abstract English
The purpose of this thesis was to design a PV system and connection to a submersible water pump for a water well so that the required power can be provided. This included evaluating possible storage and back-up options, considering the environmental conditions of the location. Using the energy system assessment methodology, the current situation was analysed, alternative solution concepts were developed, and the assessment criteria were chosen. The alternative solution concepts were assessed with a lifecycle cost analysis and a hazard analysis based on the assessment criteria. Then the results were used in a multi-criteria decision analysis that revealed the best alternative. The developed solution was a 5.28-kW photovoltaic system with a 4-kW submersible water pump and a 5-kW power gasoline generator as a back-up option. After selecting the most suitable system to operate the pump reliably, an evaluation of possible sourcing strategies according to local possibilities was made. According to the results, the system should be sourced in Germany and then transported to Mongolia.

Horw, 04.01.2021

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Abbreviations and acronyms

Abbreviations

AC	Alternating Current
AHP	Analytic Hierarchy Process
B/C	Benefit Cost Ratio
CAS	Compressed Air Storage
CBA	Cost Benefit
DC	Direct Current
DM	Decision Maker
FCF	Free Cash Flow
FU	Functional Unit
HSLU	Hochschule Luzern
ISO	International Organization for Standardization
KPI	Key Performance Indication
kW	Kilowatt
LCA	Lifecycle Assessment
LCC	Lifecycle Costs
LCCA	Lifecycle Costs Analysis
LCI	Lifecycle Inventory
LCIA	Lifecycle Inventory Analysis
LED	Light Emitting Diode
MCDA	Multi-criteria Decision Analysis
MNT	Mongolian Tugrug
NPSH	Net Positive Suction Head
NPV	Net Present Value
OPEX	Operating Expenses
PCE	Parametric Cost Estimation
PD	Positive Displacement
PtG	Power to Gas
PV	Photovoltaic
TCO	Total Cost of Ownership
WBS	Work Breakdown Structure
Wp	Watt Peak

Indices

i	In-plane
out	Consumption
STC	Standard Test Conditions

Latin Letters

E	Energy	kWh
H	Irradiation	kWh/m^2

Greek Letters

η	Efficiency

1. Introduction

This paper describes the design and sourcing of a small-scale photovoltaic system for a family of nomadic herders near Guchin-Us in Mongolia. The climate in Mongolia is arid with strong temperature fluctuations (seasonal and daily). The farmers who live at the border of the Gobi Desert are therefore dependent on wells to water their animals and for their own water supply. In 2000, the Mongolian government launched its National 100,000 Solar Ger Electrification Programme. Today, 70 % of nomads use mobile solar energy systems to power electrical appliances such as freezers, milking machines or LED televisions. (Mobile Solar Energy – Mongolia, o. J.)
This paper describes the design and sourcing of a small-scale photovoltaic system for a nomadic herder family near Guchin-Us in Mongolia. The small-scale photovoltaic system will provide energy to an electric water pump to retrieve water from a well to feed animals and irrigate the fields.

1.1 Current Situation

"Mongolia, the "Land of Blue Sky" enjoys more than 260 sunny days a year, typically between 2'250 and 3'300 hours each year. There are no more than two consecutive days without sun" (ERINA, 2003). This paper and its study look into a location near Guchin-Us in Mongolia. There already is a water pump installed. Currently, the water pump is supplied with energy from a single-phase gasoline generator with 3 kW peak power and 2.8 kW rated power.
The water pump is located 30 meters underground and consumes 0.75 kW of AC power.

1.2 Problem Description

In Mongolia, the average income per capita is $3780 (World Bank, 2020). Farmers that depend on gasoline generators to pump water from a water well spend most of their income on gasoline. Then the water is used for feeding their animals and irrigating fields. The water well is located near Guchin-Us. The herd consists of about 6000 animals. Each animal consumes 25 litres per day. During the winter months, the animals drink around 10 times per month from the water well, equivalent to 1'500'000 litres per month. In the summer months, the animals drink around 15 times per month from the water well, equivalent to 2'250'000 litres per month.
As a gasoline generator powers the submersible pump, this leads to a high gasoline consumption of 60 to 70 litres per month. That is not environmentally friendly but most important, it is costly for the family that already has a small household budget given by Mongolia's economic situation. As the gasoline price is 1'500 MNT per litre, it costs the family 90'000 to 105'000 MNT, which equals to 28 to 32 CHF per month to operate the water supply.

It can be assumed that it is a significant expense considering that the monthly Household Income per Capita reached 124.5 CHF in Dec 2019 (CEIC, o. J.).

1.3 Project aim and objectives

In the following table the project aim and objectives are described.

Project Aim	• A financially and ecologically advisable PV-system is designed • A possible sourcing strategy is chosen
Project Objectives	• Design of the PV system and connection to a water pump for the well so that the required power can be provided. • Evaluation of possible storage and back-up options, whereby temperatures can drop to minus 20°C in winter. • Selection of the most suitable system to operate the pump reliably. • Evaluation of possible sourcing strategies according to local possibilities.

Table 1: Project aim and objectives.

2. Literature Review

This chapter shows the existing research about the climate in Mongolia, energy storage systems, functionality of a photovoltaic system and water pumps.

2.1 Climate

This subchapter shows existing information about the climate in Mongolia. This information is retrieved from the software “Meteonorm” which is briefly described below.

2.1.1 Meteonorm

Meteonorm is a software that contains worldwide irradiation data, making it easier for engineers to estimate meteorological conditions. Meteonorm has a combination of reliable data sources and calculation tools. It provides access to typical years and historical time series (intro - Meteonorm (de), o. J.).

2.1.2 Mongolia

“Mongolia’s climate can be described as a highly continental dominated climate with warm summers and long, dry and very cold winters. Known as "the land of blue sky", Mongolia is a very sunny country and has usually about 250 sunny days a year. The country has the world's most typical continental climate with extreme diurnal and annual ranges of temperature” (Climate of the World: Mongolia, o. J.).

The location of the water well is marked with a red star in Figure 1 below.

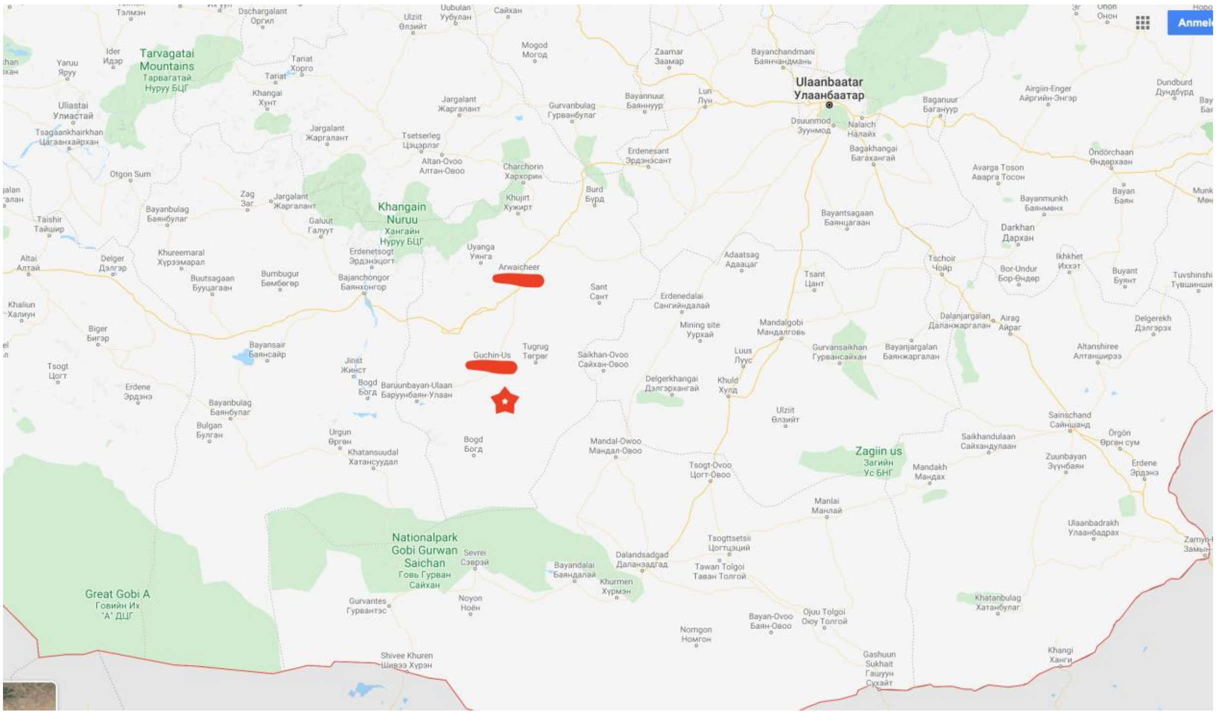


Figure 1: Location of water well.

The Meteonorm software can be used to estimate climatic conditions in the area near Guchin-Us, by plugging in the coordinates with a solar azimuth of South 35°, the results seen in Figure 2 and Figure 3 are obtained. As seen in Figure 2 the inclined surface shows a better average energy yield over the whole year than the horizontal one.

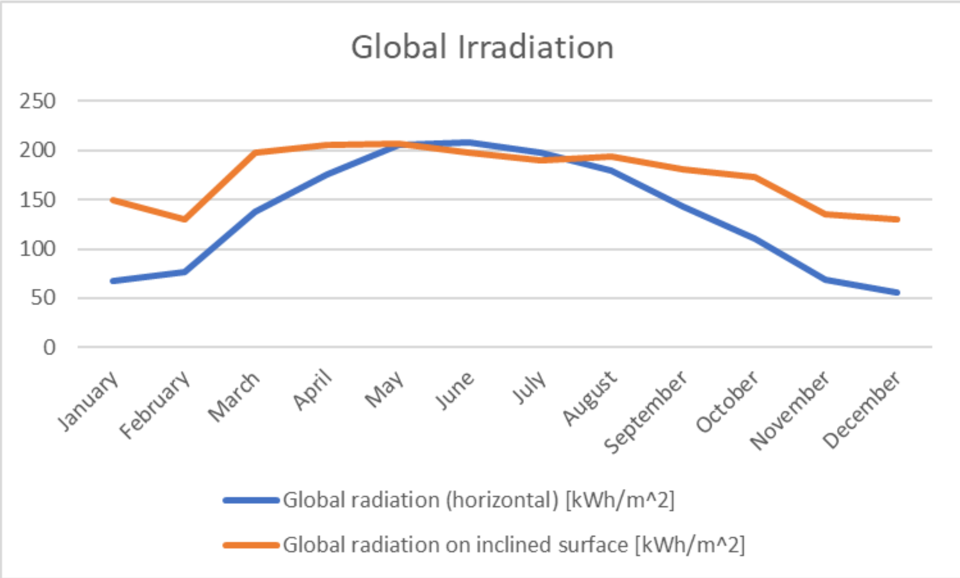


Figure 2: Global Irradiation at the location (Meteonorm).

To compute the average daily irradiation per month, the irradiation value of each month was divided by the number of days in each month, in that way the graph in figure 3 is obtained.

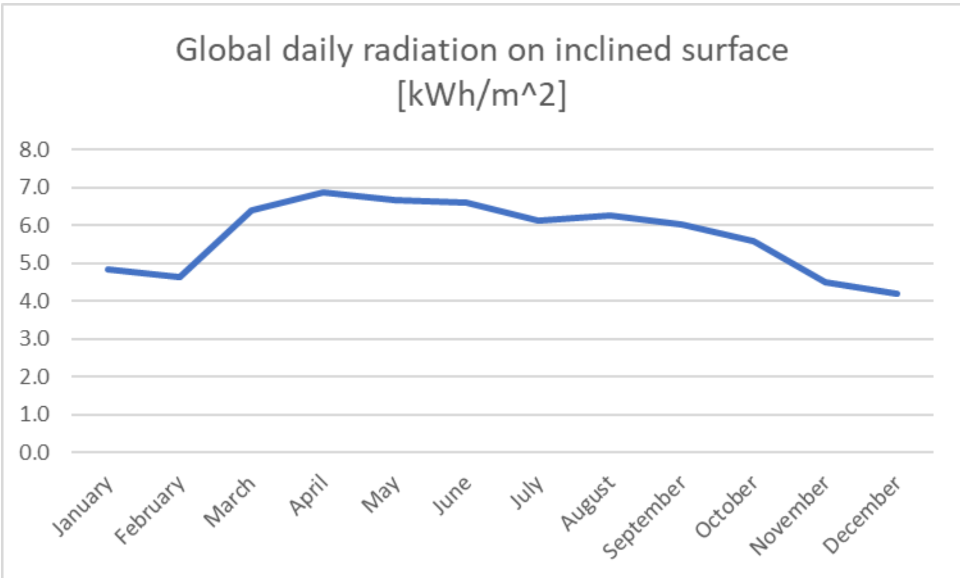


Figure 3: Global daily irradiation on inclined surface.

In Figure 4 the average temperature each month is displayed. The temperature strongly varies from winter months to summer months resulting in a delta of around 40 degrees. In the winter months, the temperatures in the data set reach -18°C, and in the summer months, the temperatures in the data set reach 22°C.

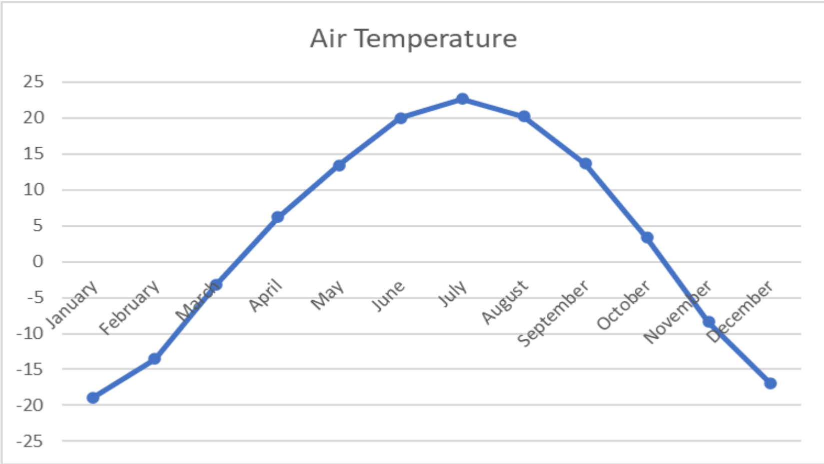


Figure 4: Average air temperature per month.

Another important information is the number of rainy days at the location. During the summer months, it is warmer, but there are also more rainy days per month. There are six rainy days at most in the month of July.

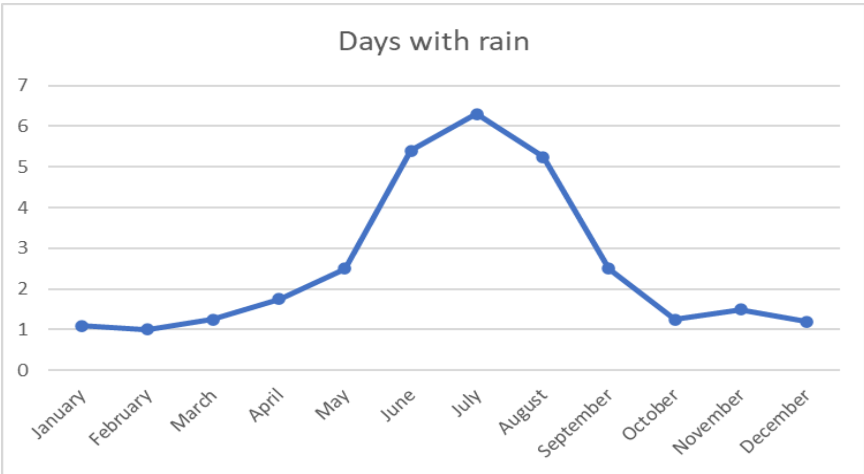


Figure 5: Days with rain per month.

Summarizing, the climate of Mongolia is very polarizing. It has high temperatures in the summer and very low temperatures in the winter. As the number of sunny days per year is high, and the irradiation per square meter is also high, the location favours the use of solar energy.

2.2 Energy Storage

"An energy storage system is an energy technology facility for storing energy in the form of internal, potential, or kinetic energy. It performs three processes: charging (loading), storing (holding), and discharging (unloading). These processes are physically implemented by energy converters (charging and discharging), storage units (holding), and peripherals. A complete facility, including all these components, is called an energy storage system." (Sterner & Stadler, 2019, S. 24)

Energy storage systems can be subcategorised in:

- Electricity storage systems
- Thermal storage systems
- Electrochemical storage systems
- Mechanical storage systems
- Chemical storage systems

Electricity storage systems store energy in the form of electricity. Examples are capacitors and superconducting electromagnetic energy storage systems. The advantage of these systems is a prevention of possible high conversion losses, the disadvantage of the low energy density and extremely high costs.

"Electrochemical systems use electrodes connected by an ion-conducting electrolyte phase. In general, electrical energy can be extracted from electrochemical systems. In the case of accumulators, electrical energy can be both extracted and stored. Chemical reactions are used to transfer the electric charge." (Sterner & Stadler, 2019, S. 230). There are commonly used low-temperature batteries such as lead, nickel and lithium batteries, and high-temperature batteries such as sodium-sulfur batteries.
The lead battery was invented over 100 years ago and is one of the best-known electrochemical storage systems. It is commonly used as a starter battery in automotive applications, but it can also be used for stationary applications such as emergency electricity supply. Lead batteries have a long service life if operated under good conditions. Conditions that accelerate ageing of lead batteries are deep-discharging, long idle periods in deep states of charge, maintaining cell temperature below 20°C or above 45°C, and not adjusting charging temperature to the cell temperature. (Sterner & Stadler, 2019, S. 245-260)
"Nickel batteries were developed to meet the need for electrochemical storage with a higher energy density and greater reliability than conventional lead batteries." (Sterner & Stadler, 2019, S. 262)
The advantages appear in the remarkably higher energy and power densities, and the low final charging voltage for a full charge. These are commonly used in consumer electronics and some hybrid vehicles.
Lithium batteries are the most common high-performance and high-energy batteries. Lithium cells must be constantly monitored and controlled for safe use. This type of battery has the longest service life of all batteries mentioned above if the state of charge remains between 30% and 70%. (Sterner & Stadler, 2019, S.280-302)

Electrochemical-energy storage offers an alternative to electrical storage without the disadvantage of low energy density and extremely high costs. Compared to other energy storage systems, the costs are still higher. The advantage of the battery systems is their flexibility. It can be used in a variety of applications without the necessity of a big investment in infrastructure.

Electrochemical energy storage reaches higher capacities than electrical storage at smaller costs, but at the expense of efficiency. This is also true for chemical energy storage. The capacity limits of batteries are reached when there is a need for a low-loss and long-term energy storage. Chemical energy storage is a large topic that entails a lot of different technologies and materials. This paper will focus on the storage of renewable energies in the form of gaseous (power-to-gas, PtG) energy carriers for electricity, more specifically in power to hydrogen.

The way PtG works is the following: Electricity is produced by renewable energies and used in electrolyses. This process produces hydrogen and oxygen. The hydrogen is then compressed and stored. The stored hydrogen can then be used in a variety of ways, such as to produce electricity in a fuel cell, in a combustion engine or in a gas turbine. Using it in a fuel cell would be the most efficient way, the efficiency in this case would be between 54-85 % (Sterner & Stadler, 2019, S.325 - 478).

Mechanical Energy Storage can be made with three storage media: Gaseous, liquid, and solid.
In Compressed Air Energy Storage, energy is used to compress air to high pressures. Later, when energy is needed, the air is released, and it flows through a turbine driving a generator. In the liquid media category, there are hydro pumped storage plants widely used around the globe. In the solid media category, there are two main systems: Flywheel and Hydraulic Rock Storage System, the ladder being a concept that has not been realised yet. The functionality of a flywheel storage system is the following: electrical energy is used to power a motor that drives a flywheel. The flywheel is located inside a low-pressure environment to reduce air friction. When energy is needed, the flywheel drives a generator.

Figure 6 shows the comparison of existing storage facilities and demonstrates how widely the characteristics and application areas of different storage technologies vary. The double-logarithmic diagram shows the discharging duration "t_{aus}" up to about a year on the vertical axis and the storage capacity on the horizontal axis (Sterner & Stadler, 2019, S.646).

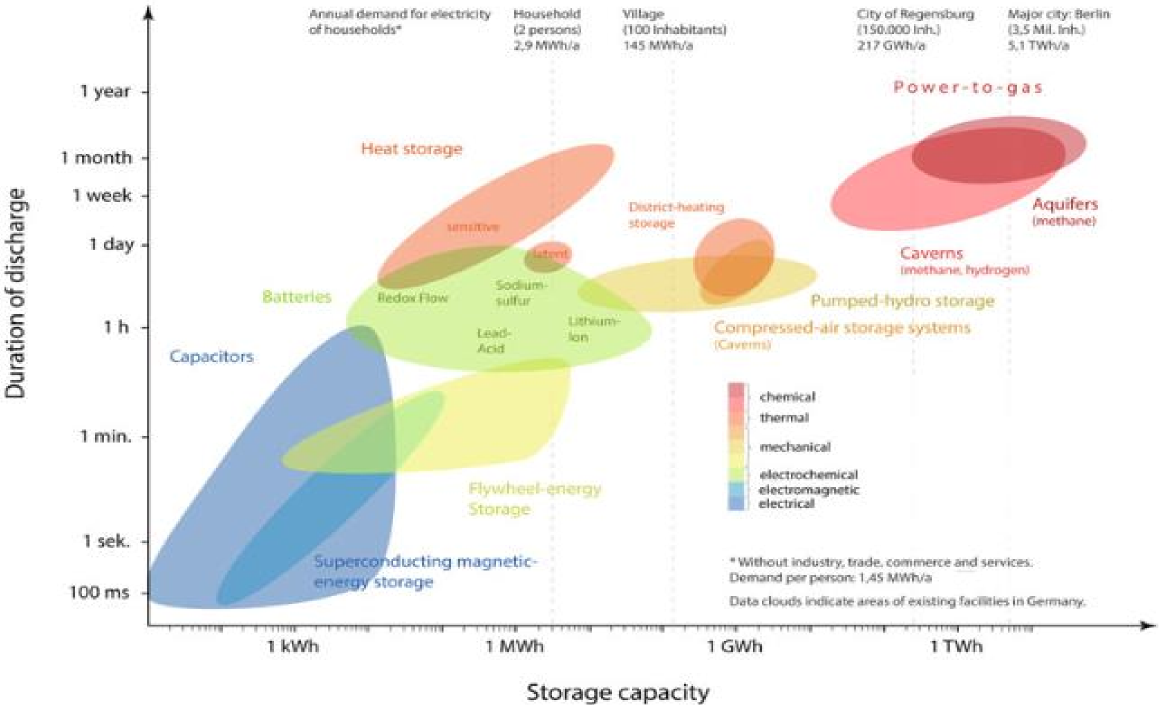


Figure 6: Storage types compared with storage capacity and discharging duration (Ragone chart): the circled areas indicate German facilities which have existed since 2013.

Figure 7 lists technical and economical parameters for storage technologies that can apply to this case. Because the levels of development differ, the parameter ranges vary substantially in some cases (Sterner & Stadler, 2019, S. 640)

Technology	Technical						Costs		
	Energy Density		Efficiency	Self-discharge	Service life		Capex		OPEX
	Gravimetric	Volumetric			Cycle life	Service life over time			
	Wh/kg	kWh/m^3	%	%/day	Cycles	a	€/kW h	€/kW	€/kW h
Pumped storage plants	0.3-1.4	0.35-1.1	70-82	0-0.5	12'800-33'000	40-100	40-180	550-2'040	0.08
Compressed air energy-storage (CAES)									
Diabatic	-	2.0-7.0	40-55	0-10	8'620-17'100	40	40-80	340-1'145	0.01-0.26
Adiabatic	-	2.0-8.0	60-68	n/a	-	n/a	n/a	600-800	n/a
Flywheel storage systems	5.0-90	210	83-93	72-100	>1 million	n/a	650-2'625	125-275	1
Capacitors	0.1-10	10	90-95%	0.004-0.013	1 million	10	5'150-12'000	125-300	n/a
Coils	1	10	92	10. Dez	> 1 million	30	13'570-75'670	300-915	n/a
Lead-acid batteries	25-40	25-65	74-89	0.17	203-1'500	10	90-355	200-490	0.16-0.76
nickel batteries	55-75	60-105	71	n/a	350-2'000	n/a	385-1'100	385-1'100	n/a
Lithium Batteries	110-190	190-375	90-97	0.008-0.041	3'500-20'000	15	140-180	100-200	0.13-0.76
Power-to-hydrogen-to-power (el. gen. at n=0.6 & compr. 80 bar)	-	-	34-44	-	-	-	-	-	-

Figure 7: Overview of averages of essential technical and economic parameters for a range of storage technologies (Sterner & Stadler, 2019, S. 641–645).

2.2.1 Summary Energy Storage

Electric-Energy Storage Systems store low quantities of energy in the kilowatt-hour range and have extremely short discharging durations. Therefore, they are only used in niche areas, ensuring voltage quality in electricity networks.

Battery storages have capacities in the range of several megawatt-hours. The discharging durations could go up to a day and can be used in a wide variety of applications. The applications span from consumer batteries in the milliwatt region to battery megapacks in the megawatt region used as storage power plants. These systems are limited to applications in the electricity and electric transport sectors.

Pumped storage or CAS differ significantly from flywheel storage. In the short-term range, the capacity and power of flywheel storage systems have considerably higher capacities than electric storage systems, but only slightly longer discharging durations. Flywheel-energy storage systems are used as phase shifters to provide short-circuit capacity in the electricity network or for recuperating braking energy in the transport sector. CAS systems have somewhat lower capacities than pumped storage over durations of a day. Both systems are bound to specific geographical sites. They can be used to supply balancing energy in the electricity sector. Pumped-storage facilities usually have several gigawatt-hours of storage capacity, resulting in an enormous quantity of total storage potential. The facility dimensions depend on the location conditions and vary widely.

Chemical-energy storage will be a key element of the future renewable energy system. Because each facility ranges in the terawatt-hours capacity, the chemical-energy storage is the storage system with the largest capacity. Chemical-energy storage is the only option for seasonal energy storage using the charging technology PtG in combination with the existing gas infrastructure for storing and converting gas into electricity.

2.3 Photovoltaic

Basic Function

Silicon is a semiconductor. That means it is neither a conductor nor an insulator. Semiconductors only conduct electricity under certain conditions. A solar cell contains two layers of two different type of silicon that have been specially doped in order to make the electricity flow through in a particular way. One type of the layer is positive-type silicon (p-type) and the other one is a negative-type silicon (n-type). When a layer of n-type silicon is set on a layer of p-type silicon a barrier is formed at the junction of the two layers. The electrons cannot cross this barrier. If the solar cell is connected to a device no current will flow. If light shines in the solar cell, the photons will transfer their energy to the atoms in the silicon. Said energy pushes electrons out of the p-type layer to the n-type by flowing around the circuit.

2.3.1 Types of modules

Figure 8 shows the market share of different solar cell technologies. Monocrystalline and multicrystalline dominate the market. Therefore, this subchapter will focus on these two technologies. Monocrystalline has a very high efficiency of 21.5%, in comparison, multicrystalline has a lower efficiency of 17%. Both cells are made of silicon a material that is widely available. Although monocrystalline has a high efficiency, it takes this cell longer to produce the same amount of energy used in the production process. The difference between these two technologies is the purity of the silicon. Monocrystalline has a higher purity which leads to a higher efficiency but also to higher costs (Mertens, 2015, S. 121–155).

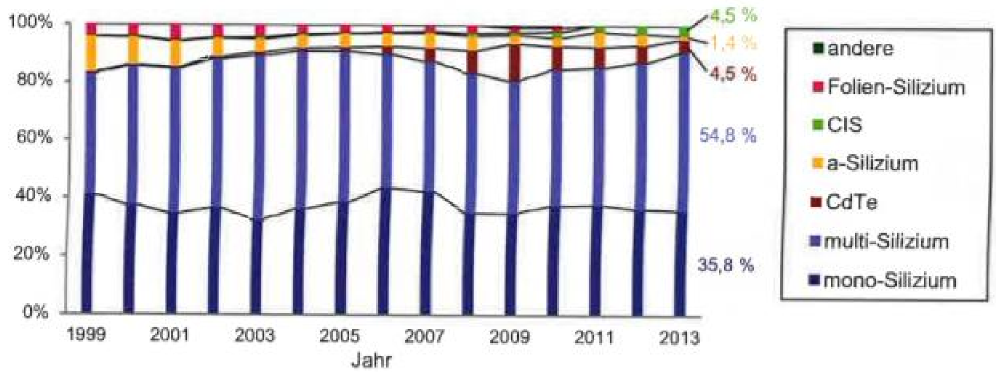


Figure 8: Share of the different cell technologies in percent over the years. (Mertens, 2015, S. 156)

2.3.2 Off Grid systems

Photovoltaic off-grid systems are usually used when an electric grid is not available or if the connection to the grid is too expensive. The basic off-grid system consists of photovoltaic modules, a PV inverter or a charge controller and a battery, a deep discharge protection, DC-Loads and AC-Loads.
DC-Loads could be lamps, radios, fridges or even water pumps.

2.3.3 Dimensioning

If the PV system is connected to the grid, it is very easy to dimension because it is always possible to draw energy from the grid in case of a shortage. For off-grid systems it is not that easy. The expected consumption needs to be determined exactly in order that the PV-Array and storage have the correct dimensions.

Consumption data should be separated in winter and summer. The important data for energy consumption is the load power and time per day which when multiplied with each other equals the energy per day. For the dimensioning of the PV-Array the data needs to be about the irradiation in the region so that the yield of the solar modules can be calculated, the efficiency of the modules and of the charger also needs to be taken into consideration. Once the data is gathered it can be plugged-in the formula 2.1.

$$PV_{STC} = \frac{E_{out}}{H_i * \eta_{charge} * \eta_{PV}}$$ (Mertens, 2015, S. 1–3) (2.1)

- E_{out}: Energy consumption
- H_i: In-plane irradiation
- η_{charge}: Efficiency of the charging process

For the dimensioning of the battery the formula 2.2 can be used.

$$C_N = \frac{E_{out} * n}{V_{sys} * DOD_{lim} * \eta_{dis}}$$ (Mertens, 2015, S. 261) (2.2)

- C_n: Battery Capacity
- n: Days of autonomy
- V_{sys}: Voltage of system
- DOD_{lim}: Limit of the depth of discharge

2.4 Water pump

A pump is an energy absorbing device that transfers most of the energy to a fluid. There are volumetric machines and turbomachines. In a volumetric machine, energy transfer is accomplished by moving the system boundary. Turbomachines use rotating shafts with attached blades to exert work on a fluid.
The following Table 2 displays the major types of positive displacement pumps including their advantages and disadvantages.

Pump	Description	Advantages	Disadvantages
Sliding Vane Pump	Rotary pump where vanes cooperate with a cam to draw liquid into a chamber and force it out with pressure from the pump chamber.	Simple construction. Self-compensating for wear. Good operation with low viscosity liquids.	Inability to pump highly viscous liquids. Cannot handle fragile solids.
Sinusoidal Rotor Pump	A rotor having the shape of two complete sine curves turns in a housing, creating four separate, symmetrical pumping compartments. A sliding scraper gate covers part of the rotor, oscillates as the rotor turns, and prevents return of the fluid back to the suction part of the pump.	Low shear. Gentle handling of fragile solids and highly viscous liquids.	Limited ability to handle highly abrasive liquids.
Flexible Impeller Pump	The rotor is made of an elastomeric material such as rubber. The elastomeric blades continuously deflect and straighten as they pass across a cam between the inlet and discharge ports. The flexing of the blades produces a vacuum that causes the liquid to flow into the space between the two blades and then moves the liquid through the pump.	Dry self-priming. Can handle liquids with solids, abrasives or entrained air. Relatively inexpensive;	Upper limits of flow and pressure. Cannot run dry longer than a couple of minutes.
Flexible Tube Pump	Rollers or cams attached to the rotor squeeze a flexible tube made of rubber as they pass across it, drawing the liquid through the pump.	Sealless. Can handle quite corrosive liquids. Dry self-priming. Relatively inexpensive.	Relatively low flow and pressure capability. Hoses require changing about every 3 months;

Progressing Cavity Pump	The threaded screw or rotor is made of an elastomeric material. As the rotor rotates inside the stator, cavities form at the suction end of the stator, with one cavity closing as the other opens. The cavities progress axially from one end of the stator to the other as the rotor turns.	Ability to pump highly viscous liquids, shear sensitive liquids, fragile solids, and abrasives. Very little pulsation. Self-priming;	Relatively high higher cost of replacement parts. Large floor space requirement. Cannot run dry for long periods. Upper temperature limit of 150°C;
External Gear Pump	External gear pumps have two meshing gear that by rotating squeeze the liquid form the low-pressure side to the high pressure side.	Can operate at relatively high speeds, producing high pressures. The pump is relatively quiet. Pulsation free. Economical;	Cannot tolerate solids or abrasives without timing gears;
Internal Gear Pump	Like external gear pumps, move and pressurize liquid by the meshing and unmeshing of gear teeth. In an internal gear pump a rotor having internally cut teeth meshes with and drives an idler gear having externally cut teeth.	Few moving parts. Low cost. Only one seal. Can operate in either direction;	One bearing must support an overhung load. Generally, will not work with abrasives or solids;
Rotary Lobe Pump	A lobe pump is similar to an external gear pump, in that the liquid is carried between the rotor lobe surfaces and as they rotate, they provide continuous sealing. One pump cannot drive the other to this pump requires timing gears.	Ideal for handling food products containing fragile solids. Low shear.	Pressure pulsations. High amount of slips with low-viscosity liquids; Must have timing gears;
Circumferential Piston	Instead of lobes the rotors have arc shaped pistons, traveling in annularshaped cylinders machined in the pump body.	Same as Rotary Lobe Pump;	Same as Rotary Lobe Pump. Large floor space requirement.
Multi-Screw Pump	The liquid is carried between rotor screw threads and is displaced axially as the screw threads mesh.	Economical. High upper limit of viscosity. High flow rates; High pressure with low pulsation;	Cannot tolerate severe abrasives.
Piston Pump	Piston pumps are reciprocating pumps consisting of a power end and a liquid end. The power end converts the rotary driver motion to reciprocating motion. The liquid end consists of a chamber having liquid inlet and outlet ports.	High pressure capability with high head; Able to handle abrasive liquids;	Limited to slower speeds because of unbalanced forces;
Plunger Pump	Similar to piston pump, except the reciprocating member is a plunger rather than a piston;	Higher pressure applications than piston pumps; Higher speed than piston pumps;	Higher maintenance expense than piston pumps; Lower abrasion resistance than piston pumps;
Diaphragm Pump	Similar to piston and plunger pumps, except that the reciprocating motion of the pump causes a diaphragm to flex back and forth, which in turn causes the liquid to flow into and out of the liquid end of the pump.	Highly accurate in measuring flow; Leak free; Sealless; Self-priming and are able to run dry; Compatible with a variety of liquids;	Low flow rates; Limitations on pressure; Large pressure pulsations; Energy inefficient;

Table 2: Major types of positive displacement pumps adapted from Volk (2014, S. 15-32).

Certain application criteria demand the use of a positive displacement pump. The ability to pump liquids with high viscosity efficiently is one of the advantages of positive displacement pumps over

centrifugal pumps. Most of the positive displacement pumps are inherently self-priming. Therefore, these pump types can be conveniently mounted on the top of transfer tanks with no special external priming devices (Volk, 2014, S. 13).
A centrifugal pump consists of an impeller attached to and rotating with a shaft and a casing that encloses the impeller. The liquid is forced into the inlet side of the pump casing by atmospheric pressure or some upstream pressure and as the impeller rotates, liquid moves toward the discharge side of the pump (Volk, 2014, S. 6). In the following Table 3 , the major types of centrifugal pumps are described.

Pump	**Description**	**Advantages**	**Disadvantages**
Close-Coupled Pumps	The liquid enters the pump from the end, with the discharge being at a right angle from the shaft. The impeller is directly connected to the motor shaft. The pump casing is directly attached to the end face of the motor.	Compactness, simplicity and lowest cost configuration for single stage pump. Does not require coupling alignment.	Limited to 60 HP; Flow, head, and temperature limitations. To access the impeller the motor must be moved.
Frame-Mounted Pumps	Like close-coupled pump but pump and motor are separated by a shaft. The pump has its own bearing frame, with radial and thrust bearing.	Larger size because of separate bearing frame which means higher HP possibilities. Can be used in high temperatures and corrosive liquids.	Oil lubrification. Larger than close-coupled pumps.
Inline Pumps	Usually oriented vertically and may be close-coupled or frame mounted. The suction and discharge flanges are located inline with each other and on the opposite sides of the pump.	Less floor space. The piping coming into and out of the pump is simpler because the suction and discharge flanges are in line with each other.	Larger sizes may require external support. Design is less stable from a structural standpoint. Leakage from the packing or mechanical seal does not always freely drip down to a collection cup, rather it can collect at the stuffing box mounting area.
Self-Priming Centrifugal Pumps	Because of the case design the pump can do the priming procedure by itself.	Self-priming. Minimizes maintenance problems. No external vacuum source is required.	More expensive. Limitations on maximum flow and suction lift.
Split Case Double Suction Pumps	The casing splits along the axis of the pump shaft with a double suction impeller.	Mechanical design is more structurally stable. Lower net positive suction head (NPSH) than single suction impeller.	Must have two mechanical seals.
Vertical Column Pumps	A single stage end suction pump that has been oriented vertically, with the addiction of the long column pipe enclosing the shaft and the discharge pipe. The impeller is immersed below the liquid level.	Relatively inexpensive. Simple construction. Easy to maintain.	Sleeve bearing tends to wear on one side because of radial loads. Limited to a length of 6 meters.
Submersible Pumps	This pump is designed to operate submerged in the pumped liquid. The motor is often encapsulated and filled with oil that is separated from the pumped liquid.	Able to operate submerged. Able to handle waste water and solids.	It must be operated underwater, which can lead to high installation costs.
Slurry pumps	Slurry pumps are used where liquids containing abrasive particles must be pumped. The two most common material choices for slurry pumps are rubber-lined and hard metal pumps.	Able to handle liquids with abrasive particles.	Lower head and efficiency

Vertical Turbine Pumps	The liquid enters the lower end of the vertical turbine pump through the suction bell. The flow passes through one or more stages that have either open or closed impellers. The liquids flows then thought a vertical pipe with a line shaft before being discharged 90° horizontally.	Design allows for optimum efficiency. Lower installation costs in many cases. No foot valve or priming necessary.	Maintenance problems. More susceptible to resonance.
Axial Flow Pump	There are two types of axial flow pump, one type is similar to the vertical turbine pump with a single impeller and a vertically oriented shaft. The other type has the impeller mounted in a cast or fabricated elbow.	High flow rate.	Low head.
Regenerative Turbine Pump	Instead of having the traditional backward-curved vanes, a regenerative turbine impeller has radially oriented teeth, having an increasing depth with increasing diameter. As the impeller rotates, it increases the liquid's velocity. As the liquid moves past the teeth, the expanding area form the increasing depth causes the liquid velocity to decrease, achieving the change to pressure energy.	High head. Low cost and compact. Can handle up to 20% vapor or noncondensable gases in the pumped liquid.	Low Flow. Not as efficient as a multistage pump. Very tight running clearances. Pumped liquid must be very clean and nonabrasive.

Table 3: Major types of centrifugal pumps adapted from Volk (2014, S.190 -227).

2.4.1 Pump Selection

One of the earliest decisions that must be made in designing a system and applying a pump is the selection of the type of pump to be used. The first issue is the general decision whether the pump should be of the centrifugal or a PD type pump.

For the selection of a pump following parameters are needed:

- Required head
- Required flow rate

Some other information should be taken into consideration:

- Pump speed
- Type of fluid
- Available space
- Maximum allowable noise level
- Temperature

Using the required head and flow rate a pump can be selected from a manufacturer catalogue (S. Deniz, personal communication, 9th of October 2020).

2.5 Dimensioning Software

Compass is a dimensioning software provided from Lorentz, a solar pumping manufacturer. This software allows to enter the exact parameters of the solar system and the software will calculate the right dimensions and the suitable parts from Lorentz.
The criteria needed for the software are the following:

- Geographical Location
- Static Head
- Pipe Friction losses
- Water temperature
- Required water volume

With these parameters and climatic data such based on over 20 years of data collected by NASA, the software provides the correct dimensioning and available parts from Lorentz.

3. Methodology

This chapter contains the used methodology of this paper, including an energy systems assessment, a life cycle assessment, a life cycle cost analysis, a hazard analysis, a cost benefit analysis and a multi criteria decision analysis

3.1 Energy Systems Assessment

The methodology "Energy Systems Assessment" was introduced by Prof. Dr. Sabine Sulzer in the module "Sustainable Energy Systems" at the Lucerne University of Applied Sciences. It is based on various literature mainly considering the toolbox of SINTEF and the Master Thesis of Thomas Schluck named "Methoden zur Erstellung angewandter, regionaler Energiekonzepte – Uettligen ein Praxisbeispiel" which translates to "Methods for creating applied, regional energy concepts – Uettligen a practical example", but also on Sulzer's experience.

The methodology has a 6-phase structure.

1. Planning
2. Situation Analysis
3. Alternative Solution Concepts
4. Selection of Assessment Criteria
5. Assessment of solution concepts
6. Recommendation

In the planning phase there are 4 sections: motivation to change, stakeholders and stakes, system definition and availability of data sources. In the motivation to chance section the energy problems in the community are analysed. The potential barriers and drivers are evaluated, and the long-term objectives of the energy supply are investigated. In the stakeholders and stakes section, the decision makers and stakeholders involved are defined and analysed. The long-term objectives of all stakeholders are evaluated. In the third section, system definition, the system boundaries are drawn and described. A system thinking approach was chosen to reduce the complexity. Systems are defined to form a single unit and are internally structured. The basic components of a system are called elements, and they have complex relationships. There are different models to reduce the existing complexity in system thinking. A common approach is to break a system down into subsystems or different functional layers such as Business, Function, Information, Communication and Component (Schönsleben, 2013). There are two distinguished approaches to system thinking: environment oriented and structure oriented. An environment-oriented approach sees the system as a "black box" and focusses on the interrelationships between system and environment. The structure-oriented approach focusses on the system and the interrelationship between the elements (Schönsleben, 2013).
The system delimitation is a structured representation forming the basis for the situation analysis.

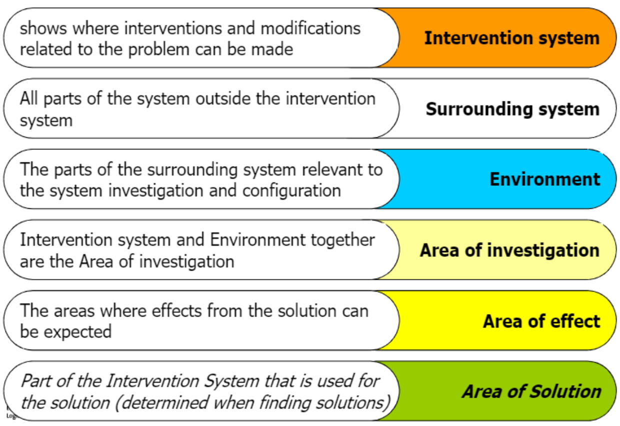


Figure 9: System Delimitation (Schönsleben, 2013).

In the last section, availability of data sources, the data sources for the project are defined.

The second phase, situational analysis, is composed of 4 sections: existing infrastructure, energy demand, potential energy sources and accounting. The first section describes the infrastructure of the base case technically, economically, and environmentally. The section energy demand quantifies the energy demand in the base case. In the third section, potential energy sources, the potential of different sort of energy sources is analysed, potential renewable energy sources such as wind, solar etc. are analysed. The section accounting looks at the existing operating and business model.

The third phase, alternative solution concepts, is divided into 3 sections: Supply options, demand options and accounting options. In the first section all possible alternatives for energy supply are evaluated, this evaluation considers a combination of energy sources, conversion, storage, and distribution. The section demands options considering future demand scenarios and flexibility options. The accounting options section deals with possible operation models.

During the fourth phase the assessment criteria are selected. The assessment criteria are Key Performance Indicators (KPI) of the energy system and can be divided into four categories: economic, environmental, social, and technical.

In the fifth phase the alternative solution concepts are assessed. First the appropriate assessment tools are chosen, these range from energy-hub modelling to cost-benefit analysis. Then the assessment procedure is conducted, and finally the uncertainties are considered in the quantified assessment criteria.

In the last phase, recommendation, a multi criteria decision analysis (MCDA) is conducted to choose the best solution concept. Afterwards a final decision is made. The final decision also entails if the project should be realised. This phase furthermore entails a realisation plan for the project.

3.2 Lifecycle Assessment

The Life Cycle Assessment (LCA) is a method that can be used effectively in evaluating various renewable energy sources for their sustainability, and it can help engineers to choose the vest energy source for a specific purpose. The present chapter is an attempt to highlight the importance of LCA of renewable energy sources. (Singh et al., 2013, S. 1)
LCA is a tool to assess the environmental impacts and resources used at all stages in their life cycle, from the extraction of the raw materials, through the processing of materials, production of product parts and product itself, and the use of the product until its disposal or recycling. LCA of renewable energy production system requires a careful design regarding the goal and scope definition, choice of functional unit, reference system, system boundaries and appropriate inventory establishment and allocation of emissions in products and by-products. The results of a LCA study are as much science based as possible thus contributing to rational decision-making. The main applications of a LCA are analyses of the origins of problems related to a particular product, comparing improvement variants of a given products, designing new products and choosing between a number of comparable products (Singh et al., 2013, S. 1–6).

As stated by the ISO norms the LCA is defined in four phases:

1. Goal and scope definition
2. Inventory Analysis or Life Cycle Inventory (LCI): compiling relevant inputs and outputs
3. Impact assessment (LCIA): evaluating potential environmental impacts associated with inputs and outputs
4. Interpretation: Evaluation of results, being as well necessary during all the other stages of the LCA

During the first phase the goals and the reason to execute the LCA are stated. The scope should include the system boundaries and the functional unit (FU). The functional unit provides a reference to which the inventory analyses can be related to and enables the comparison between different systems. In the second stage, the life cycle inventory (LCI), all the inputs and outputs for a specific system are compiled and quantified (Gerber, 2014, S. 13). The third stage, the impact assessment, the magnitude and significance of potential environmental impacts are evaluated. The impact assessment is divided into 4 steps: selection of impact category, characterization of impact potential, normalization and weighting; the last two being optional according to ISO 14040 (Klöpffer & Grahl, 2014, S. 181–188). In the last and fourth phase of the LCA, interpretation, significant issues based on the results of the LCI and LCIA phases of the LCA need to be identified and evaluated considering completeness, sensitivity and consistency checks (Klöpffer & Grahl, 2014, S. 331).

3.3 Life Cycle Cost Analysis

"Modern products can have life cycles that range from several years to decades long. One of the main challenges that engineers encounter is that early in the product development phases cost considerations are often ignored or downplayed in favour of performance factors. However, it is during these early phases that decisions have the largest impact on the LCC of a project. This tendency can lead to downstream cost overruns and potentially project failure. It is an engineer's responsibility to ensure that design factors presented early in the life cycle before costs are realized include financial considerations" (Farr & Faber, 2018, S. 13-14).

The Life Cycle Cost Analysis (LCCA) is an economic method to ascertain the total cost of owning, operating and disposing of a system over its lifecycle. The purpose of conducting a LCCA is to estimate the Total Cost of Ownership (TCO) and affordability of the program for the stakeholder. A further purpose is to reduce TCO through using Life Cycle Cost (LCC) trade-offs in the systems engineering process (Farr & Faber, 2018, S. 169-171).

The LCCA process can be structured in six stages:

1. Understand stakeholder requirements
2. Define the scope
3. Collect data
4. Develop Life Cycle Cost (LCC) Categories
5. Determine Cost Estimating Methodologies
    a. Parametric Cost Estimation (PCE)
    b. Analogy Cost Estimation
    c. Engineering build-up
6. Conduct LCCA with sensitivity analysis

In the first stage data from the stakeholder is collected with the purpose to understand the stakeholder requirements. During the second stage the scope of the LCCA is defined and work breakdown structure is detailed. The third stage focusses on data collection of costs. In the fourth stage the LCC Categories are developed. In the fifth stage the engineer needs to choose a cost estimation methodology for the LCCA (Farr & Faber, 2018, S. 169-171).
Farr und Faber (2018, S. 16–17) mention mainly 3 methodologies: PCE, Analogy and Engineering build-up. PCE is based on simple mathematical models such as linear and non-linear regression. Usually historical data from similar projects is used in the models. Analogy is based on comparison and estimation using comparable items. Engineering build-up is a "bottom-up" approach to estimation. It estimates the cost of every activity in a project WBS, adding these estimates, and adding appropriate overheads. The structure of an engineering build-up estimate provides more detail than estimates by analogy or PCE, leading to the disadvantage that conducting it is time intensive, slow and expensive (Farr & Faber, 2018, S. 16–17).

In the sixth and last stage the LCCA is executed subsequently with a sensitivity analysis (Farr & Faber, 2018, S. 169-172).

3.4 Hazard Analysis

A hazard analysis a preliminary process used to assess risks. The result of a hazard analysis is a classification, based on the worst-case severity and the probability. A hazard is a potential condition or event with a probability from 0 to 1. It may become an actual functional failure. The process is conducted in various engineering departments, including aviation, chemical engineering, safety engineering, reliability engineering and food safety. Safety and reliability risks can, in some projects, be eliminated, but in most cases a certain degree of risk must be accepted. To quantify expected costs beforehand, the potential severity and the likelihood of occurrence must be classified. Assessment of risks is made by combining the severity of consequences with the likelihood of occurrence in a hazard analysis matrix. Risks that are classified as "unacceptable" must be mitigated. (Risk Matrix Calculations – Severity, Probability, and Risk Assessment, 2018).

The severity can be classified in the following categories:

- <u>No safety effects</u>
- <u>Minor</u>: Slight reduction in functional capability
- <u>Major:</u> Significant reduction in functional capability
- <u>Hazardous:</u> Large reduction in functional capability
- <u>Catastrophic:</u> Outcome of multiple casualties and/or total failure of the system

The likelihood of occurrence can be classified in following categories:

- <u>Extremely Improbable:</u> it is not expected to take place during the entire life of an entire system or group of systems
- <u>Extremely Remote:</u> can take place a few times during the life of an entire system or group of systems.
- <u>Remote:</u> can occur various times in the life of an entire system or group of systems
- <u>Probable:</u> predicted to take place one or more times in the entire operational life of a system.

3.5 Cost Benefit Analysis

The Cost Benefit Analysis (CBA) is an accounting framework for evaluating the economic and social consequences of decisions. Guided by a list of rules, a typical analysis progresses through successive evaluation stages that culminate in a ranking of the alternatives under consideration and the selection of the ones with the highest possible net returns (Nas, 2016, S. 1–3).

A typical CBA proceeds in 5 stages:

1. Definition of scope and assumptions
2. Identification of alternatives and quantification of costs/benefits for each alternative
3. Selection of appropriate discount rate and calculation of the present value of costs/benefits
4. Selection and application of measure for comparing alternatives
5. Discussion of uncertainties and risks

In the first stage the problem and perspective are stated, the scope is defined proportionate to the expected magnitude of effects. The scope definition should also include the considered period and if the analysis is of partial or general equilibrium. In the second stage the alternatives and/or baseline are identified, then for each alternative and/or baseline the cost and benefits for each alternative during the defined period. During the third stage an appropriate discount rate is selected and with it the present value of the costs and benefits of each alternative and/or baseline are calculated. In the fourth stage the alternatives are compared with the Net Present Value (NPV) and/or Benefit-Cost ratio.

In the fifth and last stage a sensitivity analysis is conducted by varying a certain parameter in the CBA and observing the outcome variation (Wagner, 2020).

3.5.1 Net Present Value

The Net Present Value (NPV) methodology calculates the present value of all cash flows (FCF) using an interest rate called "required rate of return" (r), also called discount rate. A discount rate is a rate at which any given entity can expect to earn on the invested money because of the time value of money. This concept dictates that money you have now is worth more than the same sum in the future because of its potential earning capacity. As time has money value, a swiss franc after one year is worth less than the present swiss franc. Therefore, discounting refers to the process of calculating the costs and benefits experienced at different points in time into a single time dimension by using a discount rate that symbolises the change in the value of the money per time period (generally one year). The procedure is straightforward, and it focuses on cash inflows and outflows while considering the time value of money. Using the required rate, the present value of all expected future cash flows associated with the project are summed and subtracted by the initial investment. If the discount rate or required rate of return (r) is high, the NPV is lower and vice versa. A positive NPV means the future cashflows' present value exceeds the investment, so the project should be undertaken. A negative NPV means the inverse and the project should not be undertaken (Horngren et al., 2014, S. 453-454).

$$NPV = \sum_{t=0}^{N} \frac{FCF}{(1+r)^t} \qquad (3.1)$$

3.5.2 Inflation

Inflation is the decrease of buying power of a given currency over time. Inflation increases the price of goods and services over time, effectively decreasing the number of goods and services you can purchase with a given amount of money in the future as opposed to the same amount of money today. If wages remain the same but inflation causes the prices of goods and services to increase over time, it will take a larger percentage of your income to purchase the same good or service in the future (Fernando, 2019).

3.5.3 Benefit – Cost Ratio

The Benefit – Cost Ratio is a profitability index used to determine the feasibility of a project over a certain period. It is calculated by using the present value of future benefits and dividing it by the PV of future costs including investment and annual operating costs. The project should be accepted if the B/C exceeds 1 (Nas, 2016, S. 123–124).

$$Benefit\ Cost\ Ratio = \frac{PV_{Benefits}}{PV_{Costs}} \qquad (3.2)$$

3.5.4 Sensitivity Analysis

The NPV and B/C methods are both sensitive to the discount rate, both decline if the discount rate rises. The future is unpredictable and uncertain, because of that actual cash flows and discount rates may differ from what was predicted. A sensitivity analysis determines what would happen if the actual cash flows and/or discount rates differ from what was predicted. If a project NPV changes from positive to negative after a small change in predicted cash flow, the project is subjected to high prediction risk (Horngren et al., 2014, S. 457).

3.6 Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) is a field to help humans as decision-makers (DM) make winning decisions in complex situations. There are different methodologies in the field of MCDA. This paper will use an MCDA method which derivates from "Analytic Hierarchy Process" (AHP) developed by Saaty in 1980 and taught by Wagner at the Lucerne University of Applied Sciences.

The MCDA is structured in five stages:

1. Problem Definition
2. Problem Structuring
3. Assessment
4. Initial Results and sensitivity analysis
5. Decision / Planning

In the first stage, the DM defines the overall structure and relevant stakeholders' problem. In this stage, the significance of the problem is determined. The problem is then dissected into key components (criteria) and alternatives that can be compared. In the problem structuring phase, the relevant decision criteria are identified, and a hierarchy tree is developed using logical criteria structure. In the third stage of the MCDA, assessment, criteria are given numerical values, and the applied scale is decided. The criteria are then defined by a set of weights so that a score can be calculated. In the fourth stage, the initial results are evaluated, and a sensitivity analysis is conducted. This stage's objective is not only to check the robustness of the preferred alternative against weight changes or data error but also to check if the model is working how it is expected to work. In the fifth and last stage, the MCDA output is used to decide or plan further (Wagner, 2020).

4. Implementation

In this chapter the methodology researched in chapter 3 is implemented.

4.1 Planning Phase

This chapter describes the planning phase, which entails the motivation to change and the description of the system.

4.1.1 Motivation to change

In Mongolia, the average income per capita is $3780 (World Bank, 2020). Farmers that depend on gasoline generators to pump water from a water well spend most of its income on gasoline. The water is then used to feed animals and irrigate fields. Because photovoltaic systems have a low operating cost, it would be economically advantageous for the farmers to use solar energy instead of a gasoline generator. The long-term goal is to have lower operating costs.

The system boundary is drawn around the water well. It is dependent on the surrounding environment, in this case, the underground water network and the climate above ground. The energy system includes water demand.

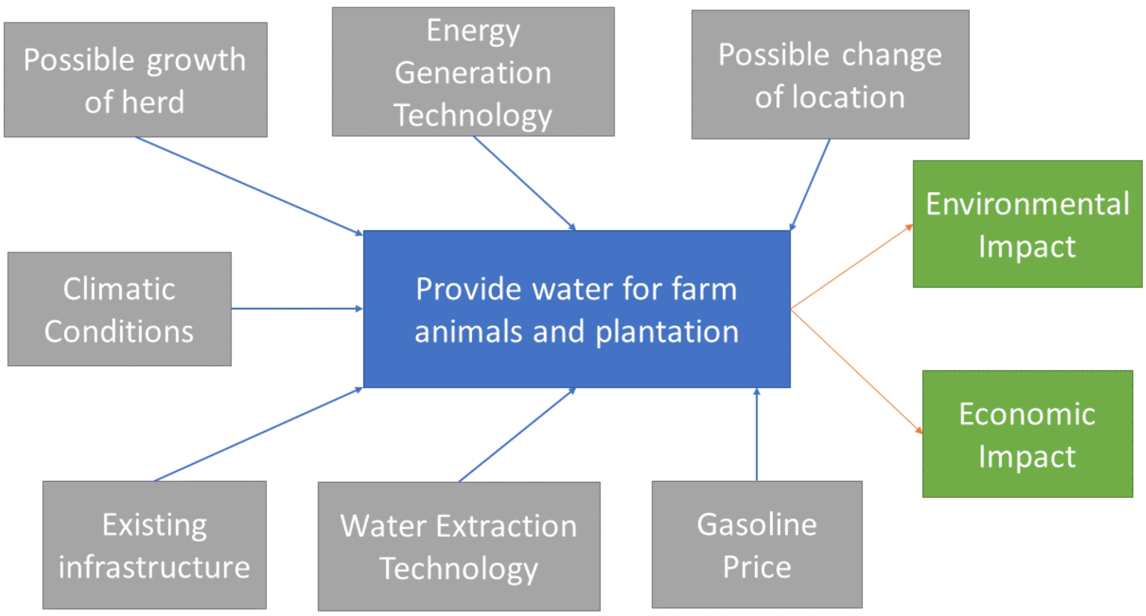


Figure 10: Intervention System with ins- and outputs.

The intervention system can be seen in Figure 10.
The electricity produced by the energy system will be used to extract water from underground with the objective of feeding the herd. The output of the system is in some extent an environmental but also economical for the owners of the system. In the base system, a gasoline generator provides AC electricity to an underground submersible pump.

4.2 Situational Analysis

In this chapter the beginning situation is described.

4.2.1 Energy Demand in Base case

The data retrieved from the family divulged that the animal count is 6000. Each animal consumes around 25 litres of water per day. However, the animals do not drink daily but drink around 10 times per month in the winter months and around 15 times per month in the summer months. Each time an animal drinks, 25 litres per animal are needed. The pump that is being operated at the moment has a maximum power of 0.75 kW and is manufactured by DAFU. The model is 4SDM4/10, which needs 220V at 50Hz.
Knowing this information, the winter water consumption, can be calculated to 50 m^3 per day, and in the summer, it is 75 m^3 per day. With further calculations, the running time per day in winter and summer can be calculated to 11.9 hours in winter and 17.85 hours in the summer. Using this information, the energy consumption per day in the winter and summer can be derived. The energy consumption in the winter in 8.92 kWh per day and in the winter is 13.39 kWh per day.
All the calculations are shown in Appendix A.

4.2.2 Energy conversion, distribution & storage technologies in current system / base case

In the current system a gasoline generator is used to power the submersible water pump. The energy is stored chemically as gasoline and converted to AC with a gasoline generator with 2.8 kW rated power. For more information see Appendix C.

4.2.3 Potential Energy Sources

The location is near Guchin-Us in Mongolia, which is located near the Gobi Desert. There are not rivers in the vicinity. The mean wind speed is 6.5 m/s with a mean power density of 317 W/m^2 at 100 meters altitude (Global Wind Atlas, o. J.).

As seen in Figure 3 in the chapter “Climate” the location has a global average daily irradiation on an inclined surface in the south direction with an azimuth of 35° of 4.5 kWh/m^2 in the cold months to 7 kWh/m^2 in the summer months.

The data shows that solar energy would be a potential energy source for the pumping system.

4.2.4 Accounting

Every month the gasoline generator consumes 60 to 70 litres of gasoline. One litre of gasoline costs 1’500 MNT. The monthly operational expense is 90’000 to 105’000 MNT which translates into 28 up to 32 CHF. It can be assumed that it is a significant expense considering that the monthly Household Income per Capita reached 124.4 CHF in Dec 2019 (CEIC, o. J.).

4.3 Alternative solution concepts

To find the best possible solution concept, two scenarios were developed. The first scenario uses a photovoltaic array with an inverter, as main energy supply for an AC powered electric submersible pump and a gasoline generator as a back-up option in low solar irradiation days. The second scenario is equal to the first scenario but without a gasoline generator. For days with low solar irradiation, an isolated water tank will be used to store water.

To use batteries as energy storage is not a viable option because as mentioned in chapter 2.2, temperatures below 20°C accelerate the ageing of batteries. As wind conditions are not very favourable seen in chapter 4.2 and the location is north of the Gobi Desert solar energy and gasoline generator are the most viable options.

In both scenarios, the system is the same, and the only difference is the back-up option. The goal of the PV pump is to pump a minimum of 50 m^3 per day.

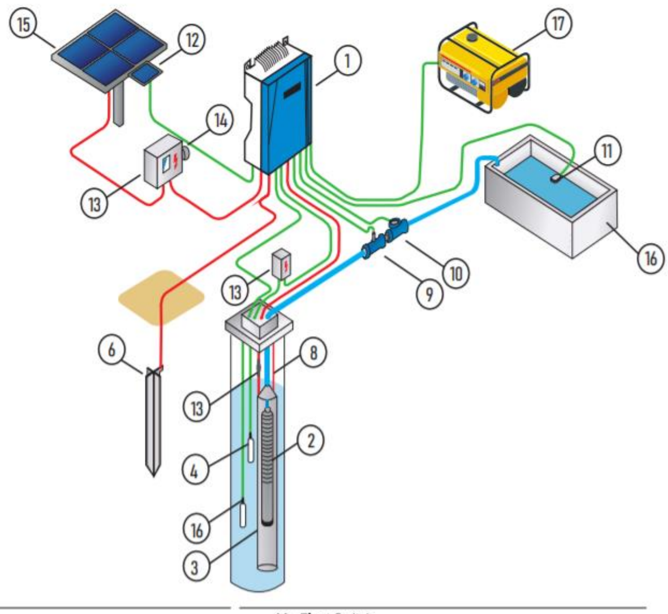
4.3.1 Scenario 1

The coordinates of the location (45°N 102°E) can be put into the software. As mentioned in the chapter 2.1 Climate the tilt angle of the PV array is 35° in the south direction. The dynamic head will be put as 40 meters because the pump is 35 meters underground, and the software has an input interval of 5 meters. As mentioned in the chapter “Energy Demand in Base Case” the minimum daily water output is 75 m^3. The software uses these inputs to calculate the rated power of the PV array and to choose the pump from the catalogue of “Lorentz”.

The results are the following:

- Rated power: 5’280 Wp (8x2 CS Wismar 325)
- Pump: PS2-4000 C-SJ8-15 with 4 kW power

As the pump has a maximum power of 4 kW the gasoline generator should also be able to deliver 4 kW electric power. For more information about scenario 1 see Appendix C.



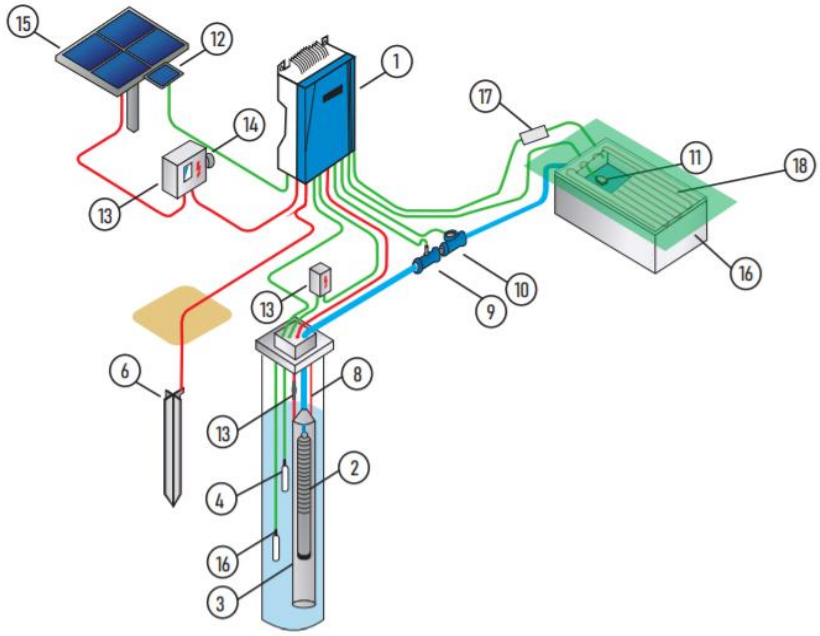
1: PS2 Controller	**11:** Float Switch
2: Submersible Pump	**12:** Sun Switch
3: Flow Sleeve	**13:** PV Disconnect
4: Well Probe	**14:** Lightning Surge Protector
5: Cable Splice Kit	**15:** PV Generator
6: Grounding Rod	**16:** Water Tank
7: Surge Protector*	**17:** Gasoline Generator
8: Safety Rope	*It is recommended to install a Surge Protector at each controller sensor input.
9: Water Meter	
10: Pressure Sensor	

Figure 11: System layout of scenario 1.

4.3.2 Scenario 2

In the second scenario the PV system has the same layout as in scenario one. The only variable is the gasoline engine and the water tank. This scenario has no gasoline generator, the reason for this is because of the low temperatures in the winter. This results in high maintenance and low reliability of the gasoline generator according to Sebastian Zenz (personal communication, 28th October 2020). In addition, an isolated tank with the possibility of electric heating is added to the system. The isolation and electric heating prevent the water inside of freezing and changing to solid.

As seen in the chapter 2.1 Climate it rains for an average of 2 to 3 days per month, with the summer bringing the most rain intense months. The water tank should be 150 m³ in volume because "there are no more than two consecutive days without sun" (ERINA, 2003). For more information about scenario 2 see Appendix C.



1: PS2 Controller	11: Float Switch
2: Submersible Pump	12: Sun Switch
3: Flow Sleeve	13: PV Disconnect
4: Well Probe	14: Lightning Surge Protector
5: Cable Splice Kit	15: PV Generator
6: Grounding Rod	16: Isolated Water Tank (Underground)
7: Surge Protector*	17: Temperature switch
8: Safety Rope	18: Heating Element
9: Water Meter	
10: Pressure Sensor	

*It is recommended to install a Surge Protector at each controller sensor input.

Figure 12: System layout scenario 2.

4.4 Selection of Assessment criteria

To select the best variant, the right criteria need to be chosen to compare the different scenarios. To be consistent with the objectives, economic criteria and reliability are the most critical criteria for the stakeholders. As mentioned in the chapter 4.1.1 Motivation to change the family uses most of its income to buy gasoline for the gasoline generator, so it is critical to reduce the operational costs while still considering the investment costs for the industrial partner.

The economic criteria chosen are:

- Investment Cost in CHF
- Operation and Maintenance Cost in CHF

The technical criteria are:

- Reliability of supply in an ordinary scale

4.5 Assessment of base case and solution concepts

In this chapter the base case and the solution concepts will be assessed.

4.5.1 Selection of appropriate tools

To be consistent with the objectives, economic and reliability criteria is critical for the project. For that reason, a life cycle cost analysis and a hazard analysis will be conducted. A cost benefit analysis was also considered but due to the uncertainty and lack of data regarding the possible benefits and costs the CBA will not be conducted.

4.5.2 Assessment Procedure

In this chapter the assessment procedures and results will be shortly described.

LCCA

The scope of the LCCA for this scientific paper was limited to investment and operating cost. Disposal Cost was not considered in because of the lack of data for PV panels in Mongolia. For more information about the calculation procedure see Appendix A.

The LCCA showed the following results:

- Base Case: 14’370.45 CHF
- Scenario 1: 12’444.77 CHF
- Scenario 2: 23’623 CHF

The base case has no investment costs but high operational costs. In year 10 the gasoline generator will be replaced as the expected life will be reached. Scenario 1 has an investment cost of 10’109 CHF and a total operational cost of 2’335.77 CHF in present value. Scenario 2 has an investment cost of 23’623 CHF due to the high cost of the water tanks and no operational costs.

In the sensitivity analysis, each parameter was increased or decreased by 10%. The discount rate was varied between 2% and 5%.

For the base case, the parameters that influence the original result the most are the discount rate and the oil price as the highest and lowest variation being notices when the two parameters are changed. In scenario 1, the parameters that have the most influence on the result is the investment cost and discount rate. In the second scenario, the only variance is in the investment costs as there are not any operational costs.

Hazard Analysis

The three systems are not completely different. The water pumping technology is the same, all systems use a submersible water pump with 4’’ in diameter. The base case uses a pump with 0.75-kW and the scenario 1 and 2 use a 4-kW submersible pump. For that reason, it can be assumed that the reliability of the pumping technology is the same for all 3 cases. The difference between the systems lies in the technology supplying the energy and the storage / back-up option.
The scope of this Hazard Analysis will be the energy supply system in the first 20 years after deployment. The objective of this analysis is to qualitatively compare the three systems to each other so that the system with the lower probability of failure can be determined.

Hazard Analysis Matrix					
Likelihood of Occurence	Hazard Severity Definitions				
	1 Catastrophic	2 Hazardous	3 Major	4 Minor	5 No Effect
(A) Probable	1A	2A	3A ●	● 4A Base Case	5A
(B) Remote	1B	2B	Scenario 2 3B	4B	5B
(C) Extremely Remote	1C	2C	3C	4C ● Scenario 1	5C
(D) Extremely Improbable	1D	2D	3D	4D	5D

Red	Unacceptable
Orange	High
Yellow	Medium
Blue	Low

Figure 13: Results of Hazard Analysis

As seen in Figure 13 the base case was classified as 4A. The base case is dependent on one single gasoline generator, the probability that a generator breaks down during its lifetime depends on operating conditions, maintenance frequency, fuel quality, and other factors. As the generator is operated in a deserted area near the Gobi desert in winter with temperatures reaching -20°C in the winter and there is no other back-up option (0% redundancy) the likelihood of one failure in the 20 years of operation can be considered to be probable. As the generator can in normal circumstances be easily repaired the severity can be categorized as minor.

Scenario 1 consists of a PV system and a back-up gasoline generator. As this system has 100% redundancy the likelihood of a complete failure of energy supply can be categorized as extremely remote, as for this the gasoline generator and the PV System would have to not be able to supply energy. The severity would be the same as in the base case.

Scenario 2 is classified as 3A. This scenario consists of a PV system an underground water tank as a back-up in case the PV system is not able to provide enough energy. As the PV System depends on sunlight to shine the probability that there will be days in the year that the PV System does not provide enough power is high. As the back-up option is a water tank, the probability that the water will freeze because of the -20°C temperature is medium-high even though the water tank is underground. For those reasons, the likelihood of occurrence is classified as probable. As the water tank is underground repairing possible problems with freezing water or heating failure is more difficult under low temperatures, which can lead to several days without being able to provide water. For that reason, the severity can be categorized as major.

Quantified Assessment Criteria with Uncertainties Considered

As mentioned in the chapter "Assessment Criteria", the criteria chosen to evaluate the three variants are the following: Investment Cost, Operational Cost and Reliability of Supply. Investment and operational cost can be quantified in CHF, the reliability of supply can be quantified in an ordinary scale from 1 to 5. "1" meaning the system is very unreliable, "2" meaning the system is unreliable, "3" meaning the system is mostly reliable, "4" means the system is "reliable" and "5" meaning the system is very reliable. The selection of a number in the scale can be derived from the hazard analysis. A system can be classified as very reliable if it unable to deliver power/water a maximum of one day a year. A system is reliable if it is unable to deliver power/water between 2 and 3 days a year. A system is classified as mostly reliable if it is unable to deliver power/water between 4 and 6 days a year. A system is classified as unreliable if it is unable to deliver power/water between 7 and 15 days a year. A system is classified as very unreliable if it is unable to deliver power/water more than 15 days a year.

After considering all uncertainties the assessment criteria are the following:

- Base Case:
  - Investment Cost: 0 CHF
  - Operational Cost: 14’370.45 CHF
  - Reliability of Supply: 4 – Reliable
- Scenario 1:
  - Investment Cost: 10’109 CHF
  - Operational Costs: 2’335.77 CHF
  - Reliability of Supply: 5 – Very Reliable
- Scenario 2:
  - Investment Cost: 23’623 CHF
  - Operational Costs: 0.- CHF
  - Reliability of Supply: 3 – Mostly Reliable

4.6 Recommendation / Results

The following results are organized into 3 sub-sections. The first section summarizes the multi-criteria decision analysis. The second section describes the final decision as a result of the MCDA. The third section is centred on the sourcing of the system described in the sub-section 4.6.2 Final decision.

4.6.1 Multi-criteria decision analysis

Using the quantified assessment criteria, a multi-criteria decision analysis can be executed to choose the best variant. As stated in the chapter 4.1 Planning Phase the motivation to change is to reduce operational costs such that the family does not have to spend most of its budget on energy to retrieve the water from the well. For that reason, the criteria "Operational Costs" has the highest weight in the score of 0.5. According to the industrial partner, the reliability is critical. For that reason, it has a weight of 0.3, and as no budget was defined, the investment costs receive the lowest weight of 0.2.
The results of the multi-criteria decision analysis show that the best variant is "Scenario 1", the second-best is "scenario 2", and the worst is "the base case".

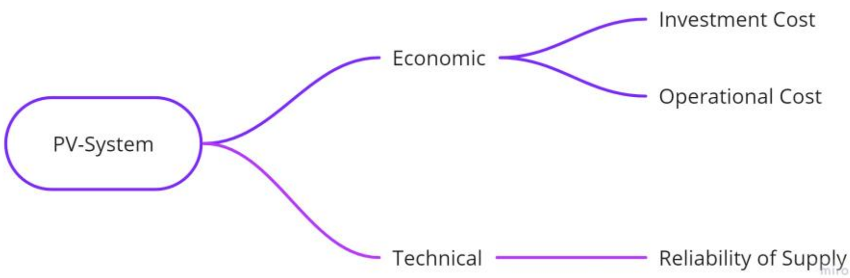


Figure 14: MCDA value three.

In the sensitivity analysis, the weighting changed to check if the result would change with small changes in weighting. Firstly, the reliability and investment cost were given the same weight of 0.25. There were no changes to the result. Secondly, the operational cost was given a weight of 0.4, and the reliability and investment cost received a weight of 0.3 each. The "Scenario 1" was still the best variant, but with this weighting, the "base case" is now the second-best variant.

4.6.2 Final decision

The solution named "Scenario 1" should be chosen. This solution includes a 5.28-kW photovoltaic system with a 4-kW submersible water pump, a 5-kW power gasoline generator as a back-up option that provides 100% redundancy.

4.6.3 Sourcing

This chapter handles the sourcing strategy for this project. There are plenty of suppliers that provide the technology for the chosen systems, the sourcing strategy evaluates which suppliers are suited for this project. The detailed approach to the sourcing is detailed in the Appendix B. The results shows that the materials should be sourced from Germany from the companies SolarKonzept GmbH, that distributes solar pumping systems from Lorentz, and EURO Elektrowerkzeug- & Maschinen Service GmbH which distributes gasoline generators from Könner & Söhnen. The costs amount a total of 12'686 CHF.

5. Discussion of results

The purpose of this thesis was to design a PV system and connection to a water pump for a water well so that the required power can be provided. This included evaluating possible storage and back-up options, considering the environmental conditions of the location. After selecting the most suitable system to operate the pump reliably, an evaluation of possible sourcing strategies according to local possibilities was made. The developed solution was a 5.28-kW photovoltaic system with a 4-kW submersible water pump, a 5-kW power gasoline generator as a back-up option. According to the results, the system should be sourced in Germany and then transported to Mongolia.

As the energy system will be installed in Mongolia, it is difficult to evaluate the accuracy of the obtained data, and therefore there are some uncertainties. For example, one uncertainty is the information of the pipe that connects the submersible pump to the surface. Another uncertainty is the actual head. The estimated head information given from the family was 25 to 35 meters. As it is favourable to have "too much" power rather than "too less" the system calculations were made with a margin of safety, assuming a head of 40 meters. Several pipe parameters influence the pipe losses, which influence the sizing of the PV Array as then, more or less power is required: length, diameter, roughness, and the number of elbows. The pipe length was estimated to be the same as the head, 40 meters; if the pipe is longer, it leads to higher losses. The diameter could only be estimated from available photos made from the existing infrastructure. The estimation was 40 mm, which can be considered a small diameter. If the diameter is larger than estimated, less power will be required. Roughness also impacts the required power, as less roughness leads to fewer flow losses, resulting in less power required. The calculations were done using the maximum roughness possible. If a pipe has multiple elbows, it also leads to higher losses, and the calculations were done considering that there were no elbows in the pipe. One other uncertainty is the location of the system. At the beginning of this thesis, the location was set near Guchin-Us, but the family relocated to 400 km away from the original location during the thesis. This relocation influences the sizing and mounting of the PV Array as it could be that the solar irradiation differs from the researched location in this thesis.

The calculated investment cost for all alternatives was very accurate, as the quotes from multiple suppliers were obtained. The results from the LCCA, as seen in the sensitivity analysis, were easily influenced by the introduced discount rate. As the discount rate shows the present value based on what we could have invested the money, the family does not directly pay for that lost value. What the family is "actually" paying is gasoline and maintenance materials and/or service, which is influenced by the country's oil price and inflation. That leads to the oil price and inflation having higher importance in the LCCA / Project results.

6. Conclusion

The purpose of this thesis was to design a PV system and connection to a water pump for a water well so that the required power can be provided. This thesis started with a literature review. In the literature review, research about the climate of Mongolia was done because the climate influences the energy output of the photovoltaic array. Additionally, research about existing options of energy storage, photovoltaic technology, water pump technology and dimensioning software is shown. In the methodology chapter, the existing methodology that can be used in this thesis is presented. This chapter showed the energy systems assessment methodology, including other methods in its assessment procedure like cost-benefit analysis, life cycle cost analysis, lifecycle assessment and multi-criteria decision analysis. The methodology is then applicated in the implementation chapter. Using the energy systems assessment procedure, and based on the available data, the life cycle cost analysis and hazard analysis were used to assess and compare the solution concepts and the base case. The results were then used in multi-criteria decision analysis to select the best option.

The objective to design a PV system and connection to a water pump can be considered as achieved because two scenarios were developed, evaluated against each other and the base case, and the best one was chosen. The developed solution was a 5.28-kW photovoltaic system with a 4-kW submersible water pump, a 5-kW power gasoline generator as a back-up option. One further objective was evaluating possible storage and back-up options, considering the environmental conditions of the location. This objective can also be considered as achieved because different storage and back-up options were researched using literature. Because of the environmental conditions, a gasoline generator that converts chemical energy in gasoline to electricity was chosen as a back-up option. Furthermore, possible sourcing strategies needed to be evaluated according to local possibilities. This objective was also achieved, as two suppliers, one from Germany and one from China, were compared. The supplier from Germany was chosen to source the parts.

Considering everything mentioned in the chapter Discussion of results above, as the project moves to the realization phase, accurate data about the new location and the existing infrastructure should be obtained. That information includes weather information, head, and piping parameters. An accurate PV sizing can then be calculated for the new location. One more consideration that can be included is adding a water reservoir to supplement the chosen system with some of the advantages of “Scenario 2”.

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Appendix

Appendix A

Technical Document: Financial Report

Life Cycle Cost Analysis

A life cycle cost analysis adds all costs of an asset over its lifespan. This includes investment, operational cost and disposal cost. This project has two perspectives. As the project investment costs will be paid by the industrial partner but the operational costs will be paid by the family using the system. Therefore there are different perspectives possible for this LCCA. The two perspectives chosen for this project are the user and the full perspective. The user perspective shows the life cycle costs of the system without considering the the investment costs. The full perspective considers the investment costs and the operational costs during the whole lifespan.
The lifespan chosen for the LCCA is 20 years, as according to Berg (2018) the average lifespan of solar panels are 25 to 30 years and most solar panels manufactures offer a power warranty of 20 years. The depreciation will not be considered in this case, or in technical term it will be fully depreciated in year 0 when the investment occurs instead of splitting it into its lifespan. The reason for this is that splitting the depreciation of the system in the lifetime is advantageous for a company for tax reasons (Tuovila, 2020).
The disposal costs were not taken into consideration because of the lack of data for PV panels in Mongolia. The prices for the investment costs in scenario 1 and 2 were provided from companies in Europe, transport costs were not included. As this thesis will also include a sourcing strategy for the chosen system the transport costs will not be included in the LCCA. For the inflation, gasoline price and discount rate some assumptions must be made. In an article by Amadeo (2019) the oil price is expected to surpass the 146$ mark by 2040 which is 365% more than the current price in 2020. As gasoline prices are heavily correlated with oil prices, the gasoline price should also increase by 365%. According to Plecher (2020) the average inflation in Mongolia in the last 10 years is 8.6%. The discount rate should lie between 2 to 5 per cent (What is a discount rate in cost benefit analysis, o. D.).
The LCCA showed the following results:

- Base Case: 14’370.45 CHF
- Scenario 1: 12’444.77 CHF
- Scenario 2: 23’623 CHF

The base case has no investment costs but high operational costs. In year 10 the gasoline generator will be replaced as the expected life will be reached. Scenario 1 has an investment cost of 10’109 CHF and a total operational cost of 2’335.77 CHF in present value. Scenario 2 has an investment cost of 23’623 CHF due to the high cost of the water tanks and no operational costs.

In the sensitivity analysis, each parameter was increased or decreased by 10%. The discount rate was varied between 2% and 5%.

Base Case

		Investment cost		Operational cost		Inflation		Discount Rate		Oil Price	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Investment Cost	Min										
	Max										
Operational Cost	Min			14253.44		14041.39	14484.92	17765.64	12837.49	13612.68	14894.21
	Max				14487.42	14254.42	14742.22	18062.32	13046.55	13846.65	15128.19
Inflation	Min					14147.91		17631.55	12743.75	13507.14	14788.68
	Max						14613.57	18223.30	13158.42	13972.80	15254.34
Discount rate	Min							17913.98		17089.94	18738.02
	Max								12942.02	12373.98	13510.07
Oil Price	Min									13729.66	
	Max										15011.20

Figure 15: Results sensitivity analysis for the base case

For the base case, the LCCA result would vary from 12’373.98 CHF to a maximum of 18’738.02 CHF with the original result being 14’370.45 CHF. As seen in figure 12 the parameters that influence the original result the most are the discount rate and the oil price as the highest and lowest variation being notices when the two parameters are changed.

Scenario 1

		Investment cost		Operational cost		Inflation		Discount Rate		Oil Price	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Investment Cost	Min	11433.866		11316.88	11550.9	11329.2	11550.5	12037.4	11193	11369.8	11497.9
	Max		13455.6665	13338.68	13572.7	13351	13572.3	14059.2	13214.8	13391.6	13519.7
Operational Cost	Min			12327.78		12233.54	12432.74	12899.94	12099.34	12263.70	12391.86
	Max				12561.75	12446.58	12690.04	13196.62	12308.39	12497.68	12625.83
Inflation	Min					12340.06		12908.92	12112.66	12275.98	12404.14
	Max						12561.39	13203.96	12305.28	12497.31	12625.46
Discount rate	Min							13048.28		12965.87	13130.68
	Max								12203.86	12147.06	12260.67
Oil Price	Min									12380.69	
	Max										12508.84

Figure 16: Results of the sensitivity analysis for scenario 1.

In scenario 1, the LCCA results vary between 11’193 CHF and a maximum of 14’059.2 CHF from the original 12’444.77 CHF. The parameters that have the most influence on the result is the investment cost and discount rate as seen in figure 13.

In the second scenario the only variance is in the investment costs as there is not any operational costs. The results vary then from 21’260.7 CHF to 25’985 CHF from a initial value of 23’623 CHF.
The results from the LCCA, as seen in the sensitivity analysis, were easily influenced by the introduced discount rate. As the discount rate shows the present value based on what we could have invested the money, the family is not directly paying for that lost value. What the family is “actually” paying is gasoline and maintenance materials and/or service which is influenced by the oil price and the inflation in the country. That leads to the oil price and inflation having a higher importance in the results of the LCCA / Project.

Excel Spreadsheet

Life Cycle Cost Analysis (LCCA)	
Project Name:	Design and sourcing strategy of PV-system for water well in Mongolia
Project Manager:	Rui Marques

Base Case		Scenario 1		Scenario 2	
Investment Costs					
Total Cost	CHF 0.00	Total Cost	CHF 11'119.90	Total Cost	CHF 23'623.00
Incentives	CHF 0.00	Incentives	CHF 0.00	Incentives	CHF 0.00
Net Cost	CHF 0.00	Net Cost	CHF 11'119.90	Net Cost	CHF 23'623.00
Replacement Costs					
Replacement Cost	0	Replacement Cost	0	Replacement Cost	
Expected Life (Years)	20	Expected Life (Years)	20	Expected Life (Years)	20

One Time Operating Costs

Year	Materials	Service	Subtotal	Year	Materials	Service	Subtotal	Year	Materials	Service	Subtotal
1	CHF 465.83	CHF 10.86	CHF 476.69	1	CHF 72.00	CHF 10.86	CHF 82.86	1	CHF -	CHF -	CHF -
2	CHF 519.46	CHF 11.79	CHF 531.25	2	CHF 79.54	CHF 11.79	CHF 91.34	2	CHF -	CHF -	CHF -
3	CHF 573.30	CHF 12.81	CHF 586.10	3	CHF 87.30	CHF 12.81	CHF 100.11	3	CHF -	CHF -	CHF -
4	CHF 627.36	CHF 13.91	CHF 641.27	4	CHF 95.28	CHF 13.91	CHF 109.19	4	CHF -	CHF -	CHF -
5	CHF 681.67	CHF 15.11	CHF 696.77	5	CHF 103.51	CHF 15.11	CHF 118.62	5	CHF -	CHF -	CHF -
6	CHF 736.24	CHF 16.41	CHF 752.65	6	CHF 112.01	CHF 16.41	CHF 128.42	6	CHF -	CHF -	CHF -
7	CHF 791.11	CHF 17.82	CHF 808.92	7	CHF 120.80	CHF 17.82	CHF 138.62	7	CHF -	CHF -	CHF -
8	CHF 846.29	CHF 19.35	CHF 865.64	8	CHF 129.90	CHF 19.35	CHF 149.25	8	CHF -	CHF -	CHF -
9	CHF 901.81	CHF 21.01	CHF 922.83	9	CHF 139.35	CHF 21.01	CHF 160.36	9	CHF -	CHF -	CHF -
10	CHF 3'239.62	CHF 22.82	CHF 3'262.44	10	CHF 149.17	CHF 22.82	CHF 171.99	10	CHF -	CHF -	CHF -
11	CHF 1'014.01	CHF 24.78	CHF 1'038.79	11	CHF 159.39	CHF 24.78	CHF 184.17	11	CHF -	CHF -	CHF -
12	CHF 1'070.75	CHF 26.91	CHF 1'097.66	12	CHF 170.05	CHF 26.91	CHF 196.96	12	CHF -	CHF -	CHF -
13	CHF 1'127.96	CHF 29.23	CHF 1'157.19	13	CHF 181.19	CHF 29.23	CHF 210.42	13	CHF -	CHF -	CHF -
14	CHF 1'185.70	CHF 31.74	CHF 1'217.44	14	CHF 192.84	CHF 31.74	CHF 224.58	14	CHF -	CHF -	CHF -
15	CHF 1'243.99	CHF 34.47	CHF 1'278.46	15	CHF 205.06	CHF 34.47	CHF 239.53	15	CHF -	CHF -	CHF -
16	CHF 1'302.90	CHF 37.43	CHF 1'340.33	16	CHF 217.89	CHF 37.43	CHF 255.32	16	CHF -	CHF -	CHF -
17	CHF 1'362.47	CHF 40.65	CHF 1'403.12	17	CHF 231.38	CHF 40.65	CHF 272.03	17	CHF -	CHF -	CHF -
18	CHF 1'422.76	CHF 44.15	CHF 1'466.91	18	CHF 245.59	CHF 44.15	CHF 289.74	18	CHF -	CHF -	CHF -
19	CHF 1'483.83	CHF 47.95	CHF 1'531.77	19	CHF 260.58	CHF 47.95	CHF 308.53	19	CHF -	CHF -	CHF -
20	CHF 1'545.74	CHF 52.07	CHF 1'597.82	20	CHF 276.42	CHF 52.07	CHF 328.49	20	CHF -	CHF -	CHF -
Total			CHF 22'674.06	Total			CHF 3'760.53	Total			CHF -

Disposal Costs

Total Cost		Total Cost		Total Cost	
Discounted		Discounted		Discounted	

Results

Base Case		Scenario 1		Scenario 2	
LCC Full	CHF 22'674.06	LCC Full	CHF 14'880.43	LCC	CHF 23'623.00
Discounted LCC Full	CHF 14'370.43	Discounted LCC Full	CHF 13'455.67	Discounted LCC	CHF 23'623.00
LCC User	CHF 22'674.06	LCC User	CHF 3'760.53	LCC User	CHF -
Discounted LCC User	CHF 14'370.43	Discounted LCC User	CHF 2'335.77	Discounted LCC User	CHF -

Sensitivity Analysis

		Input Values	Beginning	min	max
Discount Rate		0.04	0.04	0.02	0.05
Inflation		0.086	0.086	0.0774	0.0946
Oil		0.06095	0.06095	0.054855	0.067045
Operational Cost	Service	10	CHF 10.00	CHF 9.00	CHF 11.00
	Material	26	CHF 26.00	CHF 23.40	CHF 28.60
Scenario 1 Invesment Cost			CHF 10'109.00	CHF 9'098.10	CHF 11'119.90
Scenario 2 Investment Cost			CHF 23'623.00	CHF 21'260.70	CHF 25'985.00

Calculations

Base Case					Scenario 1					Scenario 2				
Year	Subtotal	Cumulative Subtotal	Subtotal Discounted	Cumulative Subtotal Discounted	Year	Subtotal	Cumulative Subtotal	Subtotal Discounted	Cumulative Subtotal Discounted	Year	Subtotal	Cumulative Subtotal	Subtotal Discounted	Cumulative Subtotal Discounted
0	CHF 0.00	CHF 0.00	CHF 0.00	CHF 0.00	0	CHF 0.00	CHF 0.00	CHF 0.00	CHF 0.00	0	CHF 23'623.00	CHF 23'623.00	CHF 23'623.00	CHF 23'623.00
1	CHF 476.69	CHF 476.69	CHF 458.36	CHF 458.36	1	CHF 82.86	CHF 82.86	CHF 79.67	CHF 79.67	1	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
2	CHF 531.25	CHF 1'007.95	CHF 491.17	CHF 949.53	2	CHF 91.34	CHF 174.19	CHF 84.45	CHF 164.12	2	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
3	CHF 586.10	CHF 1'594.05	CHF 521.04	CHF 1'470.58	3	CHF 100.11	CHF 274.30	CHF 89.00	CHF 253.11	3	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
4	CHF 641.27	CHF 2'235.32	CHF 548.16	CHF 2'018.74	4	CHF 109.19	CHF 383.50	CHF 93.34	CHF 346.45	4	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
5	CHF 696.77	CHF 2'932.09	CHF 572.70	CHF 2'591.43	5	CHF 118.62	CHF 502.12	CHF 97.50	CHF 443.95	5	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
6	CHF 752.65	CHF 3'684.74	CHF 594.83	CHF 3'186.26	6	CHF 128.42	CHF 630.53	CHF 101.49	CHF 545.44	6	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
7	CHF 808.92	CHF 4'493.66	CHF 614.72	CHF 3'800.97	7	CHF 138.62	CHF 769.15	CHF 105.34	CHF 650.78	7	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
8	CHF 865.64	CHF 5'359.30	CHF 632.51	CHF 4'433.49	8	CHF 149.25	CHF 918.40	CHF 109.06	CHF 759.83	8	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
9	CHF 922.83	CHF 6'282.12	CHF 648.36	CHF 5'081.85	9	CHF 160.36	CHF 1'078.76	CHF 112.67	CHF 872.50	9	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
10	CHF 3'262.44	CHF 9'544.56	CHF 2'203.99	CHF 7'285.84	10	CHF 171.99	CHF 1'250.75	CHF 116.19	CHF 988.69	10	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
11	CHF 1'038.79	CHF 10'583.35	CHF 674.78	CHF 7'960.62	11	CHF 184.17	CHF 1'434.92	CHF 119.63	CHF 1'108.32	11	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
12	CHF 1'097.66	CHF 11'681.01	CHF 685.60	CHF 8'646.21	12	CHF 196.96	CHF 1'631.89	CHF 123.02	CHF 1'231.35	12	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
13	CHF 1'157.19	CHF 12'838.21	CHF 694.98	CHF 9'341.19	13	CHF 210.42	CHF 1'842.30	CHF 126.37	CHF 1'357.72	13	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
14	CHF 1'217.44	CHF 14'055.64	CHF 703.04	CHF 10'044.23	14	CHF 224.58	CHF 2'066.88	CHF 129.69	CHF 1'487.41	14	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
15	CHF 1'278.46	CHF 15'334.11	CHF 709.89	CHF 10'754.12	15	CHF 239.53	CHF 2'306.42	CHF 133.00	CHF 1'620.41	15	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
16	CHF 1'340.33	CHF 16'674.44	CHF 715.62	CHF 11'469.73	16	CHF 255.32	CHF 2'561.74	CHF 136.32	CHF 1'756.73	16	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
17	CHF 1'403.12	CHF 18'077.56	CHF 720.33	CHF 12'190.06	17	CHF 272.03	CHF 2'833.77	CHF 139.65	CHF 1'896.38	17	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
18	CHF 1'466.91	CHF 19'544.47	CHF 724.11	CHF 12'914.16	18	CHF 289.74	CHF 3'123.51	CHF 143.02	CHF 2'039.41	18	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
19	CHF 1'531.77	CHF 21'076.24	CHF 727.04	CHF 13'641.21	19	CHF 308.53	CHF 3'432.04	CHF 146.44	CHF 2'185.85	19	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
20	CHF 1'597.82	CHF 22'674.06	CHF 729.22	CHF 14'370.43	20	CHF 328.49	CHF 3'760.53	CHF 149.92	CHF 2'335.77	20	CHF -	CHF 23'623.00	CHF -	CHF 23'623.00
Total	CHF 22'674.06		CHF 14'370.43		Total	CHF 3'760.53		CHF 2'335.77		Total	CHF 23'623.00		CHF 23'623.00	

Appendix B

Technical Document: Sourcing Strategy

Sourcing Strategy

This chapter handles the sourcing strategy for this project. There are plenty of suppliers that provide the technology for the chosen systems, in this chapter the different options will be evaluated and one sourcing approach will be chosen.

This thesis focuses on suppliers from Germany and from China. The suppliers from Germany are:

- SolarKonzept GmbH from Berlin
- EURO Elektrowerkzeug- & Maschinen SERVICE GmbH

SolarKonzept GmbH is one of the distributers of the solar water pump systems manufacturer Lorentz, and EURO Elektrowerkzeug- & Maschinen SERVICE GmbH is one of the distributers of the gasoline generator. The supplier from China are:

- Solartech from Shenzhen
- Weifang Yuanyu Power Equipment Co., Ltd

Solartech also provides a similar system as SolarKonzept. Weifang is a distributer of Honda gasoline generators.

The costs for the system from China are 8’740 CHF including transport costs to Ulaanbaatar. The costs for the system from Germany are 10’020 CHF not including the transport costs to Ulaanbaatar. The transport cost of the generator are around 430 CHF. The transport costs data for the PV-System from Germany to Mongolia were not available, general cargo transport to Mongolia currently does not seem to be possible due to the COVID pandemic. As the generator weighs 80kg and it costs 430 CHF to transport to Mongolia, it can be assumed that the transport costs for the PV-System are 2’418 CHF, which amounts to 12’868 CHF if the sourcing is made in Germany.

Even though the costs from the suppliers in Germany are higher than from China, the sourcing should be made from Germany for the following reasons:

- Longer pump warranty: 2 Years from Lorentz and 1 Year from Solartech
- Longer solar panels warranty: 5 Years from Solartech and 10 years product warranty and 20 years of at least 80% of power from the panels.

Quotes

SOLARKONZEPT Gesellschaft für solartechnische Anwendungen mbH
Pasewalker Str. 76, 13127 Berlin
Tel. 030 48626906 Fax. 030 48626907
www.solkonzept.de

SOLARKONZEPT Gesellschaft für solartechnische Anwendungen mbH, Pasewalker Str. 76, 13127 Berlin

Hochschule Luzern
Campus Horw
Technikumstr. 21
6048 Horw
Schweiz

Kunden Nr.: 6928
Steuernr.: 37 537 30523
USt-IdNr.: DE813415123
Datum: 20.11.2020

Angebot Nr. 2020489

Aktualisiertes Angebot zur Lieferung einer solarbetriebenen Pumpe mit Zubehör

Pos	Menge		Text	Einzelpreis EUR	Gesamtpreis EUR
1	1,00	Stück	Lorentz PS2 4000 Tiefbrunnenpumpe zur Wasserförderung Pumpentyp PS4000 C-SJ8-15 Solardirektbetrieb max. Förderhöhe 80 m max.Förderung 13 m³ / h Spannung max: 375 V Spannung MPP min: 265 V DC Strom max: 15 A Inkl. Pumpencontroller mit MPP- Tracking, Datenlogger und Bluetooth zur Datenabfrage und Programmierung der Pumpe	2.760,00	2.760,00
2	1,00	Stück	Kabel- Verbindungsset Unterwasser Verbindungsset für Lorentz ECDRIVE 2,5- 6 mm²	11,22	11,22
3	1,00	Stück	Lorentz Trockenlaufschutz Sensor zur Montage an Unterwasserpumpen zur Kontrolle des Wasserstandes und Verhinderung des Trockenlaufs der Pumpe	44,88	44,88
4	1,00	Stück	Lorentz float switch Schwimmerschalter zur Abschaltung der Pumpe bei gefülltem Tank inkl. Anschlusskabel 2 m	21,00	21,00
5	2,00		Überspannungsschutz Lorentz Lorentz surge protector max. 5 V	15,18	30,36
6	40,00	m	Pumpenkabel Lorentz Für den dauerhaften Einsatz im Trinkwasser, Verbinden von elektrischen Geräten, Tauchpumpen bis zu einer Temperatur von 70°C und bis zu 400 m Eintauchtiefe.	4,84	193,60
7	40,00	m	Sensorkabel für Lorentzpumpen	1,65	66,00
Zwischensumme					3.127,06

Bankverbindung: Berliner VB Berlin
IBAN: DE85100900007054023000
BIC: BEVODEBBXXX

SOLARKONZEPT Gesellschaft für solartechnische Anwendungen mbH
Pasewalker Str. 76, 13127 Berlin
Tel. 030 48626906 Fax. 030 48626907
www.solkonzept.de

Pos	Menge		Text	Einzelpreis EUR	Gesamtpreis EUR
Übertrag					3.127,06
8	1,00		Lorentz AC Powerpack 3 Phasen - AC-DC Converter zur Versorgung von Lorentz PS 4000 Pumpen AC input: 360V 3-phasig DC Spannung Ausgang: 180-286 V DC DC- Leistung Ausgang: 5700 W Temperaturbereich: -5°-45° Für das Powerpack wir ein 3-phasiger Generator benötigt.	1.386,00	1.386,00
9	1,00	Stück	Lorentz PV Disconnect PV-Disconnect 440-40-3 zur sicheren Verschaltung der Solarmodule Spannung max: 440 V dc Strom max.: 40 A inkl. DC-Schalter	129,60	129,60
10	16,00	Stück	Solarmodul Trina 330 Photovoltaik-Modul 330 Wp monokristalline Zellen Nennleistung: 335 Wp Leerlaufspannung: 40,7 V Kurzschlußstrom: 10,48 A Wirkungsgrad Modul: 19,9 % inkl. MC4-Steckverbinder Maße: 1690 x 995 x 35 mm Gewicht: 19 kg Toleranz: + 5 % 25 Jahre Leistungsgarantie 80% 10 Jahre Produktgarantie	99,00	1.584,00
11	8,00	Set	Tric F Montagegestell Frei für 2 Module senkrecht	98,22	785,76
12	2,00	Stück	Kabelanschluss-Set 20 m 2 x 20 m Solarkabel 4 mm² mit Steckern/ Buchsen vorkonfektioniert, ein freies Kabelende isoliert Yukita, H+S, MC 3 oder MC 4 Steckverbinder	40,19	80,38
13	50,00	m	1 x 6 mm² Solarkabel Lapp Ölflex	1,25	62,50
14	1,00		Frachtkosten Spedition Versandkostenanteil Kunde	100,00	100,00
Zwischensumme					7.255,30

Bankverbindung: Berliner VB Berlin
IBAN: DE85100900007054023000
BIC: BEVODEBBXXX

SOLARKONZEPT Gesellschaft für solartechnische Anwendungen mbH
Pasewalker Str. 76, 13127 Berlin
Tel. 030 48626906 Fax. 030 48626907
www.solkonzept.de

Gesamt Netto		7.255,30
zzgl. 16,00 % USt. auf	7.255,30	1.160,85
Gesamtbetrag		**8.416,15**

Zahlungsbedingungen:Wir bitten um Überweisung des Betrags als Vorkasse.

Bankverbindung: Berliner Volksbank
Kto. Nr.: 7054023000 BLZ: 10090000
BIC:BEVODEBB / IBAN:DE85100900007054023000
SEPA:DE85100900007054023000

Amtsgericht Berlin- Charlottenburg HRB 84291
Finanzamt f. Körperschaften II Berlin
Steuernummer 37/537/30523 UST- ID NR: DE813415123

Dieses Angebot ist bis zum 31.12.2020 befristet.
Hiermit beauftrage ich die die Firma SolarKonzept GmbH mit der Lieferung lt. AG 2020489 vom 20.11.2020

Ort,Datum Unterschrift des Kunden

Bankverbindung: Berliner VB Berlin
IBAN: DE85100900007054023000
BIC: BEVODEBBXXX

Figure 17: Quote SolarKonzept.

Feng Liu 09:48
Weifang Yuanyu Power Equipment Co., Ltd.
This style

To protect your orders, always communicate and pay through the Alibaba.com website or app.

2020-12-11 09:35

Inquiry ID: 101126234959

Hot sale factory direct price small gasoline generator 6.25kva 5kw

Rated Power: 5 kw
Rated Voltage: 380 - 440 V
Output Type: AC Three Phase
Frequency: 50 Hz
Quantity: 1 Set/s

Dear Feng Liu Weifang Yuanyu Power Equipment,

I would like to get a quote for this generator including the transport to to Ulaanbaatar, Mongolia.
The generator has to be able to work under -15°C Temperatures and maintenance/replacement parts need to be available fast.

Rui Marques
BSc Energy Systems Engineering
Energy Engineer

D. +41 76 711 81 66
rui.manuel.marques@live.com
Hochschule Luzern, Technikumstrasse 21 , CH-6048 Horw

Complete sourcing amount
Get a faster response and better service from suppliers
Complete

Feng Liu 2020-12-11 09:40
Hello

Feng Liu 2020-12-11 09:46
$3600

Figure 18: Quote from Weifang Yuanyu Equipment.

Von: gary.zhang@solartech.net.cn
Gesendet: Freitag, 11. Dezember 2020 06:53
An: rui.manuel.marques
Betreff: Re: Fw: Price Request
Wichtigkeit: Hoch

Dear Mr. Rui Marques,

Good morning.
Glad to receive your enquiry.
We have updated our solar pump system model name on our new product catalogue.
We will launch our new website soon.

The model you selected on our website "PSA4000-4 AC" is equal to our new model **SPB43K0100-4**
Please kindly find the attached data sheet.
1. The price for the solar pump kit SPB43K0100-4 is **1,172USD**
   - Solatech solar pumping inverter, PB5500H-G3
   - Stainless Steel Submersible Pump, SPB4-14-3
   - Water Level Switch, S-FS-P-01
2. The needed solar PV array power is 330W/36Vmp, 38pcs (19pcs x 2strings)
The price is 3,762USD

3. You need a solar combiner junction box, the price is **100USD**

4. The transport cost from Shenzhen, China to Ulaanbaatar is **1,200USD.**

Best regards,

Gary Zhang

Deputy Director of Overseas Sales

Solartech®
Shenzhen Solartech Renewable Energy Co., Ltd
Email: gary.zhang@solartech.net.cn Web: www.solartech.cn
Mobile: +86 136 8499 8258 WhatsApp: +86 189 8876 3703
Skype: ivorywhiteweddingshoes QQ(Wechat): 1470827326
Tel: +86 755 8615 0728 Fax: +86 755 8615 1708
Add: 4Fl., Building 9, Jiu-Xiang-Ling Industrial Park, Xi-Li, Nanshan District, Shenzhen, P.R.China 518055

Figure 19: Quote Solartech.

AW: Angebot Generator 7000 in die Mongolei

S **Seibel <seibel@euro-koeln.de>**
14.12.2020 09:38

An: Rui Marques

Guten Tag Hr Marques,

aktuell schlecht abschätzbar.
Der Spediteur rechnet mit ca. 3500 – 4000 Euro für die 600 kg.

Kind regards – Freundliche Grüße

Christof Seibel

EURO Elektrowerkzeug- & MaschinenSERVICE GmbH
Bürgerbuschweg 20 • 51381 Leverkusen • Germany
Fon: +49 2171/ 36302-18 • Fax: +49 02171/ 36302 – 29 • www.euro-koeln.de • info@euro-koeln.de

Geschäftsführer: Christof Seibel • Registergericht: Köln HRB 30166 • Steuernummer: 224 5713 1271
Ust.-Ident-Nr.: DE 192 945 385 • WEEE-Reg.-Nr.: DE 10239260
Bankverbindung: Postbank Köln • BIC: PBNKDEFF • IBAN: DE62 3701 0050 0129 1285 07
Online-Streitbeilegung gemäß Art. 14 Abs. 1 ODR-VO: Die Europäische Kommission stellt eine Plattform zur Online-Streitbeilegung (OS) bereit, die Sie unter http://ec.europa.eu/consumers/odr/ finden.

Figure 20: Quote transport from Germany to Mongolia.

KS 7000E-3

949,00 € *
inkl. MwSt. zzgl. Versandkosten
Lieferzeit ca. 8 - 10 Werktage

1 Stk | In den Warenkorb

Vergleichen Merken Bewerten Empfehlen

Artikel-Nr.: 1782376792098

Figure 21: Price of gasoline generator form Könner & Söhnen.

Appendix C

Technical Document: System Design

Base Case System Description

The current system consists of a submersible water pump that is powered by a gasoline generator.

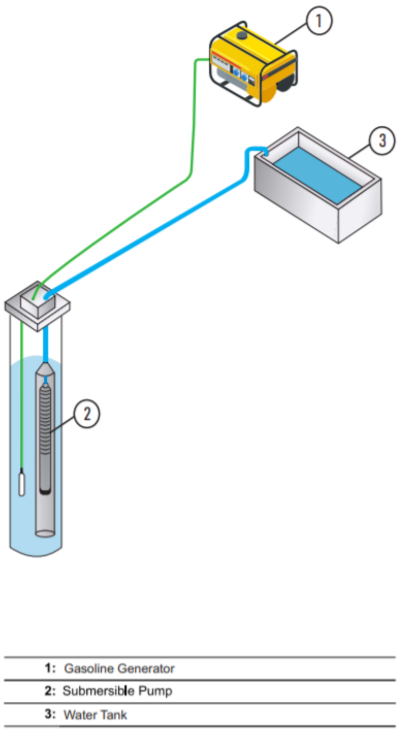


Figure 22: System layout of the base case.

The gasoline generator outputs 1 phase at 220 Volts and a frequency of 50 Hz. The peak power available is 3.0 kW and the rated power is 2.8 kW. The manufacturer is Astrakoera.

Figure 23: Data of gasoline generator.

The gasoline generator powers a 0.75 kW submersible pump that is located 30 meters underground. The pump as a maximum head of 75 meters. The detailed technical specifications of the pump model 4SDM4/10 were not available on DAFU's website. There is a similar pump version with the model name 4SDM4/9 which has the same power (0.75 kW).

The AC power is distributed to the pump with copper cables. The submersible pump also uses AC power as seen in chapter 1.1 "Current Situation" therefore no other energy conversion device is needed.

TECHNICAL DATA

MODEL		P2		DELIVERY									n=2850 r/min
1~ 220V/240V	3~ 380V/415V	kW	HP	Q	m³/h	0	1.2	1.8	2.4	3	3.6	4.2	4.8
					L/min	0	20	30	40	50	60	70	80
4SDM4/6 100QJD4/6	-	0.37	0.50	H(m)		45	42	40	37	33	27	19	9
4SDM4/7 100QJD4/7	-	0.55	0.75			60	56	54	50	44	36	25	11
4SDM4/9 100QJD4/9	-	0.75	1.0			68	63	60	56	49	40	29	12
4SDM4/12 100QJD4/12	4SD4/12 100QJ4/12	1.1	1.5			90	85	80	76	65	52	35	14
4SDM4/16 100QJD4/16	4SD4/16 100QJ4/16	1.5	2.0			120	112	107	99	89	72	50	23
4SDM4/22 100QJD4/22	4SD4/22 100QJ4/22	2.2	3.0			165	154	147	136	122	99	69	32
-	4SD4/28 100QJ4/28	3.0	4.0			210	196	187	173	156	126	88	40

PERFORMANCE CHART at n=2850 r/min

Figure 24: Technical data submersible pump (http://www.dafupump.com/product/46.html).

The farm owner divulged the following information:

- Animal count is 6000.
- Each animal drinks around 25 litres
- In the winter months the animals drink around 10 times per month.
- In the summer months the animals drink around 15 days per month.
- The water pump is manufactured by DAFU, the model is 4SDM4/10 (220V 50Hz)
- The winter water consumption is 50 m^3/day (calculated)
- The summer water consumption is 75 m^3/day (calculated)
- The energy consumption in the winter is 8.92 kWh/day (calculated)
- The running time in the winter is 11.9 hours per day (calculated)
- The energy consumption in the summer is 13.39 kWh/day (calculated)
- The running time in the summer is 17.85 hours per day (calculated)

With the above information the winter and summer monthly water consumption can be calculated:

$$Winter\ Water\ Consumption = 6000\ Animals * 25\ l * 10\ \frac{times}{month} = 1'500'000\ \frac{l}{month}$$

$$Summer\ Water\ Consumption = 6000\ Animals * 25\ l * 15\ \frac{times}{month} = 2'250'000\frac{l}{month}$$

$$Winter\ Water\ Consumption = 1'500\frac{m^3}{month} \cong 50\frac{m^3}{day}$$

$$Summer\ Water\ Consumption = 2'250\frac{m^3}{month} \cong 75\frac{m^3}{day}$$

Using this information and the information that the pump is 30 meters underground. The flowrate as seen in figure 6 is 70 litres per minute. Using this information, the energy demand and the running time of the pump can be calculated using the following equation:

$$Energy_{Winter} = 0.75\ kW * \frac{1'500'000\frac{l}{month}}{70\frac{l}{min} * 60\ min} = 267.85\ \frac{kWh}{month} \cong 8.92\frac{kWh}{day}$$

$$Running\ time_{Winter} = \frac{1'500'000\frac{l}{month}}{70\frac{l}{min} * 60\ min} = \ 357.14\ \frac{h}{month} \cong 11.9\frac{h}{day}$$

$$Energy_{Summer} = 0.75kW * \frac{2'250'000\frac{l}{month}}{70\frac{l}{min} * 60min} = 401.78\ \frac{kWh}{month} \cong 13.39\frac{kWh}{day}$$

$$Running\ time_{Summer} = \frac{2'250'000\frac{l}{month}}{70\frac{l}{min} * 60min} = \ 535.71\ \frac{h}{month} \cong 17.85\frac{h}{day}$$

One also significant information is how long the pump is running per day. If the running time is divided by 30 days in a month the results are: 11.9 hours per day in the wintertime and 17 hours per day in the summertime.

Advantages of the system

The advantages of this system is the availability of the power supply. The power supply is not dependent on the environment. Power can be supplied as long as gasoline is available.

Disadvantages of the system

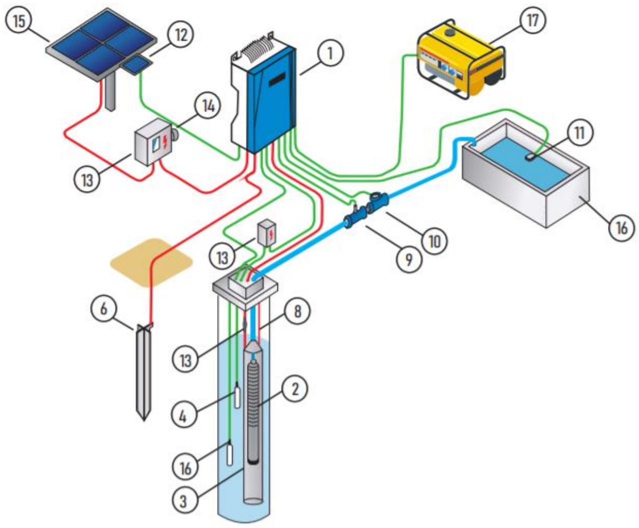
As the power supply is dependent on gasoline, the costs heavely depent on the oil price. As the generator consumes 60 to 70 liters of gasoline per month the costs are very high for the family. One other factor is the reliability of the generator. As the family revealed that the generator breaks once to twice a year.

Scenario 1 System Description

The coordinates of the location (45°N 102°E) can be input to the software. As mentioned in the chapter "climate" the tilt angle of the PV array is 15° in the south direction. The dynamic head will be input as 40 meters because the pump is 35 meters underground and the software as an input interval of 5 meters. As mentioned in the chapter "Energy Demand in Base Case" the minimum daily water output is 75 m^3. The software uses these inputs to calculate the rated power of the PV array and to choose the pump from the catalogue of "Lorentz".
The results are the following:

- Rated power: 5'200 Wp (8x2 CS Wismar 325)
- Pump: PS2-4000 C-SJ8-15 with 4 kW power

Because the pump as a maximum power of 4 kW the gasoline generator should also be able to deliver 4 kW electric power.



1: PS2 Controller	**11:** Float Switch
2: Submersible Pump	**12:** Sun Switch
3: Flow Sleeve	**13:** PV Disconnect
4: Well Probe	**14:** Lightning Surge Protector
5: Cable Splice Kit	**15:** PV Generator
6: Grounding Rod	**16:** Water Tank
7: Surge Protector*	**17:** Gasoline Generator
8: Safety Rope	*It is recommended to install a Surge Protector at each controller sensor input.
9: Water Meter	
10: Pressure Sensor	

Figure 25: System layout of scenario 1.

Parameters

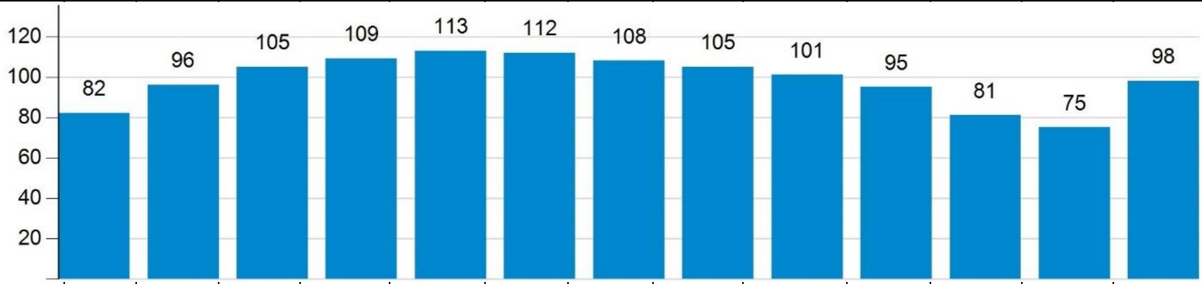
Location:	, (45° Nord; 102° East)	Watertemperatur:	25 °C		
Required daily output:	75 m³; Auslegung für Dezember	Dirt loss:	5,0 %	Motorcable:	45 m
Pipe type:	steel, slightly rusty and incrusted: 0,400 mm	Total Head:	40 m	Pipe Length:	40 m

Products	**Quantity**	**Details**
PS2-4000 C-SJ8-15	1 pcs.	Submersible pump system including controller with DataModule, motor and pump end
CS Wismar 325	16 pcs.	5.200 Wp; 8 x 2 Modules; 35 ° tilted
Motor cable	45 m	4 mm² 3-Phase cabel für for power and 1-Phase cabel for E
Pipe	40 m	50 mm (Innendurchmesser) Rohrleitung
Accessories	1 Satz	Well Probe V2, PV Disconnect 440-40-3, Surge Protector2

Sun Sensor setting in PumpScanner **min. 100 W/m²**

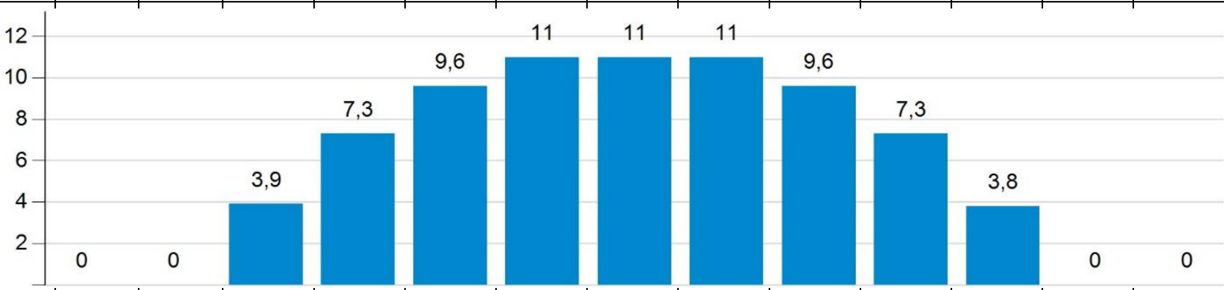
Required daily Output in December **75 m³**

Output [m³]



Daily Values	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Ø**
Energy [kWh]	22	28	32	33	31	29	27	27	27	25	20	18	27
Irradiation [kWh/m²]	4	5,2	6,2	6,6	6,4	6,3	5,9	5,7	5,7	5,0	3,8	3,3	5,3
Rainfall [mm]		0.067	0,10	0,30	0,73	1,6	2,8	2,[1]	0,73	0,23	0,10		0,73
Ambient temp. [°C]	-19	-15	-6	4	11	17	19	17	10	2	-8	-16	1

Ertrag [m³/h]

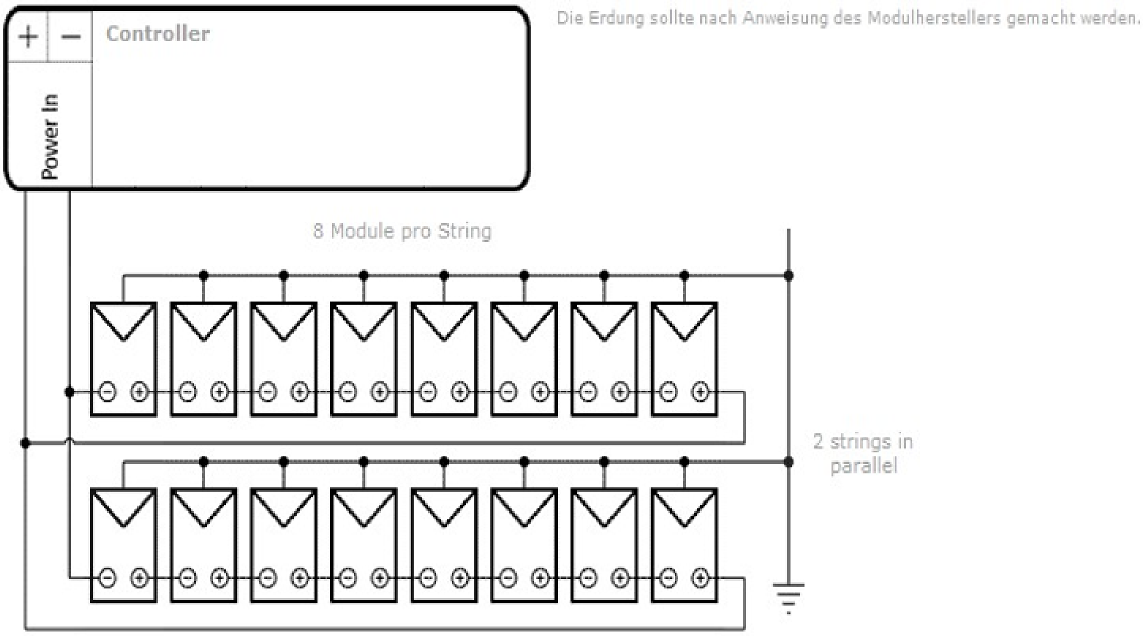


Hourly Values	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
Energy [kWh]	0	0	0,74	1,6	2,4	2,9	3,0	2,9	2,3	1,6	0,72	0	0
Irradiation [kWh/m²]	0	0	0,13	0,29	0,43	0,54	0,56	0,54	0,43	0,29	0,13	0	0
Ambient temp. [°C]	-21	-21	-20	-18	-16	-14	-12	-11	-11	-11	-11	-12	-12

System Characteristics

			Min.	800 W/m², 20 °C	Max./STC*
PV Generator	Cell temperature	[°C]		46	25
	Temperature loss	[%]		8,2	-
	Dirt Loss	[%]		5,0	-
	Pmax	[Wp]		3.630	5.200
	Vmp	[V]		249	270
	Imp	[A]		15	19
	Voc	[V]		298	323
	Isc	[A]		16	21
	Pout	[W]		3.070	-
	Vout	[V]		277	-
	Iout	[A]		11	-
Motor cable	Power Loss	[%]	0,78	2,6	2,6
Pump systems	Motor Power	[W]	220	2.970	2.970
	Motor Voltage	[V EC]	106	213	213
	Motor Current	[A]	2,1	14	14
	Motor Speed	[rpm]	1.995	2.990	2.990
	Flow Rate	[m³/h]	0	12	12
	Efficiency	[%]	0	45	58
Pipe	Flow Rate	[m/s]	0	1,6	1,6
	Friction Losses	[m]	0,001	3,8	3,8

Wiring Diagram



Solar Submersible Pump System

PP4000 AC PowerPack

AC/DC Converter to Supply PS4000 Pump Systems with Backup Power from a Generator or Mains Supply

photomaydifferfromactualproduct

PS2-4000 C-SJ8-15

Solar Submersible Pump System for 4" wells

System Overview

Head	max. 80 m
Flow rate	max. 13 m^3/h

Technische Daten

Controller PS2-4000

- Controlling and monitoring
- Control inputs for dry running protection, remote control etc.
- Protected against reverse polarity, overload and overtemperature
- Integrated MPPT (Maximum Power Point Tracking)
- Integrated Sun Sensor

Power	max. 4,0 kW
Input Voltage	max. 375 V
Optimum Vmp**	> 238 V
Motor current	max. 14 A
Efficiency	max. 98 %
Ambient temp.	-40...50 °C
Enclosure class	IP68

Motor ECDRIVE 4000-C

- Maintenance-free brushless DC-motor
- Water filled
- Premium materials, , Stainless steel: AISI 304/316
- No electronics in the motor

Rated power	4,0 kW
Efficiency	max. 92 %
RPM	900...3.300 rpm
Isolation class	F
Enclosure class	IP68
Submersion	max. 150 m

Pumpenkopf PE C-SJ8-15

- Non-return valve
- Premium materials, Stainless steel: AISI 304
- Centrifugal pump

Efficiency	max. 68 %

Pump Unit PU4000 C-SJ8-15 (Motor, Pump End)

Borehole diameter	min. 4,0 in
Water temperature	max. 50 °C

Standards

2006/42 /EC, 2004/108/EC, 2006/95/EC
IEC/EN 61702:1995, IEC/EN 62253 Ed.1

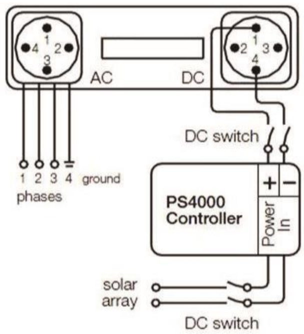
CE

ORDER INFORMATION

- **Item no.:** 19-000180 **Product name:** Power Pack 4000 380 V AC
- **Item no.:** 19-000181 **Product name:** Power Pack 4000 460 V AC

TECHNICAL DATA

Power Pack 4000 380 V AC DC output rated current:	**Power Pack 4000 460 V AC** DC output rated current:
3-Phase AC input 380 V (±20 %) 45 to 65Hz	3-Phase AC input 460 V (±15 %) 45 to 65Hz
DC output: 180-286 V DC 5.7 kW	DC output: 230-330 V DC 6.6 kW
DC output rated current: 20 A at 230 V DC	DC output rated current: 20 A at 330 V DC



- Must be protected from direct mid-day sun
- IP42
- Ambient temperature: –5 to 45°C
- Efficiency up to 94%
- Passive cooling, no fan
- All wires must be #14 AWG (2.5 mm²) or larger
- Manual with further information is available on PartnerNet
- Meets the requirements for CE

DIMENSION/WEIGHT

- Packaging dimensions: 332 x 210 x 202 mm

  15.7 x 8.7 x 8.3 in
- Total weight: 14.5 kg / 30 lbs

Gasoline Generator

The gasoline generator KS 7000E-3 has a rated power of 5 kW and a peak power of 5.5 kW. It provides 400 V with a frequency of 50Hz to the powerpack mentioned above. The generator uses a 4 stroke engine with 389 cm^3 to power a high quality alternator with a copper winding. The engine is suited to work with temperatures below zero as a back up or as a permanent energy supplier.

Advantages of the system

The advantages of this system is the lower costs of operation. Most of the energy is delivered by the sun and the gasoline generator only is used when water is needed and the sun is not shinning. As the gasoline generator is able to deliver 4 kW aswell the system as 100% redundancy in the case that either one of the systems fails.

Disadvantages of the system

Compared to the other systems the only disadvantages that this system has is the large investment cost and the operational cost compared with scenario 2.

Scenario 2 System Description

Scenario 2 consists of the same photovoltaic system as in scenario 1. The difference consists of the back-up option when the sunlight is not available which is a water tank. This is the most common place solution in third world countries in the continent of Africa.
The difference from the projects in Africa with this one in Mongolia is the ambient temperature, as in Africa in most projects the temperatures do not go under 0°C. In this project the temperatures reach -20°C in the winter months. For that reason, for isolation purposes, the tank should be located underground with added thermal isolation to prevent the water from freezing. The water tank has a diameter of 1.9 meters and a height of 2.3 meters giving it a volume of 5 m^3.
Around 75 m^3 of water are needed per day, if a back-up of 2 days is to be set, 30 tanks of 5 m^3 need to be installed.

Advantages of the system

The clear advantages of this system are the non-existent operational costs.

Disadvantages of the system

The clear disadvantage of this system if the volume needed as back-up. As the family requires 75 m^3 per day and a back-up for 2 days should be in place, 150 m^3 are required. That means that 30 of the 5 m^3 have to be installed, meaning that an area of at least 65 m^2 is needed (about 8 m x 8 m). As the tanks need to be underground, escavating that kind of mass is by itself alone burdensome, by taking into consideration that the location is in a rural area several kilometers away from the nearest city with the available means for this operation, it can be concluded that executing this scenario would demand a lot of resources. The latter conclusion is without considering the burdon of transporting 30 of the large tanks from the nearest city to the location in a rural area, which would add to the resources needed for this operation.

Appendix D

Multi-Criteria Decision Analysis

Data			
	Investment Cost	Operational Cost	Reliability
Base Case	CHF -	CHF 14'370.45	4
Scenario 1	CHF 10'109.00	CHF 2'335.77	5
Scenario 2	CHF 23'623.00	CHF -	3
Assessment - Parameters			
	0	100	
Investment Cost	25'000	0	
Operational Cost	20'000	0	
Reliability	1	5	
Weighting			
Investment Cost	0.2		
Operational Cost	0.5		
Reliability	0.3		
Total	1		
Scoring			
	Investment Cost	Operational Cost	Reliability
Base Case	100	28.14775	80
Scenario 1	59.564	88.32115	100
Scenario 2	5.508	100	60

Weighted Scoring			
	Investment Cost	Operational Cost	Reliability
Base Case	20	14.073875	24
Scenario 1	11.9128	44.160575	30
Scenario 2	1.1016	50	18
Results			
	Total Score	Rank	
Base Case	58.073875	3	
Scenario 1	86.073375	1	
Scenario 2	69.1016	2	