YRKESHÖGSKOLAN NOVIA

Energy for rural Zambia

A Model for Sustainable Off-Grid Energy

Tobias Huber, Finn Gausmann, Henrik Dierenfeld, Tom Fransen, Maaike Kamer

European Project Semester

Final Report

Vaasa, 2022

Final Report European Project Semester Autumn 2022

Author: Tobias Huber, Finn Gausmann, Henrik Dierenfeld, Tom Fransen, Maaike Kamer

Program: European Project Semester

Supervisor: Cynthia Söderbacka

Title: Energy for rural Zambia – A Model for Sustainable Off-Grid Energy

---

Date: December 12, 2022 Number of pages: 85 Appendices: 1

Abstract

Only about 4% of Zambia's rural areas are supplied with electricity. However, an electricity supply in these areas would bring great added value for the people living there and their living conditions. One possible approach to improve this situation is the use of off-grid systems.

This paper will give an overview of Zambia's geological, climatic, cultural, political and economic living conditions. Based on this background knowledge, the use of different energy sources will be evaluated and compared. With this basis, an off-grid system will be tested for its validity and feasibility with the use of a model. Different scenarios are developed to give a realistic picture of a rural area in Zambia and serve as a basis for a model. In addition, the content of this project is to create a website that presents and explains the off-grid system that has been built.

In the context of the European Project Semester, this project will be the basis for further projects. Based on the created model for an off-grid system in rural Zambia, further optimisation measures can be taken.

Language: English Keywords: Energy, Nanogrids, Zambia, Off-Grid, Sustainability

---

Acknowledgements

The team would not have been able to complete this project without the help and expertise of various institutions, lecturers and involved people.

First, we would like to thank our supervisor, Cynthia Söderbacka, for her knowledge and guidance. Also special thanks to Cephas Samende and Mathews Chibuluma from the University of Zambia and the Copperbelt University for their competence and for answering all our questions about Zambia. This project could not have been possible without the partnership between the three Universities.

The team would also like to thank the lecturers who gave us the knowledge to complete this EPS project and taught us about Finland. Thanks to Roger Nylund for guiding us through this semester and for the trustful cooperation. Also thanks to Hannah Kuusisto and Kristina Granstedt-Ketola for improving our language skills in English and Swedish. Furthermore, we would like to thank Josefin Stolpe for her helpful feedback on the mid-term report.

Many thanks also to the EPS students, with whom we had a great time here in Finland. They also gave us inspiration for new ideas and supported us with organisational challenges.

Table of Contents

List of abbreviations

EPS: European Project Semester

GDP: Gross Domestic Product

KCM: Konkola Copper Mines

kWp: Kilowatt peak

LCOE: Levelized Cost of Electricity

MCDA: Multi-Criteria Decision Analysis

MCM: Mopani Copper Mines

UAS: University of Applied Sciences

UPND: United Party for National Development

WPM: Weighted Product Model

WSM: Weighted Sum Model

List of formulas

List of figures

List of tables

1 Introduction

In this chapter, there will be a short introduction to Novia University of Applied Sciences and the European Project Semester. In addition, the purpose of this project and its objectives will be explained. At last, the team members will be introduced.

1.1 Novia University of Applied Sciences

Yrkeshögskolan Novia (Novia University of Applied Sciences) is the biggest Swedish-speaking University of Applied Sciences in Finland. There are 4500 students on 4 campuses in Vaasa, Turku, Raasepori, and Pietarsaari and 320 staff members. Novia UAS offers professions in Arts and Humanities, Bioeconomy, Business, Health and Welfare and Technology and Seafaring. Internationalization is an important goal for Novia as one of the leading Universities of Applied Sciences in their profession – national and international. The ambition is to build a considerable network of international partners. Offering the EPS contributes to this ambition. (Novia UAS, 2018)

1.2 European Project Semester

The European Project Semester is an exchange program focused on engineering students and offered by several European Universities of Applied Sciences. The EPS project is accompanied by several courses that train the student's soft skills. Project Management is designed to familiarise students with a structured way of working concerning their project. To improve the quality of the final report and to enhance intercultural interaction, the students are offered the subject English and Cross-Cultural Communication. Another aim of the EPS, to integrate the students into the local culture, is pursued by the course Swedish Survival Course. This also helps to make everyday life in a foreign country easier for the students. (European Project Semester, 2022)

1.3 About the Project

The Project “Energy for rural Zambia – A Model for Sustainable Off-Grid Energy” aims to create and simulate a model to produce affordable and renewable energy in rural regions of Zambia. The task needs to be dealt with based on off-grid technology. This project is a collaboration between the Novia University of Applied Sciences, the University of Zambia and the Copperbelt University. The Zambian Universities contribute to this project both with expertise and background information. This project is part of the EPS in the autumn semester from September to December 2022 and will be continued by following EPS groups.

In Zambia, the majority of the population has no access to electricity. In rural areas, even less than 4% of the people have access to electricity. The government aims to increase the total access to electricity to 50% by 2030. To achieve this goal the rural regions should be supplied with renewable energy. (Söderbacka, 2022)

With this low rate of electrification in the rural regions of Zambia, many negative aspects go hand in hand. As local people cook with fire, health problems arise and at the same time, deforestation is increasing. Moreover, children do not have a good education, the medical services are not high quality and there is insufficient public food security. Thus, giving rural areas in Zambia access to electricity improves people’s quality of life. (Ruiven, Schers, & Vuuren, 2011)

The main objectives of the project are:

- Development of a basis for increasing the electrification rate of rural areas in Zambia.
- Creating energy usage patterns for a village of ten households and public utilities.
- Designing an affordable solution for producing and storing renewable energy for small villages in rural Zambia.
- Creating a digital simulation for the design and dimensioning of an off-grid system.

Out of the scope of this project are the development and testing of a physical end product. It is only intended to form a basis with which a physical product in the form of a prototype could be developed in an ongoing project.

In addition to this technical report, a more process-oriented report will be written. This will focus on the roles of the team members, the planning and the risks and stakeholders that have to be kept in mind during the project. This report can be found in the appendix (chapter 15).

1.4 Team members

For this project, there were group members brought together from different backgrounds. This team consists of five members who come from two different countries and all have different study backgrounds. The Belbin and leadership tests can be found in the appendix. In this paragraph, all the team members will be shortly introduced.

1.4.1 Finn Gausmann

Finn is a student from Osnabrück in Germany. His subject is mechanical engineering with a specialization in energy technology. He can contribute background knowledge of renewable energy and typical engineering work. The EPS opens an opportunity for him to improve his communication skills and learn how to work on projects and also improve his skills on the subject. According to Belbin, Finn will mostly contribute to this project as a specialist, which fits because he has the most background knowledge of renewable energy and simulation.

1.4.2 Henrik Dierenfeld

Henrik studies industrial engineering at the Berliner Hochschule für Technik. The degree program is focused on civil engineering, so he works on a lot of projects in this field. He is generally very interested in technology, even outside the scope of his studies. During his studies, he was also able to gain knowledge about project management and team building, which he will try to implement in the project. According to his Belbin result, he will mostly contribute to the project as a resource investigator, so he will explore opportunities and develop contacts.

1.4.3 Maaike Kamer

Maaike is studying civil engineering in the Netherlands, at The Hague University of Applied Sciences. This study focuses on construction, geomechanics, water management and infrastructure. She mostly works on projects, so she is already familiar with project management and working in teams. For this project, she wants to learn more about nanogrids, simulation and working with different cultures. According to Belbin, she will contribute to this project as a coordinator and complete finisher, which means she will focus on everyone’s strengths and search out errors.

1.4.4 Tobias Huber

Tobias studies industrial engineering at the Technical University of Applied Sciences Rosenheim, in the south of Germany. His specialisation is mainly in production technology and the optimisation of processes. Tobias is especially fascinated by the question of how new technologies can be used to make processes more economical. In terms of the project, the project management experience is particularly enriching for him, but also the ability to familiarise himself with new topics. During this project, he will be the project leader because of his strong shaper features, according to the Belbin results.

1.4.5 Tom Fransen

Tom is a design student with a focus on content creation and storytelling. Everything from motion design, architecture and photography he likes to include in his projects. The projects try to capture a story by implementing storytelling assets to them. This project will be a completely different subject than Tom would normally work on. Therefore, Tom hopes to expand his technical knowledge and further improve his team working abilities. According to Belbin, he will mostly contribute to this project as a plant, which fits with his creativity and marketing ideas.

2 Methodology

The project began with gathering background information on the local climate, geography, culture, politics and economy in Zambia. This will provide an overview of the living situation in this country. Furthermore, the topics of nanogrid technology and renewable energies are examined more closely. Another important part of this is to research the storage of energy. All this information will be collected through literature research, giving a superficial impression of Zambia.

Following the research part, different concepts for the use of renewable energies can be developed, which will be analysed in terms of their economic viability. The comparison is to be calculated with the help of a standardised comparative cost calculation. In order to find the optimum for this project from the developed concepts, a Multi-Criteria-Decision Analysis will support this process.

Various scenarios can now be derived from the determined optimal renewable energy source, which should provide a basis for the subsequent modelling and simulation of the entire system with concrete values. With the help of the model, a statement can also be made about the quantitative and qualitative use of the determined renewable energy source.

In parallel with this work, a logo will be created for the project, which should reflect the contents as accurately as possible. A website, which will be created within the framework of this project, will also serve as an illustration. This should not only make the objectives and goals of the project accessible to external persons. It will also present the model in a simplified way. The website aims to present and market the project to the public. This website will visualise the knowledge gained in the simulation. Therefore, a 3D model will be created, which interactively guides interested parties through the functions. Additionally, the deliverables of the project will also be available there.

3 Background research

The project started by doing background research about Zambia. The geography and landscape, information about the climate, politics and culture, and the economic situation were examined. All this research will be presented in this chapter, while it is essential to understand the context of the project and the design choices.

3.1 Geography

Zambia is located in the south of the African continent. As can be seen in figure 1, it is a landlocked country that shares the border in the north with the Democratic Republic of the Congo and Tanzania. In the east, it is located next to Malawi and Mozambique. Zimbabwe, Botswana, and Namibia form the southern border of Zambia. The western border is shared with Angola. (Zambia Tourism, 2022)

Zambia has a population of 18 million people, with a density of 24 people per square kilometre. More than half of the population is living in rural areas. The Lusaka area and the Copperbelt region are the most densely populated areas. (World Population Review, 2022)

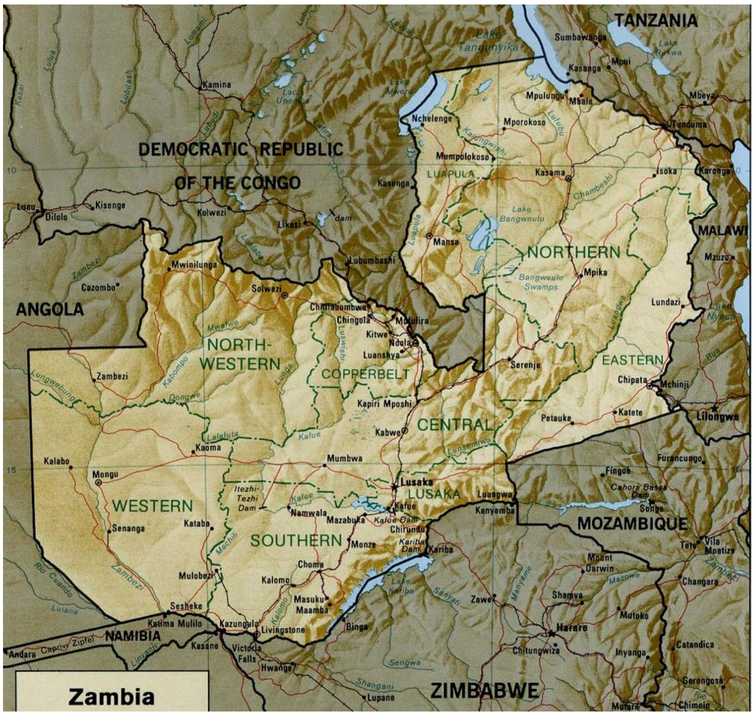

Figure 1 Relief map Zambia (World of Maps, 2022)

Zambia is located on a high plateau, with a mostly flat surface. The average height of the country is 320 to 415 meters above sea level. (Zambia Tourism, 2022) Most of the country's altitudes occur in the southeast, with its highest elevations at the border to Malawi. The Central African Copperbelt contains the largest copper and cobalt deposits in the world and runs partly through Zambia. Zambia's copper deposits are mostly located in the northwest, close to the Democratic Republic of the Congo. (African Pioneer, 2022)

The Zambezi River is the largest in Zambia. It enters the country in the northwest and then forms the Zambian border with Namibia and Zimbabwe. Other big rivers are the Kafue and Luangwa River. The Zambezi and the Kafue River stream into Lake Kariba, the biggest lake in the country. (Zambia Tourism, 2022)

Plant and animal life are incredibly diverse. A humid climate and seasonal floodings close to the rivers contribute to that. Most of the floodings take place in the upper Zambezi on the floodplains with open grasslands. (Brittanica, 2022) Zambia also contains one of the most important wetlands in Africa close to Bangweulu Lake, where many people live (African Parks, 2022). The driest part of the country is located in the southwest, with not much vegetation. The forests are mostly located in the central part of Zambia. (Brittanica, 2022)

From this research, it can be concluded that Zambia is a low-populated country where the majority of the population is living in rural areas. While it is a large country there are diverse landscapes, such as parts with high elevations, floodplains, forests and dry areas. The nanogrid system should work in all these regions.

3.2 Climate

Weather data will be needed in the remaining part of this work to be able to assess the usefulness of specific renewable energy sources. In this paragraph, the relevant climate information for the most used renewable energies will be discussed. The focus will be on wind speed and irradiation.

3.2.1 Temperature and Precipitation

A major factor influencing energy generation with off-grid systems is the local weather. Figure 2, therefore, shows the average temperature and precipitation per month. As can be seen, the highest precipitation occurs both at the end and the beginning of the year. This is the time that the temperatures are highest as well. In the months of May to September, there is almost no rainfall and the temperatures decrease.

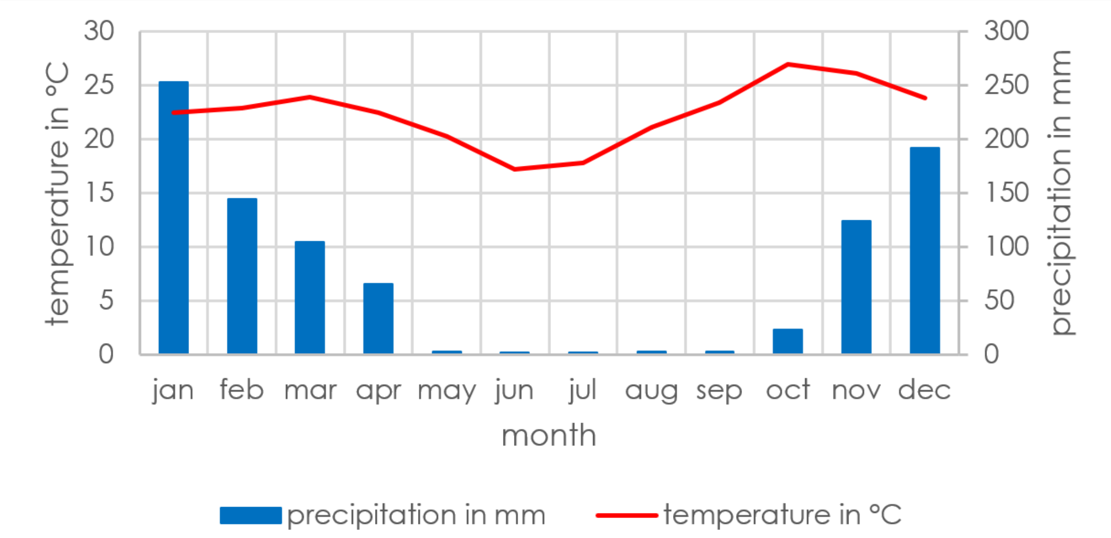

Figure 2 Average temperature and precipitation Zambia (Renewables.ninja, 2022)

3.2.2 Irradiation

The irradiation energy is an important factor in the possibility of solar panels. To find out which technical system is to be used for the project, it is important to look at and classify the irradiation conditions in Zambia. According to figure 3, Zambia has an average irradiation energy on a horizontal surface of approximately 2300kWh/m². Compared to mid-Europe, the irradiation is twice as high. (Global Solar Atlas, 2022)

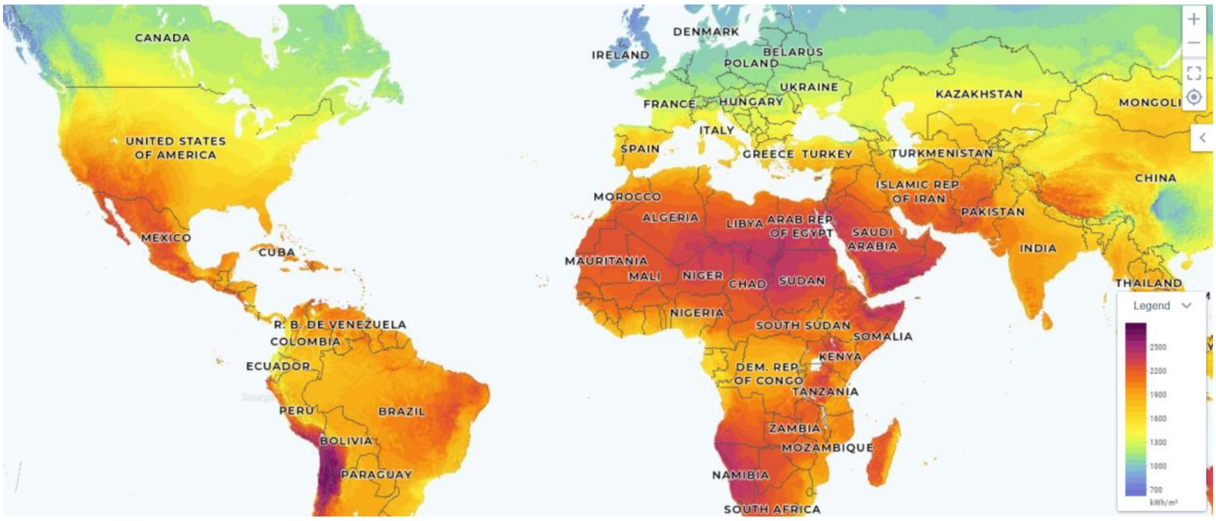

Figure 3 Global horizontal irradiation (Global Solar Atlas, 2022)

As can be seen in figure 4, Zambia has an almost constant level of irradiation throughout the year. This could make solar panels a good option as a renewable energy source. There are only some small drops in irradiation at the beginning and end of the year, which can be explained by cloud coverage.

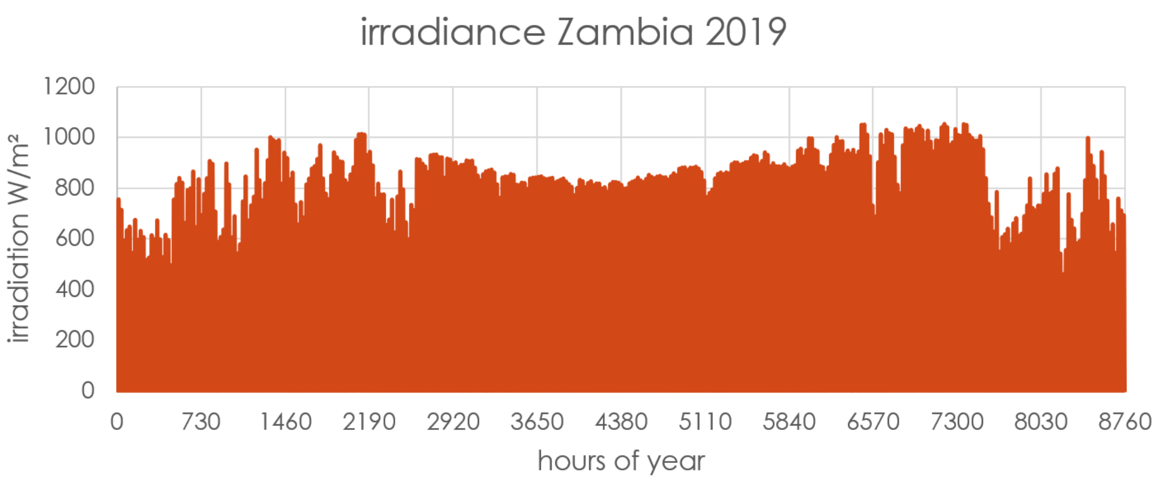

Figure 4 Irradiance 2019 (Renewables.ninja, 2022)

3.2.3 Wind speed

Wind speed is an important factor in considering the possibility of wind turbines as a renewable energy source. Thus, the wind supply must also be examined first. As can be seen in figure 5, increased wind speeds occur from the middle until the end of the year. For comparison, in Finland, the average wind speed is the same for the whole year.

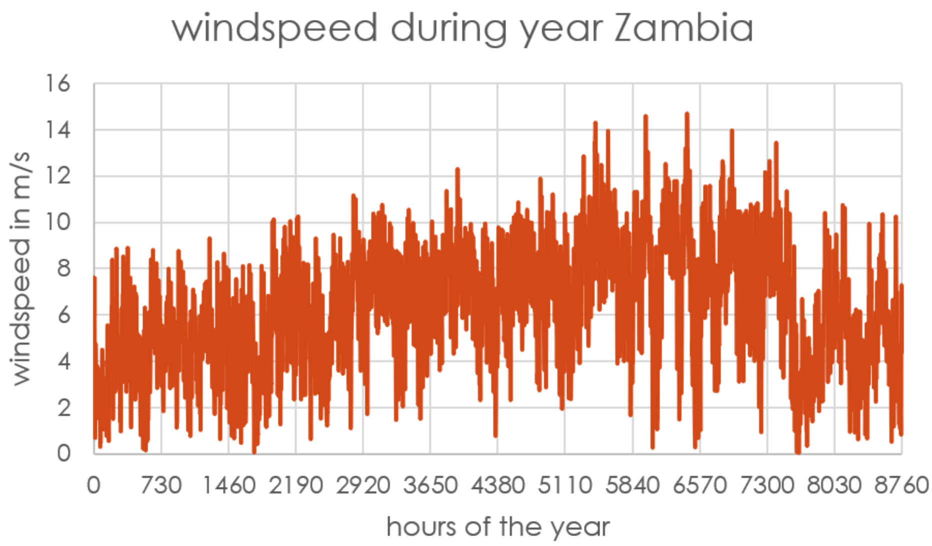

Figure 5 Wind speed (Renewables.ninja, 2022)

In figure 6 the distribution of the wind speed over the year is analysed. It can be seen that the wind speed is mostly in been three and ten meters per second. The wind speed has no peaks, which contributes positively to wind generation.

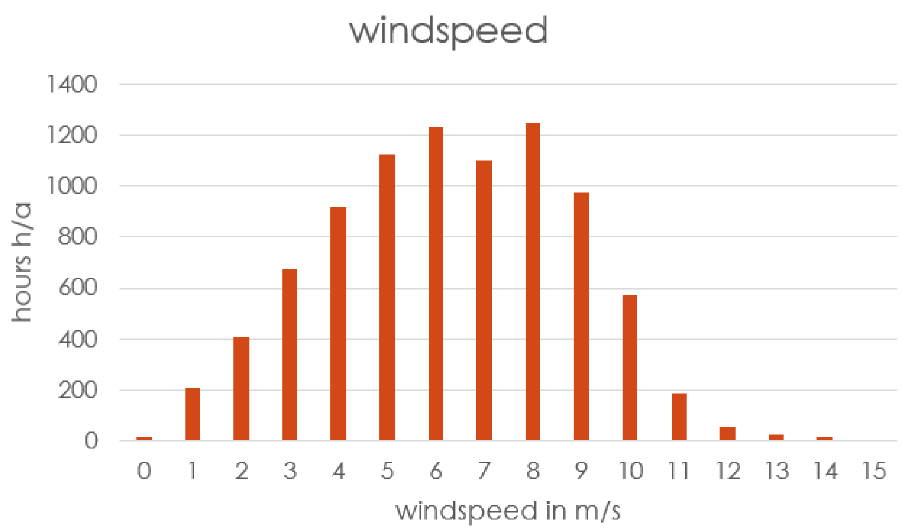

Figure 6 Distribution wind speed (Renewables.ninja, 2022)

For the measurement of wind speeds, it is important to note that the location of the measurement plays a decisive role. Coastal regions, mountainous regions or inland measurements can differ greatly. In figure 7, the measurement locations for the wind measurements are marked. Also the height of the measurement matters. In this case, the assumed height is 20 meters above ground level. (Danish Windindustry Association, 2022)

Figure 7 Measuring point (Renewables.ninja, 2022)

3.3 Politics

Zambian culture can be defined and explained by its diverse ethnic groups. With over 60 different cultural groups, Zambia has a lot of voices and opinions. Most of them come from the local tribes in rural areas. Besides this, a lot of new inhabitants are coming from neighbouring countries due to conflicts. Zambia is seen as one of the safest countries in Africa and therefore also attracts a lot of tourists. (Fatherland Gazette, 2022)

For the project, it is important to know which problems are playing in Zambia and what the government is focusing on. The political system in Zambia mostly consists of three different parties, two liberal parties, and one Social democrat party (Electoral Commission of Zambia, 2021). Despite it being considered one of the safest African countries, corruption is still a threat to its democracy. For example, the government regularly invokes restrictive laws to narrow political space and make it difficult for competition.

Zambia has a freedom index of 51/100. With 21/40 for political rights and 30/60 for civil liberties. (Freedom House, 2022) Finland has an overall freedom index of 100/100, so compared to Finland, Zambia is not a free country. Compared to other African countries, however, Zambia has an average freedom index. This index is provided by the Freedom House organization and gives insights into the political matters in different countries. (Freedom House, 2022)

The current president of the country is Hakainde Hichilema. With his political party, the United Party for National Development (UPND), he was elected as president in 2021. The UPND is a liberal party focused on social and economic issues (Brittanica, 2022).

3.4 Economics

The economy of Zambia is an important factor for the project, as it determines the budget for the electrification of rural regions. In addition, it is essential to know the biggest industries and employers as this is also part of the culture.

Zambia is one of the youngest countries by median age. Its population rapidly grows at 2.8% per year, partly because of the high fertility. Therefore, the population is expected to be doubled every 25 years. This phenomenon is likely to continue as the young population enters the reproducing age, which will put more and more pressure on social services and the economy. (The World Bank, 2022)

According to the Zambian bank, in 2021, the economy grew 3.6% after a 2.8% contraction in 2020 when Zambia became the first African country to default on its debt during the COVID-19 pandemic, which can be seen in figure 8. After this contraction, the government has managed to stabilize the economy and have a more positive outlook on the future economy of Zambia. This will be focused on unemployment and inflation and the resolution of those economic difficulties, which can be seen in figures 9 and 10. (Mfula, 2022)

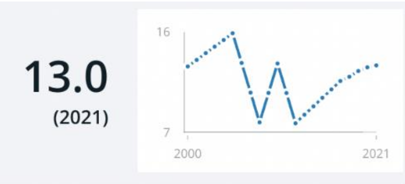

Figure 8 GDP Growth (annual %) (Economist Intelligence, 2022)

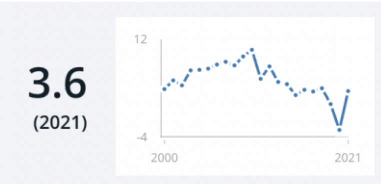

Figure 9 Unemployment, total (% of total labor force) (Economist Intelligence, 2022)

Figure 10 inflation, consumer prices (annual %) (Economist Intelligence, 2022)

3.4.1 Copper Belt

The copper mining industry makes up around 27% of Zambia's total government revenue. This means that the country is heavily dependent on copper prices (Investing News, 2022). Most of the copper is extracted from the Copperbelt area, which is located in Northern Zambia near the Congo border (Aurélien, Ousmane, & Pitiya, 2022).

Mopani Copper Mines (MCM) and Konkola Copper Mines (KCM) are the two largest copper mining firms in the Copperbelt. These mining firms act as a barometer for the state of the mining sector and, consequently, the Zambian economy. 90% of the country's GDP comes from mining, primarily concentrated in this area. (Money, 2019)

3.4.2 Lake Tanganyika

Lake Tanganyika is located in the central east of Africa on the borders of Burundi, Tanzania, Zambia, and the Democratic Republic of the Congo (Google Maps, 2022). This lake is essential for trade and transportation between the countries. Most transactions take place with small wooden boats and consist of many different products, such as food and clothes. Some bulk transportation also occurs, but Zambia mainly trades smaller products along the shore of the lake. The only Zambian port on the lake is in Mpulungu. Most of the trade here is informal with food and smaller products, but the port is also used for transportation to Burundi and Congo. The proceeds of the Mpulungu Port are estimated at 45 million US-dollar per year. (Ministry of Foreign Affairs, 2019)

3.4.3 Agriculture

Agriculture is an important part of Zambian economics and culture, as 72% of the population is working in agriculture (Dorosh, Dradri, & Haggblade, 2009). Crops, such as maize and cassava are mostly produced for their own consumption. In addition, sugar, coffee, rice and cotton are cultured for export. (International Trade Administration, 2022) The maize is mainly processed with simple hammermills and cooked into Nshima, which to some extent resembles a thick porridge. Pigs and chickens are an additional important source of food. Cattle, on the other hand, is more used in agriculture rather than for food. (Cole & Tembo, 2011) Zambian agriculture consists mostly of small farmers. The productivity of these farms is quite low because of the poverty in rural areas. The farmers cannot afford to expand their land or get more agricultural inputs. Therefore, the rural areas' infrastructure is bad, so it is not possible to transport the crops for export. (IFAD, 2022) In addition, agriculture in Zambia is mainly dependent on rainfall and has very high fluctuations in output due to more frequent weather extremes caused by climate change. All these factors lead to limited food security across the rural population. (Dorosh, Dradri, & Haggblade, 2009)

4 Nanogrids

In Zambia, nearly 20% of the population has access to electricity. While electrification in urban areas is around 48%, only about 4% of rural households are supplied with electricity (Deutsche Energie-Agentur, 2013, p. 9). The low electrification rates of Zambia's rural areas, particularly result in one of the highest deforestation rates in the world, as wood is often used as an energy source. (BMZ, 2022) One of the reasons why there is hardly any energy supply in rural areas is the local energy policy. Zambia is cutting subventions for utility companies, which leads to more profit-oriented companies. Electrification of rural regions with electricity grids is often not profitable for these companies. (Grianeza, Abo-al-ez, & Kahn, 2020, p. 1) The use of nanogrids could create a pioneering change and increase the electrification rate, especially in rural areas. In addition, renewable energies could be used to make an environmentally friendly energy supply possible.

4.1 Functionality of Nanogrids

According to Nordman, a nanogrid is defined as a single domain for voltage, reliability, and administration. It must include at least one load and one gateway to the outside. The load in this scenario could be a sink of power or also storage. (Nordman, Nanogrids - Evolving our electricity systems from the bottom up, 2012) All these components are operated by one controller, which can be seen in figure 11.

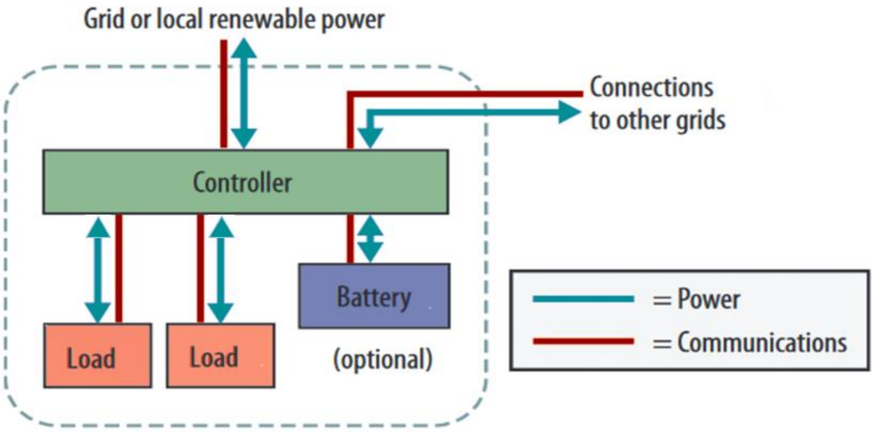

Figure 11 Schematic of a basic nanogrid (Nordman, et al., 2012)

There is no clear difference in the literature between the terms "nanogrid" and "microgrid". However, the term nanogrid is usually used for remote systems without interconnection to the utility grid, with a maximum load of 5 kilowatts or with a maximum of 100 kilowatts for grid-tied systems. Microgrids are also small power distribution systems, but they are more complex than nanogrids. While micrograds are often connected to the main power supply, nanogrids are usually only interconnected and completely disconnected from the main power grids. (Asmus & Lawrence, 2014)

The lower complexity of nanogrids provides great potential, especially in developing countries. These grids are much easier to implement than conventional energy distribution grids. In addition, nanogrids are much cheaper, which is attracting increasing interest from investors (Nordman, Nanogrids - Evolving our electricity systems from the bottom up, 2012). Nanogrids entail significantly fewer regulatory challenges because they operate completely separate from a public energy distribution system. Furthermore, nanogrids are decentralized and function completely independently of conventional energy supply methods. Another advantage is the high scalability of these systems, which makes it possible for both private households and companies to start with a minimum energy supply. Nanogrids can also be interconnected and intelligently linked with each other. This means that each element in this network functions both as a prosumer and as a consumer. (Clancy, 2014)

Nanogrid technology only becomes fully efficient when several individual nanogrids are interconnected to form an interconnected system. In this way, surplus energy can be passed on to the nearest neighbour in the grid or unusually high energy demands can be met. These networks, in which prosumers trade energy with each other, are called peer-to-peer energy trading. As there are permanent fluctuations in the energy provided and required, it is not easy to price the energy generated. This is based on supply and demand and must be recalculated at frequent intervals. (Grianeza, Abo-al-ez, & Kahn, 2020, pp. 3-4)

4.2 Potentials

If rural regions in Zambia will have access to electricity, this will result in many benefits for local people and the development of these regions. The far-reaching positive consequences of electrification cannot be predicted to their full extent. However, it can be assumed that among others health, education and food security would benefit. (Ruiven, Schers, & Vuuren, 2011, p. 387)

The most important benefit is the improvement of health, which will increase for different reasons. At the moment, the houses are lit by kerosene lighting and cooking is done by burning wood. These fuels are mostly burned inefficiently, which contributes to significant indoor air pollution. Because of this, the health of the population, especially children, is affected. If there is electric lighting and cooking, the air quality will improve significantly, which results in better health. (Torero, 2015) In addition, health care could be drastically improved, since electricity can be used to operate medical equipment that is essential for survival. Moreover, the use of water pumps could significantly improve the quality of drinking water. All these factors will improve well-being and reduce mortality in rural regions drastically. (Ruiven, Schers, & Vuuren, 2011, p. 387)

In addition, education would benefit substantially from electricity access. The quality of education can improve because of access to the internet. Moreover, students have more time to study at home, due to electric lighting and reduced household tasks. For example, there is no longer the need to collect firewood and eventually, the time of household tasks will be reduced because of electric appliances. As a result, children do not have to spend that much time on household tasks. Thus, overall educational attainment will improve and more students can attend higher education. (Torero, 2015) (Ruiven, Schers, & Vuuren, 2011, p. 387)

Another factor that will benefit from electricity access is food security. When there is electricity, farmers can irrigate their crops and grow them all year round instead of only in the rainy season (Ruiven, Schers, & Vuuren, 2011). Furthermore, the harvested crops could be processed more efficiently, which would generate a surplus that could be sold (Cole & Tembo, 2011). In the long term, electricity will also ensure that food can be stored longer (Ruiven, Schers, & Vuuren, 2011, p. 387).

As a consequence of higher quality education and more time to study at home, more students can attend higher education. This contributes to a higher income for rural people and more businesses in rural regions. As a result, there will be more jobs available, which especially creates more opportunities for females. (Torero, 2015) In addition, existing companies can automate or mechanise their production because of access to electricity and, in the longer term, higher educated people (Ruiven, Schers, & Vuuren, 2011, p. 387).

Another important factor that will benefit as a result of electricity access is the impact on the environment. Currently, the environment is affected because of the kerosene lighting and burning of wood to cook. With electricity, the overall air quality will improve and carbon emissions will reduce significantly. (Torero, 2015) In addition, deforestation will decrease (Ruiven, Schers, & Vuuren, 2011, p. 387).

Despite the many advantages, it should not be forgotten that in developing countries there is huge poverty in rural areas and people can hardly afford electrical appliances. Electrification in these areas would therefore mainly result in the lighting of the villages. (Ruiven, Schers, & Vuuren, 2011, p. 387) However, there would be more positive impacts in the long term (Torero, 2015).

5 Renewable energy

In Africa, almost half of the total primary energy is generated with renewable energies (Statista, 2022). This makes the continent a global role model. In this chapter, the main advantages and disadvantages of renewable energy generation will be discussed to understand why more and more investments are being made in this sector worldwide. (Statista, 2022)

According to Quaschning, renewable or regenerative energies are energy sources that are infinitely available in time horizons, which are defined by not taking longer than human life. Renewable energies are essentially divided into solar energy, planetary energy and geothermal energy, whereby solar energy offers the most important energy supply. (Quaschning, 2022, p. 36)

5.1 Advantages and disadvantages of renewable energy

A positive aspect of renewable energy is that it won´t run out. This ensures an energy supply that is independent of limited resources. (Thoubboron, 2021) As a result, there is strong competitiveness in terms of industrial use. Especially for companies with high energy consumption, a switch to renewable energies is inevitable (Alova, 2018, p. 9). Furthermore, it can be assumed in principle that the production of electricity from renewable energies requires less maintenance. This also contributes to longer-term staff savings and cost savings. However, the use of renewable energies does not only result in competitive and cost advantages. Positive benefits mainly arise in the environmental sector. The environment is protected by lower CO_2 emissions and more resource-efficient energy production. This sustainable use of resources can also have a positive impact on a company's image. (Thoubboron, 2021)

On the other hand, renewable energy not only has advantages. Especially for small companies, it is difficult to invest in renewables, because the upfront costs are very high. In addition, energy production with renewable energies is often fluctuating, which means that large energy storage facilities are needed to achieve a steady output. When comparing the advantages and disadvantages of renewable energy it must be taken into account that the production of renewable energy sources also often generates emissions. (Thoubboron, 2021)

A clear trend toward renewable energy sources shows that the advantages outweigh the disadvantages. For companies around the world, image benefits, cost savings, resource efficiency and resulting competitiveness play a crucial role and make investments in sustainable energy essential. (Biedermann, Vorbach, & Porsch, 2015)

Today, there is a wide range of possibilities for sustainable energy production. According to Statista, by far the most renewable energy is produced by hydropower, wind energy and solar energy (Statista, 2022). Therefore, the three mentioned energy productions are presented in this chapter.

5.2 Solar energy

Solar energy has an impact of $1.08 * 10^{18}$ kWh/a on the earth's surface. This is about 5000 times the primal energy needs of the world. Solar energy can be divided into direct irradiance and indirect irradiance. Direct irradiance uses irradiance for producing energy. The indirect irradiance can be felt as heat which is used in nature. (Quaschning, 2022, p. 38)

Direct sun energy can be used with different techniques (Quaschning, 2022, pp. 38, 39):

- Solarthermal powerplants
- Solar collector (heat)
- Photovoltaic
- Photolysis

This report only gives a closer look at Photovoltaic Panels because these solar panels produce electricity directly and do not need the step of heat energy in between. As a result, the efficiency of this system is higher.

5.2.1 Construction of solar cells

Solar cells are constructed of Semiconductors, which consist of a n-doped and a p-doped layer. The n-doped layer is mixed with phosphorus, the p-doped layer with boron atoms in a silicon crystal. Between these layers, the boundary layer forms, where the phosphorus electrons and the boron electron defects balance each other out. This charge separation creates a positive and negative pole. (EnBW, 2020), (Wesselak, Schabbach, Link, & Fischer, 2016, p. 202)

5.2.2 The function of solar cells

According to the atomic model of Bohr, the core of atoms is surrounded by electrons. These electrons are moving on certain tracks around the nucleus. The different tracks represent various levels of energy. The further away an electron is, the more energy it owns. The PV-Plant uses sun irradiation to power the electrons, so they are getting off their track and moving away from the nucleus. (Quaschning, 2022, p. 193)

Only the electrons furthest away from the atomic nucleus are considered, as these have the most energy. Solar radiation adds energy from the outside, so the electrons are excited to form pair bonds and can break away from the atom. As a result, the electrons are free in the semiconductor. Due to the charge separation, the electrons move toward the negative pole. This creates a voltage with which an electrical consumer can be operated. This process can be seen in figure 12. In this figure, it is also visible that non-usable radiation is reflected, transmitted or absorbed. (Quaschning, 2022, pp. 193-195, 200)

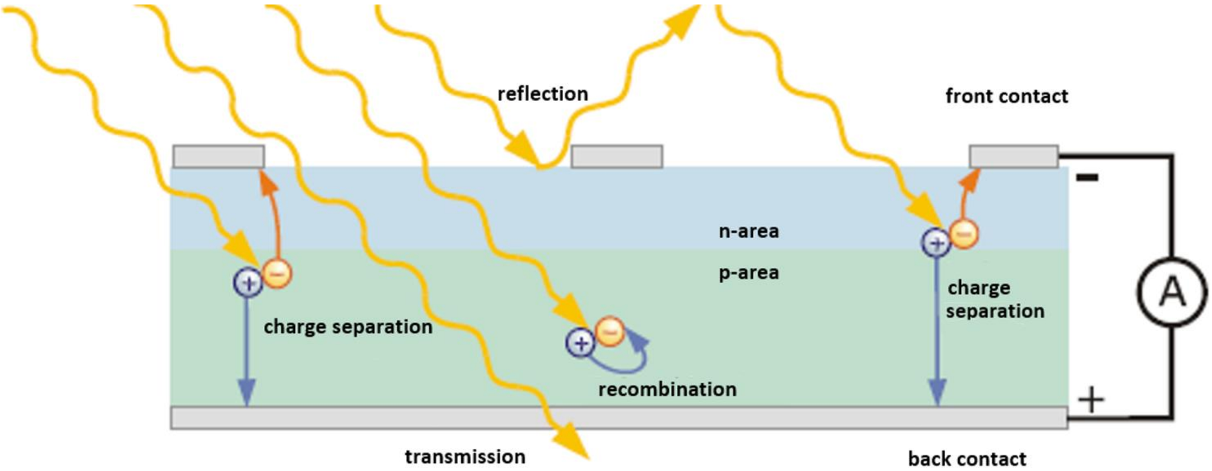

Figure 12 Function of a solar cell (Quaschning, 2022, p. 200)

5.3 Wind Energy

There are two different concepts of wind turbines: the drag rotor and the lift rotor. With the drag rotor, the rotor blade is pushed away by the wind. The second concept, the lift rotor, uses a negative pressure created by airflow. This negative pressure provides a pull on the rotor blade, which causes it to rotate. Modern turbines mostly use the second-mentioned system. (Quaschning, 2022, pp. 302-306)

Figure 13 illustrates the mode of operation of a lift rotor. The wind hits the rotor with the speed v_W. The rotation of the rotor creates an airstream velocity u. The resulting velocity v_A of the two vectors creates a wind velocity in the direction of the rotor blade. The shape of the rotor creates positive and negative pressure. This difference exerts a lifting force on the rotor. This lifting force is divided into the pushing force and the tangential force, which causes the rotor to rotate. (Rommel, Di Maio, & Tinga, 2019)

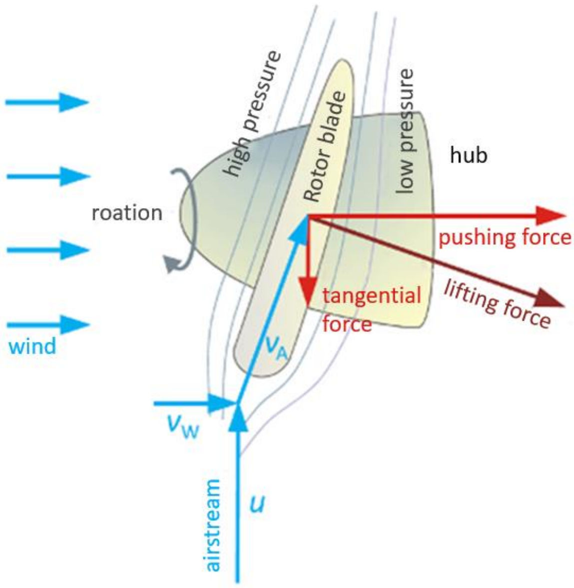

Figure 13 Velocities and forces on lift rotor (Quaschning, 2022, p. 306)

In wind turbines, the wind is slowed down. This deceleration causes a widening of the wind tunnel, while the mass flow remains identical. This can be seen in figure 14. As the mass flow should stay the same, the wind turbine cannot slow the wind down to a standstill. The optimal wind speed behind the wind turbine is one-third of the wind speed in front of the turbine. This value corresponds to the Cp-Betz value, a value that indicates the optimum wind power usage of a wind turbine: its value is 59.3%.

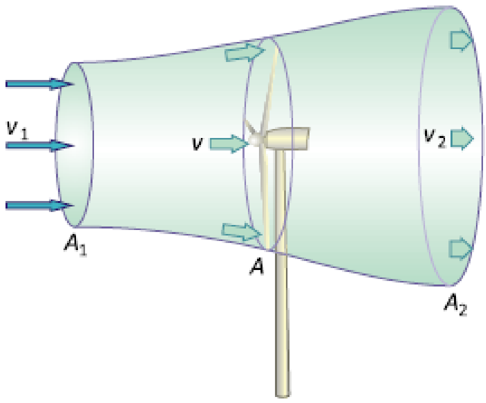

Figure 14 Widening of the wind tunnel (Quaschning, 2022, pp. 300-302)

The values of the speed quotient and the power quotient differ because the wind power uses the cubed wind speed. That means that wind speed has a huge influence on wind power. (Hau, 2016, pp. 86-89)

There are two main types of rotor forms. First is the horizontal axis, which is most seen around Europe. The advantage of this one is that the efficiency is higher and there is less use of material, compared to the vertical axis type. The advantage of this type is that it is not relevant if the rotor is oriented in the wind direction or not, so there is no need for an azimuth engine. In addition, maintenance is easier because everything except the rotor can be maintained on the ground. (Quaschning, 2022, p. 309)

5.4 Hydropower Energy

16% of the world's electricity is produced with the help of hydropower. Different types of hydropower are the run-of-river, storage and tidal power plants, which can all be equipped with different turbines. There are overpressure turbines, such as the Francis and Keplar turbines, which reduce static pressure. Turbines based on the equal pressure principle, like the Pelton and Ossberger turbines, do not change the static pressure. (Wesselak, Schabbach, Link, & Fischer, 2016) These kinds of turbines, however, are only worthwhile from an output of 45 kW, as much additional construction is required (Pionierkraft, 2020).

6 Energy Storage

For a smart power supply, not only the production of energy and its transport is important. The storage of energy also plays a significant role to serve irregular demands or to be able to store energy output. For the storage of energy there are existing several systems:

- Electrical storage
- Electrochemical storage
- Chemical storage
- Mechanical storage
- Thermal storage

The different storage systems are briefly presented below. It should be mentioned that electrical storage systems are excluded, as they can only store energy for a very limited period and therefore it does not make economic sense to consider them for this project. (Sterner & Stadler, 2019, pp. 161, 197)

6.1 Electrochemical storage

Electrochemical energy storage systems consist of electrodes that are connected via electrolytes. Electrons are released through chemical reactions that take place inside the storage unit. A distinction is made between rechargeable and non-rechargeable storage devices. Rechargeable storages are called accumulators and non-rechargeable storages are called batteries. Furthermore, a distinction is made according to temperature ranges. There are low-temperature and high-temperature storage units, as well as storage units with external storage (redox-flow-battery) and internal storage. (Sterner & Stadler, 2019, p. 197)

6.2 Chemical Storage

Compared to electrochemical and electrical storage systems, chemical storage systems have significantly lower efficiencies, but they have a good long-term storage capacity, which electrochemical storage systems do not have. A system is for example a hydrogen system or a power to gas and power to liquid. (McLarnon & Cairns, 1989) (Statista, 2012)

6.3 Mechanical Storage

Mechanical accumulators work primarily with pressure. In this process, pressure energy is injected into a medium, which can later be used again if required. Pumped storage power plants also belong to the category of mechanical storage, as do flywheel masses. (Kalhammer & Schnieder, 1976, pp. 12-14)

6.4 Thermal Storage

Thermal storage systems use heat as a form of energy. Heat is stored in a medium and released at a later time. Thermal storage can function both as cold storage and as heat storage. This depends on the ambient temperature. Thermal storage units can cover seasonal heat requirements or short-term needs. (Sterner & Stadler, 2019, p. 535)

6.5 Chosen storage

According to figure 15, electrochemical storage is the best option for this project. The storage capacity is limited, but it has enough capacity for a village of ten households. Electrochemical storages have a high efficiency of 90-95% (Statista, 2012). Compared to chemical storage with an overall efficiency of 24.5%, this is significant (Paschotta, Power to Liquid, 2021) (LEIFIphysik, 2018). Mechanical energy storages have a good efficiency of 45% to 95%. However, the flywheel masses with an efficiency of 95% tend to be short-term storage units that lose significant energy over time. Other systems, such as pressurised storage, have substantial losses for converting. (Statista, 2012), (Paschotta, Schwungradspeicher, 2022) Thermal storages have a low efficiency of 20-40% (Studyflix, 2022), (Paschotta, Organic Rankine Cycle, 2020). Figure 15 shows that electrical storage can only store energy for a short amount of time and is not designed for energy consumption. The electrochemical storage units are suitable for a storage time of one hour to one day and are in the range of one to 100 households, which also corresponds to the size of the nanogrids.

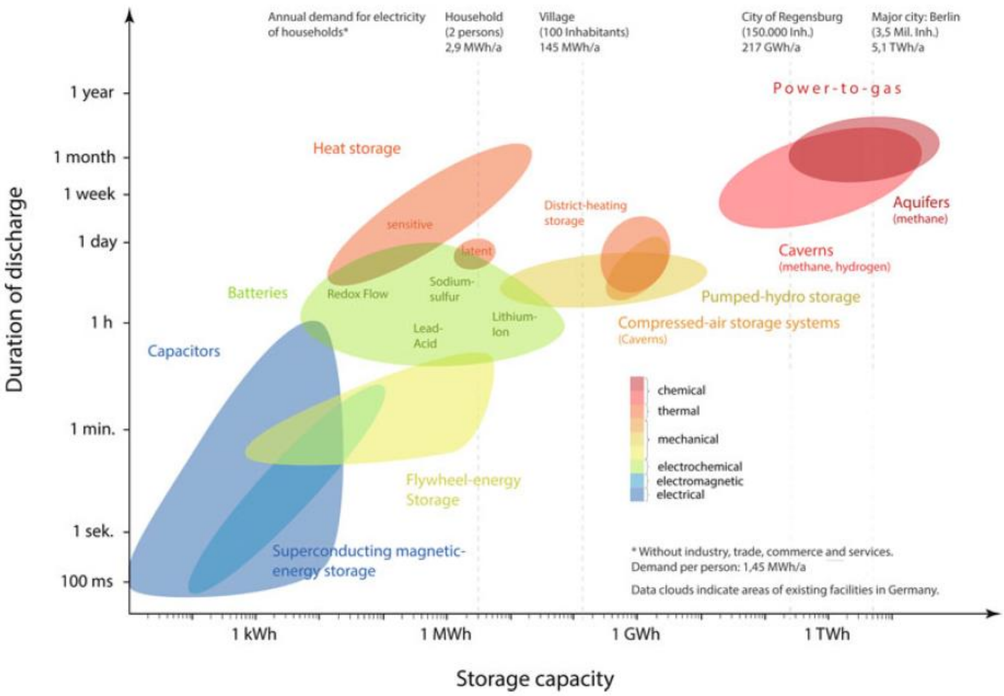

Figure 15 Storage types capacity and duration of discharge (Sterner & Stadler, 2019, p. 646)

7 Concepts

To find a good solution for providing renewable energy in Zambia, the most commonly used renewable energies are considered. In this chapter, the concepts are made more specific to choose the best concept with a Multi-Criteria Decision Analysis, which is presented in chapter 8.

To compare the different energy sources, the Levelized Cost of Energy (LCOE) is calculated below. The advantage of the LCOE is that it can be applied to any renewable energy resource. In addition, this ensures a higher degree of comparability (Generation Solar, 2021).

7.1 Solar energy

When selecting solar systems, numerous models and designs can be considered. As affordability and power output are particularly important for the implementation of the project, the LG 445 Watt model was selected. This solar panel is a high-efficiency neon h commercial solar panel, which has 445 Wp power and a price of 257 Euro/Panel (ElectroPrices, 2022).

Figure 16 shows the horizontal irradiation in Zambia. This demonstrates that irradiation fluctuates and is variable in certain areas. For the following calculations, an average horizontal irradiation of $1750 \frac{kWh}{kWp*a}$ is assumed.

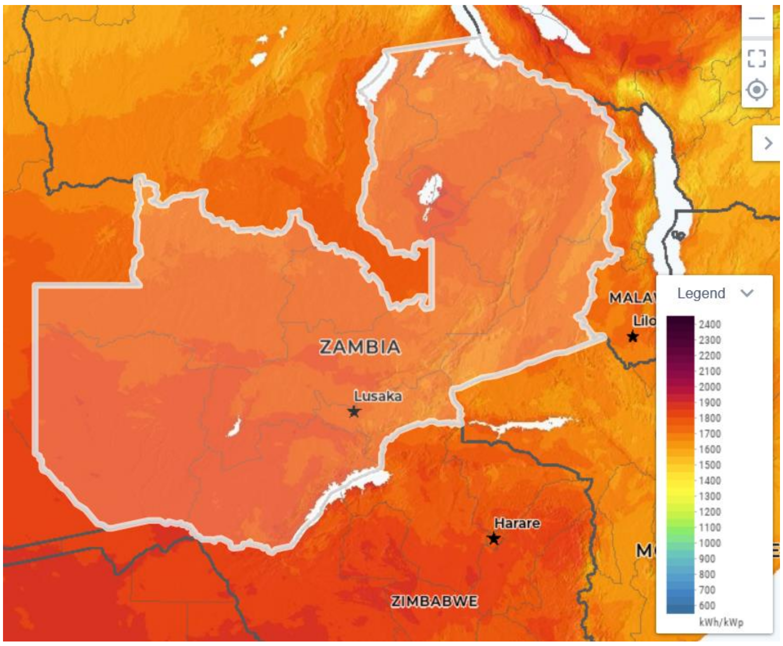

Figure 16 Horizontal irradiation (Global Solar Atlas, 2022)

In the following section, the price for one-kilowatt hour of electricity generated by solar panels will be calculated based on various assumptions.

For the calculation of the energy price, the energy generated by solar panels per year needs to be calculated first.

$$Solarenergy_{year} = \frac{Solarpanel\ energy}{peak\ power \times year} \times Solarpanel\ peak\ power \tag{7.1}$$

$$Solarenergy_{year} = 1750 \frac{kWh}{kWp \times a} \times 0.445 kWp = 778.75\ \frac{kWh}{a}$$

To further calculate the Levelized Cost of Electricity (LCOE), the lifetime costs must be determined. The warranty period of the LG 455 W solar panel used is 25 years. For this reason, a life expectancy of 25 years is taken into account in the following calculation.

$$Lifetime\ costs_{solar} = Acquisition\ costs + Maintenance\ costs \tag{7.2}$$

$$Lifetime\ costs = 257€ + (1.5\% \times 257€) \times 25 = 353.38€$$

The LCOE can therefore be calculated as follows.

$$LCOE_{solar} = \frac{Lifetime\ costs}{Life\ expectancy \times Energy_{year}} \tag{7.3}$$

$$LCOE_{solar} = \frac{353.38€}{25a \times 778.75 \frac{kWh}{a}} = 0.018 \frac{€}{kWh}$$

The price of a kWh with these assumptions is 1.8 cents. With this value, it should be possible to make a comparison in terms of affordability with other renewable energies.

7.2 Wind energy

For the generation of wind energy, the model Rutland FM1803 was selected as the wind turbine. This is particularly suitable for off-grid systems, as it is smaller, more affordable and easier to install than conventional models. This turbine has a power of around 850 watts maximum and costs 3014.68 to 3384.53 Euro. (Marlec, 2022)

For the calculation of the LCOE, the life expectancy of the system is assumed to be 25 years, which corresponds to the warranty period of the system.

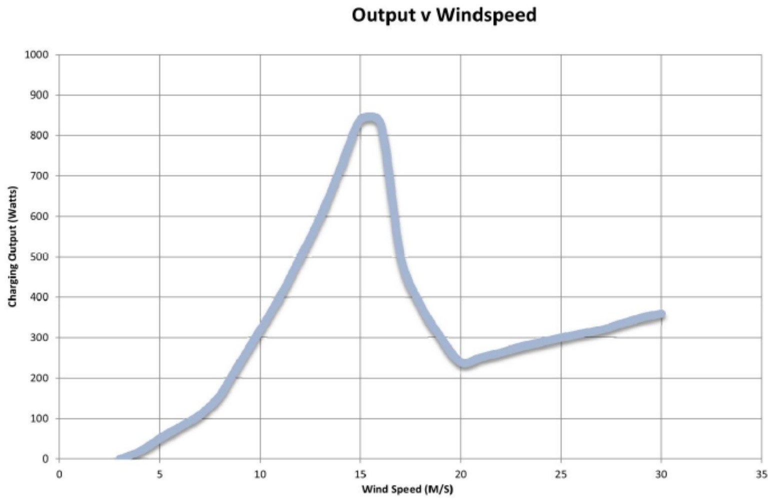

Figure 17 Power output wind turbine (Marlec, 2022)

The approximate power gained from wind power can be calculated with the performance curve in figure 17, and the wind speed in hours per year with the following calculation. The curve displays the cut-out and the starting speed. Outside of these boundaries, the wind turbine is not producing energy. The general approach is that the energy is the product of the power of the wind turbine and the wind speed hours as can be seen in formula 7.4.

$$Windenergy_{year} = \sum_{n=0}^{13} Power_{Rutland_n} \times Windspeedhours_n \tag{7.4}$$

As shown in figure 18, the wind energy produced varies with the wind speed. Thus, to calculate the total wind energy generated in a year, the wind energy produced per wind turbine must be summed up.

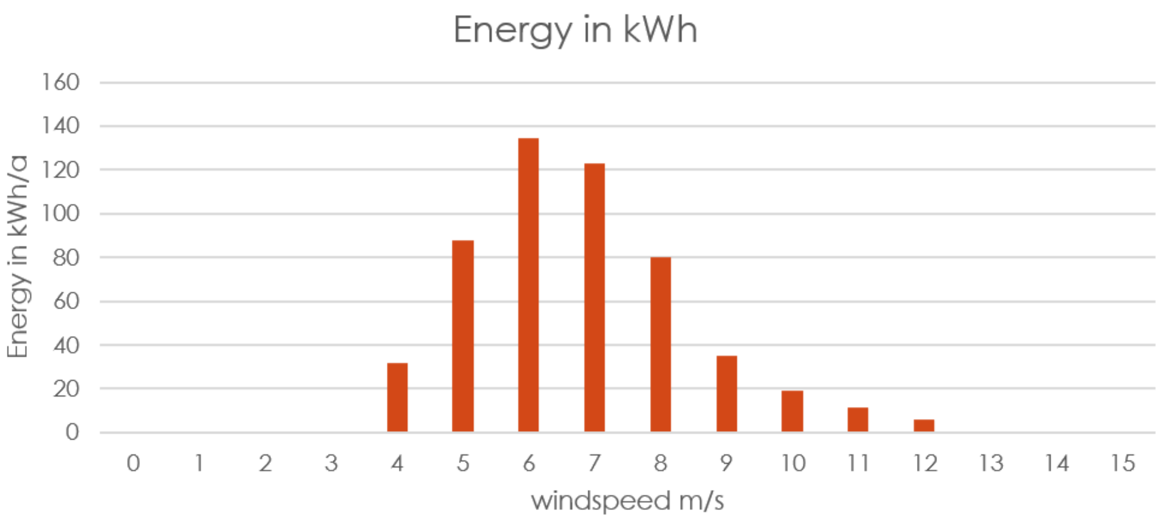

Figure 18 Distribution wind speed (Renewables.ninja, 2022) (Marlec, 2022)

$$Windenergy_{year} = [(0 \times 25) + (0 \times 336) + (0 \times 690) + (0 \times 1287) + (25 \times 1597) + (50 \times 1685) + (87.5 \times 1491) + (125 \times 946) + (187.5 \times 445) + (255 \times 153) + (312.5 \times 64) + (400 \times 29) + (500 \times 12) + (600 \times 0)] \times Wh/a$$

$$Windenergy_{year} \approx 533\ kWh/a$$

To be able to calculate the LCOE, the lifetime costs need to be calculated first. For the acquisition costs of the wind turbine, an average value of 3200€ is used.

$$Lifetime\ costs_{wind} = Acquisition\ costs + Maintenance\ costs \quad (7.5)$$

$$Lifetime\ costs_{wind} = 3200€ + (2\% \times 3200€) \times 25 = 4800€$$

The LCOE is calculated as follows:

$$LCOE_{wind} = \frac{Lifetime\ costs}{Life\ expectancy \times Energy_{year}} \quad (7.6)$$

$$LCOE_{wind} = \frac{4800€}{25a \times 533\ kWh/a} = 0.36 \frac{€}{kWh}$$

In the above calculation, only rounded values and approximations were used. One kilowatt hour of produced wind energy costs 36 cents after calculating the levelized costs of electricity.

7.3 Water energy

For certain scenarios, there is the possibility of additionally integrating hydrokinetic in-stream water turbines into the nanogrid system. These can continuously produce electricity regardless of the time of day and weather conditions. The turbine used for this concept is the Smart Free Stream, which can be seen in figure 19.

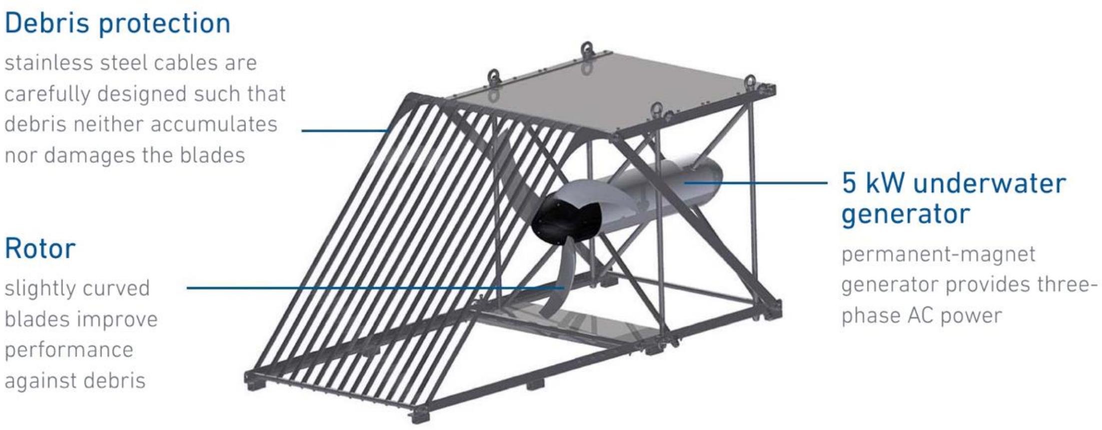

Figure 19 Smart Free Stream (Smart Hydro Power, 2022)

The Free Stream is installed on the riverbed and the injection point can be 500 meters away from the grid. As can be seen in figure 20, the permanent magnet generator installed in the turbine can generate a maximum power output of up to 5000 W under optimal conditions. (Smart Hydro Power, 2022)

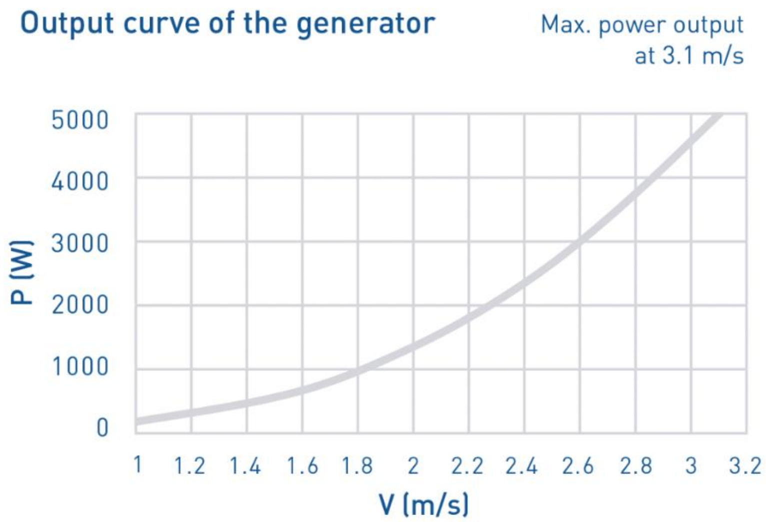

Figure 20 Output curve (Smart Hydro Power, 2022)

Since the mean flow speed of rivers in Zambia is difficult to determine, a mean value of 2.2 m/s is assumed. According to figure 20, this corresponds to a power output of 1.8 kW. It can be expected that the system runs constantly throughout the year without interruptions.

The energy produced over a year is calculated as follows:

$$Waterenergy_{year} = Output_{Generator} \times Performance\ hours_{year} \tag{7.7}$$

$$Energy_{year} = 1.8\ kW \times 8760h = 15768\ kWh\ /a$$

According to the manufacturer of the turbine, there are no significant maintenance costs, therefore only the acquisition costs of 12490€ are used for the lifetime costs. (Smart Hydro Power, 2022) For the lifetime of the plant, a value of 25 years is assumed again.

$$LCOE_{water} = \frac{Lifetime\ costs}{Life\ expectancy \times Energy_{year}} \tag{7.8}$$

$$LCOE_{water} = \frac{12490€}{25a \times 15768kWh} = 0.031€$$

In the calculation above, it should be noted that many assumptions were made and that the calculation is only intended as a guide for comparison with other systems. The LCOE for the water turbine is 3.1 cents.

7.4 Comparison of LCOE

When comparing the Levelized Costs Of Electricity of solar energy, wind energy and hydro energy, it is clear that these costs fluctuate greatly, as can be seen in table 1. Furthermore, wind energy has the highest electricity generation costs.

Source of Renewable Energy	**Calculated LCOE in €/kWh**
Solar Energy	0.018
Wind Energy	0.36
Hydro Energy	0.031

Table 1 Comparison of LCOE

Within the framework of this project, it was decided to exclude hydro energy for further consideration and the application of a Multi-Criteria Decision Analysis. This results from several reasons. One of the objectives of this project is that the solution should work in all the rural areas in Zambia. This water energy generator can only be used in the rivers, which excludes most of Zambia. Moreover, there are not many people living close to the rivers because of the floodings during the rainy season (Venkateswaran, 2011). Because of this, the energy produced with a water generator should be transported which results in energy loss. Although it is worth mentioning that the calculated LCOE for water energy is comparatively low, the disadvantages listed for this project outweigh the benefits.

8 Multi-Criteria Decision Analysis

The Multi-Criteria Decision Analysis (MCDA) is a method that makes it possible to find an optimal solution from different concepts. This approach attempts to quantify possible solution concepts using various criteria. The method mainly differentiates between the weighted sum method (WSM) and the weighted product method (WPM). Since the WSM is much more widespread, only the WSM will be discussed.

The total WSM score is calculated from the sum of the choices A_n. The selected criteria C_n must first be multiplied by the choices. This results in formula 8.1 (Pokehar & Ramachandran, 2003):

$$WSM_{Score} = \sum_{i=1}^{n} A_n \times C_n; for\ i = 1, 2, 3, \dots, m. \quad (8.1)$$

The criteria that the solution should meet in the context of the project are efficiency, reliability, affordability, maintenance and ease to install. Based on these criteria, every concept will get points from 1 to 5 on each criterion. In addition, each criterion will get a weight from 1 to 5 to show its importance. The total points of each concept will decide which concept is the best and which solution should be chosen.

A side note should be made that this method is not fully objective. The team decided the weight of each criterion and the number of points it would get. To make this method as objective as possible, the research or reasoning behind the points is given in the following paragraphs.

8.1 Criteria

First, the meaning of each criterion will be explained, to get a good understanding of the criteria and the number of points given. Efficiency is the percentage of the total incoming energy that is converted into sustainable energy. This criteria measures if a lot of energy is getting lost while converting it. The reliability of the concepts is measured by the presence of wind and sun. If there is an absence of this during a longer period of the year, the reliability of this energy source is lower. The affordability is calculated in costs per kWh. It considers the purchase costs, running costs, repairing costs, the likeliness of repairs and transportation costs. To be able to compare the maintenance of renewable energy sources, only the cost factor is considered. It should be mentioned that only approximate estimates can be made for the maintenance costs, as the costs are different for each system. As the project relates to a rural setting in Zambia, it is important to include the factor of how easily the renewable system can be implemented, the ease to install. The packing dimensions for the order and how transportable the system is should be taken into account.

8.2 Wind energy

In this paragraph, all the criteria of the Multi-Criteria Decision Analysis are discussed for the renewable energy wind power. For every criterion, there will be a short discussion that is used to give the points for the MCDA.

8.2.1 Efficiency

The efficiency of wind turbines essentially depends on the number of rotors. For this project, a 3-bladed wind turbine is chosen. The cp-value is the quotient of the wind turbine power and the produced electrical power, thus it is equal to the efficiency. The cp of 3-blade rotors can be seen in figure 21. It is at the optimum speed count at approximately 0.48, which means the efficiency is 48%. The highest mathematical useable wind power efficiency is 59%. This corresponds to the cp-Betz value. (Hau, 2016, pp. 88, 89)

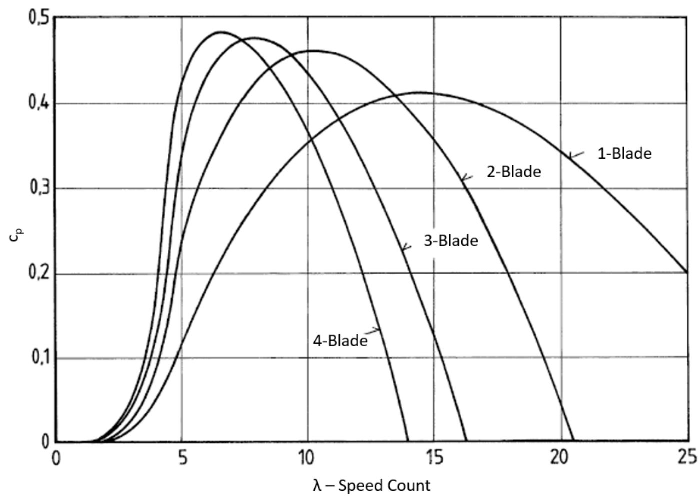

Figure 21 cp Values different rotor types (Hau, 2016, p. 150)

8.2.2 Reliability

Wind energy can be produced from a wind speed of 3 m/s. This is the minimum wind speed that can be used to produce energy, but it is not efficient at this point. (Marlec, 2022) The wind speed in Zambia is mostly higher than 3 m/s. However, there are long periods during the year when the wind speed is lower than 3 m/s. (Renewables.ninja, 2022) If wind energy would be the only energy resource, there would be no energy during these times of the year. Therefore, wind energy would not be a reliable energy source in Zambia.

8.2.3 Affordability

As stated in chapter 7.2, the LCOE of wind energy usage is 0.36€ per kWh. For the cost analysis, it is important to look at different variables instead of only producing costs. For instance, the height and diameter of the wind turbine have a substantial impact on the amount of produced energy. This means it will be less cost-efficient to produce the same amount of energy with small turbines. (Bulder, Bot, & Bedon, 2018)

8.2.4 Maintenance

The maintenance costs for a wind turbine vary according to the place of commissioning. The costs amount to approximately 1.5% to 2 % of the original investment costs per year. It is worth mentioning that maintenance costs increase slightly over time. (Danish Wind Industry Association, 2003)

8.2.5 Easy to install

The wind turbine selected, the Rutland FM1803, has a relatively small packing size of 120 x 67.5 x 52 cm. The transport weight is 74 kg. For the installation, a mast is needed, which can be made of aluminium or local wood. (Mishnaevsky, et al., 2011) This will have a final height of 20 meters. The mast will be dug in and fixed with wire ropes. The net weight of the turbine is 29.2 kg, so no additional equipment is needed for the installation. (Marlec, 2022)

8.3 Solar energy

After the criteria for wind energy have been described in detail, the same criteria for solar energy will be outlined in this paragraph. For every criterion, there will be a short discussion that is used to give the points for the MCDA.

8.3.1 Efficiency

The efficiency of the chosen solar panel is 20.2% (ElectroPrices, 2022). This means that only 20.2% of the whole irradiation is getting used for electric energy. The main reasons for this low efficiency are the wavelength of sunlight, the recombination of protons and electrons, the temperature and reflection. (Energy.gov, 2022)

8.3.2 Reliability

As mentioned in chapter 3.2.2, the irradiance in Zambia is almost constant. At the beginning of the year, the end of the year and during the rainy season, there is less irradiation. However, energy can still be produced. The energy production will be lower during this time of the year, but it would still be reliable because there are no times that there will be no energy production. (Renewables.ninja, 2022) As can be seen in figure 22, Zambia has a constant level of hours of daylight during the year. There are no longer periods of darkness, like in the north of Finland. The problem of less energy production can be solved by installing more solar panels and by using energy storage to compensate for fluctuations. This makes solar panels a reliable energy source in Zambia.

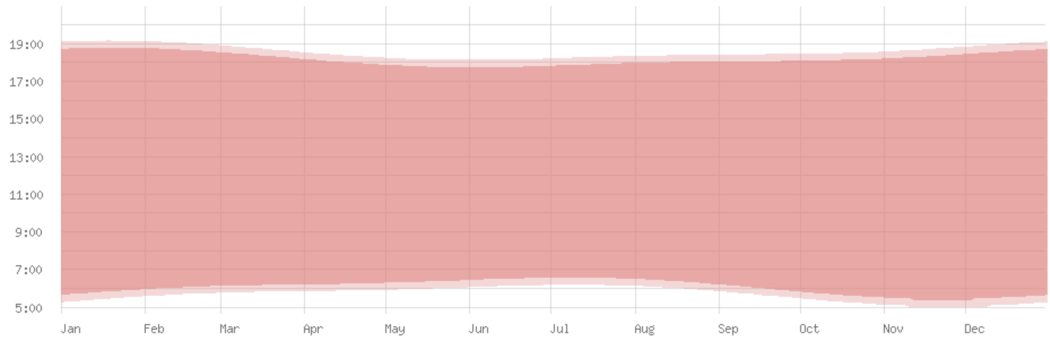

Figure 22 Hours of daylight during the year (WorldData.info, 2022)

8.3.3 Affordability

As shown in chapter 7.1, the price for the generated kWh is 0.018€. This is valid using the LG 445 Watt model as solar panel. This is already much cheaper than wind energy. The use of solar panels is also more suitable than wind turbines in terms of cost efficiency, which corresponds to the energy costs in relation to the space required.

8.3.4 Maintenance

Maintenance, servicing, insurance and operating costs of solar panels amount to approximately one to two per cent of the investment costs per year. The maintenance costs are quite constant over the lifetime of the system. (Photovoltaik.org, 2022)

8.3.5 Easy to install

The chosen solar panel, the LG NeON H, weighs 22 kg. The packing size is 216 x 112 x 121.3 mm. For on-site installation, a stand supplied in individual parts must be installed. No other large machines are required for this. (LG, 2022)

8.4 Multi-Criteria Decision Analysis

As can be seen from table 2, solar energy is more suitable as a renewable energy source for implementation in a nanogrid in the rural areas of Zambia. Solar energy has important advantages compared to wind energy, especially in terms of affordability, which was strongly weighted. Only in the criterion of efficiency, wind energy is superior to solar energy. However, efficiency is not a decisive factor for the project and was therefore given a low weight.

Criteria	Weight	Wind Energy	Solar energy
Efficiency	1	2	1
Reliability	4	2	4
Affordability	5	1	5
Maintenance	4	2	4
Easy to install	3	3	4
Total		34	71

Table 2 Multi-Criteria Decision Analysis

Since the result is quite unambiguous, a clear choice can be made even with an imprecise and subjective method as the Multi-Criteria Decision Analysis. Therefore, the use of solar panels will be the main focus for the rest of the project.

9 Scenarios

For the further course of the project, the scenarios first need to be defined. A case study of Nyari in Kitwe, which was published by the Copperbelt University, serves as the data basis for this (Mvula, 2022). In order to understand the following scenarios, it should be mentioned that many assumptions had to be made due to insufficient data.

9.1 Scenario 1

In the first scenario, a small village consisting of 10 households is to be supplied with electricity. According to Mvula, an electricity consumption of 1.3 kWh per day per household can be assumed if the village is rural and has minimal technical equipment. In addition, a hammermill is to be operated. Since no data are available for the use of this machine, a consumption of 3.5 kW is assumed. Expert statements by employees of Zambia University serve as a reference value for this.

These statements also indicate the frequency of the use of hammermills. In the case of particularly intensive use of the hammermill, it was assumed for that it is used by each household for one hour every two weeks. Up to three households may use a hammermill on one day. A possible pattern of hammermill use is shown in figure 23. The values were assumed in such a way that scenario 1 shows a particularly frequent use of the hammermill.

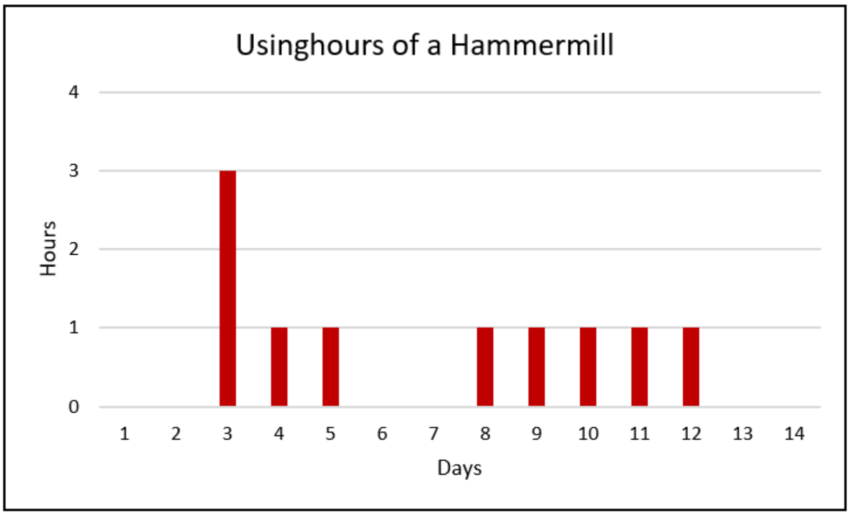

Figure 23 Usinghours hammermill scenarios 1 and 3

In addition, an energy storage system will be implemented in the nanogrid system, as well as a controller that will intelligently control the power requirements. The power grid is fed with the energy generation method decided in chapter 8. The described nanogrid system is shown schematically in figure 24.

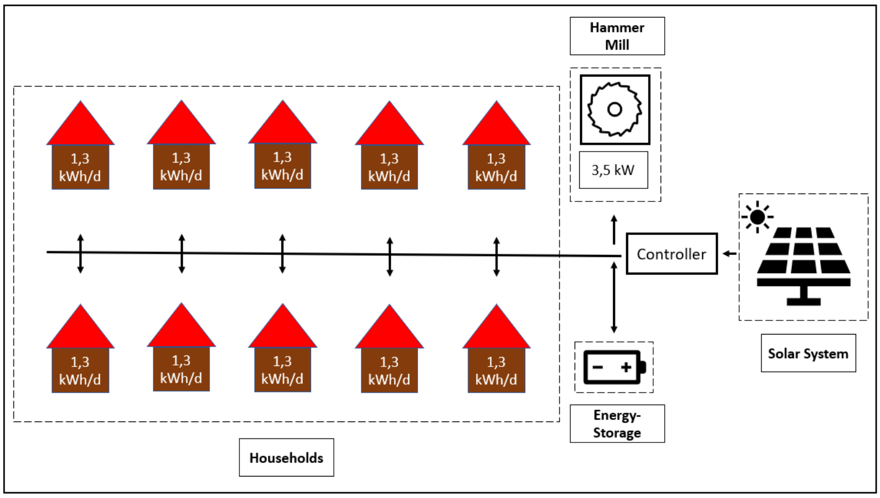

Figure 24 Schematic representation of a nanogrid in a small village

9.2 Scenario 2

The second scenario, like the first scenario, refers to a small village with limited technical equipment, which can be seen in figure 24. However, there is a difference in the regularity of the use of the hammermill. Figure 25 shows the usinghours of a hammermill for Scenarios 2 and 4. For these scenarios, it is assumed that the hammermill is used less. The ten households use the machine for five hours in four weeks, thus half an hour in four weeks per household. Again, it is assumed that the hammermill is used by a maximum of three households a day.

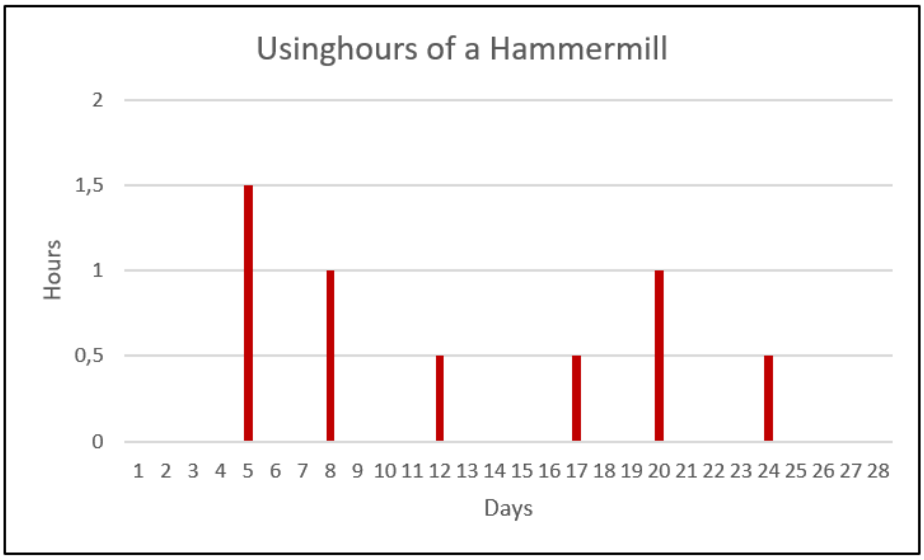

Figure 25 Usinghours hammermill scenarios 2 and 4

9.3 Scenario 3

The third scenario, like the two previous scenarios, refers to the same schematic structure of a village. A crucial difference, however, is that a village with higher technical equipment is used as a reference for this scenario. Instead of a consumption of 1.3 kWh per day, a value of 2 kWh per day per household is now assumed. Figure 26 is a schematic view of a civilised village in Zambia (Mvula, 2022). It is important to mention that the data for the calculation of the load per day per household is incomplete and values for electricity consumption had to be assumed for several hours. For this scenario, the usage of the hammermill is the same as for scenario 1, which can be seen in figure 23.

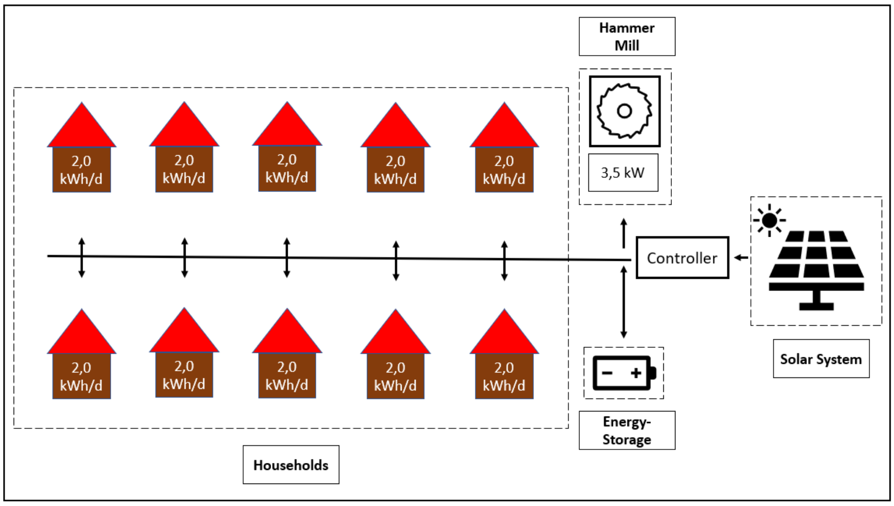

Figure 26 Schematic representation of a nanogrid in a civilised village

9.4 Scenario 4

The fourth scenario involves a civilised village with ten households, with the same energy usage as scenario 3. The schematic view of this can be seen in figure 26. It differs from the third scenario in the regularity of the use of the hammermill. The hammermill is used as in figure 25. This corresponds to the low use of this machine in direct comparison to the third scenario.

The four scenarios differ, on the one hand, in the regularity of hammermill usage and, on the other hand, in the technical infrastructure of the households. On this basis, simulations for the different cases can be carried out. It should be noted, however, that the informative value is limited, as the data situation was unclear and many assumptions had to be made.

10 Modelling/Simulation

Modelling and simulation allow designers to check the validity of certain specifications by performing virtual rather than physical assessments. Virtual prototypes have the advantage of reducing development time and costs. (Sinha, Liang, Paradis, & Khosla, 2001)

These advantages will be used in the project to create a model based on the previously defined scenarios, which should come close to a realistic representation of the situation in a rural area in Zambia. The procedure of how this model can be realized will be explained in the following section.

10.1 PV-SOL

For the model and the simulation, a professional programme is used to design solar systems for buildings. This programme is PV-SOL from the company Valentin GmbH. A 30-day trial version of the programme is used for this project. Alternative programmes have proven to be too complex to be used meaningfully without in-depth knowledge of the programme or good instruction. PV-SOL offers a simple and familiar interface for parts of the group and is therefore the best option.

10.2 Development of a model

The model is designed after some preliminary considerations. Since there is no specific village as an example, the model must be adapted to the scenarios as generally as possible. A town in the centre of Zambia was chosen as the basis for the climate so that it is as representative for the whole of Zambia. The design point is at latitude -13° and longitude 28.65°. This corresponds to the city of Ndola. The hammermill and 10 households are used as consumers according to the assumed scenarios. The hammermill, which is the main supply of food, has priority. If the battery level falls below 10%, the households are disconnected from the grid to keep enough energy for the hammermill. As soon as an energy level of 30% is exceeded, the households are reconnected to the grid. This is an assumption to make sure the hammermill is working whenever necessary. A 230-volt 50Hz AC system is also adopted. The reasoning behind this is that appliances from Zambia can be connected to the mains normally (Sambia - Stecker & Steckdosen, 2022).

The secondary systems consist of inverters from SMA and Sunny Island. However, these only serve as an example and are not considered further. A sample system from the programme is used as the battery system, which can be expanded. There are no expected system losses due to cables in the model.

10.3 Results of the simulation

The outcomes of the simulation of the scenarios are explained below. The results differ in many ways. Due to the different energy demands and the power distribution over the day and the week, various constellations of the solar plants and battery systems result.

10.3.1 Scenario 1

In table 3 the chosen configuration of the system is visible. A quantity of ten solar panels is calculated, based on the electrical consumption calculated in chapter 9.1. The simulation also indicates that a battery with a capacity of 59.4 kWh is needed to run the system without breakdowns.

Solar panels	Quantity: 10 Solar panels Power: 4.45 kWp
Battery	Capacity: 59.4 kWh Power: 7.5kW

Table 3 Configuration scenario 1

The model results in an energy production forecast with consumption, which is given in figure 27. The y-axis represents the amount of energy in kWh and the x-axis shows the timeline. The grey and dark green bars in the diagram, which extend into the negative energy range, correspond to the energy consumption. This consists of battery charging and the direct consumption of the PV-energy. The yellow and light green bars in the diagram, which are positively directed, represent the energy production. This contains the PV-energy production and the battery coverage of consumption. The amount of energy consumption and production are identical. This is because the system is an off-grid system and no energy is fed into the system from outside. All the energy produced by the defined system is therefore provided for its own needs and the system is thus self-sufficient.

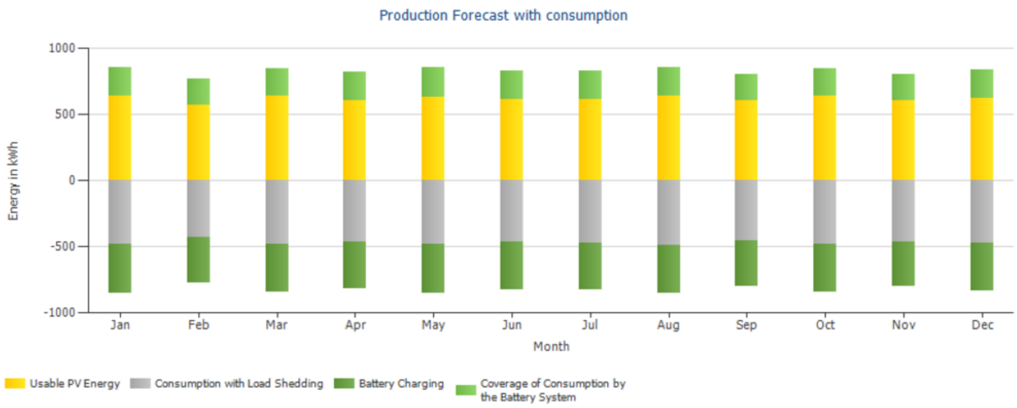

Figure 27 Production forecast with consumption scenario 1

Differences in battery charging and coverage of consumption by the battery system, which corresponds to the discharging can be illustrated with the charging and discharging losses as shown in figure 28. The energy flow graph shows how the produced energy is distributed. As part of this system, the PV-system with inverter is visible on the left-hand side of the figure. The battery system and its inverter are set at the bottom and the load is set on top of the figure. Load shedding can also be seen in this illustration.

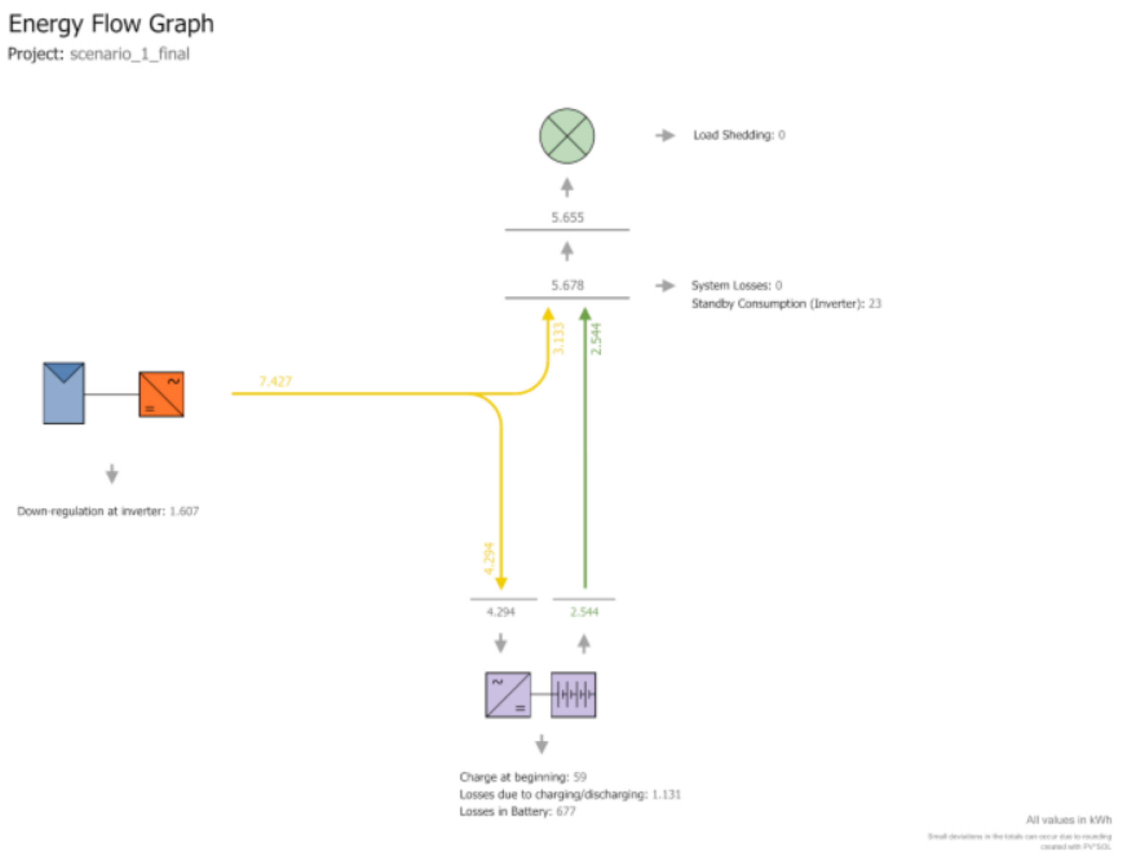

Figure 28 Energy flow graph scenario 1

A significant part of the produced energy is used to charge the battery and another major part is used for the current energy consumption. In this scenario, there is no load shedding, but there is significant load shedding as soon as the system is made slightly smaller. Also, inverter losses at the PV-system, battery system and load system are shown. These losses are also significant, due to the regulations of the inverter.

10.3.2 Scenario 2

Table 4 defines the system parameters for scenario 2. Eight solar modules are needed to provide the consumption calculated in chapter 9.2. For the system to function without interruptions, a battery with a capacity of 3.794 kWh is used.

Solar panels	Quantity: 8 Solar panels Power: 3.56 kWp
Battery	Capacity: 3.794 kWh Power: 7.5kW

Table 4 Configuration scenario 2

The results of scenario 2 can be seen in figures 29 and 30. The production forecast with consumption looks similar, compared to those in scenario 1. One noticeable exception, however, is that energy production and energy consumption are lower on average. This is due to the lower need for energy and smaller PV and battery plant. It is visible that the battery charging does not correspond to the battery discharging. The energy flow diagram explains this difference as well.

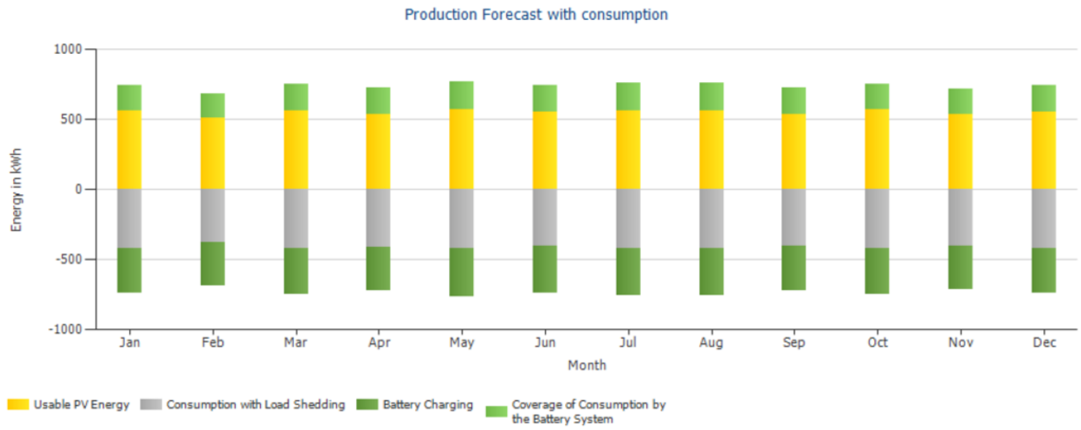

Figure 29 Production forecast with consumption scenario 2

Figure 30 indicates that load shedding is not expected. If the plant is modelled a bit smaller this would be the case. The inverter losses are also explained by the regulations of the inverter. The energy production is smaller than in scenario 1, which results in smaller losses as well.

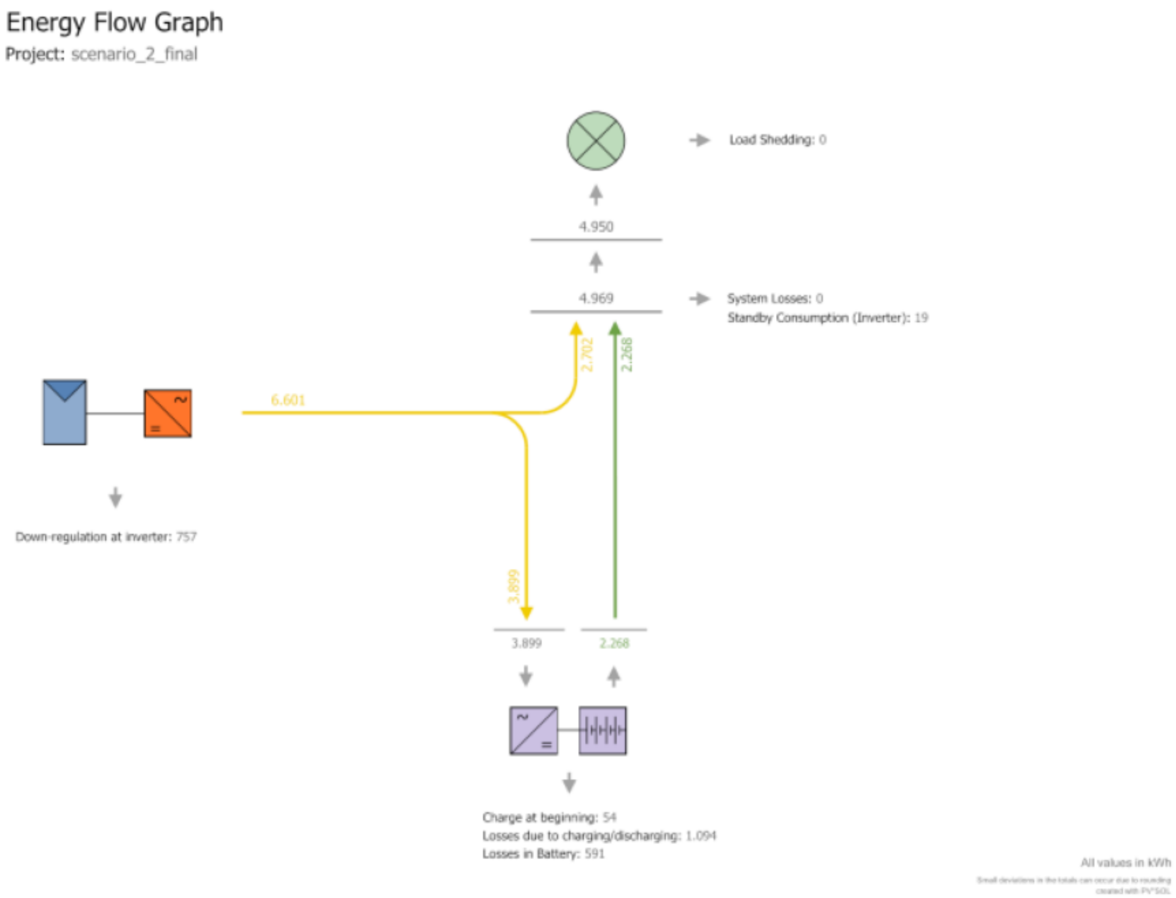

Figure 30 Energy flow graph scenario 2

10.3.3 Scenario 3

Table 5 shows the chosen configuration of the scenario 3 system. The number of solar panels used for this scenario is 13, based on the theoretical energy consumption calculated in chapter 9.3. Also included is a battery system that provides energy storage for times without irradiation.

Solar panels	Quantity: 13 Solar panels Power: 5.79 kWp
Battery	Capacity: 100.8 kWh Power: 7.5kW

Table 5 Configuration scenario 3

The energy consumption is higher than in the previous scenarios, because of the more civilised households. This is noticeable due to the larger system, but also because of the higher energy usage due to the often-used hammermill. Figure 31 demonstrates this.

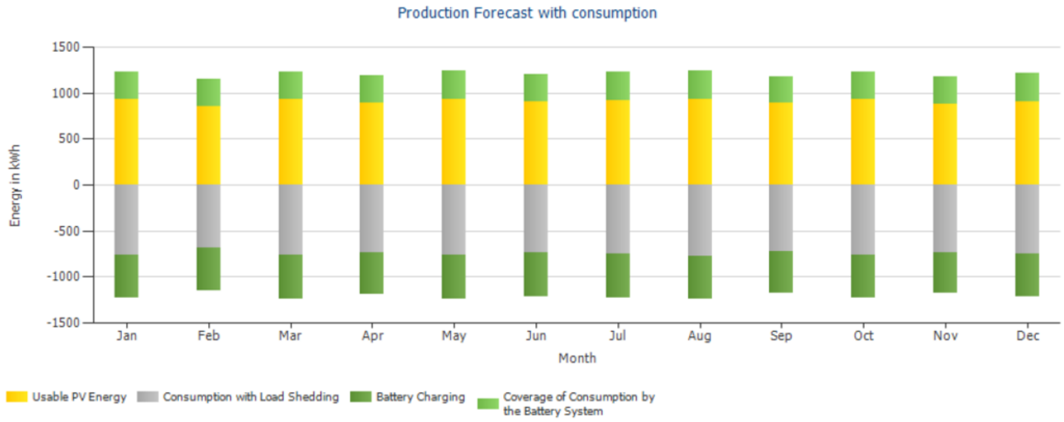

Figure 31 Production forecast with consumption scenario 3

The energy flow graph in figure 32 shows that there is no load shedding. It can also be seen that a lot of energy is lost due to conversion losses in the inverter.

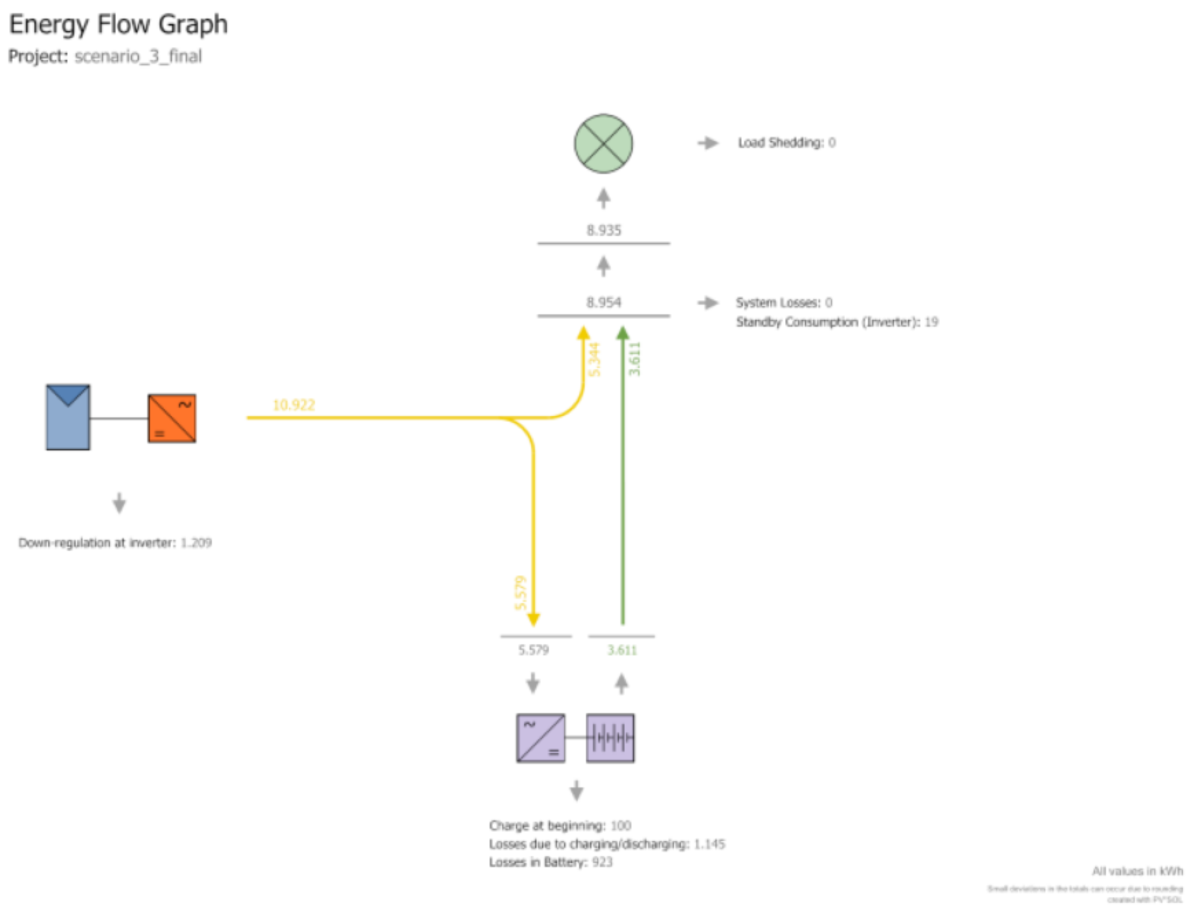

Figure 32 Energy flow graph scenario 3

10.3.4 Scenario 4

In the last scenario, the scenario with civilised households and a rarely used hammermill, twelve solar panels are used for the simulation. The configuration of the system can be seen in table 6, which shows the battery and solar system.

Solar panels	Quantity: 12 Solar panels Power: 5.34 kWp
Battery	Capacity: 86.88 kWh Power: 7.5kW

Table 6 Configuration scenario 4

Figure 33 displays the production and consumption forecast. It looks very similar to the forecast of scenario 2 and corresponds to the size of the plant and the energy usage. Differences in battery charging and coverage of consumption by the battery system can be explained by losses due to charging and discharging displayed in figure 33.

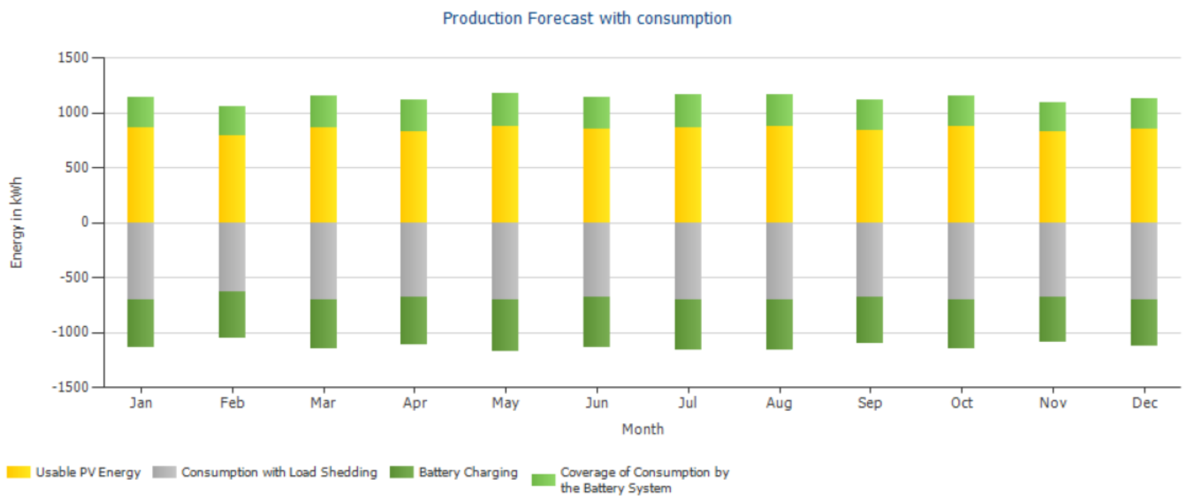

Figure 33 Production forecast with consumption scenario 4

Figure 34 displays the energy flow graph. It illustrates the distribution of solar energy and battery energy. It can be seen that there is similarly no load-shedding. The only losses occur due to inverters and charging.

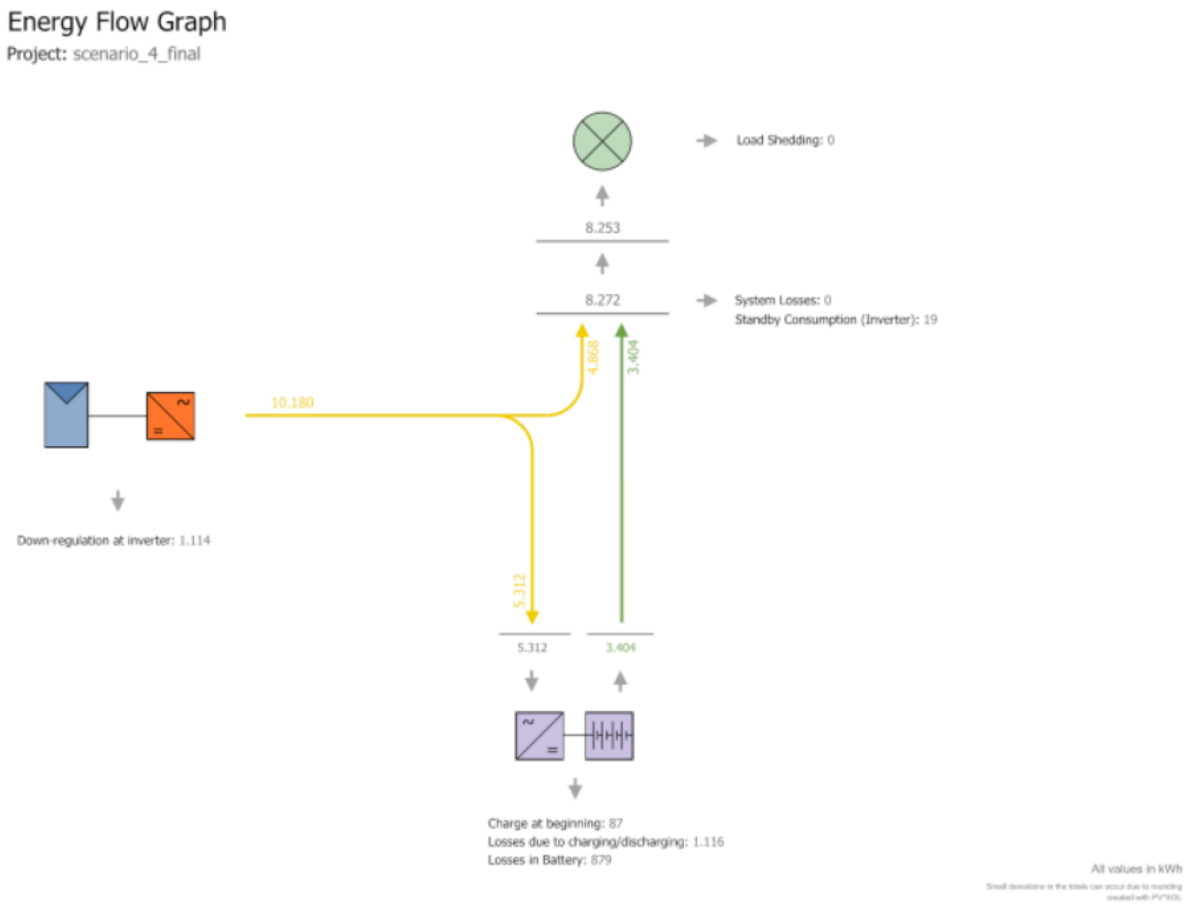

Figure 34 Energy flow graph scenario 4

10.4 Interpretation of the results

After the results of the simulation have been explained, they will be analysed and interpreted. The different scenarios produce different results. The larger the energy consumption, the larger the size of the system consisting of the battery and PV system. In scenario 2, which is the smallest system, the comparatively very small battery is remarkable. With a storable energy amount of about 3.784 kWh, it is 25 times smaller than the battery in scenario 3. Scenario 3, however, is the scenario with the highest energy consumption and thus the largest system.

Comparing scenario 1 with scenario 2, it can be seen that the battery is fifteen times larger. From this, it can be concluded that the hammermill has a large impact on energy consumption because of the peak load. When the hammermill is used more frequently, the peak load is reached more often. This can only be absorbed by a large solar system or battery.

When comparing scenarios 3 and 4, with the energy consumption of the civilised village, the differences in the energy consumption of the hammermill are not noticeable. The system still has to be enlarged for scenario 3 but on a smaller scale. This can be explained by the higher total energy consumption, which results in a lower percentage of energy consumption of the hammermill.

The differences between scenarios 1 and 2 compared to 3 and 4 are therefore mainly caused by the energy consumption of the households. Thus, the total energy consumption per month in scenarios 1 and 2 fluctuates at over 500 kWh, where this is 1000 kWh in scenarios 3 and 4.

As a result of all the simulations conducted, a system with eight solar modules and a 3.794 kWh battery is assumed as the minimum requirement. The maximum requirement consists of a system with thirteen solar modules and 100.8 kWh. Thus, a design is supposed to be based on scenario 3.

Unused energy can be used for other systems. For example, water pumps can provide clean drinking water, electric cooker tops can make cooking easier, or agriculture can be run more independently of environmental influences.

11 Marketing & Application

In this chapter, there will be an overview of the marketing design process. The fonts that will be used during the project and the logo will be presented. Because of this, the brand identity will be clear.

11.1 Design Process

As a start for the designing process, a brainstorming session was held to help form new ideas for the brand identity. The mind map that was made during this session is visible in figure 35. This includes basic information about the project, visual properties, objectives, and background thoughts about the project. This mind map will be used to design a logo and other marketing ideas for the project.

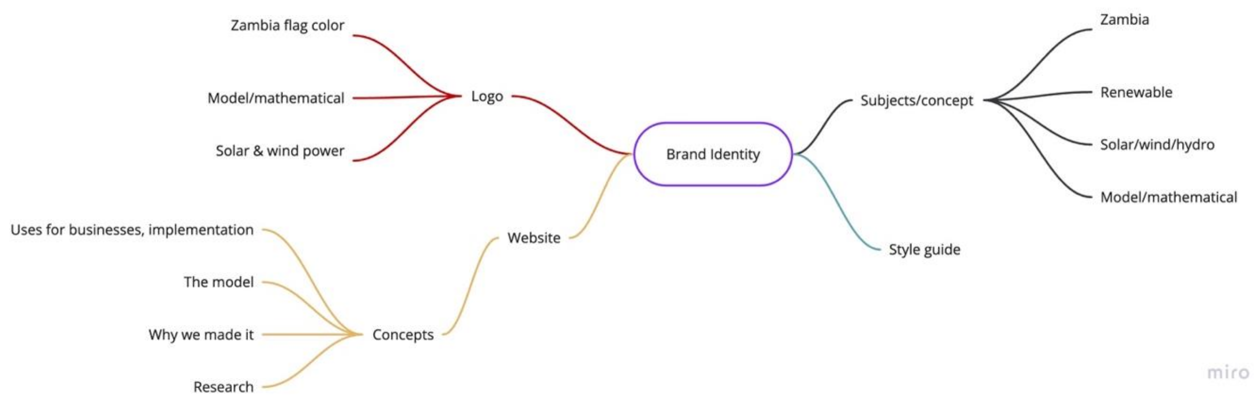

Figure 35 Mindmap design – made with Miro

11.2 Logo

The logo, which can be seen in figure 36, is made up of three elements that give a hint of what the project is about. The renewable energy systems the project is focusing on, are sketched by solar panels, wind turbines and the sun. The wireframes on the left show that the project is not a physical product but a model. At last, the Zambian colours are used to give the viewer an impression of the origin of the project.

Figure 36 Logo

11.3 Font

The text font is an important part of marketing because of the first impression it gives. If the logo gives an impression that corresponds to the project, the readers already know what to expect. In this paragraph, the chosen text fonts for the logo are described.

2.3.1 Heading font

Coolvetica - Energy for Rural Zambia

The Coolvetica font is chosen because it is a sans-serif font that is made for modern, clean purposes. The model that is being created is for a clean and sustainable purpose as well, so this font was chosen to enhance this feeling.

2.3.2 Text font

Roboto - A Model for Sustainable Off-grid Energy

Roboto is a widely used font, compatible with most heading fonts. It is a modern version of a scientific font commonly used in design studies and developed by Google (Vyas, 2022). This font is easily readable and a sign of quality.

11.4 Marketing visuals

To help the audience understand what the context of the marketing could be, some visual applications are visible in figure 37. This will help form a visual impression of how the marketing could be implemented and used.

Figure 37 Visual applications

12 Website

For better visualisation and presentation of the project, it was decided to create a website. This website will contain general information about the project. The focus was set on the visualization of the simulation. For this purpose, a 3D model is created and presented in a functioning scroll-based website.

12.1 Design Process

As mentioned in chapter 11, the designing process started with choosing a colour palette and the development of the logo. Hereafter, a brainstorming session was held to come up with new ideas and concepts for the website and further visuals. The result of this brainstorming session can be seen in figure 38.

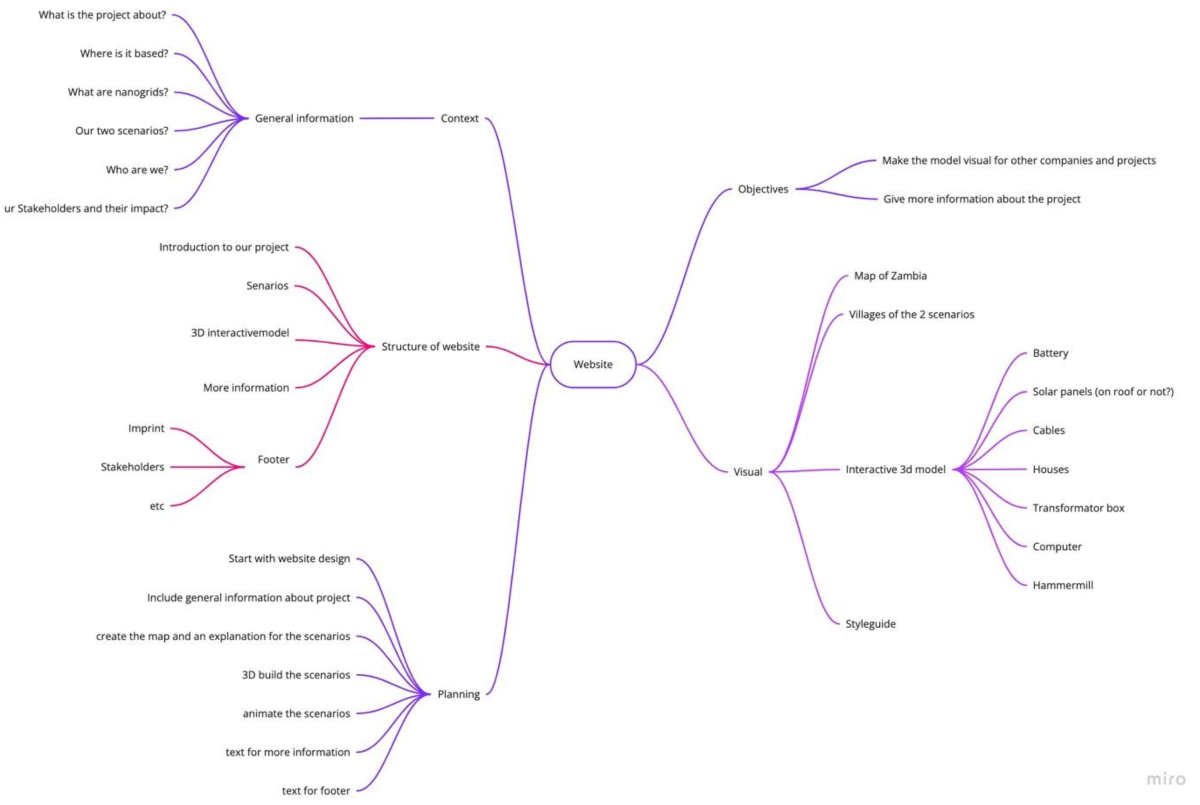

Figure 38 Brainstorm for the website

List of deliverables and information

Based on the brainstorming session, the following list was made, which shows what the product must showcase and communicate through its medium.

- Website
  I. Information on the problem the project tries the solve.
  II. The objectives of the project.
  III. Information about the stakeholders and team behind the project.
  IV. The four scenarios the project focuses on.
  V. Deep dive into the model, nanogrid system and potential output of the system.
- 3D model
  I. Animation of the village and how the nanogrid will be implemented.
  II. Visually explained how the nanogrid works via animation.
  III. What the different scenarios are and how it will influence the model.

12.2 Building the 3D model

The development of the 3D model is done via Blender, an open-source software made for visual development. The process of making the complete 3D model can be seen in figure 39. This process can also be viewed in Miro with the following link:
https://miro.com/app/board/uXjVPE07XUE=/?share_link_id=600305972219

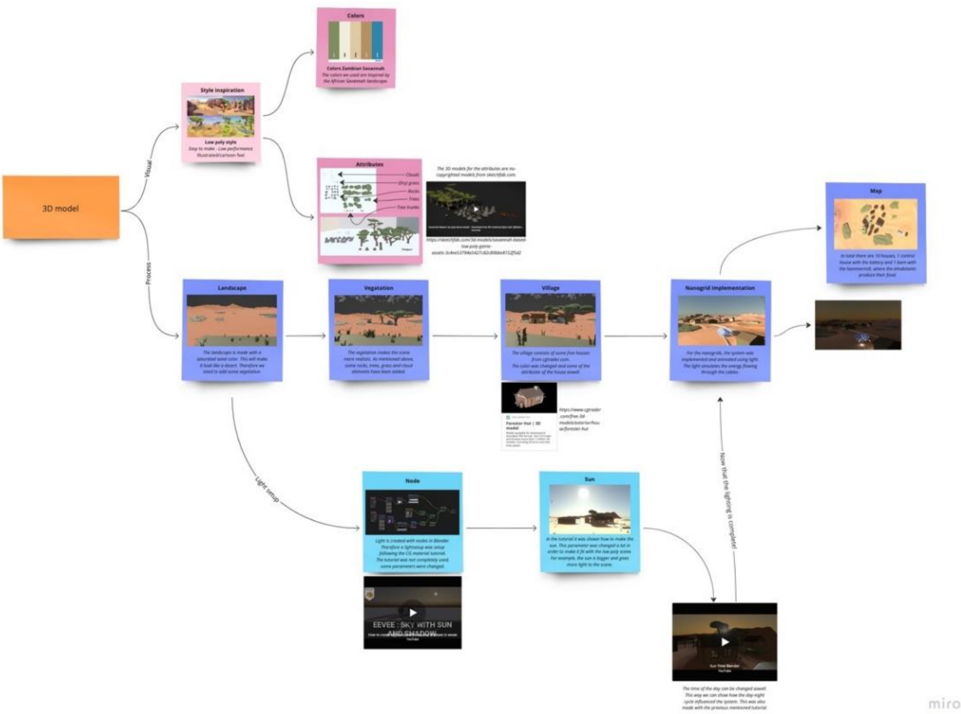

Figure 39 Miro process showcase

12.3 Building the Webpage

To create an effective website, a few design steps have to be made before creating the website. After the brainstorming session, a design has to be made and at last, the website is made and hosted using a web builder of the developers' choice.

12.3.1 Basic design setup using Figma

The basic design for the website was made in Figma, which is a free software used by many designers. Its purpose is to make wireframes for various mediums and, in the end, translate them to websites or apps. As shown in figure 40, the wireframe only shows the basics of the website. The header, home screen and footer are created to support a clean structure of the website. The translation to a full-functioning website is done manually via WordPress using Elementor, a WordPress web builder.

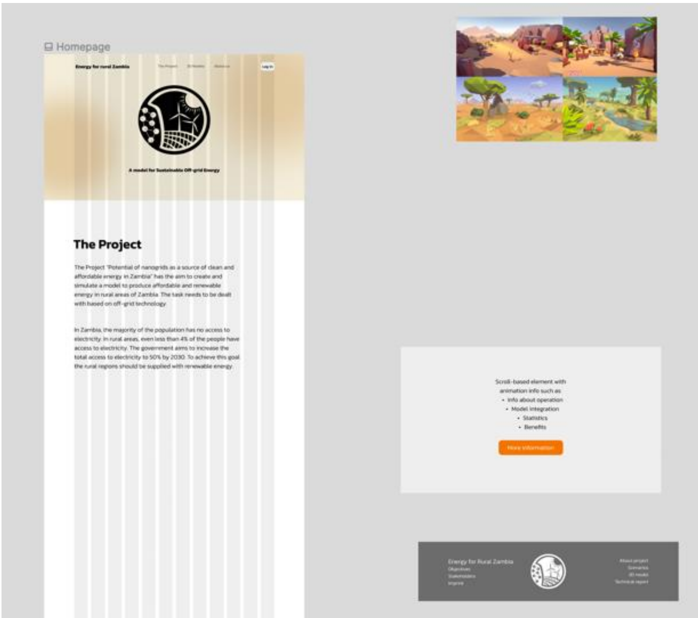

Figure 40 Figma UI Design

12.3.2 Realising the website using WordPress

In the end, the website is made using WordPress. With this software, all the pages are created, customized, and uploaded with content like pictures, text and optionally videos. The finished website can be seen on:

http://energyforzambia.eu/

The link will be updated at the latest 15.12.2022 and work until 22.11.2023

13 Conclusion

The aim of this study was to develop a concept for the electrification of rural villages based on off-grid technology. The study considered various influences, including Zambia's geographic and demographic situation. A major challenge is that the energy supply is founded on affordable and renewable energies. In order to evaluate the system parameters, a simulation was created in PV-SOL with the assistance of a local study.

To realise these aspects, research work had to be done first. With the help of the information gained, it was possible to get an impression of living conditions in Zambia. The focus was on the local climate, which plays a decisive role in the selection of renewable energy sources. Furthermore, different possibilities for the use of renewable energies were examined with the support of a Multi-Criteria-Decision Analysis. Considering numerous aspects, including affordability and reliability, solar energy emerged as the energy source to be used. This served as the power source for the modelling of the off-grid system and the following simulation.

In addition, various scenarios were created as realistically as possible. These are intended to show the energy consumption of civilised households and villages with minimal technical equipment. Each scenario also includes a hammermill, which contributes to typical local food production. In these scenarios, a concrete consumption of the households was determined. This provided the basis for the creation of a model.

The model that was realised with PV-SOL defines the system completely. As a result, the number of solar panels and also the size of the battery can be resolved. Moreover, these simulations also show weak points at which times of the year the least electricity can be produced.

In order to better visualise the results, a website was created. For this, a design was first created with the help of Figma. This design was then transferred to WordPress and made into a website. In addition, a detailed 3D simulation was created in Blender. This simulation was also integrated into the website and describes the details of the simulation with the help of text.

14 References

African Parks. (2022). *Bangweulu Wetlands*. Retrieved September 19, 2022, from African Parks: https://www.africanparks.org/the-parks/bangweulu

African Pioneer. (2022). *The Central African Copperbelt*. Retrieved September 20, 2022, from African Pioneer: https://africanpioneerplc.com/central-african-copperbelt/

Alova, G. (2018). *Integrating Renewables in Mining.* OECD Development Policy Papers. Retrieved October 1, 2022, from https://www.oecd-ilibrary.org/docserver/5bbcdeac-en.pdf?expires=1669286046&id=id&accname=guest&checksum=B55EFACF272AACBB241B4D7DA5BD8FD4

Asmus, P., & Lawrence, M. (2014). *Executive Summary: Nanogrids.* Retrieved October 7, 2022, from https://de.scribd.com/document/413124005/NANO-14-Executive-Summary

Aurélien, N., Ousmane, S., & Pitiya, R. (2022, March 1). *Zambia's Copperbelt Area and Copper Mining*. Retrieved September 20, 2022, from Scientific Research: https://www.scirp.org/journal/paperinformation.aspx?paperid=115816#ref23

Belbin. (2022). *Belbin team roles*. Retrieved October 12, 2022, from Belbin: https://www.belbin.com/about/belbin-team-roles

Biedermann, H., Vorbach, S., & Porsch, W. (. (2015). *Sustainability Management for Industries.* München u. Mering: Rainer Hampp Verlag. Retrieved October 1, 2022

BMZ. (2022). *Klimawandel und Waldverlust*. Retrieved September 20, 2022, from Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung: https://www.bmz.de/de/laender/sambia/umweltsituation-16296

Brittanica. (2022). *Zambia*. Retrieved September 16, 2022, from Brittanica: https://www.britannica.com/place/Zambia

Brittanica. (2022). *Zambia in the 21st century*. Retrieved September 16, 2022, from Brittanica: https://www.britannica.com/place/Zambia/Government-and-society

Bulder, B., Bot, E., & Bedon, G. (2018, March). *Optimal wind farm power density analysis for future offshore wind farms*. Retrieved October 13, 2022, from ECN: https://publicaties.ecn.nl/PdfFetch.aspx?nr=ECN-E--18-025

Clancy, H. (2014, July 16). *Nothing small in the promise for nanogrids*. Retrieved September 19, 2022, from GreenBiz: https://www.greenbiz.com/article/nothing-small-promise-nanogrids

Clean Energy Reviews. (2022, July 28). *Most Efficient Solar Panels 2022*. Retrieved October 7, 2022, from Clean Energy Reviews: https://www.cleanenergyreviews.info/blog/most-efficient-solar-panels

Climate Change Knowledge Portal. (2020). *Zambia - Climatology*. Retrieved from Climate Change Knowledge Portal: https://climateknowledgeportal.worldbank.org/country/zambia/climate-data-historical#:~:text=Zambia%20experiences%20a%20predominantly%20sub,May%20to%20mid%2DAugust).

Cole, S. M., & Tembo, G. (2011). *The effect of food insecurity on mental health: Panel evidence from rural Zambia.*

Danish Wind Industry Association. (2003, May 12). *Betriebs- und Wartungskosten von Windkraftanlagen*. Retrieved October 19, 2022, from Danish Wind Industry Association: http://drømstørre.dk/wp-content/wind/miller/windpower%20web/de/tour/econ/oandm.htm

Danish Windindustry Association. (2022). *Roughness and Wind Shear*. Retrieved from Xn--Drmstrre-64ad.dk: http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/shear.htm

Deutsche Energie-Agentur. (2013). *Länderprofil Sambia.* Berlin: Deutsche Energie-Agentur GmbH (dena).

Dorosh, P. A., Dradri, S., & Haggblade, S. (2009). *Regional trade, government policy and food security.*

Duke, R. (2022). *What is a Work Breakdown Structure?* Retrieved October 10, 2022, from Workbreakdownstructure.com: https://www.workbreakdownstructure.com/

Economist Intelligence. (2022). *Zambia*. Retrieved September 20, 2022, from Economist Intelligence: https://country.eiu.com/zambia

Electoral Commission of Zambia. (2021). Retrieved from Elections.org.zm: https://www.elections.org.zm/category/2021-general-election/

ElectroPrices. (2022). *Lg 445w High Efficiency Neon H Commercial Solar Panel*. Retrieved October 10, 2022, from ElectroPrices: https://electroprices.com/fi/solar-panel/lg-445w-high-efficiency-neon-h-commercial-solar-panel-285

EnBW. (2020, August 11). *Wie funktioniert eine Solarzelle?* Retrieved September 20, 2022, from EnBW: https://www.enbw.com/blog/energiewende/solarenergie/was-passiert-eigentlich-in-der-solarzelle/

Energy.gov. (2022). Retrieved from Solar Performance and Efficiency: https://www.energy.gov/eere/solar/solar-performance-and-efficiency

European Project Semester. (2022). *About EPS*. Retrieved October 14, 2022, from European Project Semester: http://europeanprojectsemester.eu/concept

Fatherland Gazette. (2022, February 7). *The people and culture of Zambia*. Retrieved September 16, 2022, from Fatherland Gazette: https://fatherlandgazette.com/the-people-and-culture-of-zambia/

Freedom House. (2022). *Explore the map*. Retrieved November 28, 2022, from Freedom House: https://freedomhouse.org/explore-the-map?type=fotn&year=2022

Freedom House. (2022). *Freedom in the world*. Retrieved September 16, 2022, from Freedom House: https://freedomhouse.org/country/zambia/freedom-world/2022

Generation Solar. (2021, May 31). *What´s Levelized Cost of Energy?* Retrieved October 5, 2022, from Generation Solar: https://www.generationsolar.com/solar-101/whats-levelized-cost-of-energy/

Global Solar Atlas. (2022). *Global Solar Atlas*. Retrieved September 20, 2022, from Global Solar Atlas: https://globalsolaratlas.info/map

Google Maps. (2022). Retrieved from https://www.google.com/maps/@-6.0742798,27.8850523,7z

Grianeza, M., Abo-al-ez, K., & Kahn, M. T. (2020). *Nanogrid Based Energy Trading System for Rural Off-Grid Community in Africa.* AIUE Proceedings of the 18th Industrial and Commercial Use of Energy Conference 2020. Retrieved October 4, 2022, from https://www.researchgate.net/publication/346994937_Nanogrid_Based_Energy_Trading_System_for_a_Rural_Off-Grid_Community_in_Africa/link/5fd76a71299bf140880aa27d/download

Hau, E. (2016). *Windkraftanlagen.* Munich: Springer Vieweg.

Hofstede Insights. (2022). *Country comparison*. Retrieved October 11, 2022, from Hofstede Insights: https://www.hofstede-insights.com/country-comparison/

Hofstede, G. (2022). *Hofstede Insights*. Retrieved September 25, 2022, from https://hi.hofstede-insights.com/national-culture

Idoniboyeobu, D., Ogunsakin, A., & Wokoma, B. (2018). *Forecasting of Electrical Energy Demand in Nigeria using Modified Form of Exponention Model.* Retrieved October 7, 2022, from ResearchGate: https://www.researchgate.net/profile/Biobele-Wokoma/publication/322529926_Forecasting_of_Electrical_Energy_Demand_in_Nigeria_using_Modified_Form_of_Exponential_Model/links/5a5e5005458515c03ee0afb8/Forecasting-of-Electrical-Energy-Demand-in-Nigeria-using-M

IFAD. (2022). *Zambia*. Retrieved September 21, 2022, from www.ifad.org: https://www.ifad.org/en/web/operations/w/country/zambia

International Trade Administration. (2022, August 7). *Agriculture*. Retrieved September 21, 2022, from International Trade Administration: https://www.trade.gov/country-commercial-guides/zambia-agriculture#:~:text=Agriculture%20contributes%20about%2019%20percent,as%20well%20as%20horticultural%20produce.

Investing News. (2022, February 24). *A Closer Look at Copper Mining in Zambia*. Retrieved September 20, 2022, from Investing News: https://investingnews.com/a-closer-look-at-copper-mining-in-zambia/

Julian, T. (2011, April 9). *What is right with risk matrices?* Retrieved October 11, 2022, from https://31000risk.wordpress.com/article/what-s-right-with-risk-matrices-3dksezemjiq54-4/

Junglas, P. (2022). *Clausius-Rankine-Prozess*. Retrieved October 28, 2022, from http://www.peter-junglas.de/fh/vorlesungen/thermodynamik2/html/kap4-1.html

Kalhammer, F., & Schnieder, T. (1976). *Energy Storage.* Retrieved November 8, 2022, from annualreviews: https://www.annualreviews.org/doi/pdf/10.1146/annurev.eg.01.110176.001523

LEIFIphysik. (2018). *Viertakt-Ottomotor*. Retrieved October 18, 2022, from LEIFIphysik: https://www.leifiphysik.de/waermelehre/waermekraftmaschinen/grundwissen/viertakt-ottomotor

LG. (2022). *445W High Efficiency LG NeON® H Commercial Solar Panel*. Retrieved October 10, 2022, from LG: https://www.lg.com/us/business/neon-2/lg-lg445n2w-e6

Libanda, B. (2022, August). *Modelling wind speed across Zambia: Implications for wind energy.* Retrieved September 27, 2022, from ResearchGate: https://www.researchgate.net/profile/Brigadier-Libanda/publication/362472250_Modelling_wind_speed_across_Zambia_implications_for_wind_energy/links/62f789e079550d6d1c78fcca/Modelling-wind-speed-across-Zambia-Implications-for-wind-energy.pdf

Marlec. (2022, July 15). *Rutland 1200 Terrain Windcharger*. Retrieved October 10, 2022, from Marlec: https://www.marlec.co.uk/product/rutland-1200-terrain-windcharger/

Marlec. (2022, May 24). *Rutland FM1803*. Retrieved October 10, 2022, from Marlec: https://www.marlec.co.uk/product/rutland-fm1803/

McLarnon, F. R., & Cairns, E. J. (1989). *Annual Review of Energy, Energy Storage.* California.

Mfula, C. (2022, Sept 9). *Zambia expects economy to grow 4% in medium-term, president says*. Retrieved September 20, 2022, from REUTERS: https://www.reuters.com/world/africa/zambia-expects-economy-grow-4-medium-term-president-says-2022-09-09/

Ministry of Foreign Affairs. (2019, July). *Maritime Trade of Lake Tanganyika.* Retrieved from https://www.rvo.nl/sites/default/files/2019/08/Final-report-Maritime-Trade-on-Lake-Tanganyika.pdf

Mishnaevsky, L., Freere, P., Sinha, R., Acharya, P., Shrestha, R., & Manandhar, P. (2011). *Small wind turbines with timber blades for developing countries: Materials choice, development, installation and experiences.*

Money, D. (2019, Sept 30). *'Aliens' on the Copperbelt: Zambianisation, Nationalism and Non-Zambian Africans in the Mining Industry.* Journal of Southern African Studies. Retrieved September 20, 2022, from Taylor & Francis Online: https://doi.org/10.1080/03057070.2019.1658406

Mvula, A. P. (2022). Design and Analysis of an off grid solar system: A case study of Nyari in Kitwe. Zambia: Copperbelt University.

Nkomoki, W., Bavorová, M., & Banout, J. (2019). *Factors Associated with Household Food Security in Zambia.*

Nordman, B. (2012). *Nanogrids - Evolving our electricity systems from the bottom up.* Berkeley: Lawrence Berkeley National Laboratory. Retrieved September 20, 2022, from http://assets.fiercemarkets.net/public/smartgridnews/Smart_Grid_News_-_LBNL_Nanogrid_Report.pdf

Nordman, B., Christensen, K., & Meier, A. (2012). *Think Globally, Distribute Power Locally: The Promise of Nanogrids.* Virginia: Kirk W. Cameron, Dept. of Computer.

Novia UAS. (2018). *About Novia UAS*. Retrieved October 14, 2022, from Novia UAS: https://www.novia.fi/about-us/about-novia-uas

Office of Energy Efficiency & Renewable Energy. (2022, August 16). *Wind Turbines: the Bigger, the Better*. Retrieved October 19, 2022, from energy.gov: https://www.energy.gov/eere/articles/wind-turbines-bigger-better

Paschotta, R. (2020). *Organic Rankine Cycle*. Retrieved November 7, 2022, from RP-Energie-Lexikon: https://www.energie-lexikon.info/organic_rankine_cycle.html

Paschotta, R. (2021, July 24). *Power to Liquid*. Retrieved November 7, 2022, from RP-Energie-Lexikon: https://www.energie-lexikon.info/power_to_liquid.html

Paschotta, R. (2022). *Schwungradspeicher*. Retrieved November 7, 2022, from RP-Energie-Lexikon: https://www.energie-lexikon.info/schwungradspeicher.html

Photovoltaik.org. (2022). *Photovoltaik Kosten*. Retrieved October 18, 2022, from Photovoltaik.org: https://www.photovoltaik.org/betrieb/photovoltaik-kosten

Pionierkraft. (2020, December 4). *Kleinwasserkraftwerk: Das Wasserkraftwerk für zuhause!* Retrieved November 4, 2022, from Pionierkraft: https://pionierkraft.de/2020/12/04/kleinwasserkraftwerk-das-wasserkraftwerk-fuer-zuhause/

Pokehar, S. D., & Ramachandran, M. (2003). *Application of multi-criteria decision making to sustainable energy planning - A review.* Pilani, India: ELSEVIER. Retrieved October 7, 2022

Quaschning, V. (2022). *Regnerative Energiesysteme Technologie-Berechnung-Klimaschutz.* Berlin: Carl Hanser Verlag München.

Renewables.ninja. (2022). *Renewables.ninja*. Retrieved September 22, 2022, from Renewables.ninja: https://www.renewables.ninja/

ResearchGate. (2022, June 14). *Modelling wind speed across Zambia: Implications for wind energy.* International Journal of Climatology. Retrieved October 5, 2022, from ResearchGate: https://www.researchgate.net/profile/Brigadier-Libanda/publication/362472250_Modelling_wind_speed_across_Zambia_implications_for_wind_energy/links/62f789e079550d6d1c78fcca/Modelling-wind-speed-across-Zambia-Implications-for-wind-energy.pdf

Rommel, D. P., Di Maio, D., & Tinga, T. (2019). Calculating wind turbine component loads for improved life. *Renewable Energy*, 223-241.

Ruiven, B. J., Schers, J., & Vuuren, D. P. (2011). *Model-based scenarios for rural electrification in developing countries.* Bilthoven, Utrecht: Elsevier Ltd. Retrieved October 7, 2022, from https://reader.elsevier.com/reader/sd/pii/S0360544211007687?token=605808D0C79246B59FB5926516B84D47260E050C3C29CEEA9608C3ED6A77CE74D6E25083A04A4A6E4FC8EA13723521C9&originRegion=eu-west-1&originCreation=20221124093554

Sambia - Stecker & Steckdosen. (2022). Retrieved from STECKDOSEN DER WELT: https://www.welt-steckdosen.de/sambia/

Sinha, R., Liang, V.-C., Paradis, C. J., & Khosla, P. K. (2001). *Modeling and Simulation Methods for Desgin of Engineering Systems.* The American Society of Mechanical Engineers.

Smart Hydro Power. (2022). *Smart Free Stream Turbine*. Retrieved November 11, 2022, from Smart Hydro Power: https://www.smart-hydro.de/wp-content/uploads/2015/12/Datasheet_SMART_Freestream.pdf

Söderbacka, C. (2022, September 5). Potential of Nanogrids as a source of clean & affordable Energy in Zambia. Vaasa, Finland. Retrieved October 2, 2022

Statista. (2012). *Wirkungsgrade verschiedener Stromspeicher*. Retrieved November 7, 2022, from Statista: https://de.statista.com/statistik/daten/studie/156269/umfrage/wirkungsgrade-von-ausgewaehlten-stromspeichern/

Statista. (2022, May 3). *Anteil Erneuerbarer Energien an der Primärenergieerzeugung nach Region weltweit im Jahr 2017*. Retrieved November 7, 2022, from Statista: https://de.statista.com/statistik/daten/studie/490403/umfrage/anteil-der-ee-an-der-energieerzeugung-nach-region-weltweit/

Sterner, M., & Stadler, I. (2019). *Handbook of Energy Storage - Demand, Technologies, Integration.* Berlin: Springer.

Studyflix. (2022). *Kohlekraftwerk - Aufbau, Funktion, Energiediagramm*. Retrieved November 7, 2022, from Studyflix: https://studyflix.de/erdkunde/kohlekraftwerk-4415

The World Bank. (2021). *The World Bank in Zambia*. Retrieved October 10, 2022, from The World Bank: https://www.worldbank.org/en/country/zambia/overview

The World Bank. (2022, April 17). *Zambia Economic Overview*. Retrieved September 20, 2022, from The World Bank: https://www.worldbank.org/en/country/zambia/overview

Thoubboron, K. (2021, November 22). *Advantages and disadvantages of renewable energy*. Retrieved September 22, 2022, from Energysage: https://news.energysage.com/advantages-and-disadvantages-of-renewable-energy/

Torero, M. (2015). *The Impact of Rural Electrification: Challenges and Ways Forward.* De Boeck Supérieur. Retrieved from https://www.cairn-int.info/article-E_EDD_293_0055--the-impact-of-rural-electrification.htm

usability.gov. (2022). *Wireframing*. Retrieved November 15, 2022, from usability.gov: https://www.usability.gov/how-to-and-tools/methods/wireframing.html

Venkateswaran, K. (2011). *The vulnerability of Zambian communities living along the Zambezi River basin to floods.* Retrieved November 7, 2022, from ResearchGate: https://www.researchgate.net/publication/280300519_The_vulnerability_of_Zambian_communities_living_along_the_Zambezi_River_basin_to_floods

Vyas, K. (2022, Feb 17). *Google's new Roboto Serif font makes reading more comfortable*. Retrieved October 5, 2022, from xda-developers: https://www.xda-developers.com/google-roboto-serif-font/

Weather Atlas. (2022). *Climate and monthly weather forecast Zambia*. Retrieved September 14, 2022, from Weather Atlas: https://www.weather-atlas.com/en/zambia/venture-climate#daylight_sunshine

Wesselak, V., Schabbach, T., Link, T., & Fischer, J. (2016). *Handbuch Regenerative Energietechnik.* Nordhausen: Springer Vieweg.

World of Maps. (2022). *Relief map Zambia*. Retrieved September 16, 2022, from World of Maps: https://www.worldofmaps.net/en/africa/maps-of-zambia/map-of-zambia-relief-map.htm

World Population Review. (2022). *Zambia Population 2022*. Retrieved November 25, 2022, from World Population Review: https://worldpopulationreview.com/countries/zambia-population

WorldData.info. (2022). *Average length of day in Lusaka*. Retrieved October 18, 2022, from WorldData.info: https://www.worlddata.info/africa/zambia/sunset.php

Zambia Tourism. (2022). *Geography of Zambia*. Retrieved September 19, 2022, from Zambia Tourism: https://www.zambiatourism.com/about-zambia/geography/

Zambia Tourism. (2022). *Map Zambia*. Retrieved September 19, 2022, from Zambia Tourism: https://www.zambiatourism.com/

Zhang, C., Wu, J., Long, C., & Meng, C. (2017). *Review of Existing Peer-to-Peer Energy Trading Projects.* Cardiff: Elsevier Ltd.

Appendix: Project Management

15.1 Belbin

The results of the Belbin tests are displayed in figures 41 to 45. From the Belbin test, it became clear that everyone in our team has another team role. These team roles are specified on the Belbin Website and taken into account in the following Belbin analysis of each team member (Belbin, 2022).

15.1.1 Belbin roles Finn Gausmann

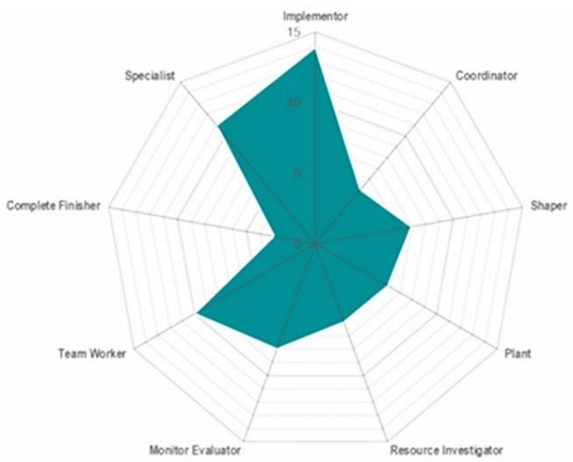

Figure 41 Belbin test Finn

Finn can be seen as an implementor and specialist. But we notice that work is easier for Finn if someone is telling him what he should do. Finn is not able to organise and split up the work for himself. That is the main point which is against the Implementor role in Finn's Belbin test results.

Role	Strengths	Allowable weaknesses	Don't be surprised to find that…
Implementor	Practical, reliable and efficient. Turns ideas into actions and organises work that needs to be done	Can be a bit inflexible and slow to respond to new possibilities	They might be slow to relinquish their plans in favour of positive changes
Specialist	Single-minded, self-starting and dedicated. They provide specialist knowledge and skills	Tends to contribute on a narrow front and can dwell on the technicalities	They overload you with information

Table 7 Belbin roles Finn (Belbin, 2022)

15.1.2 Belbin roles Henrik Dierenfeld

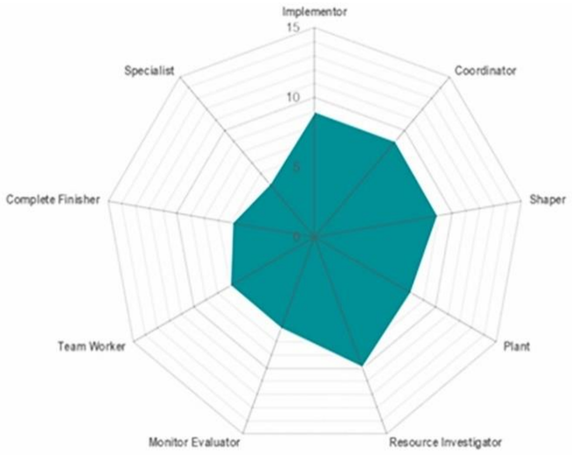

Figure 42 Belbin test Henrik

Henrik is an implementor, coordinator, shaper and resource investigator. In all of these categories, he has nine points. He has a wide range of competence. This is also what Henrik is like. He cannot be put in one box. His outstanding feature is the Resource Investigator. This is clear from the way he works as he likes to explore different opportunities.

Role	Strengths	Allowable weaknesses	Don't be surprised to find that…
Implementor	Practical, reliable and efficient. Turns ideas into actions and organises work that needs to be done	Can be a bit inflexible and slow to respond to new possibilities	They might be slow to relinquish their plans in favour of positive changes
Coordinator	Mature, confident, identifies talent, Clarifies goals	Can be seen as manipulative and might offload their own share of the work	They might over-delegate, leaving themselves little work to do
Shaper	Challenging, dynamic, thrives on pressure. Has the drive and courage to overcome obstacles	Can be prone to provocation, and may sometimes offend people's feelings	They could risk becoming aggressive and bad-humoured in their attempts to get things done
Resource Investigator	Outgoing, enthusiastic. Explores opportunities and develops contacts	Might be over-optimistic, and can lose interest once the initial enthusiasm has passed	They might forget to follow up on a lead

Table 8 Belbin roles Henrik (Belbin, 2022)

15.1.3 Belbin roles Maaike Kamer

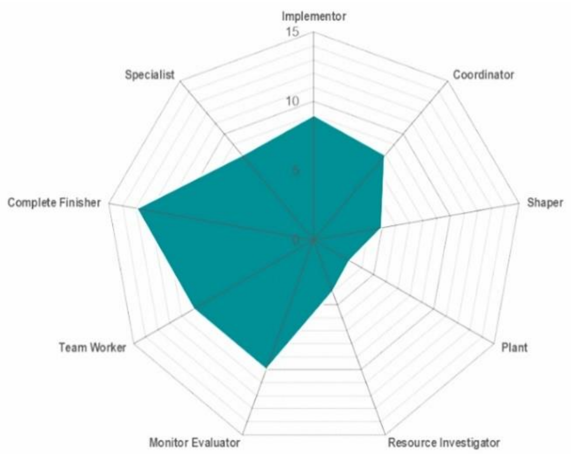

Figure 43 Belbin test Maaike

Maaike is a complete finisher, team worker and monitor evaluator. These Belbin results fit very well with Maaike's work and behaviour in general. She searches out errors, keeps an overview of what needs to be done and looks at all options. One of her weaknesses is that she is reluctant to delegate and tends to do more than necessary. She combines all assets of her roles, which makes her important for the team.

Role	Strengths	Allowable weaknesses	Don't be surprised to find that…
Complete finisher	Painstaking, conscientious, anxious, Searches out errors, Polishes and perfects	Can be inclined to worry unduly, and reluctant to delegate	They could be accused of taking their perfectionism to extremes
Team worker	Co-operative, perceptive and diplomatic, Listens and averts friction	Can be indecisive in crunch situations and tends to avoid confrontation	They might be hesitant to make unpopular decisions
Monitor Evaluator	Sober, strategic and discerning. Sees all options and judges accurately	Sometimes lacks the drive and ability to inspire others and can be overly critical	They could be slow to come to decisions

Table 9 Belbin roles Maaike (Belbin, 2022)

15.1.4 Belbin roles Tobias Huber

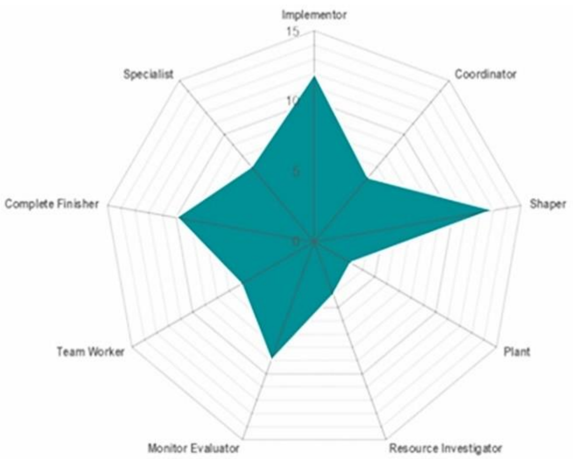

Figure 44 Belbin test Tobias

Tobias is a shaper and implementor. The impression of Tobias is more that he stays with his point of view. This fits the role of the shaper. He is also a good organiser which is a benefit for the whole team.

Role	Strengths	Allowable weaknesses	Don't be surprised to find that...
Shaper	Challenging, dynamic, thrives on pressure Has the drive and courage to overcome obstacles	Can be prone to provocation, and may sometimes offend people's feelings	They could risk becoming aggressive and bad-humoured in their attempts to get things done
Implementor	Practical, reliable and efficient. Turns ideas into actions and organises work that needs to be done	Can be a bit inflexible and slow to respond to new possibilities	They might be slow to relinquish their plans in favour of positive changes

Table 10 Belbin roles Tobias (Belbin, 2022)

15.1.5 Belbin roles Tom Fransen

Figure 45 Belbin test Tom

Tom is an implementor and plant. He is the only creative person in the team. This goes hand in hand with his study subject: communication and multimedia design. He is also an implementor but like Finn not good at work organisation. So, this part of the Belbin test is not true for him.

Role	Strengths	Allowable weaknesses	Don't be surprised to find that…
Implementor	Practical, reliable and efficient. Turns ideas into actions and organises work that needs to be done	Can be a bit inflexible and slow to respond to new possibilities	They might be slow to relinquish their plans in favour of positive changes
Plant	Creative, imaginative, free-thinking, generates ideas and solves difficult problems	Might ignore incidentals, and may be too preoccupied to communicate effectively	They could be absent-minded or forgetful

Table 11 Belbin roles Tom (Belbin, 2022)

15.1.6 Conclusion

The implementors in our team are Finn, Tobias, and Tom. They turn the ideas that we have into actions. Maaike is the coordinator, which means that she clarifies goals and delegates effectively. Tobias and Tom are the shapers of the team, they have the drive to overcome obstacles. Henrik and Tom are the plants as they are creative and generate ideas. Henrik is the resource investigator, he explores opportunities. Tobias and Maaike have the roles of monitor evaluator, which means they consider every option and work strategically. All the team members are team workers as we listen to each other and avert friction. It is a good sign that we are all team workers, but this also means that our weakness as a team is that we avoid confrontation and could be indecisive. The complete finisher of the team is Maaike, she polishes everything and searches out the errors. Finn is the specialist as he provides knowledge for the project.

It is positive for our teamwork that all the roles are present in our team. We also do not have too much overlap in the roles, so our team does not have a lot of weaknesses. The only thing that we have to be cautious about, is that we are all team workers on some level. We need to be careful that we do not avoid confrontation or become indecisive.

15.2 Leadership test

The results of the leadership test are displayed in figures 46 to 50.

Figure 46 Leadership test Finn

Finn has his best results for leadership and creative thinking. But compared to a typical project manager he fails in dealing with uncertainty.

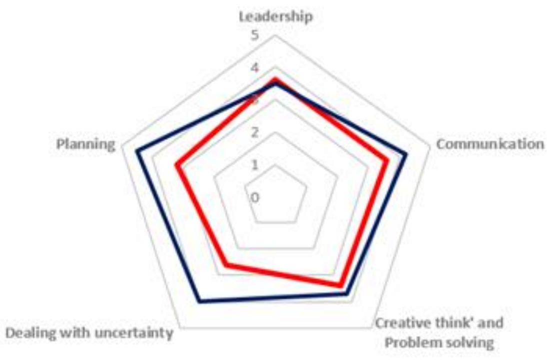

Figure 47 Leadership test Henrik

Henrik's strongest points are leadership, communication, and creative thinking. He is very strong in the leadership aspect. In this he is stronger than the compared average project manager.

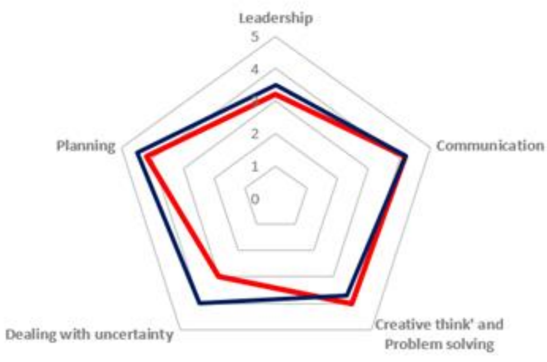

Figure 48 Leadership test Maaike

Planning, communication, and creative thinking are Maaike's best project management skills. This is already very similar to the project manager.

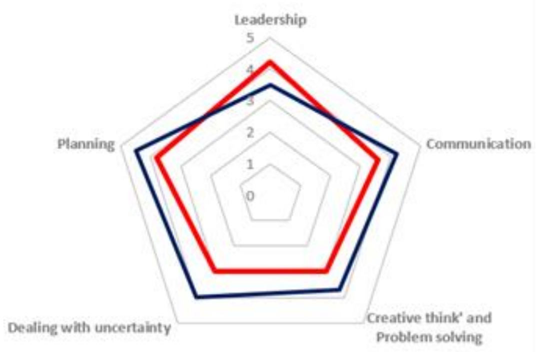

Figure 49 Leadership test Tobias

Tobias scored the highest for leadership. His results are close to the typical project manager, but all the skills except leadership are a bit lower. Tobias is especially strong in leadership, so he became our project leader.

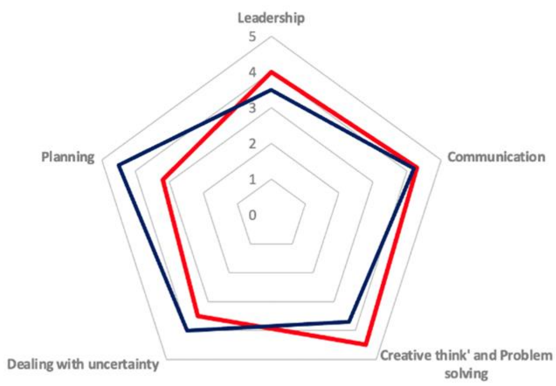

Figure 50 Leadership test Tom

Tom's strongest points are leadership, communication, and creative thinking. You can see that his creative and communication values are stronger than the values of the average project manager. Also his value of dealing with uncertainty is compared to others of the group very high.

In general there are two possible negative points in the team. Dealing with uncertainty is generally lower than the average. This may be a risky area and might lead to stressful situations while dealing with an uncertain topic. But because the team is broadly experienced in different faculties, this is only a small and unlikely risk. In addition to this, communication skill is also mostly underdeveloped. This could cause misunderstandings and unpleasant work experiences.

To conclude, almost all skills are achieved by the team. This will have a positive influence on the outcome of our project since no skill is dangerously underdeveloped. The team will strengthen the skill to make the project successful in all areas.

15.3 Work Breakdown Structure

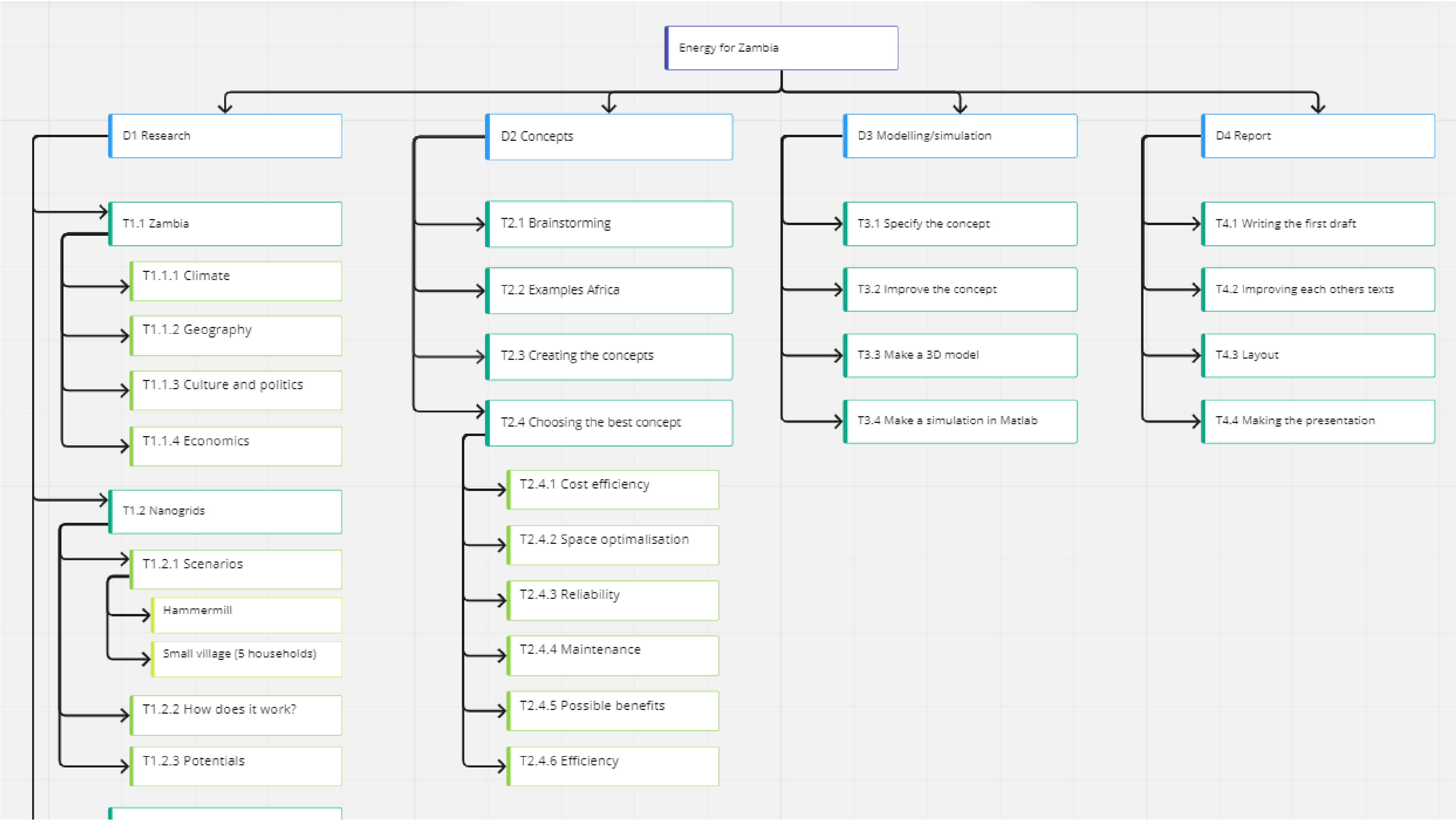

Figure 51 Work Breakdown Structure

The Work Breakdown Structure (WBS) is a tool, which aims to split a task up into smaller pieces of work content. This diagram also makes it possible to break down the project scope and visually display the work content (Duke, 2022).

The work is presented more clearly and made accessible to all project participants. First, the deliverables are listed and then the tasks to be completed are written underneath. The main components of the project are Research, Concepts, Modelling/Simulation and Report. The work content can then be broken down into these components.

15.4 Gantt chart

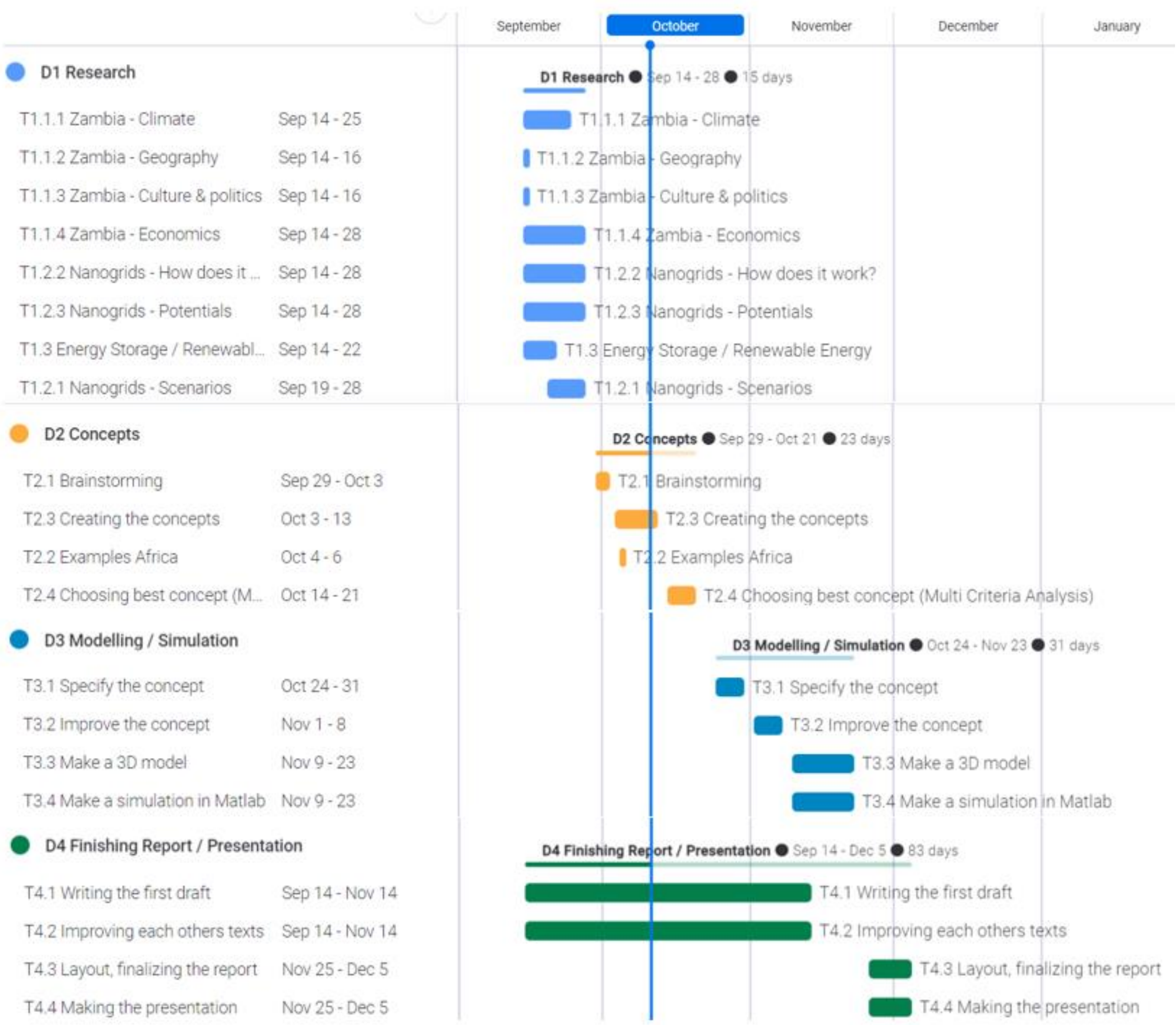

Figure 52 Gantt-Chart of the EPS-Project

15.5 Stakeholder Analysis

Stakeholders are people that are interested in our project. The internal stakeholders are the people who are really involved in the project. External stakeholders are affected by our project, but they do not influence it directly. The stakeholders for our project are Novia, the University of Zambia, the Copperbelt University, Cynthia Söderbacka, Roger Nylund, the Rural Electrification Authority and the end user. These stakeholders are divided into groups of people that have to be monitored, kept informed, kept satisfied and managed closely. These groups are based on the amount of power and interest that the stakeholders have. In figure 53, the stakeholders are displayed in a graphic based on their power and interest.

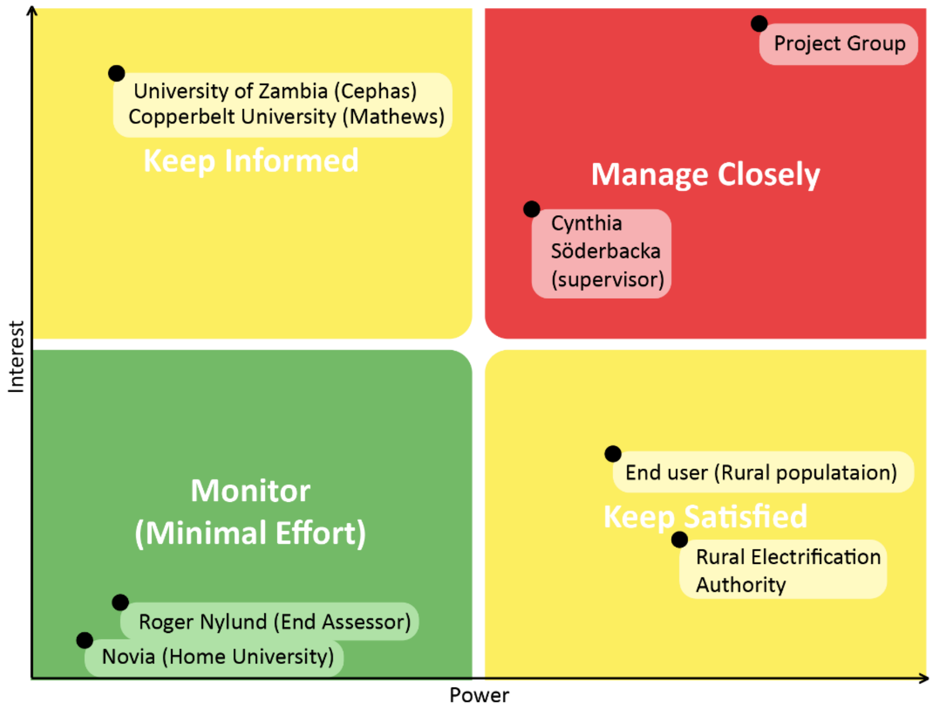

Figure 53 Stakeholder matrix

15.5.1 Monitor

The stakeholders that we have to monitor during our project are Roger Nylund and Novia University of Applied Sciences. Roger Nylund is one of our end assessors and the head of the EPS project. We have to inform him if there are problems with our project or the cooperation with our supervisor, but other than that he is not involved in our project. Novia is our University and has the interest that we deliver a good end result.

15.5.2 Keep informed

The University of Zambia and the Copperbelt University are the partner Universities for this project. We have to keep them informed on our progress so we can work together and get more information about the situation in Zambia.

15.5.3 Keep satisfied

The stakeholders we have to keep satisfied are not contacted, but we need to keep the aspirations and needs of these people in mind while designing our solution. These stakeholders do not have direct power to change our project, but our end product is influenced by them. The Rural Electrification Authority is an organisation of the Zambian Government that provides electricity in rural areas. During our project, we need to have their aspirations and regulations in mind. We also have to keep the end users of our product satisfied, we need to design with them in mind.

15.5.4 Manage closely

The most important stakeholder of our project is our team itself. The team members need to form a good team and all work efficiently to finish this project successfully. Another important stakeholder is Cynthia Söderbacka, our supervisor. She is going to grade our work. We need to have regular meetings with her to keep her informed of our work and get feedback.

15.6 Risk Analysis

When the workflow is worked out in a project, this brings with it the challenge of having to identify and classify associated risks. The risk matrix is a structured tool to identify critical risks. It should also enable methods to be developed to avoid the risk as much as possible or to keep it as small as possible. Figure 54 shows a risk matrix that contains risks related to the project "Development of an energy model as a basis for sustainable electrification of rural areas in Zambia by using off-grid systems" (Julian, 2011).

Impact			
High	-Takes more time than expected	-Russia war	-Reliability vs affordability
Medium	-Conflicts in team	-Product doesn't meet expectation.	-Bad communication with stakeholders (Zambia)
Low	-No resources to implement	-Absence of team member (sick)	-Bad planning
	Low	**Medium**	**High**
		Likelihood	

Figure 54 Risk matrix

In the risk matrix, the impacts are plotted against the likelihood. Risks with a high impact and a high probability of occurrence are to be considered much more critical than those with low values. For a better understanding, the risk areas were therefore marked in colour, whereby methods should be worked out for the red and yellow areas to keep the risk low, while the risks marked in green can be accepted, but should still be kept in mind.

The biggest risk for the project is the trade-off between reliability and affordability in terms of the elaborated results. One possibility, for example, would be that a cost-effective solution to the problem would have the disadvantage that the system would no longer work reliably. On the other hand, systems with very high reliability are often not affordable in the poor areas of Zambia. The greatest risk for the entire project would therefore be that this conflict cannot be resolved, and the result is insufficient for further projects. To actively counteract this risk, regular communication between the stakeholders must take place so that the expectations of all involved remain realistic. In addition, all stakeholders should be able to accept that it may not be possible to guarantee the perfect reliability of the system under the given circumstances.

With the measure just mentioned, however, there is also an additional risk. Poor communication between the stakeholders, especially with the universities in Zambia, can lead to the project working in the wrong direction. Regular consultation, a precise definition of objectives and also the definition of project objectives are essential. The high-level planner is the optimal measure here, as it can be checked whether all the essential points of the project have been correctly understood.

The current global political situation is very tense due to the war in Ukraine. A worst-case scenario could result in further countries becoming involved in this war and the project having to be cancelled. This risk is difficult to assess and cannot be influenced by measures.

Risks classified by the project team as medium-high are that expectations regarding the project duration or the final product will not be achieved. In addition, the project was inadequately planned from the ground up and the goal is therefore missed. Suitable measures, in this case, are also regular communication between the stakeholders, as well as good project management and time planning. In concrete terms, these risks can be minimised using a Gantt chart, for example.

No specific measures are developed for risks that are classified as low likelihood and low impact. Nevertheless, it is important to recognise these risks so that in the occurrence of such a risk, a timely reaction can be taken.

15.7 Cultural dimensions

Category	Description
Power Distance	The distribution of power between the individuals of the society.
Individualism	This describes the degree of interdependence between the members of the society.
Masculinity	A high masculinity score indicates a competition-driven society.
Uncertainty Avoidance	The way a culture deals with unknown and ambiguous situations.
Long Term Orientation	If links with the past are maintained while dealing with challenges of the present and future.
Indulgence	The extent people try to control their desires and impulses.

Table 12 Cultural Dimensions (Hofstede Insights, 2022)

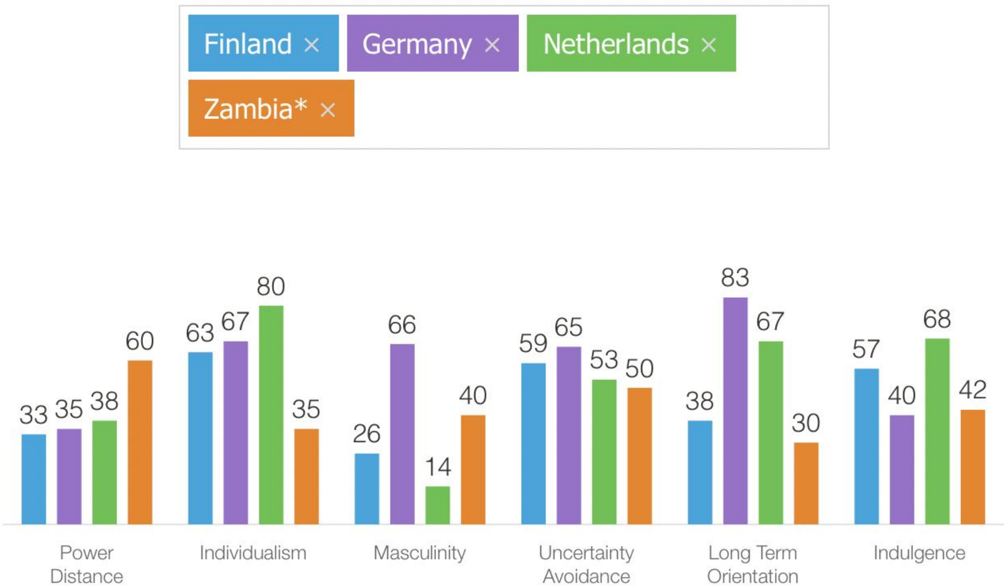

Figure 55 Hofstede comparison (Hofstede Insights, 2022)

We decided to compare the cultural dimensions of the Netherlands, Germany, Finland, and Zambia. Our group only consists of the German and the Dutch nationality, but to make a more diverse comparison we decided to add Zambia and Finland. Since we are in Finland during our project and could already get an impression of the culture, we added it. Zambia is also of great interest, as we are doing a lot of research on this country for our project.

One can see that all the compared countries have similar Power Distance scores except for Zambia. The lower income and higher rates of corruption contribute to an exceedingly hierarchical society (The World Bank, 2021).

In terms of Individualism, the Netherlands has the highest score. That Indicates that the Dutch people are very interdependent. Germany and Finland have similar points. Zambia scores significantly lower due to the lower welfare.

In the third category, Masculinity, Germany noticeably marked the highest points. We agree on that point, because German society is strongly driven by competition. Both Finland and the Netherlands have relatively low scores. This also agrees with our first impression of the Finnish society. Maaike and Tom, as our Dutch team members agree that achievement and material rewards do not play such a big role in their society.

At Uncertainty avoidance, all the countries have achieved similar high points with Germany having the most.

When looking at the Long-Term Orientation we disagree with the high score from Germany. We believe that the Dutch society is more encouraged to modern education and long-term preparation for the future. We also cannot understand Finland's low score. Our impression so far suggests a higher score.

In the last category, Indulgence, Finland and the Netherlands stand out with the highest number of points. That implements that the Finns and the Dutch have a free society that is less suppressed by social norms. The drive for enjoying life is higher in general (Hofstede, 2022).

15.8 Project charter

1. General Project Information	
Project Name:	Sustainable Nanogrid Energy for Zambia
Team Leaders:	Cynthia Söderbacka
Sponsors:	Novia UAS
Date:	01-09-2022 / 20-12-2022

2. Project Team				
Name	**Title**	**Responsabilities**	**Way of contact**	**Contact Information**
Tobias Huber	Team Member	Project leader	Informal: Whatsapp and calling	+49 174 8186416
Finn Gausmann	Team Member	Technical expert in renewable energy	Informal: Whatsapp and calling	+49 163 8749811
Henrik Dierenfeld	Team Member	Technical support and quality control	Informal: Whatsapp and calling	+49 1573 2120718
Maaike Kamer	Team Member	Complete finisher and coordinator	Informal: Whatsapp and calling	+31 6 46774113
Tom Fransen	Team Member	Creative thinker and technical support	Informal: Whatsapp and calling	+31 6 81638466
Novia UAS	Support Institution	Do formalities and provide access to university tools	Formal : Mail	chrysi.dresnali@novia.fi
Roger Nylund	End assesor	Responsible for team building	Formal : Mail	roger.nylund@novia.fi
Cynthia Söderbacka	Supervisor	Support writing, feedback and stakeholder's manager	Formal : Whatsapp	cynthia.soderbacka@novia.fi

3. Project Scope Statement
Purpose Of The Project
Our Project "Potential of nanogrids as a source of clean and affordable energy in Zambia" has the aim to create and simulate a model for affordable and renewable energy production in rural regions in Zambia.
Objectives
Development of a basis for increasing the electrification rate of rural areas in Zambia.
Creating energy usage patterns for a village of five households.
Creating an affordable solution for producing and storing renewable energy for small villages in rural Zambia.
Creating a digital simulation for the design and dimensioning of an off-grid system.
Deliverables
Model and simulation of the nanogrid system
Group project report
Ending presentation
Scope
The scope of our project is to do research on all areas of the problem, compare different scenarios and concepts. In addition to that a model is created for the concept and a simulation is provided to check the results. This simulation is used as a basis for future projects in this context.

Table 13 Project Charter