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Off-grid portable production and distribution of sustainable energy

A product service system solution developed for the energy market

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The authors declare that they are the sole authors of this thesis and that they have not used any sources other than those listed in the bibliography and identified as references. They further declare that they have not submitted this thesis at any other institution to obtain a degree.

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ABSTRACT

Background. At the year of 2021, 770 million people worldwide were living without access to electricity. In parallel with this, electrification of vehicles and other equipment constantly increases which results in a demand for access to reliable off-grid energy to allow for operation in remote locations or places without sufficient energy infrastructure due to external factors such as natural disasters. As the use of fossil fuels is predicted to decrease, the need for sustainable energy production utilizing renewable energy sources has proved to be critical. The combination of these factors results in a need for the development of sustainable off-grid energy systems utilizing renewable energy sources.

Objectives. The objective of this thesis is to highlight needs and present a developed solution to portable off-grid energy production and distribution utilizing renewable energy sources. The goal is to highlight problems within the area of focus and present a potential solution to one, or multiple, of these problems. The presented solution shall be based on a solid engineering foundation and meet the technical requirements developed from needs that arise during the project.

Methods. The work presented in this thesis was conducted with the use of DRM, Design Research Methodology, as the choice of research methodology while Design thinking was the choice of design approach. The use of DRM allowed for a structured and efficient research process that allowed for the possibility to validate result. The use of Design thinking as design approach provided methods and tools to support innovation while working with problems that were initially unknown or vaguely defined.

Results. The result of the work presented in this thesis provides information regarding multiple problems and critical aspects within the area of focus. A list of requirements for a sustainable energy system to satisfy in order to enter the market is presented where portability, reliability and redundancy are marked as key requirements. A proposed solution in the form of a portable modular sustainable energy production trailer utilizing different renewable energy sources was developed to allow for off-grid electricity generation. This combined with an energy distribution solution in the form of a energy storage module mounted on the Volvo TA15 system allows for autonomous energy transportation to the location of the energy need.

Conclusions. As the need for sustainable energy constantly increases, development of sustainable energy production and distribution systems that can operate off-grid has proven to be critical. The utilization of renewable energy sources has also been identified as a critical factor in parallel with the phasing out of fossil fuels. The proposed solution has provided evidence of the potentials for a portable off-grid energy system and its potential impact on the global 2030-agenda goals for sustainability.

Keywords: Off-grid, Renewable energy generation, Electrified construction equipment, Portability.

SAMMANFATTNING

Bakgrund. År 2021, levde 770 miljoner människor världen över utan tillgång till elektricitet. Parallellt med detta ökar elektrifieringen av fordon och annan utrustning ständigt vilket resulterar i en efterfrågan på tillförlitlig energitillgång utanför elnätet. Denna energitillgång utanför elnätet krävs för drift på avlägsna platser eller platser utan tillräcklig energiinfrastruktur på grund av yttre faktorer såsom skador från naturkatastrofer. Eftersom användningen av fossila bränslen förutspås minska, har behovet av hållbar energiproduktion som drivs av förnybara energikällor visat sig vara avgörande. Kombinationen av dessa faktorer leder till ett behov av utveckling av hållbara energisystem som kan användas utanför elnätet och drivs av förnybara energikällor.

Syfte. Syftet med denna uppsats är att belysa behov samt presentera en lösning för portabel energiproduktion samt energidistribution utanför nätet med förnybara energikällor som drivmedel. Målet är att lyfta fram problem inom fokusområdet och presentera en potentiell lösning på ett, eller flera, av dessa problem. Den presenterade lösningen ska bygga på en grund av omfattande ingenjörskonst och möta de tekniska krav som uppstår under projektets gång utvecklade från identifierade behov.

Metod. Arbetet som presenteras i denna uppsats utfördes med användning av DRM, Design Research Methodology, som val av forskningsmetodik medan Design thinking var valet av designmetodik som användes som ramverk i designprocessen. Användningen av DRM möjliggjorde en strukturerad och effektiv forskningsprocess med möjlighet att verifiera slutresultatet. Användningen av Design thinking som designmetodik försedde författarna med metoder och verktyg för att stödja innovation även då man arbetade med problem som från början var okända eller vagt definierade.

Resultat. Resultatet av arbetet som presenteras i denna uppsats ger information om flera problem och kritiska aspekter inom fokusområdet. En lista över krav som ett hållbart energisystem ska uppfylla för att lyckas på marknaden presenteras, där portabilitet, tillförlitlighet och redundans markeras som nyckelkrav. Ett förslag på en lösning presenteras i form av en bärbar modulär släpvagn för hållbar energiproduktion som utnyttjar olika förnybara energikällor för att möjliggöra för elproduktion utanför elnätet. Detta i kombination med en energidistributionslösning i form av en energilagringsmodul monterad på Volvo TA15-systemet möjliggör för autonom energitransport till platsen för energibehovet.

Slutsatser. Eftersom behovet av hållbar energi ständigt ökar, har utveckling av hållbara energiproduktions- och distributionssystem som kan drivas utanför nätet visat sig vara avgörande. Utnyttjandet av förnybara energikällor har också identifierats som en kritisk faktor parallellt med utfasningen av fossila bränslen. Den föreslagna lösningen har gett bevis på potentialen för ett bärbart energisystem utanför nätet och dess potentiella inverkan på de globala 2030-agendansmålen för hållbarhet.

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NOMENCLATURE

IEA – International Energy Agency

EU – European Union

GDP – Gross Domestic Product

CE – Construction Equipment

PESS – Portable Energy Storage Solution

SESS – Stationary Energy Storage Solution

HAWT – Horizontal-Axis Wind Turbine

VAWT – Vertical-Axis Wind Turbine

EV – Electric Vehicle

CHP – Combined Heat and Power

PSS – Product-Service System

DRM – Design Research Methodology

HMW – How Might We

MVP – Minimal Viable Product

FEA – Finite Element Analysis

CAD – Computer-Aided Design

DC – Direct Current

AC – Alternating Current

OSB – Oriented Strand Board

PLA – Polylactic Acid

USB – Universal Serial Bus

EMF – Electromotive Force

PWM – Pulse-Width Modulation

ABS – Acrylonitrile Butadiene Styrene

CNC – Computerized Numerical Control

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INTRODUCTION

At the year of 2021, 770 million people worldwide were living without access to electricity [1]. One of the biggest factors affecting this number is an underdeveloped energy infrastructure in large parts of the world, mostly in African and Asian developing countries, leading to serious consequences regarding the living standard in these regions [1]. The International Energy Agency (IEA) [1] states that the global Covid-19 pandemic has slowed down the expansion of access to energy and a 9% annual improvement between 2015 and 2019 has over the last three years ceased. The increase rate of people getting access to electricity is too low if the global goal of universal access to electricity by 2030 is to be achieved and would require large financial investments [1]. Over two thirds of the world's population that does not have access to electricity are located in sub-Saharan Africa, where, for example, Chad merely had sufficient electricity infrastructure to supply 8.4% of its population with electricity the year of 2019 [2]. Achieving the goal of global access to electricity requires major investments in the development of energy infrastructure in exposed parts of the world, which then would require a stable supply of energy resources to remote and sometimes inaccessible locations.

At the time of writing, there is a global conversion regarding the use of fossil fuels. The transition to a society independent of fossil fuels has started to gain momentum. As a result, the use of fossil fuels will be reduced, limited, and eventually completely banned due to new restrictions, laws, and shortages. This will be very costly, not only for individual companies and organizations but also society in general. As of October 2021, the European Union and 44 countries, which together account for about 70% of global CO_2 emissions and gross domestic product (GDP), have promised to meet the net zero emission target by 2050, or earlier [3]. This, in combination with several other global environmental goals, results in a need for locally environmentally friendly electricity production on a large and small scale in places with damaged or non-existent infrastructure.

Developments in phasing out fossil fuels have also resulted in large-scale electrification of various types of vehicles. In the year of 2022, Volvo Construction Equipment offers electrical construction machinery in 16 different markets globally and states that they work to ensure that their products are powered by alternative environmentally friendly energy sources [4]. One of Volvo Group’s goals for the future is to only provide fossil fuel free enabled vehicle by 2040 [5]. An approach to this challenge is to replace the vehicles utilizing fossil fuel with electrified versions. For that, Volvo need their vehicles to connect to the energy infrastructure in order to receive energy in the form of electricity. However, there are situations when there are significant roadblocks in the infrastructure, particularly in remote areas, developing countries, and areas of crisis. The problems and concerns raised by Volvo also extends to other markets where electrification starts to emerge in parallel to the phasing out of fossil fuels. Locations and markets that rely on independent energy production in the form of fossil fuelled generators will encounter major problems when fossil fuels for several reasons become inaccessible, which could result in high social and economic costs to society [6]. This results in that access to electricity will be of the utmost importance to be able to operate the vehicles, either taking the form of direct connection to the electricity grid, or portable energy distribution. Increasing development of electrified construction machinery also raises other issues. How should a previously non-existent infrastructure network be constructed or expanded if the machines have nowhere to get the energy from? This issue can also be applied in cases of natural disasters where the infrastructure could be damaged, and electricity not available, hence, resulting in that the infrastructure cannot be rebuilt using electric construction equipment. If electrified construction machinery in the future will occupy large market shares, as expected, it brings great risks that could lead to limited areas of use in parts with non-existent or insufficient infrastructure network.

1.1 The use of fossil fuels

According to M. Florinda et al. [7], fossil fuels have been the main source of energy for centuries in developed and developing countries. Despite the awareness of global warming and active changes in energy policies, fossil fuels remain as the primary energy source and is estimated to account for at least 60 % of the energy consumption in most European countries [7]. In some countries, this number reaches as high as 80 % such as Germany and United Kingdom [7]. There is a long road ahead before reaching carbon neutral or even low carbon energy systems, regardless of the current changes and improvements that have been done to fight climate change. However, a trend that has been emerging for the past decades is the transition to more sustainable solutions, systems, products, and services. This can be observed throughout most industries, especially the energy and transport sector. There is also an evident shift within countries that start investing heavily in renewable energy sources to become less dependent on fossil fuels [7]. In addition, the price on fossil fuels is projected to surge in the future due to it becoming more difficult to extract and slowly depleting, resulting in higher costs on the supply-side as well as the demand-side [6]. The transition to renewable energy in combination with increasing prices on fossil fuels, provide opportunities for solutions that are brought up in this thesis.

There are many challenges that needs to be addressed in order to break away from fossil fuel production since it is deeply embedded within many countries' economy and has generally been perceived as a key pillar for development [8]. Due to this dependency, subsidies and direct state investments have been awarded to fossil fuel production companies. This has strengthened their geopolitical influence and has been wielded to obstruct any policy regarding energy and climate that would be of inconvenience to them [8]. Therefore, it is significant that countries impose supply-side policies that allow for substantial emission reductions instead of relying only on demand-side policies. Not only does supply-side policies address carbon leakages that can occur during the extraction and production processes of fossil fuels, but it can also reduce carbon lock-in effects. Reducing carbon lock-ins can give lower-carbon alternatives the chance of competing with fossil fuels and becoming more viable energy sources. The combination of weakening carbons clutches to the economy and strengthening the stance of lower-carbon alternatives can allow for governments to adapt stronger climate policies [8].

The transition from fossil fuels to renewable energy in the manufacturing and service industries has proven to spur economic growth for high income and middle-income countries [9]. While the extraction process of non-renewable energy is presenting diminishing returns, the technical solutions for harvesting renewable energy are subjected to improvements, resulting in increasing returns [9]. Since services are considered high growth sectors in high-income countries, and manufacturing is considered high growth sectors in middle-income countries, they both have a high demand for energy, which could be the reason investments in renewable energy in these sectors has led to economic growth. The slow and steady transition to renewable energy in the residential sector has yet to be proven that it can lead to economic growth on a national level.

1.2 Project partners

1.2.1 Volvo Group

The Volvo Group is a manufacturing company that was founded 1915 in Sweden and currently has their headquarters located in Gothenburg [4]. The Volvo Group consists of ten subsidiaries, whereas the ones most relevant for this project are Volvo Construction Equipment, and Volvo Connected Solutions Innovation Lab. Volvo CE manufactures construction vehicles for excavation, road development and compact construction equipment, and is working heavily towards becoming both ecologically and socially sustainable. As their goal is to provide 100 % fossil fuel free vehicles by 2040 [4], Volvo CE has already begun manufacturing electric compact construction machines such as the ECR25 electric compact excavator, see Figure 1, and the electric compact hauler L25, see Figure 2 [4].

Figure 1. Volvo ECR25 electric compact excavator. [10]

Figure 2. Volvo L25 electric compact hauler. [11]

1.2.2 Stanford University ME310

Stanford University, also known as Leland Stanford Junior University, was founded in 1885 and named after Leland Stanford's son who had passed away the year prior. The university is privately funded, enrols approximately 17 000 students, and is highly prominent, ranking among the top universities around the world [12]. The ME310 design and innovation course is a global capstone project course that involves the collaboration between students from global university partners, such as Blekinge Institute of Technology, and Stanford University. The students are assigned an innovation challenge by corporate partners, with the aim of designing and building a complete system solution that is viable, feasible, and desirable. The corporate partners are also involved in the project, providing the students with information, experience, and expertise, offering them the opportunity of collaborating with a global organization [13]. The authors of this thesis have been an active part of the ME310 project conducting many of the design steps described in this thesis together in a team of ten students.

1.3 Goal and scope

The purpose of the thesis is to investigate the needs and present a developed solution for a portable energy system that can generate and distribute energy from renewable sources in places with insufficient or damaged infrastructure, such as remote areas, developing countries, or areas in crisis. The goal is to highlight shortcomings within the area of focus and present a solution to one, or multiple, of these specific shortcomings. The solution shall be based on a foundation of extensive engineering and meet the technical challenges that arise during the project.

1.4 Research questions

- What are the needs and possibilities for portable production and distribution of environmentally friendly energy in places with damaged or insufficient infrastructure?
- How does a system of this kind contribute to the global 2030-agenda goals and increased quality of life?
- How can a system of this kind be scaled to enable application to specific problem situations?
- How can a a system of this kind be implemented utilizing technologies available on the market today?

1.5 Limitations and Boundaries

The work conducted in this thesis mainly focuses on concept development on a system perspective. Profound analysis of technical aspects for specific parts within the area of focus have therefor been excluded in this thesis. As the need for sustainable energy production extends over different market, the subject of interest in this thesis has been off-grid energy systems aimed for construction equipment with the goal of being able to further expand the area of application in retrospect. This approach was chosen to be able to optimize a potential solution for a specific area of application.

This thesis addresses the implementation of an energy storage solution called Nomad developed by students at Stanford University also being a part of the global ME310 team. This solution is implemented as an externally developed product and aspects related to the development of Nomad will not be addressed in this thesis. Furthermore, economic aspects are included in this thesis, however, on a basic level as this area has not been of focus.

2 RELATED WORK

2.1 Transition to renewable energy sources

Battery storage has proved to have a crucial role when transitioning to renewable energy systems, as it allows for reducing or phasing out the use of fossil fuels. Lithium-ion batteries has a high storage efficiency and energy density, making them ideal for small scale electronics and are predominantly used for renewable energy and micro grid systems [14]. A portable utility scale battery storage solution is being tested in California, which can provide an on-demand service accommodating areas with energy. Studies done by He Guannan et al. [15] indicate that a portable energy storage system (PESS) has the potential of increasing the life cycle revenue by up to 70 % in comparison to its stationary counterpart, while also improving the integration of renewable energy. Thus, relieving transmission congestions that occur locally. Compared to a stationary energy storage solution (SESS), a PESS has a much higher utilization rate since it can be shared among multiple areas that are suffering from congestion [15]. A PESS can be described as a truck that is charged in areas where energy is cheap, and then delivering it to areas where energy is either expensive or congested, as seen in Figure 3.

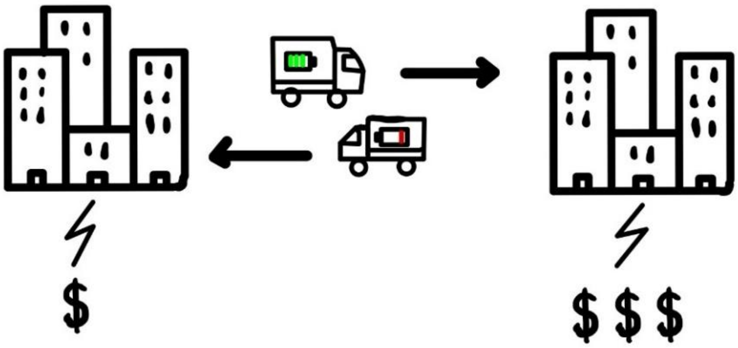

Figure 3. Portable energy storage system usage (Inspired by [15, p. 378])

However, it important to note that a PESS will not replace the electrical grid, but function as a complement that facilitates the expansion of transmission and distribution lines. The article dismisses the exploration of solutions that could function as a temporary replacement of the electrical grid. The solar and wind capacity of today is greater than the storage capacity due to high upfront costs and low utilization rates of the current SESS, and economic disadvantages of intermittent revenue streams from renewable energy sources [15].

2.2 Micro grids

The cost of renewable energy solutions and technologies has been falling drastically for the last two decades, thus sparking a growth in off-grid investments and expansions across the world [16]. An off-grid technology can be defined as a product or system that incorporate resources of energy that is not connected to the national grid [16]. These systems incorporate both renewable energy technologies such as wind turbines, solar panels and hydro power, as well as traditional technologies such as diesel generators, as illustrated in Figure 4.

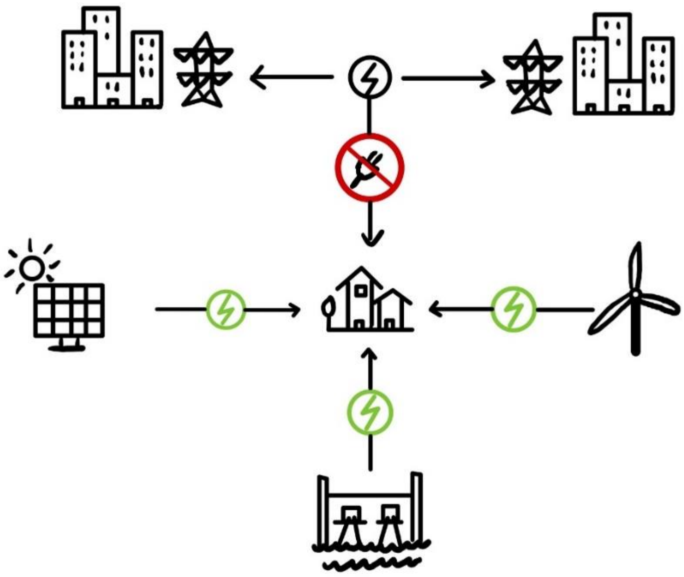

Figure 4. Micro Grid

According to the article *"Institutional influence on power sector investments: A case study of on- and off-grid energy in Kenya and Tanzania,"* [16] these solutions have been targeted towards rural communities around the world, with a focus on African villages due to Africa having some of the largest off-grid technology markets on the planet [16]. Although the national regimes of both Kenya and Tanzania has their focal point on predominantly on-grid solutions and its expansion, international venture capitals and private businesses heavily invest in their off-grid potential. This is partly due to the combination of raised awareness and interest for the technology, and the popular mobile-enabled pay-as-you-go financing schemes that has been spreading across the continent in the last decade [16]. Today, micro grids are playing an important role when electrifying a country, and although it might not be the ideal solution on its own, the combination of using micro grids while expanding the national grid is a prominent step for a sustainable future [14]. The increasing investments in off-grid technology in African countries create a potential market for renewable energy solutions that are further explored in this work.

As the demand for micro grid solutions are increasing and the technology is getting more viable, a proper energy management strategy is critical [17]. The implementation of a control system that can operate and integrate the various elements of the energy system, transforms the micro grid into a smart grid. The management strategy considers both economic and technical parameters with the aim of reducing operating and maintenance costs, extend lifetime, and provide sufficient energy on demand [18]. The development of smart grids or smart energy systems has created a shift, from focusing on single sector thinking to taking a holistic approach. It incorporates affordable and feasible solutions during the transition to renewable energy that can support the storage and infrastructure needs, which has been proven on both a national and European level based on numerous case studies [19].

2.3 Electrified construction equipment

Today, the electrification of on-road vehicles is progressing at a fast rate in parallel to an increasing demand. However, according to F. Un-Noor et al. [20] the electrification of off-road construction equipment such as, excavators, haulers, and loaders have during this progression been absent and development is still at an early stage with only a few hybrid and battery electric commercial products available on the market. As fossil fuel operated construction equipment have proven to contribute with both air pollution and noise, most notably in densely populated areas, electrification could have a significant impact on the industry regarding sustainability aspects [20]. In the article "*Operational Feasibility Assessment of Battery Electric Construction Equipment Based on In-Use Activity Data*" [20], the authors specifies that larger batteries and faster charging equipment can increase the capabilities of electric construction equipment. The increased capabilities could result in electric construction equipment being more competitive compared to construction equipment operated using fossil fuels. The study also identifies better charging solutions, such as mobile charging systems, as a way to optimize charging logistics for better efficiency and should also be considered as an important aspect for broader use of electric construction equipment [20]. However, the requirement of large batteries in electric construction equipment naturally result in longer charging times. Faster-charging equipment could increase the capabilities, and productivity, of electric construction equipment, however, fast charging of lithium-ion batteries that are most commonly used in electric vehicles has according to P. Sheng and S. Zhang [21] proved to result in degradation of performance and lower efficiency of the batteries over time. Further development of batteries and charging systems should hence be considered critical for further adoption of electrical construction equipment and these aspects.

2.4 Hybrid energy-generating systems

As the need for energy is constantly increasing worldwide, in parallel with the phasing out of fossil fuels, new innovative system solutions that utilizes different combinations of energy sources and technologies for energy generation are required [22]. Many of the energy systems that utilizes renewable sources such as wind and solar radiation are dependent on climate related factors. This results in systems of this kind being very unpredictable and difficult to control when operating on their own [22]. Hybrid energy-generating systems that combines the use of multiple energy sources such as wind, solar radiation, geothermal or biomass, can provide a higher rate of redundancy, hence, being more suitable for off-grid energy generation. However, systems of this kind require some form of energy storage solution. As the energy generation does not follow a linear output rate, but has a constant production rated during operation hours, the excess energy produced when the need is lower than the amount produced must be stored. The stored energy can then be used when the energy generation system is not able to supply enough to meet the load demand due to weather conditions of other external factors [23].

Today, the use of batteries is the most common choice of storage solution due to its accessibility and low cost in comparison to many other solutions. However, the use of hydrogen as a storage solution is predicted to become more competitive, despite the low efficiency of a hydrogen storage system, as the cost decreases in parallel with the increasing fossil fuel prices [22]. The use of short-term storage could also be applicable utilizing technologies such as super capacitors, and a system combining short-term storage with long term storage has the potential to meet demands from load spikes and requirement of long term when utilizing sources such as wind power [22]. Research has also shown that the need for proper control and energy management of a hybrid energy system is of significant importance in for the system to achieve high reliability and operational efficiency [24]. Energy management systems are critical for monitoring the energy system and controlling the output power required from each energy sources in the hybrid system to meet the load demand [24].

Hybrid energy generation is often complemented with a fossil fuel driven generator such as a diesel generator. Systems of this kind have proven to achieve higher performance when comparing to standalone systems dependant on one energy source [23]. The use of a fossil fuel-driven generator would also make the use of a hybrid system more plannable, as the system will become less dependent on external factors such as climate, and the system could be used independently when needed. However, research have identified that factors such as accurate estimation of load demand and performance prediction of the systems when not utilizing the fossil fuel driven generators, could be considered as challenges when combining fossil fuel driven generators with renewable energy systems [23]. Environmental and economic aspects should also be considered; hence, maximum utilization of the energy storage solution should always be desired for minimal use of a fossil fuel driven generator. An important aspect is also the lower operational and maintenance related costs for solar and wind energy systems in comparison with a diesel generator of comparable size, though, diesel generator have a lower initial investment cost [22].

3 THEORY

This section addresses important background information regarding the design approach used for this project as well as underlying information regarding electric vehicles, renewable energy sources and technologies utilized during the concept development.

3.1 Sustainability

Sustainability can be defined as "a people-centred and conservation-based concept that implies the development of the standard of human life by respecting nature's capacity to afford life-support facilities and resources" [27, p. 4], and is based on the environmental, economic, and social pillars. The environmental pillar includes biodiversity, pollution, and natural resources. The economic pillar includes efficiency, growth, and stability. Lastly, the social pillar includes culture, empowerment, and poverty. Development that includes all three pillars can be considered sustainable.

The global sustainability goals also known as "Agenda 2030" are based on the previously mentioned three pillars, and consists of 17 goals as follows [28]:

1. No poverty
2. Zero hunger
3. Good health and well-being
4. Quality education
5. Gender equality
6. Clean water and sanitation
7. Affordable and clean energy
8. Decent work and economic growth
9. Industry, innovation, and infrastructure
10. Reduced inequalities
11. Sustainable cities and communities
12. Responsible consumption and production
13. Climate action
14. Life below water
15. Life on land
16. Peace justice and string institutions
17. Partnerships for the goals

Each goal has a set of targets attached to them, as well as related resources and actions that are needed to achieve them. The global goals were planned and agreed upon by world leaders in 2015, and it is intended to achieve each one by 2030 [29].

Sustainability is important to embed in the early stages of product development processes and strategies of companies [30]. Embedding sustainability is a process, requiring a mutual understanding of how it is to be defined at all levels ranging from the employees to the head of the company [30]. These strategies are customized by the company with the aim of acquiring sustainability attributes that they desire, such as transparency and resilience. Sustainability-focused innovation recognizes the necessity of having a holistic approach and can provide great business value, such as increased revenue, reduced energy expenses, and increased employee productivity, as described by Bob Willard [31].

3.2 Renewable Energy

Renewable energy is a part of the broader term *sustainable energy* and can be defined as energy derived from a continuous and repetitive flow in the local environment. The most common renewable energy sources, available to societies, are solar radiation, wind power, hydropower, geothermal heat, and biomass [32]. These types of energy sources are also referred to as *green energy*. The opposite of renewable energy is non-renewable energy, which refer to a limited number of resources and are typically stored underground. These static resources contain energy potential that can be released when exposed to external forces, such as human interactions. The most common non-renewable sources are coal, oil, natural gas, and nuclear fuels. These energy resources are also referred to as *finite supplies* or *brown energy* [32].

3.3 Energy harvesting and energy storage technologies

3.3.1 Solar panels

Solar panels are made of solar cells that generate electricity through the absorption of light. This is the result of the photovoltaic effect, in which photons of electromagnetic radiation separates positive and negative charges that are carried in semi-conductor materials, as illustrated in Figure 5.

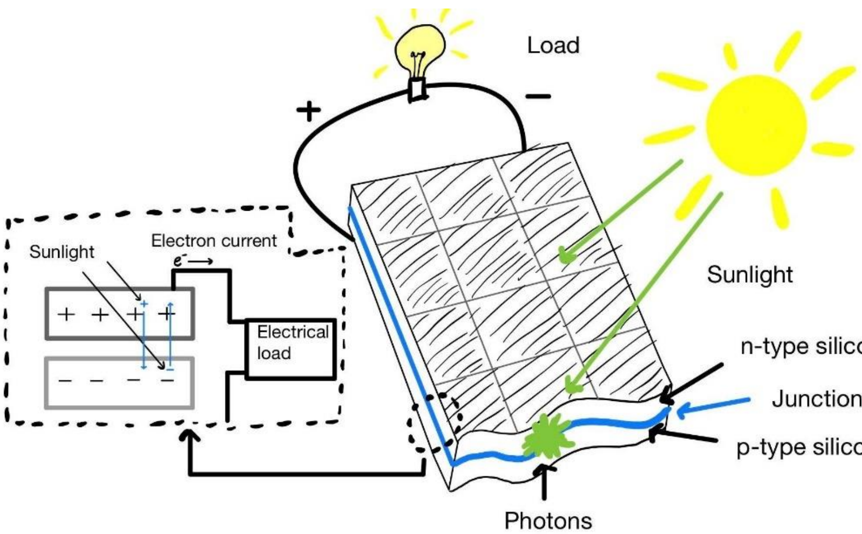

Figure 5. The photovoltaic effect and the structure solar panels (Inspired by [32, p. 155])

The power output of a solar panel can be calculated based on the solar photoelectric conversion efficiency, ε, the area of the solar panel, A, and the forecasted solar irradiance in the specific location, G_T. Equation 1, presented below, is used for calculating the power output from solar panels [33].

$$P_{PV} = G_T A \varepsilon \tag{1}$$

Commercial solar cells have an efficiency ranging between 12 % and 25 % but can reach as high as 50 % when concentrating the sunlight using mirrors [32]. The open circuit voltage ranges between 15 and 30 V, depending on the number of cells that are connected in series. The current that is generated by the cells is inherently direct current, which is changed to alternating current using electric inverters. A commercial solar cell module generates on average 0.5 to 1 kWh per (m^2 per day) depending on the solar energy intensity and number of sun hours [32]. However, this number can be improved using solar concentrators and tracking devices that angle the solar cells towards the sun.

Solar panels have no moving parts and require little to no maintenance, making them a very reliable solution for harnessing renewable energy. Their high reliability makes them ideal in rural and remote areas where a low amount of energy is enough to power lights and telecommunication [32]. The major downside of solar cells is that they require a large footprint at a utility scale, as well as only being able to generate energy during the day.

3.3.2 Wind turbines

A horizontal-axis wind turbine (HAWT) is generally made up of the following parts: presented in Figure 6 [34].

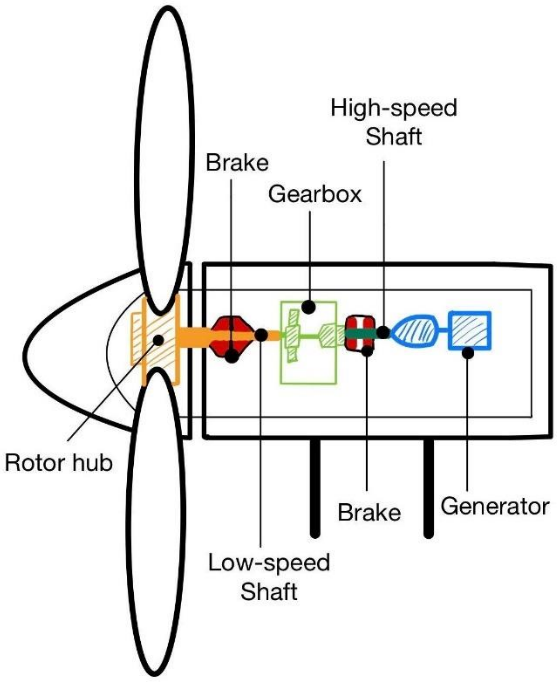

Figure 6. Simple overview of the general parts in a Wind Turbine (inspired by [34, p. 4])

The process of generating electrical energy is basically the transition from wind energy when the wind hits the blades, to rotational energy when the blades and gearbox starts rotating. The rotational energy is then transmitted to an electric generator that converts the energy to electricity. HAWT's are the most common type of wind turbine and is dominating the market with sizes ranging from as small as 1m in diameter generating tens of watts, to roughly 150m in diameter generating up to ten megawatts [32]. Vertical axis wind turbines (VAWT) are growing in popularity and is seen to have a greater potential in urban areas as they emit less noise and require a smaller physical footprint as illustrated in Figure 7. Emerging technologies such as Vortex Bladeless is a revolutionizing wind energy harvesting solution that harvest energy through air flow-induced vibrations of mechanical systems [35]. Wind turbines are essential for the expansion of renewable energy and is primary for power generation in countries that possesses the potential for wind power [32].

Figure 7. Vertical axis wind turbine

3.3.3 Second life batteries

As electrical vehicles (EV) are growing in popularity, reaching a market share of 4 % in China and as high as 46 % in Norway, the amount of batteries being produced also increases [14]. When the battery of an electric vehicle reaches 70-80 % of its nominal capacity, it needs to be replaced as it is no longer sufficient for automotive use. A first life battery lasts roughly 7-10 years before reaching its end of life and instead of being discarded it can be given a new life, hence, the name second life batteries. A second life battery can be utilized for energy storage system solutions and prolong its lifetime by 7-10 years. The utilization of second life batteries addresses the environmental concern of discarding batteries as well as providing an exceptional opportunity for generating revenue. It is estimated that the demand for battery capacity will increase 14 times by 2030 compared to 2018 due to cost reductions. Although there are great opportunities for second life batteries, critical challenges such as the lack of standardized assessments and lack reliable information on the subject due insufficient case studies, need to be addressed [36].

3.3.4 Fuel cells

Fuel cells operates with the use of electrochemical reactions that combines a fuel source, most commonly hydrogen, with oxygen to produce electricity [37]. There are multiple types of fuel cells in existence, and they are all, with some exceptions, based on the same principle with an anode, cathode, and an electrolyte. When adding hydrogen to the anode and oxygen to the cathode, the electrolyte will allow for ions to move from the anode to the cathode through the electrolyte while electrons will move from the anode to the cathode through an external circuit, hence, producing current. In Figure 8, an operational scheme of a fuel cell is illustrated. The fuel cell technology has been in use and development for over 180 years and are as of today established as a sustainable alternative to traditional combustion engines. When comparing the fuel cell technology to traditional combustion engines driven generators such as diesel generators, benefits of the former can be identified. First, the electrochemical reaction is pollution free with only water and heat as residual products [37]. The theoretical efficiency of fuel cells is also higher than for combustion engines driven generator where fuel cells can achieve a theoretical efficiency of over 60% while traditional combustion engines generator have an efficiency of up to around 40% [38]. When also capturing the heat generated during the electrochemical reaction, an energy efficient technology called CHP (Combined heat and power), fuel cells can achieve an efficiency of up to 85% [37].

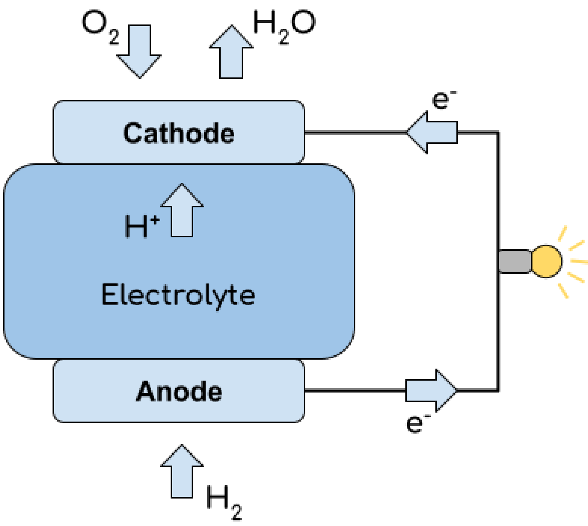

Figure 8. Fuel cell operation scheme. (Inspired by [37, p. 2])

Despite benefits compared to competing technologies, the fuel cell technology has not yet reached a commercialization level that allows it to fully enter the energy market. Reliability, durability, and cost are main factors identified that hinders the fuel cell technology to reach a higher commercialization level [39]. The purchase cost of fuel cells is much higher than for traditional combustion engines which results in a greater investment needed when implementing the technology [39]. As fuel cells are more efficient, less fuel cell stacks can be used in order to achieve the same output as for a diesel generator. However, as the parts used in the fuel cells has a higher cost, maintenance and repair cost will be much higher and an unreliable system can result in high cost per produced kWh, hence, low viability [39].

3.4 Product-Service System

A product service system (PSS) is defined by L. Ai Qiang et al. [40] as a combination of products , and services that produce a better result for the customer, in comparison to them being provided separately. This strategic shift, of offering a combined package of products and services, is an ever-growing trend that has been going on since the 1980s and is widely used in today's globally competitive market [40]. A PSS solution can improve the efficiency and utilization of a product resulting in higher revenues. It also simplifies the process of replacing the old product with an upgraded and new version, creating sustainable relationships with the customer [41]. The take back of older products can function as an incentive for the company to optimize their products, which has an economic, social, and environmental advantage by increasing the utilization of resources and increase the competitive edge [41]. Furthermore, a successful implementation of PSS can be considered as a key factor for success and has been proved in several case studies that has explored the use of PSS in various industries [41]. This includes car sharing, food delivery services, office space renting, and leasing of solar panels and healthcare equipment.

4 METHOD

The following section contains information and description regarding the use of tools, methods, and strategies during the project. The section describes the initiation process and also the inspiration phase where different methods and tools were used while conducting needfinding and research. The section also describes the ideation phase and the methods used during concept development. Finally, this section describes the implementation phase where the concepts generated were realized with the help of various tools and methods.

4.1 DRM, Design Research Methodology

DRM was the choice of research methodology for this thesis on order to fully understand the designs investigated and to allow for continuous design improvements. DRM could be described as a design research methodology aimed at supporting a rigour approach to design research which allows for an efficient research process with valid results as the outcome [42]. The methodology was used as a framework and can be defined as a set of guidelines and methods for conducting design research. The framework consists of four phases, as can be seen in Figure 9, with dark blue arrows illustrating the main process and light blue arrows illustrating iterations. Each stage utilizes different inputs called basic means resulting in what is called deliverables and at the end main outcomes. During the design research, continuous work to achieve the deliverables was conducted with emphasis on the objectives described under each stage presented in the remaining part of this section.

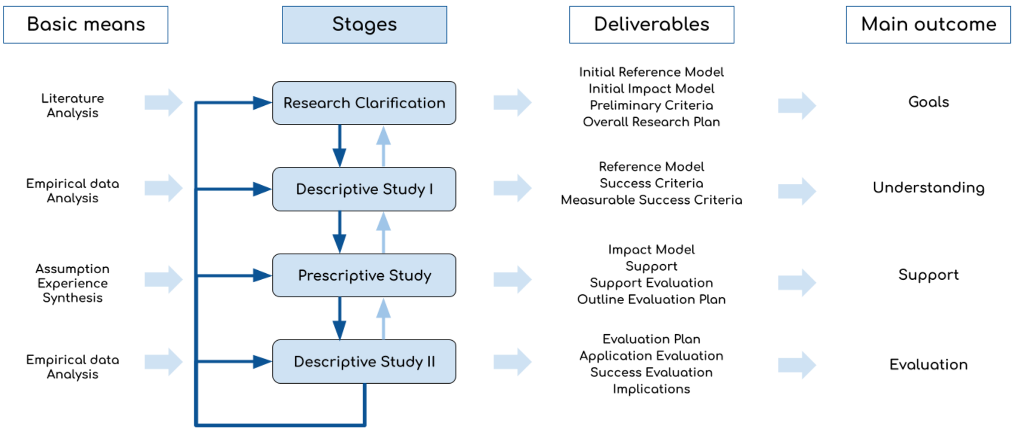

Figure 9. The DRM framework stages including basic means, deliverables, and main outcomes. (Adapted from [42, pp. 15,39])

4.1.1 Research Clarification

In the first stage of DRM, the goal was to formulate research goals based on findings from literature to specify the focus of the research [42]. It is important that the formulated research goals should be realistic and worthwhile for them to result in valuable and accurate outcomes. During this stage, initial descriptions of the existing situation as well as the desired situation was developed with the intent of making assumptions explicit. Criteria's were also be formulated during this stage which was later be used as measurable when evaluating the result of the research [42]. The objectives of the Research Clarification are presented below [42]:

- Identifying goals, area of focus, research problem including questions and hypothesis, relative discipline and in what area the contribution of the research is expected.
- Development of initial reference and impact models.
- Identifying preliminary success criteria and measurables to be used during evaluation of the research outcome.

- Providing a focus for the Descriptive Study I stage regarding identification of factors that contributes to, or hinders, success.
- Aiding the focus for the Prescriptive Study stage regarding development of support to address factors that have a strong influence on success.
- Providing a focus for the Descriptive Study II stage regarding evaluation.

4.1.2 Descriptive Study I

During the Descriptive Study I stage, further literature review was conducted with the intent of identifying more influencing factors that was then be used to further elaborate on the descriptions developed during the previous stage [42]. The new findings and further elaboration on the descriptions allow for determining what factors that are in need of further investigation for efficient improvement of task clarification. During this stage, empirical data was collected through interviews and observations which are described further down in this section, to complement the literature findings to allow for a deeper understanding of the existing situation. Objectives of the Descriptive Study I are presented below [42]:

- Identifying and in detail clarifying factors influencing the preliminary criteria through better understanding of the existing situation.
- Completing the reference model and previously identified success criteria and measurables.
- Identifying factors suitable to be addressed in the Prescriptive Study stage.
- Providing a basis for the Prescriptive Study stage.
- Providing details used during evaluation in the Descriptive Study II stage.

4.1.3 Prescriptive Study

In the Prescriptive Study stage, the increased understanding of the existing situation was used to further elaborate on the description of the desired solution resulting in further development of design support [42]. Objectives of the Prescriptive Study are presented below [42]:

- Determining suitable key factors to be addressed in the Prescriptive Study stage to allow for further improvement of the existing situation using understanding and learnings obtained from previous stages.
- Describing the desired improved situation which is expected as an outcome from addressing the key factors. This is realized through the development of an impact model based on the initially developed impact model and the initial reference model.
- Selecting what part of the impact model to address in addition to also selecting related success criteria and measurables.
- Development of the intended support that in a systematic way addresses key factors. The result should be detailed enough to allow for evaluation of the effect and outcome in comparison to the selected measurable criteria.
- Evaluation of the actual support to determine if the effects of the support are ready for evaluated during the Descriptive Study II stage.
- Developing an outline plan to be used when initiating the Descriptive Study II stage.

4.1.4 Descriptive Study II

During the Descriptive Study II, the impact of the support and how the desired situation is realized was evaluated and investigated [42]. Objectives of the Descriptive Study II are presented below [42]:

- Identifying if the support has the expected effects on the key factors and evaluating if the support can be utilized for the intended task.
- Identify if the support contributes to success and if the expected impact has been realized.
- Identifying improvements necessary for the concept, elaboration, realisation, introduction, and context of the support.
- Evaluating assumption related to the current and desired situation.

4.2 Design Thinking

Design thinking was the choice of design approach for the design process described in this thesis. Design thinking could at its core be defined as a powerful human-centric design methodology that with a strong end-user focus combine different expertise to support innovation [43]. Design thinking can be divided into four different phases, Initiation, Inspiration, Ideation, and Implementation [44], see Figure 10. However, it is of significant importance to emphasise that, as shown in , design thinking is not a linear process but rather an iterative way of approaching problems of undefined nature. Each phase includes different steps and activities developed to support innovation and to encourage creative thinking.

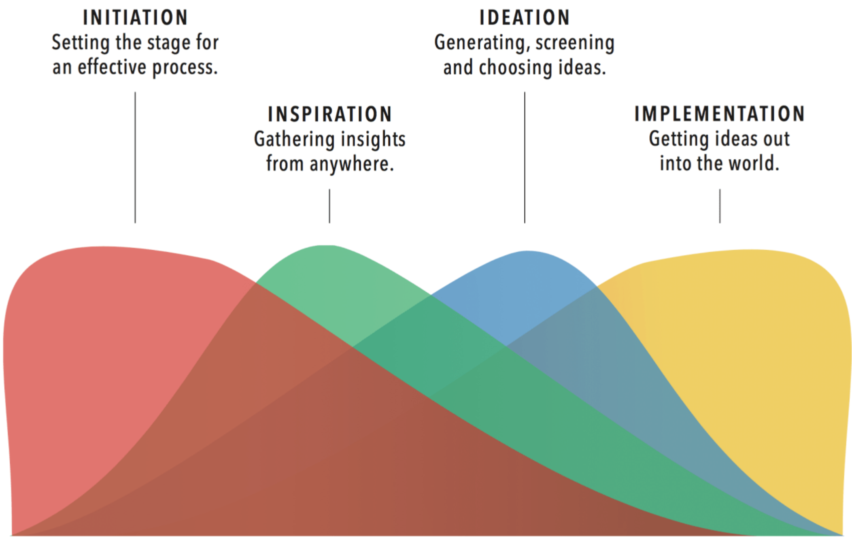

Figure 10. Integration of design thinking phases. ([45, p. 4], Used with permission)

Another common and important term within Design Thinking is the micro cycle which could be described as a loop that aims at creating prerequisites for iterative ideation [44]. Micro cycle can be divided into six different phases, see . The first step was to acquire an understanding of the actual need and target group. Questions such as who, why, what, when, where and how were asked to allow for fundamental insights. The second step was to observe real situations and the people related to the problem. The third step was to define a point of view to establish a common knowledge base. The fourth step was to start ideating and develop concepts, ideas, and solutions that with the initial problem in mind aims at creating value. The fifth step was to prototype and realize the concept into tangible products. The sixth step is close related to the prototypes an aim at testing the prototypes from the previous step in order to gain insight of what challenges and accomplishments the prototype has resulted in. After each micro cycle loop, reflection is of great importance to gain insight from the decision making create a knowledge base used in future iterations [44]. The results from each loop were hence carefully analysed and reflected upon.

The micro cycle term is closely related to the macro cycle, which can be described as a process containing multiple iterations of the micro cycle with the aim of understanding the problem and develop a concrete vision of the solution [44], see Figure 11. The macro cycle was initialized by iterating towards divergence to then transition into the groan zone and later convergence. It is of important to emphasize that the sequence needs to be adapted to the specific project and the time between each step can differ between projects. In the remaining part of this chapter, tools and methods utilized during each phase are described.

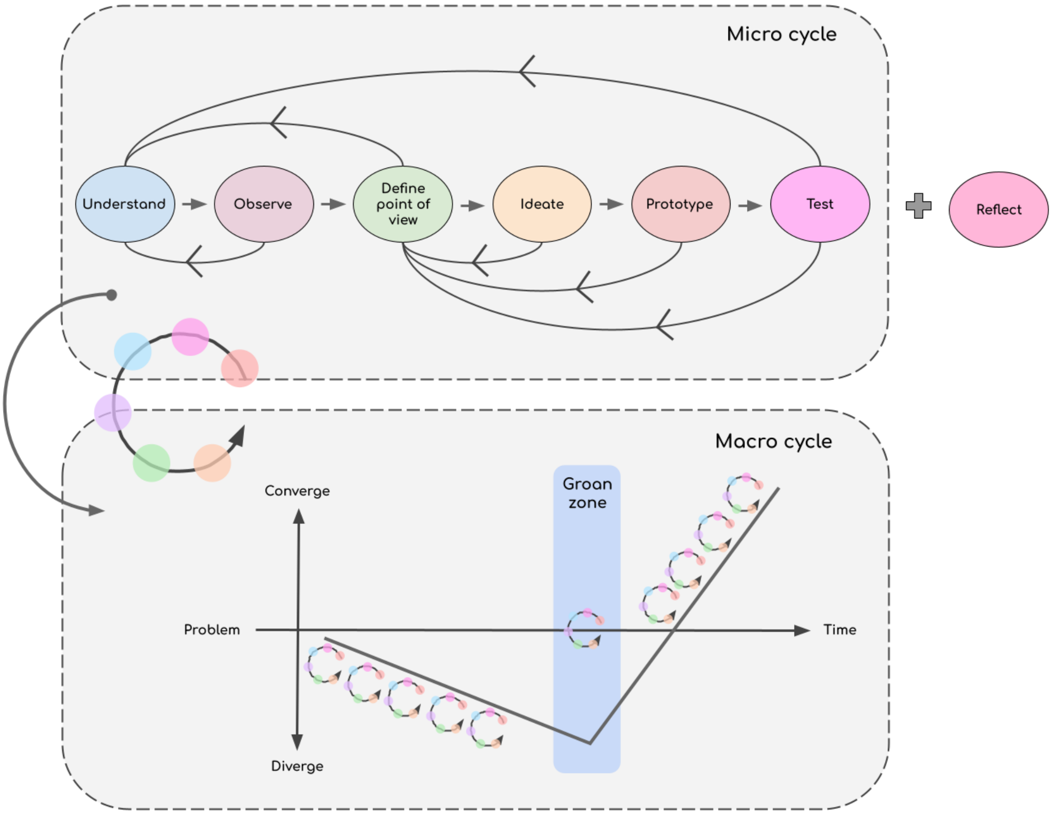

Figure 11. Interaction between micro cycle and macro cycle. (Adapted from [44, pp. 38,45])

4.3 Initiation

At the start of the initiation phase the focus was to create a team canvas to organize the team, bring members on the same page and create a productive culture that increase performance. The team canvas consists of the following nine sections: people and roles, common goals, personal goals, values, needs and expectations, rules and activities, strengths and assets, weaknesses and risks, and most importantly purpose. Each section was filled out by all members of the team. A How Might We statement (HMW) rwas framed collectively to ensure that everyone share a mutual understanding of the prompt and what must be accomplished. Lastly, a GANTT scheme was created using google spreadsheets with the aim of composing a structured timeline for the project. Each design phase, initiation, inspiration, ideation, implementation, and other activities were assigned a specific time frame in which they would be accomplished. It is important to note that the time frames were used as guiding references on where one should be along the project. However, since the design thinking phases tend to overlap and are iterative in its nature, the time frames are flexible and adaptable to changes.

4.4 Inspiration

4.4.1 Interviews and Observations

During the project, multiple interviews and observation sessions were conducted with companies and people of interest within the area of focus. Interviews were used to collect data for qualitative research while observations were used to collect qualitative data. To collect accurate usable data, substantial preparations and planning adapted to each specific session and interviewee is required. The interviews should also be structured, semi, lightly or in-depth, with a logical sequence that guides the interviewee through their experiences within a limited period [46] [47]. The structure of the interviews conducted in this project was based on a structure used for needfinding presented in *The Design Thinking Playbook* by Lewrick, Link, and Leifer [44] and can be used as follows:

1. Introduction – Prior to the interview, one must introduce I and explain the reason behind the interaction. It is wise to ask for permission to record the interview with the intent of taking comprehensive notes. Try to make the interviewee feel comfortable by stating your appreciation and informing them that their time, knowledge, and expertise is valuable.

2. Actual beginning – As the interviewees are introducing themselves, the next step is to establish a reference to the problem. This is done through a brief introduction of the goal and scope and asking general or open-ended questions regarding the relevant theme. Note that it is important to make the interviewees feel comfortable in all the steps to gain their trust.

3. Create reference – When creating a reference, it is great to find an example that brings the interviewee closer to the desired topic or identified problem. If the information given by the interviewee is insufficient, it is preferable to ask for further experiences and stories that could provide additional information to fill the gaps.

4. Grand tour – The grand tour is a key step when aiming for gathering both qualitative and quantitative data that can be essential for the research. This requires as much details as possible as well as a deep dive into the topic. It also includes attempts of identifying contradictions. If enough trust has been established, the chances are greater of the interviewee sharing hidden or unspoken needs.

5. Reflection – As the interview is approaching its end, take a moment to express gratitude and appreciation for the findings and important information that was discovered. Take the time to do a quick recap on what has been said throughout the interview and allow for the interviewee to intervene at any point to point out inconsistencies, emphasize important items or add further information. This is a great opportunity to ask further questions if necessary.

6. Wrap-up – Once the interview is finished it is time to thank the participant once again for taking their time and sharing their expertise, experience, and knowledge. Afterwards, take some time to reflect and summarize the most critical findings.

Regarding observations, access was gained to desired study sites of interest. The techniques used for the data-gathering strategy included continuous processes of observing, analysing, developing categories or classes of phenomena and their links, and searching for new data [46]. It is important to ask broad questions at the beginning of observations, since it renders everything as potentially important and interesting. The follow-up questions can be adjusted to the situation and the answers that are provided to the participant. Lastly, it is essential to record, with permission, and observe as much as possible, since smaller actions or words that might seem insignificant at the time can be of great significance at a later stage [47]. In the remaining part of this section, the respective interviews and observations performed are presented.

Volvo Construction Equipment:

Multiple interviews were conducted with employees from different departments within Volvo CE. Interviews with a product manager was conducted three times during the project in order to gain product specific information with focus on both diesel fuelled and electric construction equipment within Volvo CEs product line. All the sessions were recorded and later on analysed. The sessions contained both structured interview questions, presentation from the interviewee with supplemental questions and open discussions on specific subjects. During the project, recurring meetings were also held with a technology specialist at Volvo CE. These sessions had in the initial phase of the project a semi-structured interview sequence which at the later phases transitioned into a more discussion-based structure as the employee gained deeper knowledge on the project.

Mining company:

In the initial phase of the project, an interview session was conducted with a senior project manager at one of Sweden's most established mining companies. The company offer services within extraction and processing of a wide range of metals and is considered to be an industry leader in sustainable metal production. The interview was structured with focus on electrical vehicles used within the company's operations and allowed for both a presentation from the interviewee and a structured session of interview questions. The session was recorded and later analysed.

Quarry A:

A site visit was conducted at a mid-sized quarry in the south part of Sweden. The company operating in the quarry offers different sizes of gravel which are sold mostly around the Baltic regions. The organization is known to be an adopter of new technologies within the operation. The visit was initialized with a structured interview session with the manager at the quarry. This session was not recorded and only documented in text. After the interview session a guided tour of the quarry was conducted which allowed for observations of the operation and the use of construction equipment, see Figure 12 and Figure 13. The guided tour was documented with pictures and video footage.

Figure 12. Site visit at quarry A observing a larger excavator.


Figure 13. Overview of quarry A during site visit.

Quarry B:

A site visit was conducted at one of the largest quarries in Sweden. The company operating in the quarry have previously been involved with a development project on electrical construction vehicles which was the main reason for this visit. The visit was structured in the same way as the visit to quarry A and was initialized with a structured interview session with the manager at the quarry. The session was not recorded and only documented in text. After the interview session a guided tour of the quarry was conducted which allowed for observations of the operation and the use of construction equipment, see Figure 14 and Figure 15. The guided tour was documented with pictures and video footage.


Figure 14. Overview of a part of the quarry B during site visit.


Figure 15. Observation of the operation during site visit to quarry B.

Construction companies in Mozambique

To gain information and insight of the use of construction equipment in developing countries, multiple interviews were conducted with employees from different construction companies in Mozambique. The companies operated in the road construction sector, housing construction sector and also construction of infrastructure in general. Mozambique was prior to the interviews identified as a remarkably interesting subject as the energy infrastructure in the country is greatly underdeveloped in comparison to the infrastructure in Sweden. As a result of the large distance between the countries of Sweden and Mozambique, the interview sessions were conducted over telephone. The sessions were not recorded and only documented in text.

4.4.2 Persona

Creating personas is a method used in design thinking with the aim of creating a visual representation of a “character” that the design team can engage and use efficiently in the design process. These “characters” represent different user types that might use the service or product. This method is used to help identify the user’s needs and desires. Personas are recommended to be created during the inspiration phase of design thinking when empathizing or defining the needs of the user [48]. After conducting interviews and observation, several personas were created based on insights and learnings extracted from these sessions.

4.4.3 Trendwatching and Techwatching

Trendwatching is a method used for identifying key trends and factors that can have an influence on a business or industry. This allows for creating a forecast for potential products or services that will be demanded in the future. This method is essential in product development as it targets future consumer needs, getting ahead of competitors [49]. In addition to trendwatching, techwatching is a good method to use to fully understand the existing market. This method involves scanning the market for existing and emerging technologies which can result in essential insights regarding gaps and opportunities in the market in addition to material used during benchmarking [45]. It is important to emphasise the need of exploring other markets in addition to the subject of interest to procure a broad perspective and understanding of the technologies and their areas of application. During the project, both trendwatching and techwatching was done through extensive explorative research and mapping of different markets and technologies. Information and material were gathered through extensive literature review and interviews with people of interest operating in different markets, see section 4.4.1.

4.4.4 Forecasting and Backcasting

Forecasting and backcasting were methods used for providing a framework for strategic thinking and also to allow for creating innovative and transformative solutions. Forecasting aims at predicting future trends and scenarios that are likely to happen, based on current and historical data. It allows for creating desirable goals to be accomplished. It is of importance to note that in comparison to trendwatching, forecasting predicts future trends while trendwatching identifies existing trends or upcoming trends close in time. Backcasting aims looking back at the present time, creating a strategy that will lead to the desired future, while also identifying opportunities and obstacles that can occur on the way [50].

4.5 Ideation

4.5.1 Concept Map

To develop a concept map, the online collaboration platform Miro was utilized [51]. The concept map was created with the project prompt as an anchor point. It states as follows; "How might we support sustainable energy adaption in places with insufficient infrastructure?". The next step was to identify potential users, usages, locations, and objectives that were relevant to said HMW statement.

4.5.2 Scenarios

To gain a better understanding of where a potential solution would be utilized and how it would perform, it was decided to investigate various scenarios around the world. The power output of solutions utilizing renewable energy sources such as wind and solar radiation is highly dependent on the weather conditions. This requires specific climate data such as wind speeds and daily solar irradiation to determine the power output [52]. Scenarios were developed using information obtained from interview and observations in combination with the developed personas and weather conditions.

4.5.3 Brainstorming

Brainstorming is a method used to generate ideas, increase creative efficiency, or find solutions to a problem [53]. This can be done individually or collectively as a group. The three fundamental principles for a good brainstorming session are (I) aiming at generating as many ideas as possible, (II) avoid criticizing ideas, and (III) encourage new and wild ideas.
The basic procedures of group brainstorming can be carried out in the following 4 steps, as described by C. Wilson [53].

The first step is to find and select participants that will be actively participating in the brainstorming session. It is ideal to have a group with diverse backgrounds and experiences.
For the second step it is important to introduce a clear problem, question, or topic to the group and to verify that there is a mutual understanding among the participants.
The third step is to ask the group to come up with as many ideas or solutions as possible. This is a divergent phase where it is ideal to generate a vast number of ideas, and it is therefore important to refrain from any kind of censorship such as criticism or attempts to limit the type of ideas.
The fourth and last step is the converging phase where all the ideas are winnowed down to the ones that the participants find most applicable to the problem. This is done through discussing, prioritizing, and critiquing each idea.

Brainstorming sessions were done repeatedly throughout the project, both individually and collectively [53]. Rapid ideation was done using a timer that was set between 5-10 minutes where each team member tried to generate as many ideas as possible. Each idea was then presented to the rest of the group. Once all ideas had been presented, participants could reflect and improve on the ideas that were brought up. For the convergence phase, the members of the group were to decide on which ideas would be most applicable to the problem statement.

4.5.4 Storyboard

A storyboard can be described as a series of images that sequentially illustrate how a service, event or process is executed. A story board can be developed using drawings, photographs, or any other form of visual illustration. A storyboard could be considered as an essential tool for product development as it is used to communicate ideas and concepts. Great ideas can be overlooked if the person on the receiving end does not understand [54]. After working with concept development, several versions of story boards were created in order illustrate to how the developed concepts would be operated and used. The illustrated story boards used digital drawings of the concept in a step-by-step structure as shown in Figure 16.

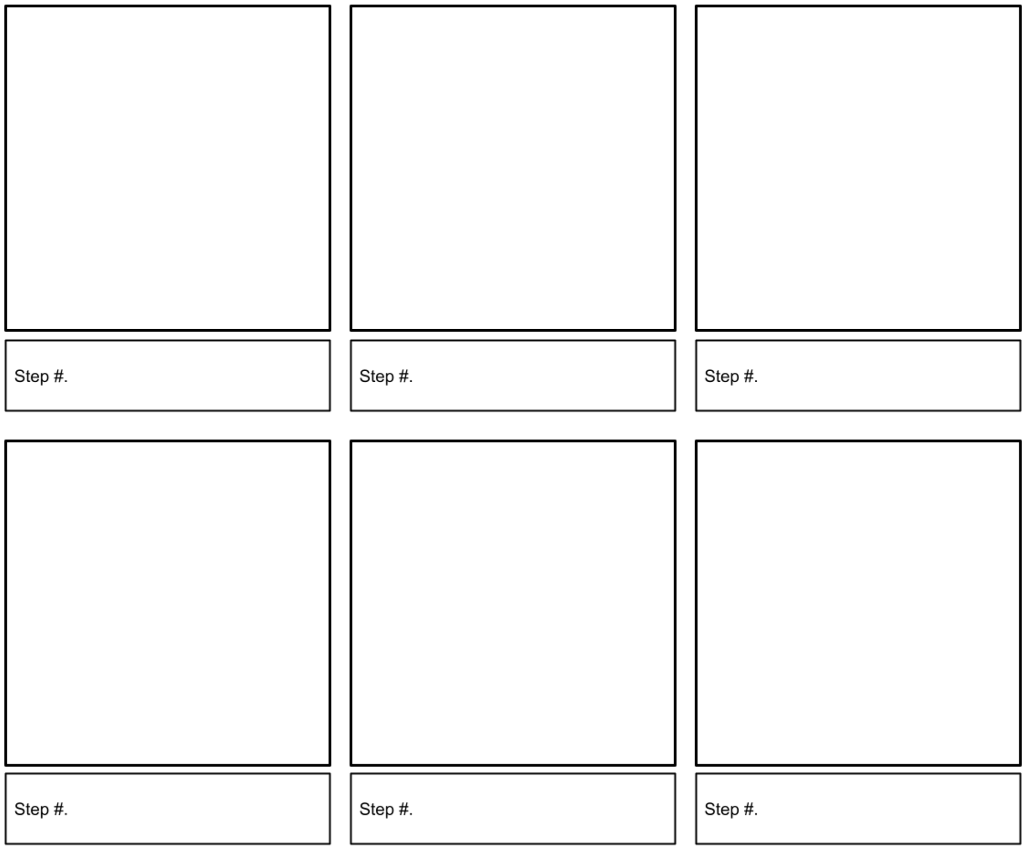

Figure 16. Storyboard template

4.5.5 Business Model

The business model canvas is a tool used with the aim of identifying key inputs in the following 8 building blocks [55]:

1. Value proposition
2. Customer relationships
3. Customer segments
4. Key partnerships
5. Key activities
6. Key resources
7. Cost structure
8. Revenue streams

Each building block is illustrated in Figure 17.

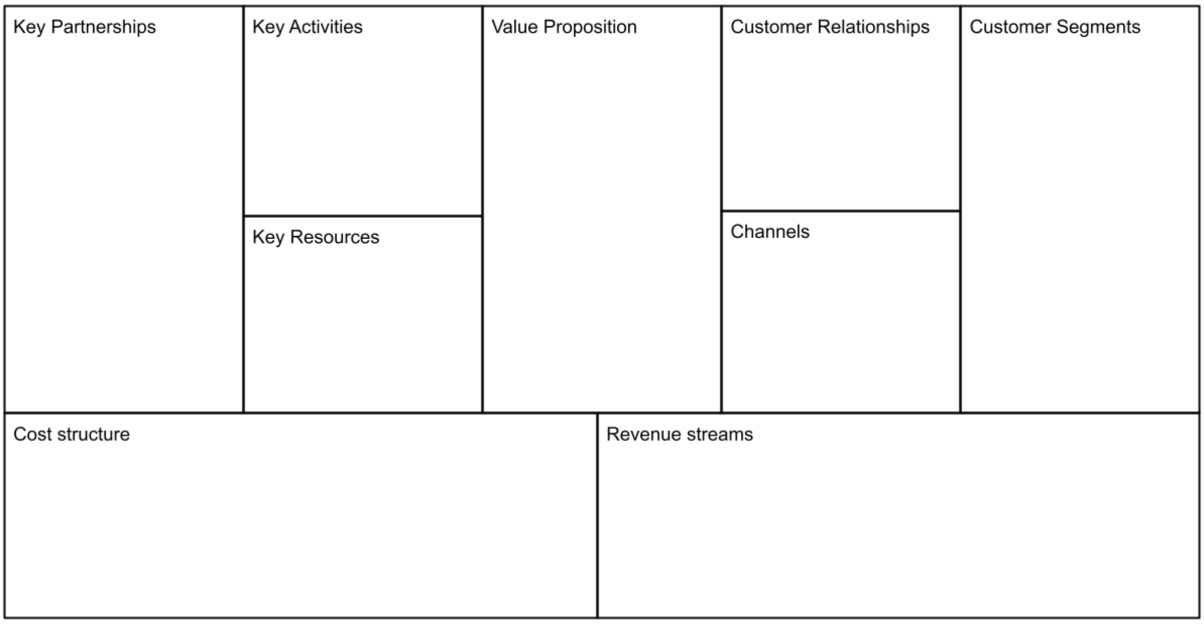

Figure 17. Business model canvas template (Inspired by [55, p. 3])

The canvas gives the reader a comprehensive overview of the business plan and how the company will function. A business model also describes three different aspects of the value chain. How it is created. How it is delivered. How it is captured. For this tool it is important to focus on quality over quantity. The business model canvas is highly useful within strategic management, not only for new ideas or solutions, but also existing ones that lack documentation [55].

4.6 Implementation

4.6.1 Prototyping

During the project, different prototypes were constructed to realize the concepts and ideas with the help of tangible products [44]. These prototypes were built to give essential insights regarding technical and implementation related problems that may have been overlooked during the ideation process and allow for tests to be conducted with potential users [44]. Three different types of prototypes were built using equipment from different laboratory facilities located at Blekinge institute of Technology and Stanford University such as 3D-printers, woodwork equipment and metal work equipment, see Figure 18. Each prototype was thoroughly evaluated and documented in order to allow for progression where insights from each prototype would be used during further development.

Figure 18. Mills parts for one of the constructed prototypes.

The first tangible product developed was a functional system pretotype of the concept. A pretotype could be described as a stripped-down version of a product and is used to test a concept quickly and cost-effectively to validate interest. The pretotype was built using cheap and accessible materials including cardboard boxes, straws, duct tape, pieces of string, and thin wooden sticks. After analysing the results from constructing the pretotype, a more sophisticated functional system prototype was created in order to test and visualize core system functionalities of the Oasis concept with the aim of providing important insights regarding technical and implementation related issues that had not yet been considered. The third and final prototype construction in the project took the form of a minimal viable product, described below.

4.6.2 Minimal viable product

At the end of the project, a minimal viable product (MVP) was constructed to have a tangible product that has enough working functionalities and features to allow for testing under real condition [44]. The goal of the MVP was to implement and test the core functionalities in order to validate the concept to allow for the potential future construction of a final fully working prototype. An MVP should be sophisticated and functional enough to operate as a working product that could be utilized under real conditions and deliver similar results as a fully functional product. The result from testing the MVP is later used to build upon when finalizing a final fully working prototype [44]. The MVP was developed based on the information and ideas generated during the needfinding and ideation process combined with insights from previous prototyping iterations. To construct the MVP, woodwork equipment and metal work equipment was utilized.

4.6.3 Simulation

In order to test if the construction of the products developed during the project were dimensioned correctly, multiple stress analyses were conducted. To conduct the analyses, finite element analysis (FEA) was utilized using the stress analysing software Autodesk Nastran. Computer-aided design (CAD) models of parts used in the products developed were created in Autodesk Inventor. These models were then imported as subjects of analysis in the Nastran software to allow for data extraction on stresses occurring in the constructions. To calculate the force applied to the structures analysed in

Nastran, rotational equilibrium was assumed. Force diagrams were constructed and used to identify and visualize forces acting upon the part. Rotational equilibrium was assumed as the force required to move or deform the structures was of interest. Equilibrium of a rigid body has the following conditions and equations:

- The resultant external force is zero [57]:

$$\sum F = 0 \tag{2}$$

- The resultant external torque is zero about any origin [57]:

$$\sum \vec{\tau} = 0 \tag{3}$$

5 RESULTS AND ANALYSIS

The following section describes the results from using the methods and tools described previously in section 3. The section also presents the outcome from analysing results generated during the process. Key insights from the needfinding process are presented as well as the outcome from the concept development where a suggested solution to the identified needs is presented. The outcome from the implementation phase is also presented in this section where prototypes, an MVP and also simulation and test results are included.

5.1 Interviews and Observations

During the project, multiple interviews and observations were conducted with companies and people of interest. All sessions were documented and analysed to allow for in-depth understanding of different markets of interest. Below, summarized insights and key takeaways from all the sessions are presented.

Volvo Construction Equipment:

- The transition to fossil fuel-free vehicle operations is for the company of significant importance and will continue to progress.
- Electrically powered construction vehicles are identified as an important product in the progression towards fossil free vehicle operations.
- As of today, the electrification of vehicles is limited to smaller sized machinery because of battery weight and especially charging times.

Mining company:

- The company is using electrical mining machinery including electrified trucks at a daily basis as a pilot project. The company will continue to replace parts of the existing transportation system with electrified trucks.
- The operation is fully dependent on the energy infrastructure connected to the mining site. The company has a contract with a large energy provider to supply the energy and infrastructure.
- The electrified trucks use a trolley cable system instead of a battery only based system. This eliminates the need for charging and as a result removes downtime which is considered to be of significant importance.

Quarry A:

- The quarry operates using a small amount of electrical quarry equipment, however no electrical vehicles except for smaller forklifts.
- The use of electrical equipment requires a lot of energy, and the site is limited by the existing energy infrastructure which do not allow for further use of electrical equipment or electrical vehicles.
- Minimal downtime is of significant importance and the vehicles need to be available 80% of the work hours. The company considers this to be a problem that discourage the use of electrical vehicles as a result of charging time.
- Reliability is of significant importance and all the components in an energy system needs to be plannable. The operation cannot be dependent on weather conditions or logistics-related problems.
- If the problem of downtime and insufficient energy infrastructure to the quarry were to be resolved, the use of electrical quarry vehicles would be very sought-after.

Quarry B:

- The quarry operates using some electrical quarry equipment, however no electrical vehicles.
- The quarry has previously been a part of a pilot project involving electrified haulers.
- The company is very interested in electrical machinery and would transition from diesel operated vehicles if more electrical equivalents were available on the market.

- The company raised the same concerns regarding downtime as the company that operates in quarry A. Minimal downtime is of significant importance and charging of electrical vehicles is considered to be a critical aspect.

Construction companies in Mozambique:

- Construction companies often do off-grid work as the energy infrastructure is underdeveloped.
- The existing energy grid is very unreliable, 3-4 outages a month.
- Redundancy is of significant importance.
- As of today, all the on-site electricity is supplied by diesel generators. This is predicted to continue for 20-30 years.

5.2 TrendWatching and TechWatching

During techwatching, multiple technologies and solutions for energy harvesting and energy storage were identified on various markets. Some of the technologies, such as solar panels and wind turbines, are today considered to be established in the energy sector. However, during research, it was found that continuous development of technologies such as the ones mentioned, still takes up a lot of resources on the energy market as many of the technologies have relatively low efficiency. It was also found that most of the existing technologies and solutions on the energy market are not optimized or used for portable energy production or energy distribution. Most of these are adapted to be used on a large scale and connected to an already existing energy grid infrastructure. Below, technologies and solutions found to be of interest for this project are presented:

- Solar panels
- Wind turbines
- Second life batteries
- Fuel cells
- Fossil-fuel operated generators such as diesel generators
- Hybrid energy systems
- Autonomous transportation
- Micro grids

5.3 Needfinding and research key takeaways

During the needfinding process that included extensive research, interviews and observations, several key takeaways and insight were found. The global energy sector is constantly evolving, and development of new, and already existing, solution follows a continuous progression each year. During research of different markets, it was found that all the companies and people involved, agreed on the importance of progression towards sustainable energy production. However, there is a large disparity with regards to fundamental conditions for continuous progression towards sustainability when comparing markets and especially countries. When examining mining companies in Sweden, it was found that the electrification of mining vehicles and equipment have been progressing for a long time because of the risk of pollution when using diesel-operated equipment in enclosed spaces. However, the market is heavily dependent on a reliable energy infrastructure as the mines often are located in remote places. Power outage or limited energy supply could be devastating for a mining company and would require back-up energy supply, most often in the form of diesel generators. When examining the quarry industry, with emphasis on the Swedish market, it was found that the use of electric vehicles and machinery has been limited and the progression towards electrification has just begun. This has resulted in that quarries often do not have a sufficient connection to a grid that can supply enough energy as there has been no previous need. Companies within the quarry industry have demonstrated a willingness to transition to electrification of quarry machinery, however, the transition is limited as large investments needs to be put on further development of the energy infrastructure in parallel with the investments needed for electrification of vehicles.

When examining companies operating in Mozambique, it was found that as a result of the underdeveloped energy infrastructure in the country, off-grid work is common, and the reliability of the existing infrastructure is deficient. Close to all the sources interviewed, identified redundancy, reliability, and portability as factors of significant importance. Cost was also identified as a key factor and many companies within the industry would preferably invest in the cheapest and most reliable technology available, today diesel generators, without the sustainability aspect in mind. Furthermore, as previously mentioned, portability was also identified as crucial for products entering the market as constantly moving work sites is common, for example within road construction.

The needfinding process resulted in a clear understanding of the requirements for a potential solution to enter the energy market and be able to compete with existing solutions such as diesel generators. For a product to be adopted by the industries of interest, the product must be redundant, reliable, and portable. With minimal effort, a product should be able to be moved to an off-grid work site and constantly supply enough energy when needed. A potential product would also require to be plannable and cannot be dependent on a single specific source of energy unless the source is constantly accessible. A potential system would need to be redundant and have multiple safety nets of different kinds in case of off-grid failure. One important type of system impacting the redundancy for energy generation systems has proved to be storage solutions storing the energy to be used when the energy generation system is not able to supply enough to meet the load demand due to weather conditions or other external factors [23].

It is also of significant importance to consider vehicle downtime during charging. Downtime was required by all the companies to be minimal and charging of electrical construction equipment was identified as a critical challenge. As recharging batteries naturally results in downtime, a solution based in battery replacement could be considered as a more optimal solution to this problem. However, this requires multiple batteries per machine which would result in higher costs, both regarding manufacturing of multiple batteries and also transportation to and back from the site. As larger batteries are utilized in electric construction equipment it has also proven to be of importance to have an efficient and innovative charging solution for optimal charging performance [20]. Potential integration and usage of fast charging should carefully be considered as fast charging of lithium-ion batteries have proved to accelerate performance degradation in parallel to lower efficiency [21].

5.4 Concept Mapping

During the concept mapping stage, aspects related to the concept area were identified and documented. A concept map can be seen in appendix A Figure A.1. Different personas were also developed based on the results from interviews and observations. The personas represented different potential users from different areas in the industry such as workers using the construction equipment and people working with management in the construction industry, see appendix B Figure B.1 and appendix C Figure C.1.

5.5 Scenarios

The locations for the developed scenarios including weather data [52] are presented in Table 1. Each scenario was based on the energy need for one L25 in combination with one ECR25 as this was identified during needfinding as potential real-life case. The energy needed to sustain a construction site with these settings is calculated to be 60 kWh as the L25 has a battery capacity of 40 kWh and the ECR25 has a battery capacity of 20 kWh. The vehicles are assumed to be fully charged once per day for each vehicle.

Table 1. Climate data for the locations used in the developed scenarios.

City	Wind Speeds (m/s)	Daily Solar Irradiation (kWh/m^2)	Month
Los Angeles	3,5	7,7	August
Maputo	5,3	6,5	October
Perth	6,25	8,7	January
Karlskrona	4,9	2,7	March

5.6 Concept development outcome

5.6.1 The Oasis

The Oasis concept was designed with the intention of creating a product that can generate electricity, primarily from renewable energy sources, while also being portable and easy to set up. Its purpose is foremost to provide a sustainable energy solution that can reduce or completely replace the use of fossil fuels. There are numerous applications for the Oasis. The first is to provide sufficient energy to support electric construction vehicles that operate in remote locations that has insufficient, damaged or no infrastructure. The second, is supporting residential areas that has damaged infrastructure due to natural disasters. The third, is supporting the expansion of the national grid by functioning as a temporary micro grid in rural regions that are not connected to the grid. It has a modular platform and drawers that can support solar panels, wind turbines, and fuel cells. The modularity has been integrated with the purpose of adapting Oasis to its surroundings and be able to optimize the energy generation depending on where it is geographically located and the customer demands.

The Oasis has a length of 6,12 m, a width of 2,9 m and a height of 2,0 m when detracted as seen in Figure 19. When the trailer is deployed, the width is increased to 11,0 m and the height is increased to 5,6 m as seen in Figure 20. CAD model of a deployed Oasis.. During transportation of the Oasis, the blades and rudder of the wind turbine can be disassembled and placed inside a storage compartment in the back of the trailer underneath the drawers for the solar panels which is illustrated in Figure 21. Oasis can be configured into three different combinations of solar panels and wind turbines. The first configuration can hold 2 wind turbines and 18 solar panels. The second configuration can hold one wind turbine and 20 solar panels. The third configuration can hold 22 solar panels. The different configurations are illustrated in Figure 22, Figure 23, and Figure 24.

Figure 19. CAD model of a detracted Oasis

Figure 20. CAD model of a deployed Oasis.

Figure 21. CAD model of Oasis in transportation mode

Figure 22. CAD model of Oasis configuration 1

Figure 23. CAD model of Oasis configuration 2

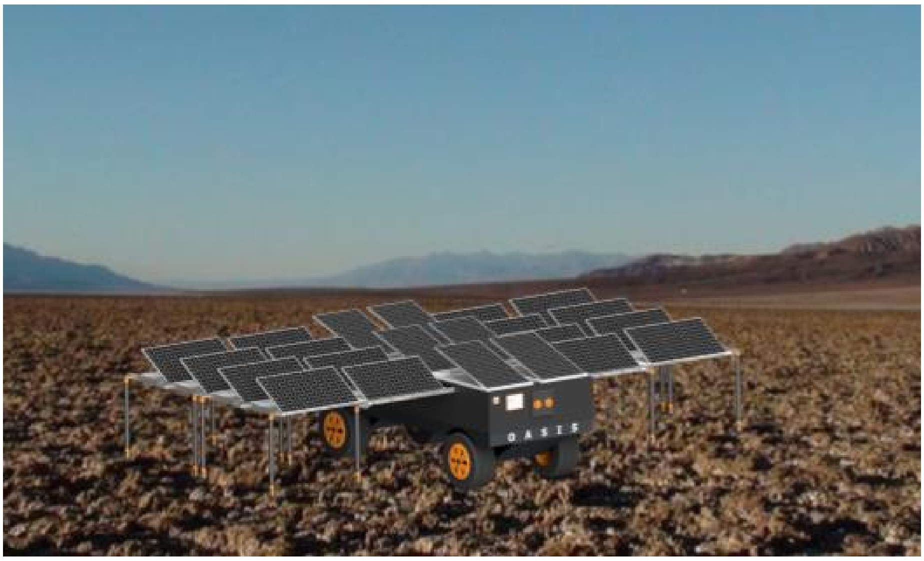

Figure 24. CAD model of Oasis configuration 3

The solar panels that are stored in drawers can be extracted using telescopic rails that can extend up to 2 meters. During the extraction of the solar panels, two sets of wheels can be folded down and act as support while also aiding the process of pulling out the drawers. The solar panels can be angled between 20 and 40 degrees to face the sun for as long as possible to optimal sun hours. The tower for the wind turbine can be raised and lowered through the combination of a horizontal rail and a vertical rail that are connected using a fixed beam. A wire, originating from the crank/lever system, is guided through a pulley system that is mounted to the base platform of the Oasis. The wire is first attached to the horizontal rail that is fixed to the base platform and is then guided through an additional pulley system that is mounted to the tower. Lastly, the wire is fastened to a plate at the top of the tower. This pulley system is illustrated in Figure 25. Rotating the lever will result in raising and lowering the wind turbine tower.

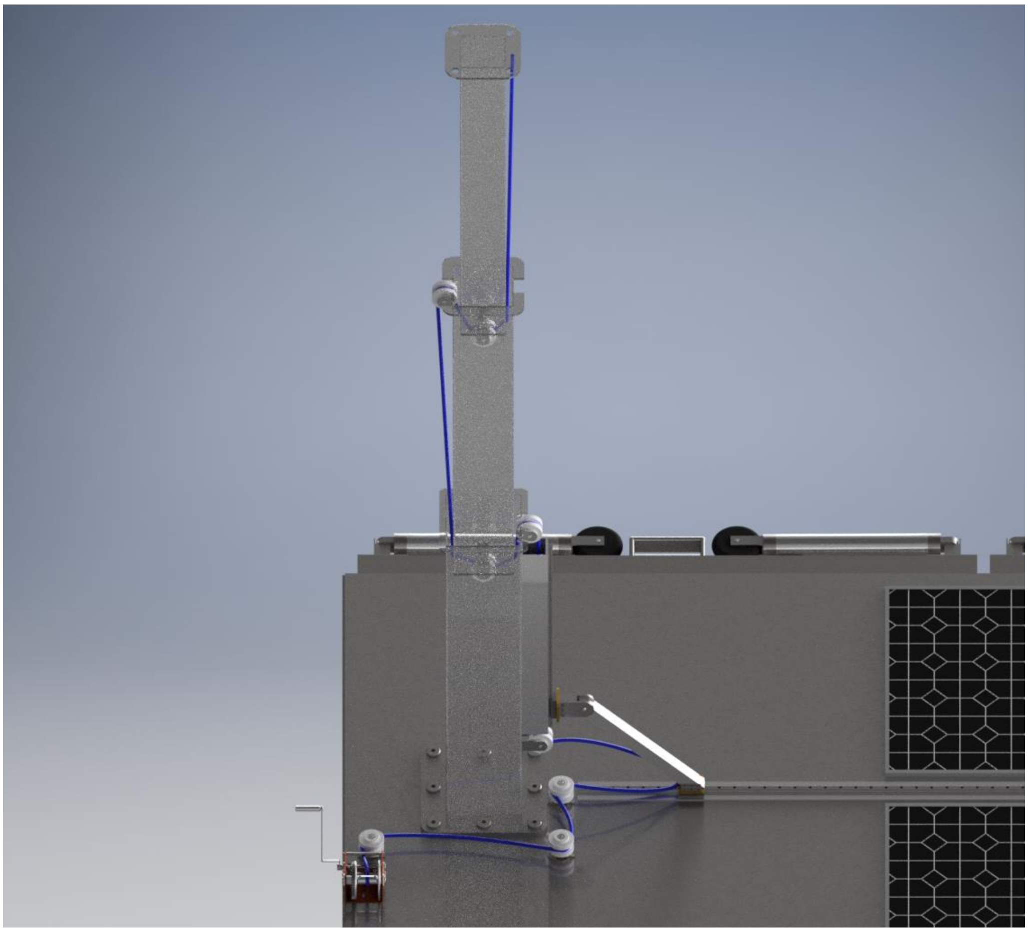

Figure 25. CAD model of pulley system of the Oasis

The concept consists of a trailer with a wheelbase. The trailer houses the power modules consisting of wind turbines and solar panels. The electronics consisting of a hybrid charge controller, battery packs, battery monitor, an AC/DC inverter, and a DC (Direct Current) and AC (Alternating Current) power outlet. Solar energy and wind energy is generated from the power modules that transfer the energy to the hybrid charge controller, which is then stored in the battery packs. The stored energy can be used to charge machines, vehicles and housing through the AC and DC power outlets. A separate fuel-based generator can be used as a back-up energy solution if the Oasis cannot provide sufficient energy. As of today, diesel could be considered as a viable option as fuel for the generator due to the accessibility and reliability, however, this solution could transition to a fossil free fuel-cell based system at a later stage when fuel-cell generators are more financially viable, and hydrogen has a more sustainable production process. As for the energy generating modules, the energy storage system of Oasis can be adapted to specific needs and the storage capacity adapted by adding or removing storage modules. The method of energy storage was chosen to be second life lithium-ion batteries. In the standard configuration proposed for the solution, five second life lithium-ion battery modules with an individual capacity of 30 kWh each were utilized resulting in a total system capacity of 150 kWh. To counteracts performance degradation of the second life lithium-ion batteries, the charging protocol of the system should only utilize for 60% of the battery capacity, resulting in a usable battery capacity of 90 kWh. In practice, the charge percentage of the system will be between 20% to 80% of the total capacity. A system diagram of the Oasis can be seen in Figure 26 and an inside view of the CAD model representing the Oasis can be seen in Figure 27.

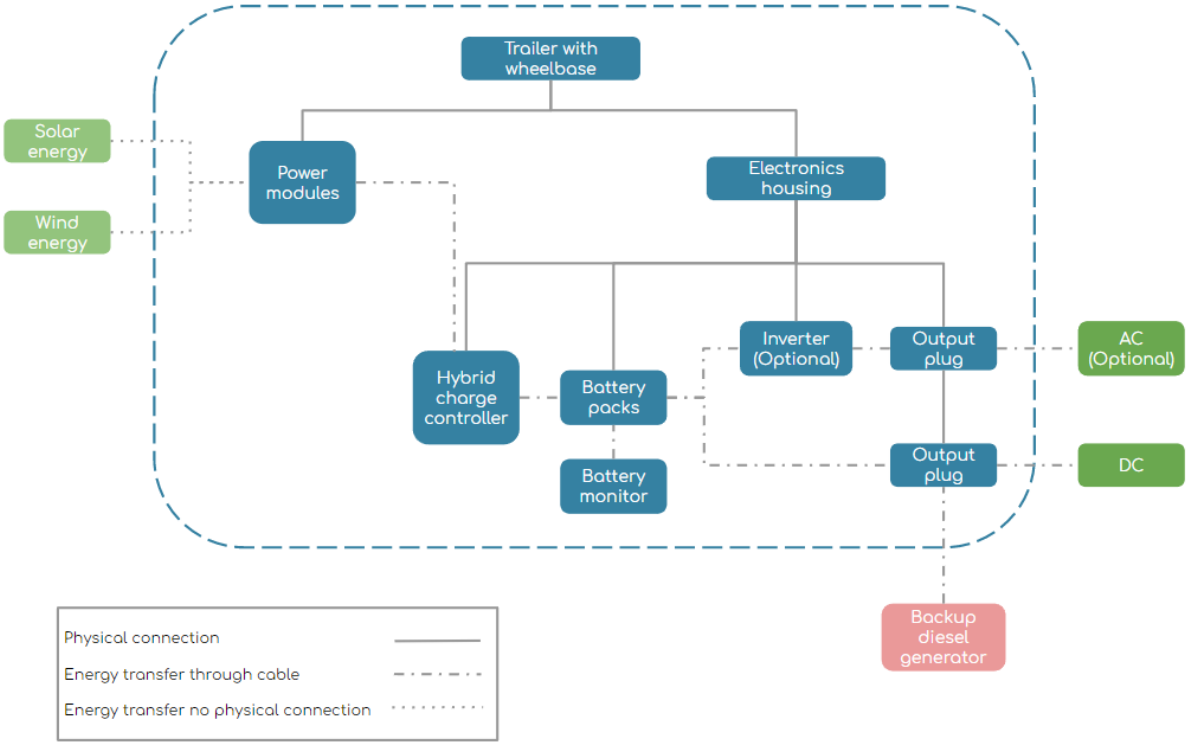

Figure 26. Oasis system diagram

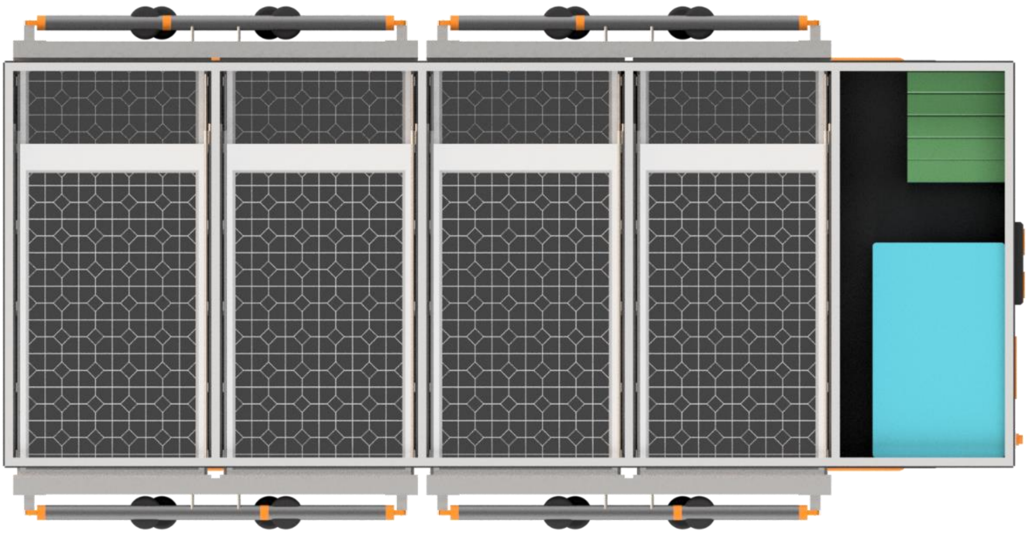

Figure 27. CAD model of the inside view of Oasis

5.6.2 Nomad

In parallel with the development of the Oasis system, students from Stanford University developed an energy distribution system aimed at complementing the Oasis to create a product service system that meets both energy generation and energy distribution related needs. As an answer to the off-grid energy distribution needs, Nomad could at its core be described as mobile energy storage transportation platform. In order for Nomad to store energy, the product utilizes ten 30 kWh second life batteries that can store up to 300 kWh of energy. The amount of energy possible to be stored in Nomad is designed to meet the energy need of a Volvo ECR25 electric excavator or a Volvo L25 electric loader for up to five days of work. As for the method of transportation, Nomad utilized the Volvo developed autonomous electric dumper TA15, also known as the TARA-system. The energy storage module is mounted on top of a TA15 using already integrated fastening points on the body of the dumper as a replacement for the otherwise mounted bed. With the use of the Tara system, Nomad can transport itself autonomously to locations where there is a need for energy such as the location of an electric vehicle in need of charging, or a disaster area in need of portable electricity. In Figure 28 below, an illustration of the Nomad system is presented.

Figure 28. Illustration of Nomad.

5.6.3 The system

The system accounts for the merging of the Oasis and Nomad that becomes a complete solution. They complement each other as the Oasis is used for generating and storing energy, while the Nomad collects the energy and moves it to an area in need, providing the stored energy much like a portable power bank. The system is mobile and can be delivered to its designated location using a truck. All batteries are fully charged prior to transportation for the system to have an energy buffer and to ensure that it can be utilized immediately. The aim is being able to provide a construction site, disaster relief area or any other customer with sufficient energy from renewable energy sources and reduce downtime for as long as possible. The system was designed to generate enough energy daily to support 2-3 electric construction vehicles, such as one L25 loader and one ECR25 excavator. Thanks to the mobility of the whole system, the Oasis can be deployed in an optimal location within the vicinity of the site, while the Nomad covers the rest of the distance. The Nomad will be able to charge vehicles while they are in operation and performing stationary tasks, such as digging and loading. The system relies heavily on the weather conditions since it consists primarily of wind and solar power. Since the wind speed and peak sun hours can vary daily, a diesel generator or fuel cell is implemented as an energy back-up device for redundancy. The system is designed to be scalable so that it can meet higher energy needs. Scalability in this case is the ability of using multiple Oasis and Nomad on a larger site.

Storyboards were created to illustrate how Oasis and Nomad are utilized and how they function together. In Figure 29 the use of Oasis and Nomad working together is illustrated. The first step in the process is to assemble the energy modules in accordance with the customer demand. This includes the number of wind turbines, solar panels, and battery capacity of both Oasis and Nomad. Once the assembly is finished, the system is transported to the site and deploy it. When it is fully deployed, the system will start generating energy. Nomad will go back and forth between the location of the energy need and the Oasis to recharge during the night from the energy generated by the Oasis during the day. This cycle is continued throughout the time that the customer has leased the system. Once the lease has expired, the system is packed and brought back to the leasing company. Regular quality control is conducted to ensure that all parts are functioning properly and to detect any malfunctions.

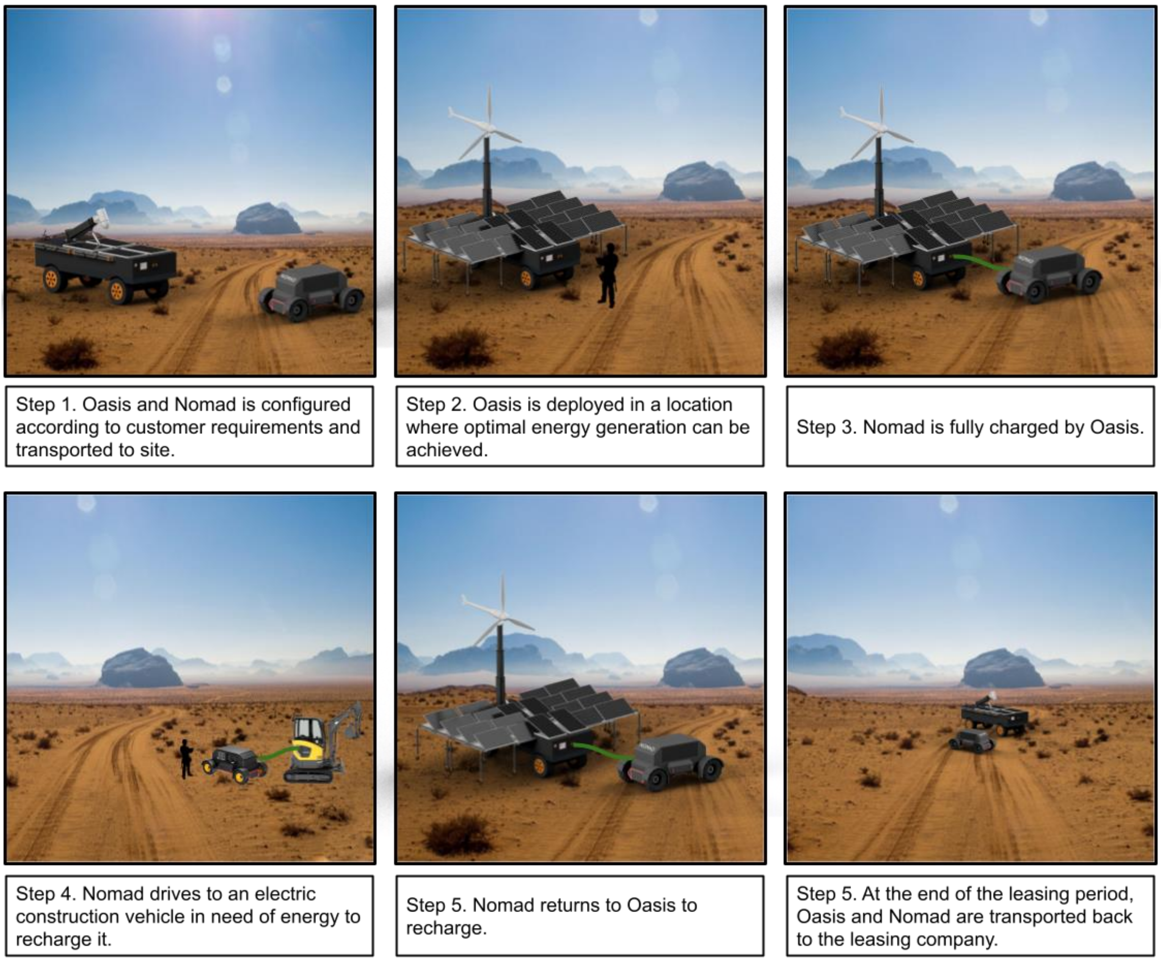

Figure 29. Storyboard for the system

5.6.4 Energy output

The solar panels nominal power is 430 W and has a panel efficiency of 22,7 %. Each solar panel has a width of 1046 mm, a length of 1812 mm and is 40 mm thick. The wind turbine has a rotor diameter of 4,3 m, weighs 165 kg, and has a side length of 3,4 m. The wind turbine generates 4 000 W at a nominal wind speed of 11 m/s. The estimated energy generated from the wind turbine at various wind speeds is based on the power output capacity from a specific commercial wind turbine utilized in the concept. The energy generation capacity of the system ranges from 44-74 kWh depending on the configuration. This is based on the global average peak sun hours and wind speeds as illustrated in Table 2. Additional scenarios were created, as seen in Table 3, Table 4, Table 5, and Table 6 to get a better understanding of the energy generating capacity of the Oasis.

Table 2. Oasis daily energy generation globally

Total average daily energy generation globally (Average wind speed: 5 m/s, daily solar irradiation: 5 kWh)		
Number of Solar panels	Number of Wind turbines	Energy generated (kWh)
18	2	74
20	1	59
22	0	44

Table 3. Oasis daily energy generation in Los Angeles

Total average daily energy generation in Los Angeles (August) (Average wind speed: 3.5 m/s, daily solar irradiation: 7,7 kWh)		
Number of Solar panels	Number of Wind turbines	Energy generated (kWh)
18	2	72
20	1	70
22	0	68

Table 4. Oasis daily energy generation in Maputo

Total average daily energy generation in Maputo (October) (Average wind speed: 5,3 m/s, daily solar irradiation: 6,5 kWh)		
Number of Solar panels	Number of Wind turbines	Energy generated (kWh)
18	2	90
20	1	75
22	0	59

Table 5. Oasis daily energy generation in Perth

Total average daily energy generation in Perth (January) (Average wind speed: 6,25 m/s, daily solar irradiation: 8,7 kWh)		
Number of Solar panels	Number of Wind turbines	Energy generated (kWh)
18	2	129
20	1	104
22	0	79

Table 6. Oasis daily energy generation in Karlskrona

Total average daily energy generation in Karlskrona (March) (Average wind speed: 4,9 m/s, daily solar irradiation: 2,7 kWh)		
Number of Solar panels	Number of Wind turbines	Energy generated (kWh)
18	2	56
20	1	40
22	0	24

5.6.5 Business model

The systems value proposition is to provide primarily green energy to EV’s in remote areas that for distinct reasons lack sufficient energy infrastructure. The portability of the system increases the utilization as it can be transported to different sites depending on the demand. The modularity aspect allows the system to be adapted and customized to specific customer requirements and locations, switching between solar panels, wind turbines, and fuel cells. The customer segments consist of construction companies that operate in areas that has no, or damaged, infrastructure, and crisis management agencies in case of natural disasters. The customers are reached through retailer channels that sell or lease electric construction machinery. The potential customer is then contacted directly by sales. The customer relations are maintained through direct contact and online customer support services.

The key activities for the system require that it can generate sufficient energy and distributes it to the subject in need of energy. It also requires transportation, to and from sites, as well as deployment and maintenance services. The key resources that are essential to the system are the energy modules, second life batteries, transportation, and staff that has the expertise of handling energy systems. The key resources will be provided through key partners such as green energy harvesting. The second life batteries would be provided by companies such Volvo CE or other manufacturers of electric vehicles. Volvo Trucks would be an excellent partner for providing ideal transportation alternatives. The cost structure consists of materials, aluminium, and stainless steel, which are needed for the trailer, and training staff that will assemble the system and deploy it. The solar panels, wind turbines, batteries and DC to AC converters represent a substantial cost for the system. The long transportation distances to the remote locations of the customers must also be taken into consideration when it comes to additional costs. The main revenue for the product service system is the leasing of the complete system. This will generate a continuous revenue stream and ensure optimal utilization of the system. The key aspects are illustrated in Figure 30

<table>
<tr><td rowspan="2">Key Partnerships

Green energy harvesting

Volvo CE

Volvo Trucks</td><td>Key Activities

Generate sufficient amount of energy.

Distribution of the energy.

Deployment and maintenance.</td><td rowspan="2">Value Proposition

Providing EV’s with a portable renewable energy system in locations that have an insufficient electrical infrastructure.

Ability to adapt the system to customers energy needs.</td><td>Customer Relationships

Direct customer contact

Online customer support service</td><td rowspan="2">Customer Segments

• Construction companies

• Disaster relief agencies</td></tr>
<tr><td>Key Resources

• Energy modules
• Second life batteries
• Transportation vehicles
• Trained staff</td><td>Channels

Retailer channels</td></tr>
<tr><td colspan="2">Cost structure

Materials: Aluminium and stainless steel

Maintenance: Staff and education

Energy modules: Solar panels, wind turbines, fuel cells, and second life batteries

Transportation</td><td colspan="3">Revenue streams

Leasing the system to the customer based on the time it will be used.</td></tr>
</table>

Figure 30. Business model canvas for the system

Table 7 illustrates the costs of the essential parts of the Oasis and includes a rough estimation of additional manufacturing costs. In comparison a 30-kW diesel generator consuming 80 l of diesel is estimated to cost 1120 SEK per day. If Oasis would be leased at the same cost as the diesel generator, the time until reaching break-even is estimated to be 950 days which is the equivalent of 2,6 years.

Table 7. Cost calculation for manufacturing the Oasis.

Parts	Cost (SEK)
20 Solar Panels	97000
1 Wind turbine	150000
150 kWh Second Life Battery	120000
DC to AC inverter	200000
Manufacture & Labour	500000
Total Cost	**1 067 000**

5.7 Implementation

5.7.1 Functional system pretotype

A pretotype was constructed to translate the Oasis into a tangible product for quick validation of the feasibility of the concept. Cardboard boxes were cut into pieces that represented the floor, walls, and ceiling of a downscaled trailer, as well as the solar panels. Duct tape was used to fastening all the parts. The wind turbines were built using cardboard as a base while the straws and wooden sticks were used to create the blades and rotor hub. To represent a hoisting mechanism for the tiltable wind turbine modules, a piece of string was attached to the side of the wind turbines and on the other end a crank inserted to the side walls.

The construction resulted in a simplified tangible version of the Oasis that could carry two wind turbines and two sets of foldable solar panels, see Figure 31. Deployment of functional system pretotype. The effectiveness of the method for deployment and the viability of the formfactor was analysed and assessed. The assessment resulted in a decision to move forward with the concept and build a functional system prototype as the feasibility of the concept was determined to be high. Key takeaways from the result are presented below:

- The overall formfactor of the concept is considered feasible but has room for optimization.
- It could be beneficial to have the hoisting mechanism and the retraction system for the wind turbine synchronised into one system.
- Having two wind turbine modules on the same part of the platform could be technically challenging without expanding the size of the trailer and needs to be assessed further.

Figure 31. Deployment of functional system pretotype.

5.7.2 Functional system prototype

The initial functional system pretotype confirmed initial expectation regarding feasibility of the concept and a working small-scale prototype was decided to be of great importance in order to further investigate the concept. The goal was to have a functional platform that could house three different power modules, two solar panels and one wind turbine, that would be integrated in a working small scale power generating system. After further assessment of the functional system pretotype, it was decided to exclude one wind turbine module when constructing this prototype to optimize the size of the trailer to fit with Swedish road regulations. As the energy output was not of interest for this specific prototype, a scale of 1:10 for the platform and all the power modules were decided to be suitable for the system. Critical questions regarding the outcome of the prototype were decided on before constructing and are presented below:

- Is the formfactor feasible to house three power modules of the size needed including electronics needed?
- How reliable is an automatic deployment system for the wind turbine module?

The wheelbase and mounting platform for functional system prototype was built using oriented strand board (OSB) cut to 1:10 of the dimensions of the full-size concept. When in transportation mode, the prototype measures 50cm x 26cm x 30cm. When deployed, the prototype has a footprint of 3800 cm^3, see Figure 32 for step-by-step deployment.

Figure 32. Deployment of functional system prototype.

Three aluminium wheels were mounted on a custom wheelbase made out of wooden blocks; however, this functionality was not of importance for the prototype and therefore not scaled correctly nor included in the testing phase. Two 20W solar panels were mounted on the sides of the small-scale trailer and wired two separate voltage regulators adjustable from 5v to 25v. The voltage regulators were connected to two separate USB-ports (Universal Serial Bus) used as external connection port. The USB-ports were glued into a custom-made 3D-printed polylactic acid (PLA) housing. A scaled 3D-printed PLA rotor hub with blades were mounted on a small DC-motor to represent a wind turbine. When spinning, the DC-motor produced energy as a result of counter-electromotive force (EMF). The wind turbine model was placed on a custom designed telescopic tower that utilizes a DC-motor connected to a lead screw inside the tower which allows for motorized automatic retraction, see Figure 33. When the DC-motor start spinning, the lead screw will move two nuts integrated to the tower up or down depending on the rotational direction of the motor. A limit switch was mounted on the inside of the tower which will be activated when the tower is fully retracted to prevent over-retraction and damage to the leadscrew mount and motor.

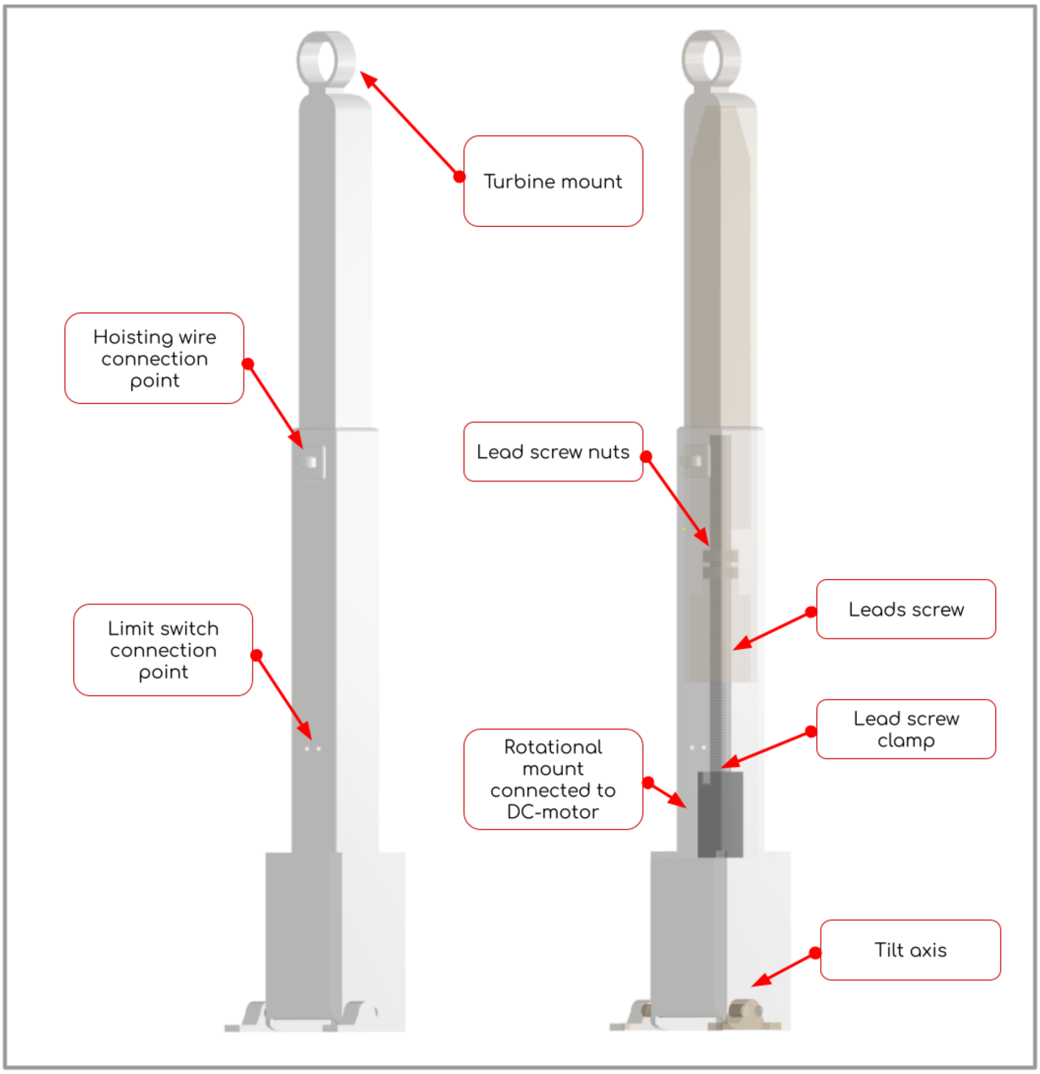

Figure 33. Telescopic tower for wind turbine, solid and transparent view.

A wire system connected to a stepper motor was used to be able to raise the tower from a horizontal position during transportation to a vertical position during operation state. A limit switch was added at the bottom of the tower to detect when the tower is in a vertical position which will stop the motor from over-retracting the hoisting cable. To control the movement of the telescopic tower, both the telescopic and hoisting functions, an Arduino micro-controller connected to a motor driver was used, see appendix D Figure D.1 for source code. The operation is controlled using two buttons, green button controlling extension and red button controlling retraction, both connected to the Arduino board. The extension and retraction of the tower was synchronised with the hoisting system to allow for simpler operation using only two buttons. The placement of the parts used in the prototype is presented in Figure 34 and a system diagram of the prototype can be seen in Figure 35.

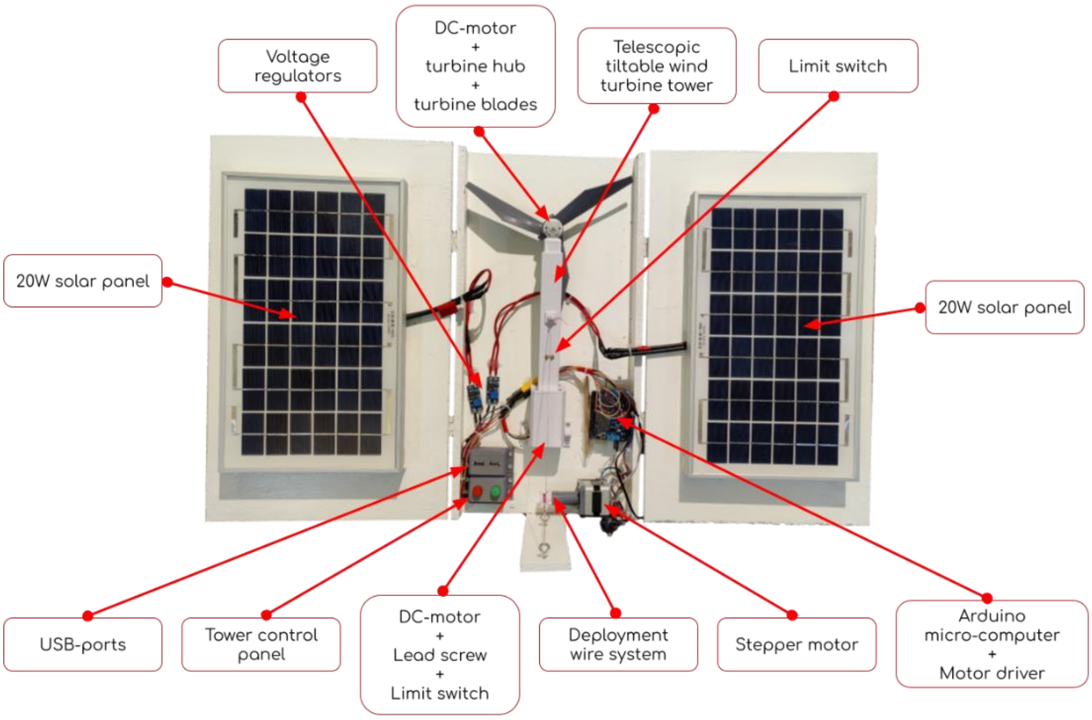

Figure 34. Functional system prototype part placement

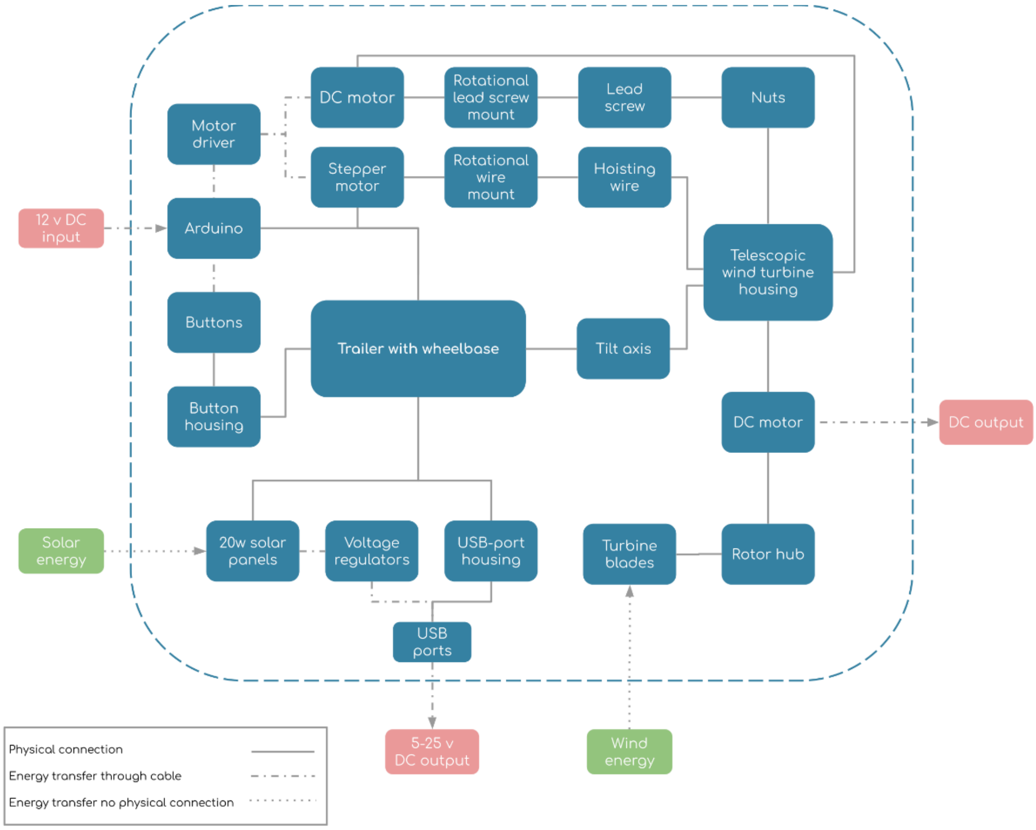

Figure 35. System diagram of the functional system prototype.

5.7.3 Minimal viable product

The final physical version of the Oasis during the project was represented as an MVP. The aim of this construction was to visualize the concept and to have enough working functions so that the product could be validated by external sources during a presentation at an exhibition at Stanford University. The initial goal was to construct an energy generating wagon at 1:3 scale in comparison with the full-size concept. As the amount of energy being generated by the wagon was not of interest for the MVP, it was decided that the MVP could be scaled down without any considerable impact on the functionalities and features of the system. As for the functional system prototype, the goal was to equip the MVP with three power generating modules, two solar panels and one wind turbine. This goal was achieved with the implementation of an 800W wind and solar energy system. The system consists out of two 195W solar panels, one 400W wind turbine, one 20A PWM hybrid charge controller and two 100Ah GEL batteries. The system can generate up to 3 kWh per day and output 12V DC. With and 1additional 1500W off-grid inverter, the system is capable of outputting 100-120V AC. An additional battery monitor was also added to allow for information regarding battery status, power output, current and daily energy output. A system diagram of the MVP's energy system can be seen in Figure 36.

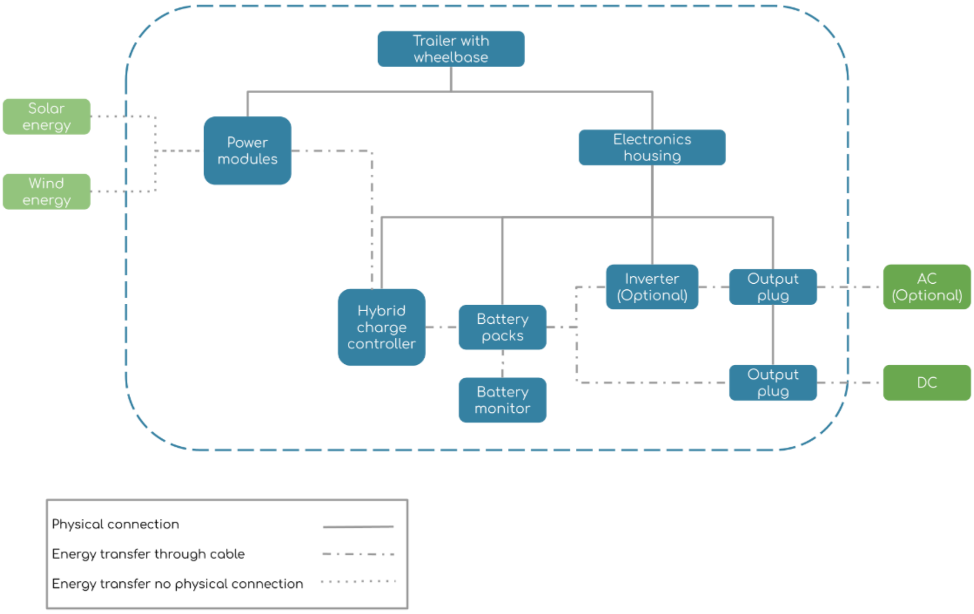

Figure 36. MVP energy system diagram.

From analysis of the previous prototype iterations, the hoisting system was identified as a critical area of focus for the MVP. The telescopic tower designed for the second prototype iteration was determined to be overly complex to construct for the MVP. It was decided that an external wire system would allow for the same functionality but whit less complexity at the scale of choice. The use of a lead screw at a larger scale would also add financial cost without providing any extra value except for potential visual appeal. It was also noted that an automatic motorized system would add unnecessary sources of error in parallel with also adding extra components and financial costs. As a result of this, a manual winch system was decided to be the best alternative for operating the hoisting system. In Figure 37, an illustration of the hoisting system function is presented.

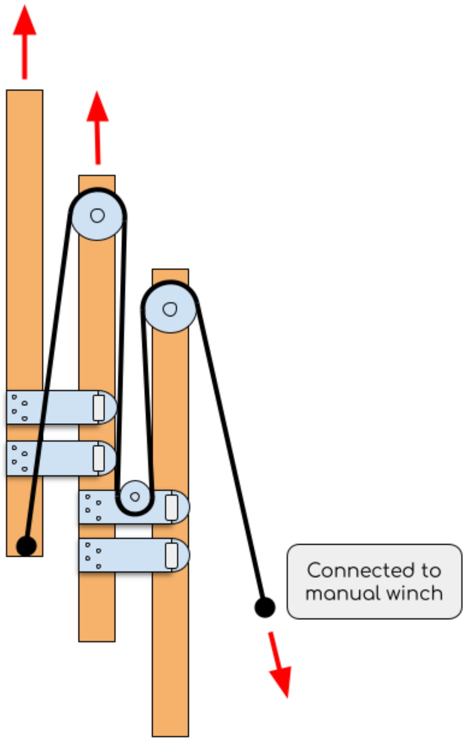

Figure 37. MVP hoisting system function illustration.

The three parts that make up the mast are constructed out of four press-glued 12mm plywood sheets that are cut to create 48x48 mm poles. Press-glues plywood was selected as the choice of material to reduce the risk of cracks or cavities which is common in wooden poles that are cut out from one solid piece of wood. This allows for a more stable construction when the mast is put under stress from the wind turbine. For each part of the mast to be able to slide up and down, a sliding system was constructed which can be seen in Figure 38. The parts that make up the sliding system are made from steel to allow for high structural integrity. The wheels and offsets between the housing and wheels are 3D-printed in acrylonitrile butadiene styrene (ABS) which is a durable thermoplastic. A custom pulley was also constructed to allow for the wire to be connected to the mast, see Figure 39 and Figure 40. The pulley was constructed out of an CNC machined steel block together with a tuned steel axis that holds a 3D-printed ABS pulley wheel press fitted on a ball bearing for minimal friction.

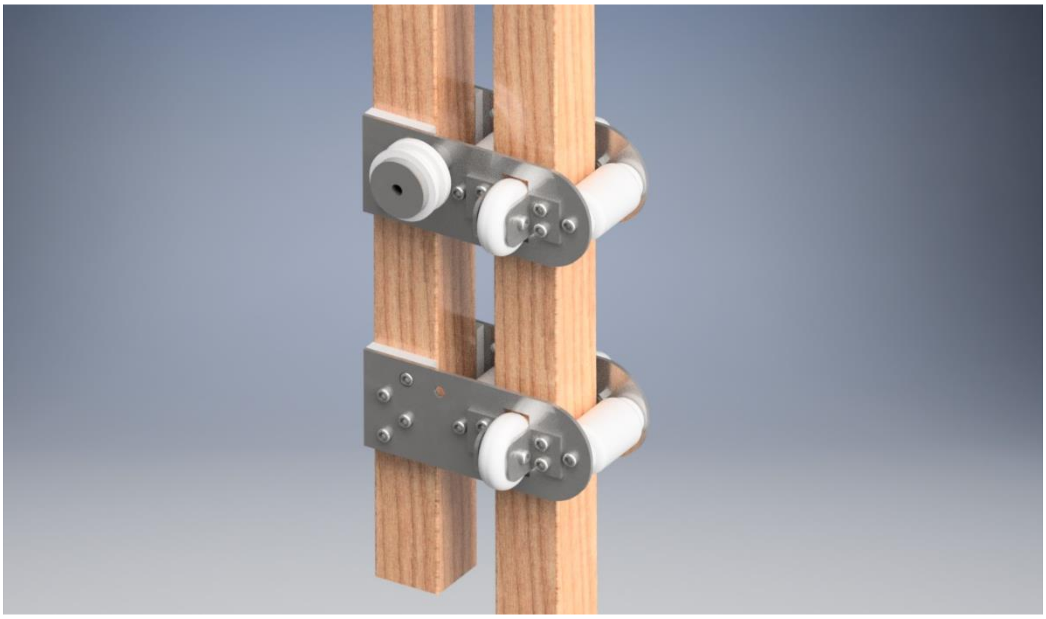

Figure 38. CAD model of the sliding system for the MVP attached to two wooden poles.

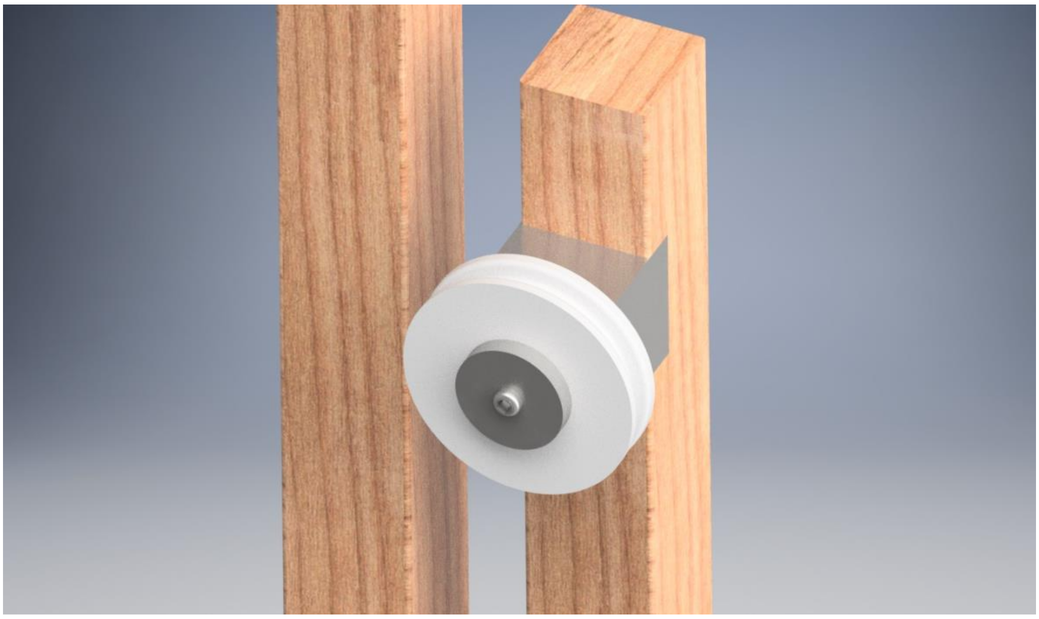

Figure 39. CAD model of custom pulley mounted on a wooden pole.

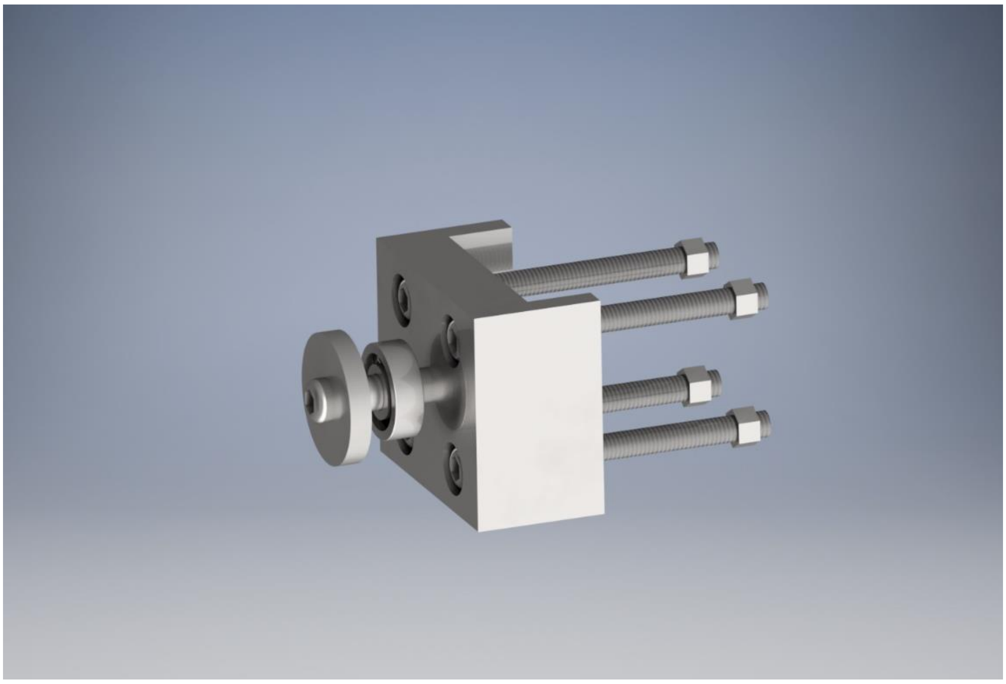

Figure 40. CAD model of the custom pulley without pulley wheel and where bearing and screws are visible.

A platform to house all the components were constructed out of OSB sheets and square lumber for support. The solar panels were placed on linear rails for them to be inserted into the housing and easily pulled out during operation in the same way as for the full-size concept. The telescopic mast that houses the wind turbine was placed on top of the scaled trailer connected to a manual winch that was fastened to the front of the housing. In the front part inside of the hosing, all the electrical components including the batteries and hybrid charge controller were mounted for optimal protection. An opening for a hatch was cut out in the front of the top OSB sheet to allow for easy access to the electrical components when needed. In Figure 41 and Figure 42, CAD models of the deployed MVP and the MVP in transportation mode are presented. In Figure 43, the inside of the MVP can be seen and in Figure 44, the physical version of the MVP is presented. Figures showing the deployment of the wind turbine tower and the solar panels on the MVP can be found in appendix E figure E.1 and appendix F figure F.1.


Figure 41. CAD rendering of the deployed MVP.


Figure 42. CAD rendering of the MVP in transportation mode.

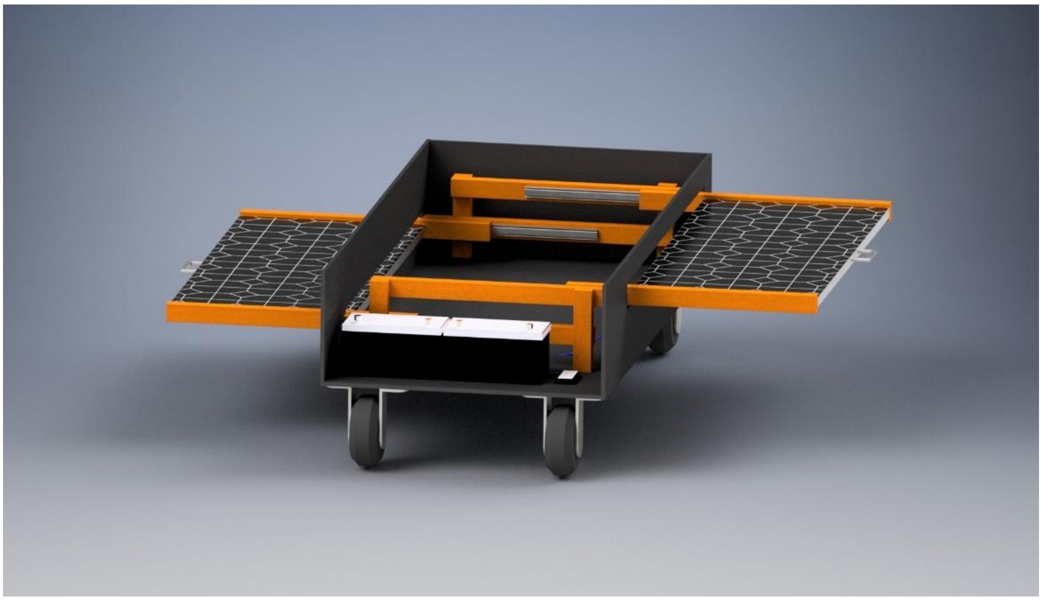

Figure 43. CAD rendering of the inside of the MVP.

Figure 44. MVP during first test of the energy system.

5.8 Simulation

5.8.1 The Oasis concept

During analysis of the construction of the Oasis concept, the horizontal beam was identified as a critical part as it would be exposed to high load. A finite element analysis was conducted to verify the structural integrity of the critical part. In order to simulate the displacement, the force required to start an angular motion in relation to the angle of the wind turbine while being raised was calculated using equation (4)-(8) based on the assumption of rotational equilibrium [57]. A force diagram of the wind turbine is presented in Figure 45. The distance, h, between the anchor point of the horizontal beam on the tower and the bottom of the tower changes in relation to the angle with a maximum value of 1.3m and a minimum value of 0.46m. The distance from the bottom of the tower to the centre of gravity, w, was calculated to be 1.4m using equation (9) and (10) based on the force diagram presented in Figure 46. The mass of the tower, m_1, was extracted from the CAD model with a value of 267 kg and the mass of the turbine, m_1, was determined to be 165 kg resulting in a total mass, m, of 432 kg.

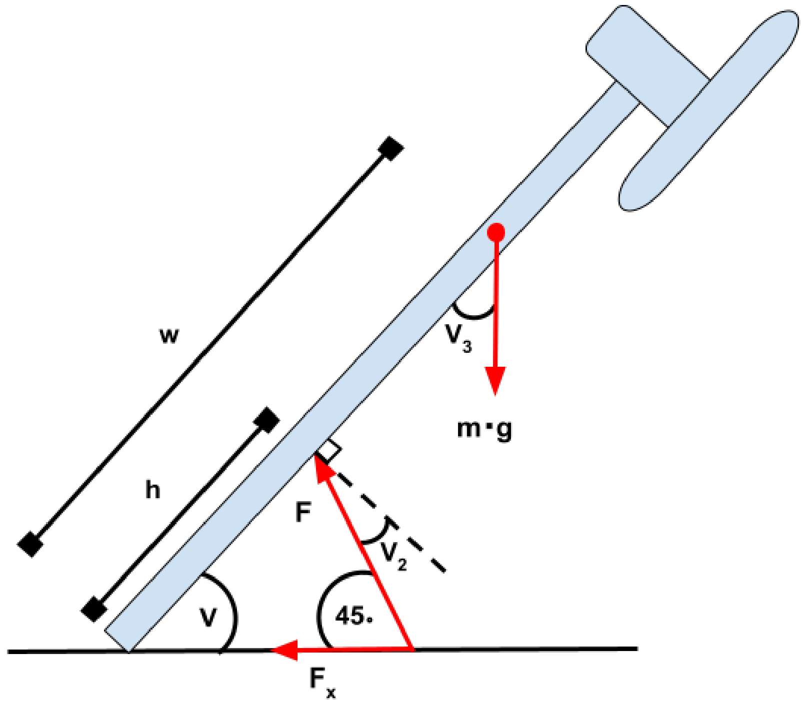

Figure 45. Force diagram of the wind turbine utilized in Oasis.

$$F \cdot \cos V_2 \cdot h - mg \cdot \sin V_3 \cdot w = 0 \quad (4)$$

$$\rightarrow F \cdot \cos(180 - 45 - V - 90) \cdot h = mg \cdot \sin V_3 \cdot w \quad (5)$$

$$\rightarrow F \cdot \cos(45 - V) \cdot h = mg \cdot \sin(90 - V) \cdot w \quad (6)$$

$$\rightarrow F = \frac{mg \cdot \sin(90 - V) \cdot w}{\cos(45 - V) \cdot h} \quad (7)$$

$$F = F_x \cdot \cos 45 \rightarrow F_x = \frac{F}{\cos 45} \qquad (8)$$

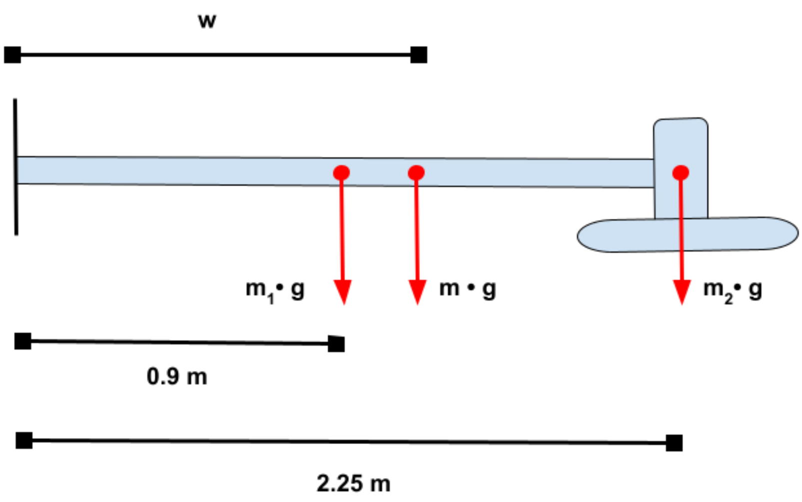

Figure 46. Force diagram of the wind turbine tower when calculating center of gravity.

$$m_1 \cdot g \cdot 0.9 + m_2 \cdot g \cdot 2.25 = m \cdot g \cdot w \qquad (9)$$

$$\rightarrow w = \frac{m_1 \cdot 0.9 + m_2 \cdot 2.25}{m} = \frac{267 \cdot 0.9 + 165 \cdot 2.25}{432} = 1.4\, m \qquad (10)$$

The horizontal force acting upon the horizontal beam when tilting the tower from a standstill can be seen in the graph presented in Figure 47. The maximum force was calculated to be 10 414 N and can be found at the angle of 50°. The maximum force was used in the simulation of the displacement of the horizontal beam, see Figure 48. The maximum displacement of the horizontal beam was simulated to be 0.02 mm.

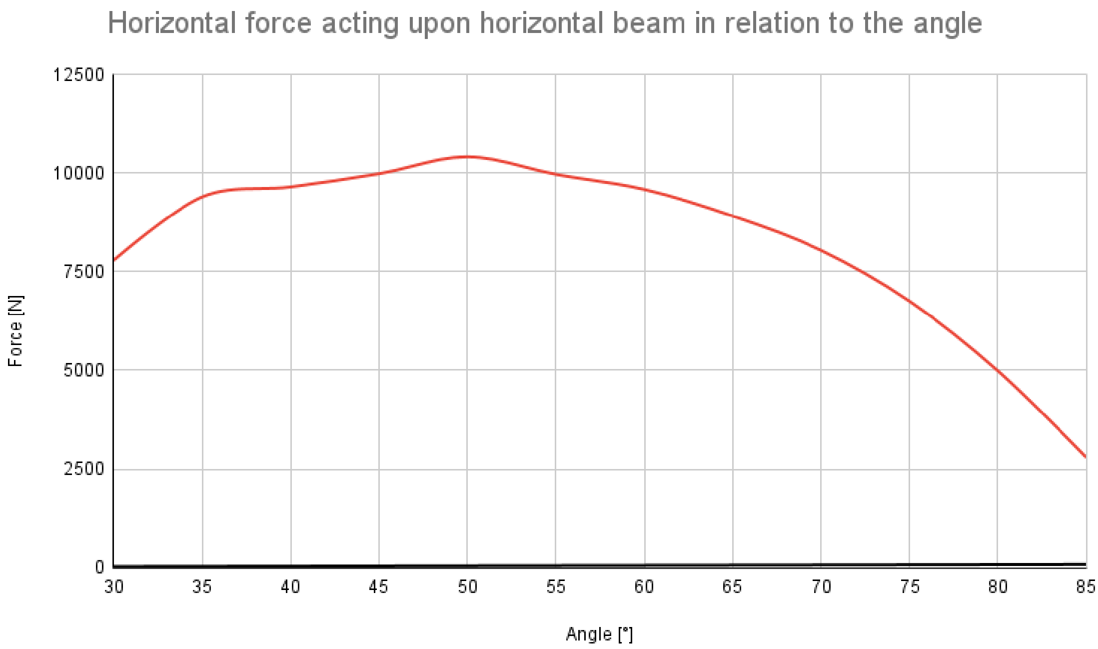

Figure 47. Horizontal force acting upon horizontal sliding beam in relation to the angle.

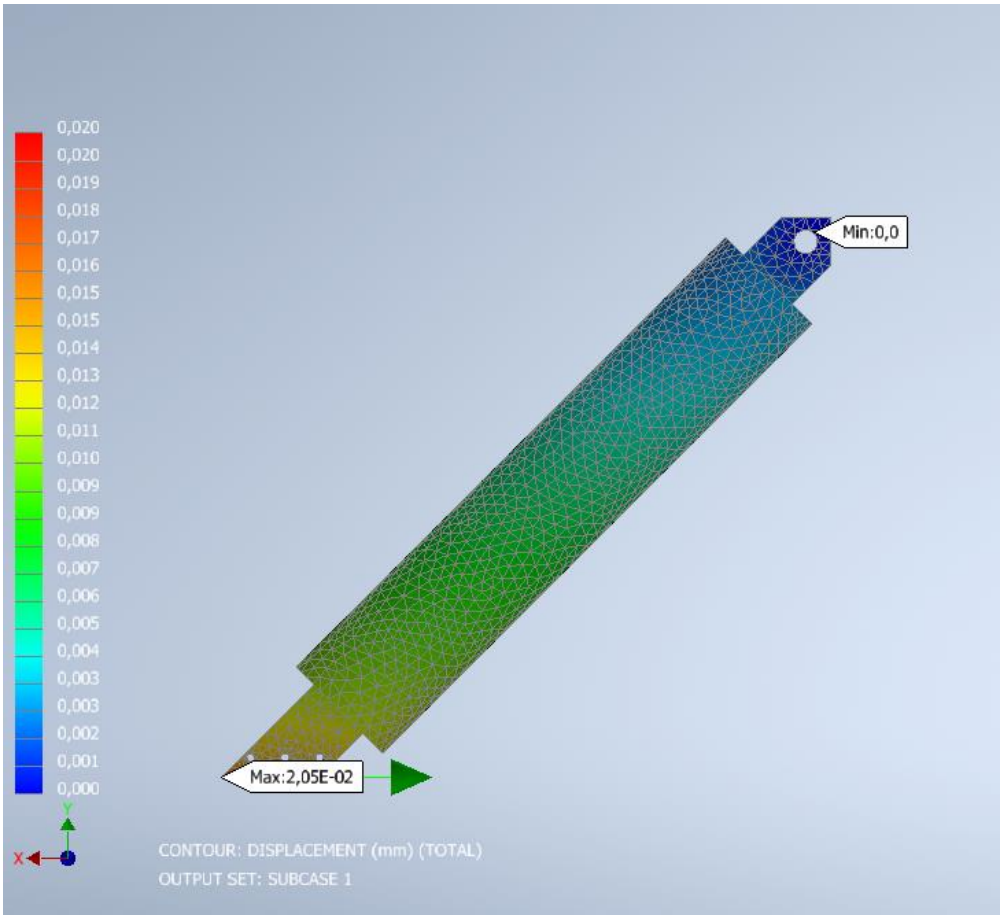

Figure 48. Total displacement in mm of horizontal sliding under maximum load.

5.8.2 Minimal viable product

A finite element analysis was conducted on the pulley system for the MVP in order to calculate the maximum displacement of the constructions under load. The pulley system was identified as the most critical objects prone to break under load, hence, analysis was determined to be critical. A bearing load of 400N was placed on the pulley wheel axis which equals the total mass of the tower, including turbine, times the standard gravity. This was calculated to be the maximum predicted vertical load if one pulley would carry the whole weight of the wind turbine mast. As can be seen in Figure 49, the maximum displacement of the pulley wheel axis was calculated to be $9{,}76 \cdot 10^{-4}$ mm.

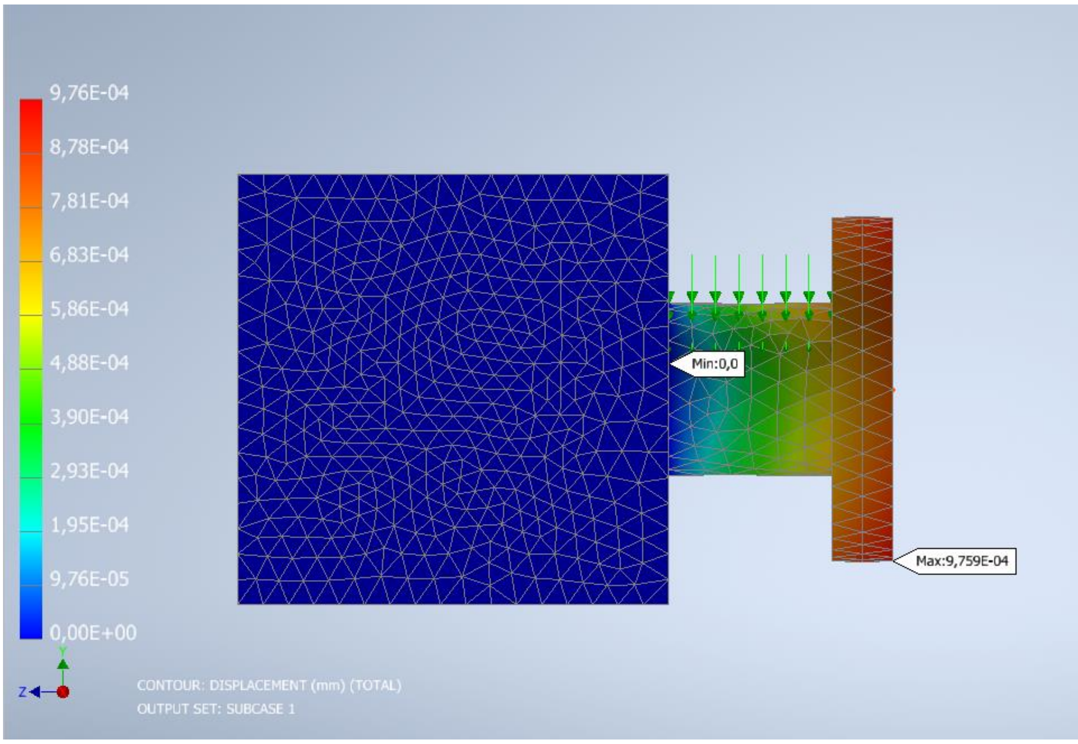

Figure 49. Displacement presented in mm of the pulley under maximum load.

6 DISCUSSION

The following section contains reflections regarding the work and research conducted throughout the project described in this thesis. Aspects related to global collaboration, sustainability, the choice of methods and concept development are discussed by the authors of this thesis.

6.1 Global collaboration

The global collaboration between the authors of this thesis and students at Stanford university participating in the ME310 project proved to be both challenging but also resulted in benefits. As the distance between BTH and Stanford university is roughly 9000 km, most of the collaboration was conducted using a various amount of online communication tools. Due to the nature of online communication, some aspects were difficult to convey, and discussions do not get the same depth in comparison to face-to-face communication. As a result of this, some phases such as the ideation phase, was more challenging. The ideation phase was based on extensive amounts of iterative sessions including brainstorming and brainwriting. These types of sessions are particularly hard to conduct during inline communication as underlying messages are hard to identify. The participants in the projects also identified the prototyping session to be challenging to conduct which resulted in a strict distribution of work. This could be considered as the main reason the Oasis and Nomad were developed separately by different sub-teams. In conclusion, the strict distribution of work between the students at Blekinge Institute of Technology and the student at Stanford University brought some benefits regarding the development and implementations of the two product concepts each sub-team could focus on their own part of the project. However, a structure of this kind entails the risk of having non optimized systems when integrating two externally developed product as effective communication is of immense importance.

Another factor making global collaboration more challenging is the difference in time zones. The is a difference of nine hours between Sweden and California which resulted in meetings having to be scheduled during late nights for one part of the team while the other part had to work early mornings. This could also be considered as an impactful aspect regarding challenges in communication as the people involved often were tired during work sessions. The difference in time zones also resulted in the teams having to work separately during parts of the project. Discussion regarding design choices and other decision during the project often had to take place after decision already had been made. As a result of this, progression in relation to the time spent could not be considered as optimal as a lot of time was spent on waiting for feedback, hence, making the iteration process more challenging.

6.2 Choice of method

At the beginning of the research conducted in this thesis, the initial problem statement provided by the original problem owner, Volvo Construction Equipment, was vaguely defined. Examining problem areas of this nature tend to make the research process overwhelming as the steps needed for further progression can be difficult to predict. The use of DRM as research methodology proved to be useful with regard to these types of challenges as the framework provided by DRM allowed for a structured research process. The framework provided a clear structure to follow which allowed for predictability regarding the next steps in the process which simplified decision making, hence allowing for higher efficiency. Furthermore, the use of DRM also provided clear expectations of the outcome from each stage which allowed for the research to focus on these specific outcomes, hence, allowing for results of higher legitimacy.

Design thinking, the choice of design methodology, proved to be useful in this project since the initial problems that were identified were either unknown or vaguely defined. Design thinking as a methodology created the conditions for finding and understanding the root causes of the problems and encouraged innovative thinking and problem solving. However, one aspect of Design thinking that complicated the process was that the methodology is based on extensive interaction with end users to understand the value process. In this project, there were limitations in the form of time zone differences and distance between participants. These limitations made it considerably more difficult to interact with the collaborating team, the end users, or other people of interest. Furthermore, the broad scope and area of interest also made it difficult to define an end user which further thwarted the process.

6.3 Concept development

6.3.1 Oasis

The Oasis was designed to provide remote areas with renewable energy using solar panels and wind turbines. One of the key insights that were identified during the development of the Oasis was the wider range of suitable application areas. The intended use of the trailer was to support the use of compact construction vehicles on remote sites that had no electric grid. However, upon further research the solution was found to be applicable in other areas such as disaster relief in places that has been affected by natural disasters, or as a temporary micro grid for rural areas to aid the expansion of the national grid. It is also applicable to support renewable energy investments, for example building solar parks. In this case the Oasis can support the EVs, housing and lighting at the site until the solar park can support itself and produce sufficient energy. Another key insight is that it is possible in theory to design a portable solution that can generate enough energy to support small construction vehicles that has a much greater energy need compared to housing, lighting, or light electric machinery, such as power tools, used at the sites.

A limitation of the Oasis is the dependency on road infrastructure in order to be transported to its destination. This could be a problem for the disaster relief applicability, since roads might be damaged or destroyed, hindering its path to the area where it would be optimal for deployment. A limitation from an energy generation aspect is the low efficiency of solar panels as they require large areas to produce sufficient energy. Nonetheless, trends are showing promising progress in the development of solar cells that can increase their efficiency, resulting in smaller solar panels that can generate the same amount of energy but use less space. It also means that the current size of solar panels will generate more energy, increasing their energy generating density. A similar limitation exists with wind turbines. Yet, the continuous technological development and advancements illustrate favourable prospects for the increase of energy efficiency and energy generating density of wind turbines.

Furthermore, the solar and wind modules are fixed to the trailer which has both advantages and disadvantages. The disadvantage is that it could prove to be more efficient to have stand-alone modules that could be removed from the trailer and placed in an optimal manner, increasing the energy generating capacity. The advantage of having the modules fixed to the trailer is that it enables a faster and easier deployment. The importance of this feature relies on the demand from the customer and can vary depending on the context from a construction site or disaster relief agency.

6.3.2 Nomad

The Nomad concept was developed by students at Stanford University to complement the Oasis concept. The development of Nomad is therefore not taken into consideration in this thesis as Nomad was implemented as an externally developed product. After implementing Nomad into the product service system, some key insights were identified with regard to Nomad as a product. As described in this thesis, Nomad utilizes the autonomous Volvo TA15 dumber called the TARA system. This allows Nomad to autonomously transport itself to the location of the energy need. However, the autonomous technology used for the Nomad is limited and operates mainly in demarcated areas which makes transportation on public roads challenging. Furthermore, the need for an autonomous energy transportation system has not proved itself to be critical in the current energy market. As a result of this, Nomad could initially be controlled manually by an operator at the time of entering the market to then, at a later stage when the autonomous technology becomes more viable, transition to the use of an autonomous transportation system as this has proved to be a future trend.

The use of lithium-ion batteries as energy storage method is also an aspect that could be further assessed. Today, lithium-ion batteries are considered to be the most viable option for energy storage, however, other storage methods such as hydrogen are predicted to become more competitive and should therefore be considered as future options for energy storage methods [22]. Furthermore, a modularity aspect of Nomad could also be something to consider as multiple options for energy storage could potentially extend the area of application as the system could be customized after specific energy needs and demands.

6.3.3 The system

The intention was to offer the system as one complete solution, however, analysis of the system has proved that they could perhaps be utilized as stand-alone products depending on the customer demand. If Oasis was to be used as a temporary micro grid for a remote village or an area that has been struck by a natural disaster, the Nomad might be excessive or would not be able to get through the damaged terrain. On the other hand, smaller construction sites that are close to urban areas could use the Nomad as a power bank and bring it back to be recharged using the electric grid when needed. In this case the Oasis would be excessive or not economically viable. Although the combined market size of the Oasis and Nomad as stand-alone products is likely to be larger, the competition would increase since there are similar products on the market. It is the combination of the two products that create a unique product service system which has not yet been identified within the energy market.

Furthermore, as one of the goals for the system is to be able to provide enough energy to fulfil the customer needs, and the implementation of a diesel generator serving as a back-up source of energy increases the redundancy of the system. It is fair to say that the choice of using a diesel generator is environmentally unsustainable, nonetheless, reducing the total amount of diesel usage is a step in the right direction of becoming independent from fossil fuels. Improvements of solar panels and wind turbines could make it possible to phase out the use of a diesel generators in the future. There is also the possibility of replacing it with fuel cells which have been further examined in this thesis.

When designing a system of this kind, it is also important to consider how parts of a product will be disassembled, remanufactured, repaired, reused, and recycled, from an economic and environmental standpoint. This includes avoiding non-biodegradable adhesives such as glue. Most of the parts of the Oasis and Nomad were designed to be assembled using screws, nuts, and bolts. This decision might increase the manufacturing and assembly time resulting in higher costs. However, the ability to be disassembled, hence allowing for reuse of parts, could potentially reduce future manufacturing costs as these parts can be integrated in the manufacturing of new systems. Furthermore, the whole system would be easier to disassemble, recycle and remanufacture, and should result in reduced waste.

An important aspect to consider is that the project presented and described in this thesis had a focus on concept development-based learnings and insights gathered from extensive research. The system presented may not have gone through extensive optimisation iterations regarding mechanical or technological details as the core concepts and system perspective has been the main area of focus. The work presented aims at setting a foundation for future work within the area of portable energy production and the suggested solution is not, and should not, to be considered as a final solution.

6.4 Minimal viable product

The Minimal viable product is the proof of concept regarding technical feasibility for a portable solution that can rapidly be deployed and start generating energy from renewable sources such as solar and wind power. The MVP, being one third of the size of the full-scale concept, does not provide evidence that the energy generation capacity, or cost of manufacturing would also be one third in comparison to full size concept output. Solar panels and wind turbines follow a non-linear scaling model [32], hence the energy produced by the MVP is not related to the actual size. Furthermore, the same principle goes for the financial cost of the various technical parts used for constructing the MVP such as solar panels, wind turbines and lithium-ion batteries.

The mechanical winch that is used to raise the telescopic tower can be considered as a feasible solution for the MVP due to the light weight of the wind turbine, tower, and hoisting mechanisms. However, applying the same solution on the full-scale concept could prove to be challenging due to the much heavier weights of the wind turbine and telescopic tower. An option could be to implement an electric motor that raises the tower as was tested in the construction of the functional system prototype. However, this could in turn increase the level of complexity of the system in addition to also adding additional critical parts prone to failure. These are aspects to consider with regard to constructing the product at full-scale, weighting the pros and cons of the different options.

The wheelbase of the MVP allows for it to be transported anywhere as long as there is proper road infrastructure. Furthermore, the quick and easy deployment of the solar panels and wind turbine enhances its level of utilization. This feature could be very prominent for disaster relief since the need for energy is more urgent compared to a construction site where the solution could be deployed a couple of days prior to the start of a project.

6.5 Simulation

The use of FEA analysis utilizing Autodesk Nastran allowed for the structural integrity of the designs to be verified. It is important to note that not all parts in the designed concepts were anayzed, hence, there is still room for further confirmation of the structural integrity in general. However, the two parts analyzed, the horizontal beam of the full scale concept and the pulley system for the MVP, were identified as the most critical parts prone to break when applying load. When calculating the maximum force applied to the horizontal beam, rotational equilibrium was assumed in order to allow for more accurate calculations as no real tests could be conducted on the system due to the full scale concept only existing digitally. In a real case scenario, the horizontal beam would also have a velocity which would affect the forces. However, by assuming rotational equilibrium, accurate results regarding the force required to start lifting the tower could be acheaved. The calculated displacement of 0.02 mm was considered acceptable with room for variation when comparing to calculating the displacement with an additional velocity applied to the horizontal beam. Furthermore, the calculated displacement of $9{,}76 \cdot 10^{-4}$ mm of the pulley system for the MVP could be also considered acceptable. It is important to emphasise that the maximum vertical load possible to be acheaved by the mast was applied to only one pulley system. As the displacement was very small, and the fact that the MVP has two additional pulley systems that would result in a distribution of the load, the structural integrity of the pulley system can be verified.

6.6 Sustainability aspect

This thesis has proved to be highly relevant to the global 2030-agenda goals for sustainability, and especially touches on the following goals [28]:

1. No poverty
2. Affordable and clean energy
3. Decent work and economic growth
4. Industry, innovation, and infrastructure
5. Reduced inequalities
6. Sustainable cities and communities
7. Partnership for goals

Creating portable and environmentally friendly solutions that generate or supply remote areas with energy contribute to sustainable cities and communities. Investments in renewable energy systems from international venture capitals and private businesses accelerate the transition from fossil fuels to renewable and clean energy in developing countries [16]. This could allow them to skip the steps that developed countries had to take with fossil fuelled transportation, as well as nuclear and coal power plants. The more immediate transition results in reduced emissions of toxic substances such as carbon dioxide, methane, and nitrous oxide.

To achieve an increased affordability and availability to clean energy, agencies, countries, and organisations must form strong collaborations with a common goal. It also requires continuous investments in research and development of innovative solutions, much like the concepts of the Oasis and Nomad. There are rural villages that are dependent on fossil-fuel based energy, where the previously mentioned solutions could aid the transition to renewable energy and be a temporary energy alternative during the development of the electric infrastructure. It could also become more viable due to the ever-increasing prices of fossil fuels [6].

High poverty rates and lack of competitiveness is deeply correlated to the lack of electricity in rural developing countries. The extreme remoteness and geographical isolation of villages is a major obstacle when expanding the national grid making it non-viable from an economic standpoint [25]. Various scientific literatures have done field research in Thailand, China, India, and Indonesia with the aim of identifying the impact that a developed infrastructure has on areas affected by poverty. Their results show that a proper energy infrastructure has numerous benefits and an immense impact on poverty reduction. Electrification reduces energy costs, increase agricultural productivity, and promotes the development of small-scale industries, which in turn leads to increased generated income. Electrification also improves the quality of health care services and education, and making people feel safe thanks to the basic need of street lighting [26].

Access to electricity can open possibilities of utilizing electric vehicles such as bicycles, motorcycles, cars, and busses. Investments in transportation also have a positive impact on poverty alleviation. The two key benefits are decreased costs for travel and transportation of goods, and increased range of opportunities such as education, health care services and waged employment [26]. The mentioned effects on poverty alleviation highlight the importance of having a sufficient energy infrastructure which can include the roll-out of off-grid renewable energy solutions, and the expansion of the national grid [25].

7 CONCLUSION AND FUTURE WORK

7.1 Conclusion

As the global population constantly increases in combination with the electrification of vehicles and other equipment becoming more and more common, the need for off-grid energy is becoming critical worldwide. In parallel to this, the phasing out of fossil fuels results in a demand for sustainably produced energy utilizing renewable energy sources. Based on the problem identified, the following research questions were produced:

- What are the needs and possibilities for portable production and distribution of environmentally friendly energy in places with damaged or insufficient infrastructure?
- How does a system of this kind contribute to the global goals and increased quality of life?
- How can a system of this kind be scaled to enable application to specific problem situations?

Extensive research and needfinding including literature review, interviews, and observations with the use of DRM and design thinking as frameworks identified an existing need for sustainable energy generating and distributing solutions. Critical factors including portability, reliability and redundancy was proved to be of significant importance for a potential solution to possess to enter the off-grid energy market. Regarding electrical construction equipment, minimal downtime was identified as critical, hence, the need for an effective off-grid energy distribution solution was identified.

A proposed solution to the identified needs and problems was developed. The proposed solution includes two developed products, Oasis and Nomad, integrated into a system with the aim of generating and distributing sustainable energy for off-grid applications. Oasis was designed as a portable modular hybrid energy generating trailer utilizing different energy modules such as solar panels and wind turbines to produce electricity off-grid. Nomad was externally designed as an autonomous energy storage solution that can transport itself to the area of application. Together, the two productions form a product service system that allow for sustainable energy to be generated off-grid at an optimal location to then autonomously be transported to the location of the energy need. To prove the technical feasibility of the proposed concept, a minimal viable product was created at the scale 1:3.

In conclusion:

- A need for an off-grid sustainable energy generating system was through extensive research and needfinding identified.
- Critical aspect for a potential energy solution being able to address was identified to be portability, reliability, and redundancy.
- A proposal for a sustainable energy system solution was presented.
- The system has been identified to contribute to the global 2030-agenda goals for sustainability with emphasis on goals 1 to 7.
- The system can be scaled for larger, or smaller, application by integrating multiple Oasis and Nomad systems in relation to the energy need.
- An MVP of the Oasis system was constructed using only materials and technologies available on the market which proved the feasibility of the system.

7.2 Future work

The proposed solution presented in this thesis should be considered as the first iteration of the system and therefore some questions have not yet been answered. The development of the MVP and modelling of the concept aimed at proving technical feasibility and system viability, however, some aspects, such as the total efficiency of the charging system were not included in the area of focus and would need to be addressed. As the Oasis and Nomad needs to be transported on public roads, regulations demand certain certifications. Regulations differ between different countries and continents which results in a need for future work regarding certifying the proposed solution and determine what requirements that needs to be fulfilled. The transportation on public roads also results in stricter requirements for the autonomous driving system utilized by Nomad. Today, the system utilized by TARA, the transportation platform used by Nomad can operate in demarcated areas and is not ready for full autonomous transportation on public roads. This autonomous system would need further development in order for the system to be fully operational as described in this thesis.

Furthermore, fuel cell technology is in this thesis identified as a potential energy generation module that could replace the use of diesel generators for backup power. As of today, this technology has not yet proved economic viability, however, in this thesis evidence of future viability has been identified. For fuel cells to be fully implemented in the system, further work in the area of technical implementation is required including design of hydrogen storage containers and placement of the fuel cell modules. The technical feasibility of this implementation should however be considered to be high as other commercial solutions in this area has already entered the market.

The proposed solution was based on the two products, Oasis and Nomad, working together to form a system. However, the use of Oasis or Nomad operating as independent systems was identified as a potential use case for some application areas. This aspect should however be evaluated further in order to determine the impact of having Oasis and Nomad working independently. Also, the specific application areas and the limits of having the products working independently would need to be examined.

In summary, the work conducted, and the proposed solution presented in this thesis was developed to inspire future work and development in the area of off-grid sustainable energy systems. The proposed solution is a first iteration of a potential sustainable energy generation and distribution system which was created to highlight possibilities in the market. In order for this system to be fully operational in the areas of application, further work is required. However, the work presented in this thesis has proved the feasibility and viability of a system of this kind.

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9 APPENDIX

9.1 Appendix A

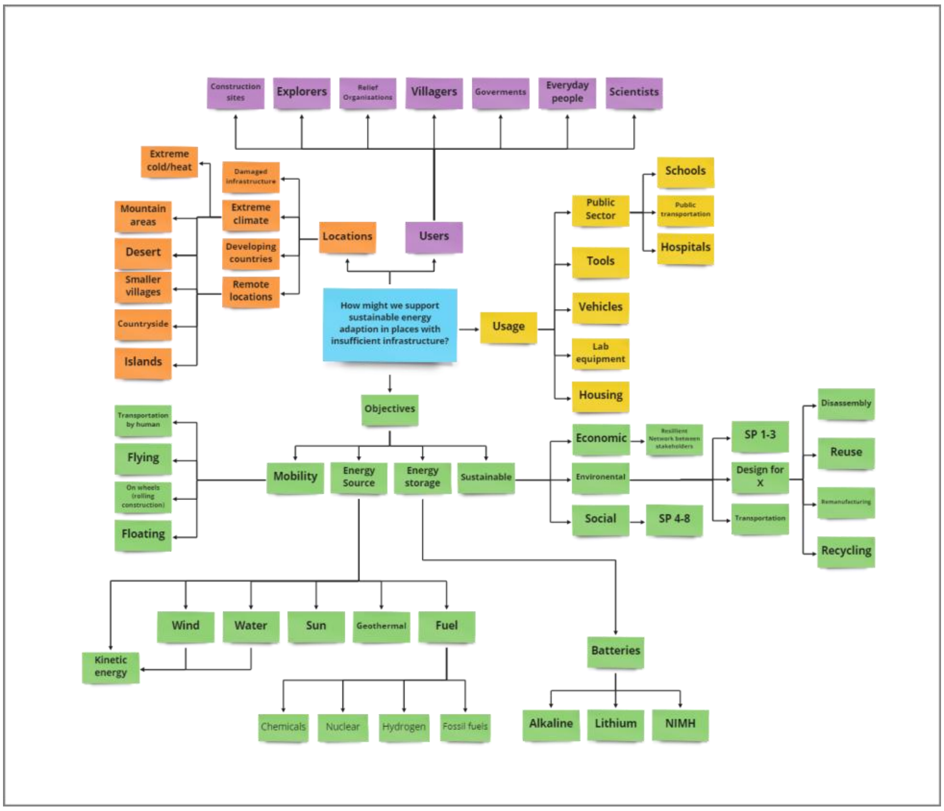

Figure A.1: Concept map.

9.2 Appendix B

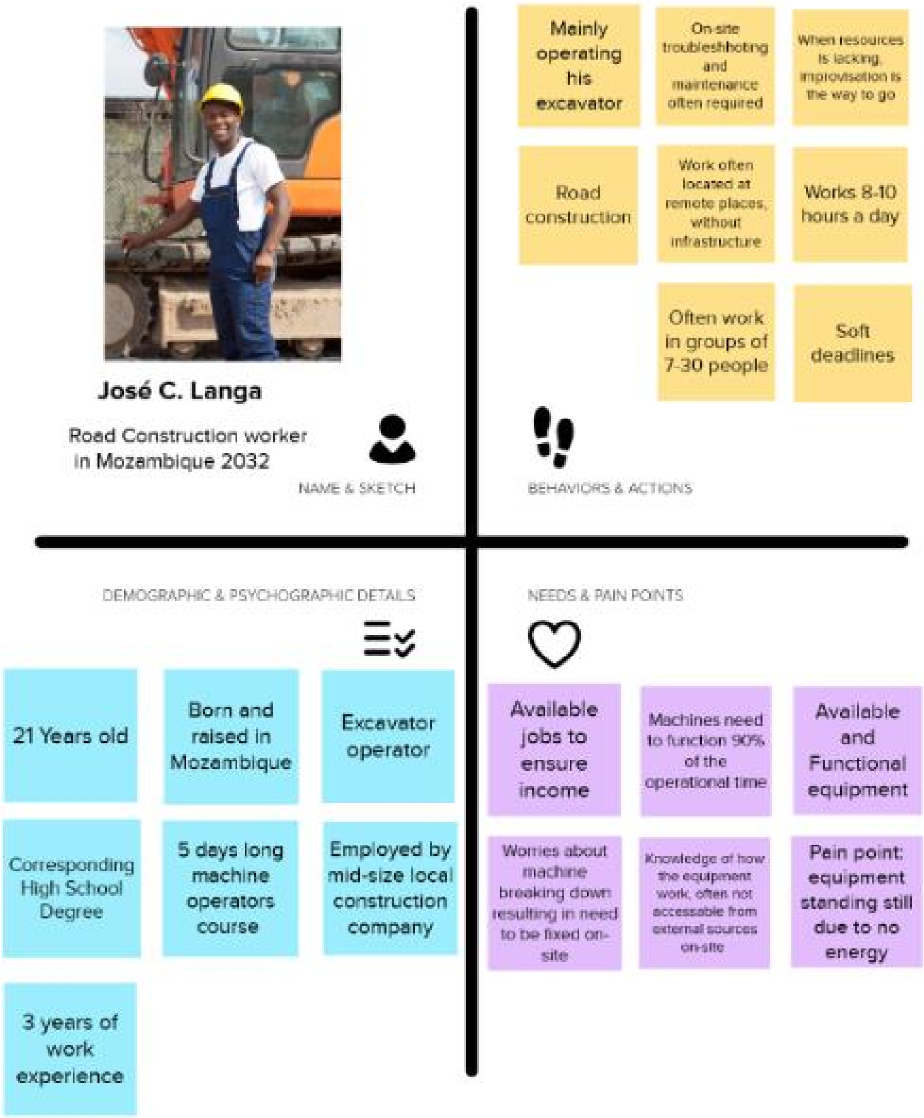

Figure B.1: Road construction persona working in Mozambique.

9.3 Appendix C

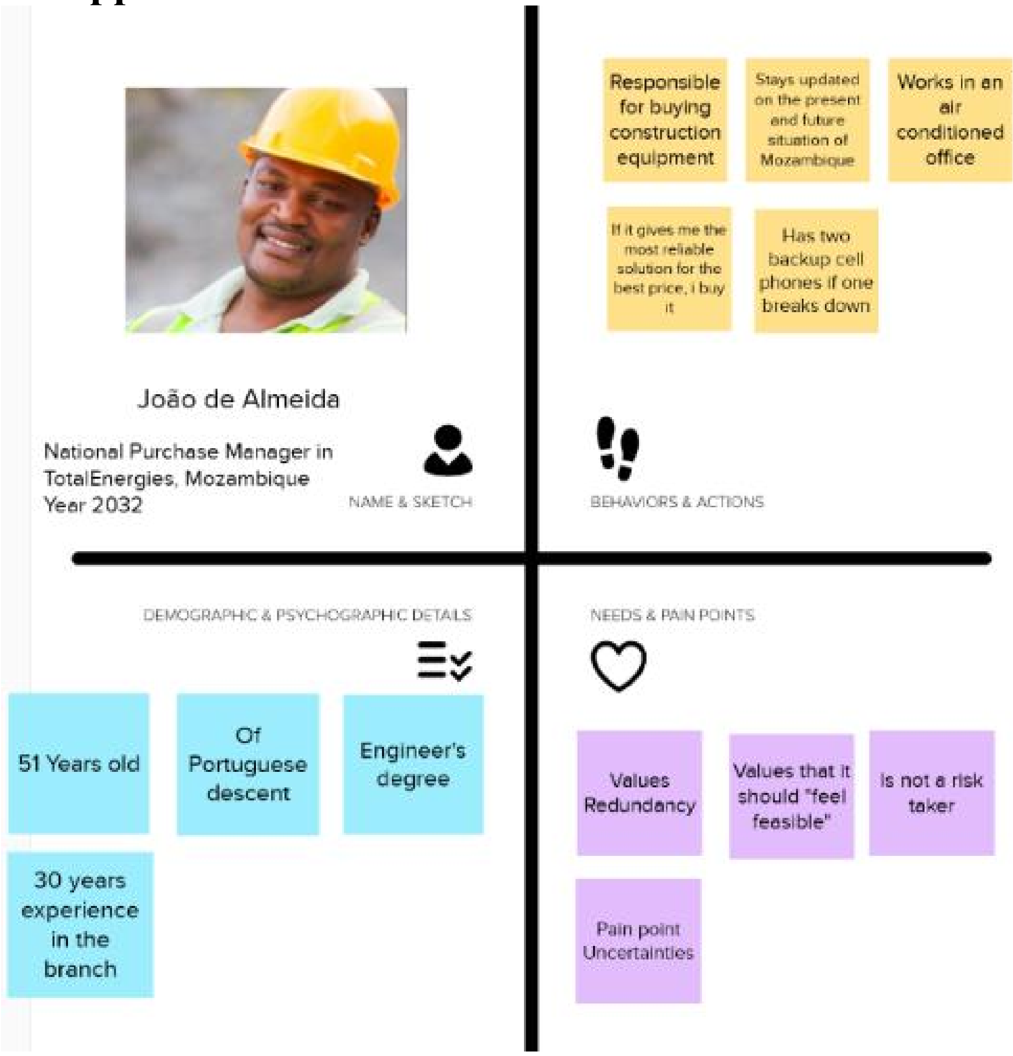

Figure C.1: National Purchase manager persona working in Mozambique.

9.4 Appendix D

```
#include <ezButton.h> //Includes the required imit switch libary

#include <Adafruit_MotorShield.h> // Includes the required motor driver libary

Adafruit_MotorShield AFMS = Adafruit_MotorShield(); //Creates the Adafruit_MotorShield object

Adafruit_DCMotor *myMotor1 = AFMS.getMotor(2); //Created the DC motor object
Adafruit_StepperMotor *myMotor2 = AFMS.getStepper(200, 2); //Creates the stepper motor object

ezButton limitSwitch1(2); //creates limit switch 1 that attach to pin 2;
ezButton limitSwitch2(4); //creates limit switch 2 that attach to pin 4;

const int buttonPin1 = 8;  //defines the input pin from button 1
const int buttonPin2 = 9;  //defines the input pin from button 2

void setup() {
  Serial.begin(9600);

  pinMode(buttonPin1, INPUT); //initializes the pin for button 1 as an input:
  pinMode(buttonPin2, INPUT); //initializes the pin for button 2 as an input:

  if (!AFMS.begin()) { //Connecting to the controller
    Serial.println("Could not find Motor Shield. Check wiring.");
    while (1);
  }
  Serial.println("Motor Shield found.");

  limitSwitch1.setDebounceTime(50); //sets the debounce time for limit switch 1 to 50 milliseconds
  limitSwitch2.setDebounceTime(50); //sets the debounce time for limit switch 2 to 50 milliseconds

  myMotor2->setSpeed(100); //Sets default speed for the DC motor
}

void loop() {
  limitSwitch1.loop();
  limitSwitch2.loop();

  if(digitalRead(buttonPin1) == HIGH && limitSwitch2.getState()==HIGH){ //checks if button 1 is pressed and if limit switch 2 is not activated
    myMotor1->run(FORWARD); //Extends the telescopic tower
    myMotor1->setSpeed(250); //Sets the speed of the DC motor
    myMotor2->step(50, FORWARD, SINGLE); //Raises the telescopic tower
    delay(50);
    myMotor1->run(RELEASE); //Releases the DC motor

  }

  else if (limitSwitch2.getState()==LOW  && digitalRead(buttonPin1) == HIGH){ //checks if button 1 is pressed and if limit switch 2 is activated
    myMotor1->run(FORWARD);
    myMotor1->setSpeed(250);
    delay(50);
    myMotor1->run(RELEASE);
  }

  else if (digitalRead(buttonPin2) == HIGH && limitSwitch1.getState()==HIGH ){ //checks if button 2 is pressed and if limit switch 1 is not activated
    myMotor1->run(BACKWARD); //Retracts the telescopic tower
    myMotor1->setSpeed(255);
    myMotor2->step(50, BACKWARD, SINGLE); //Lowers the telescopic tower
    delay(50);
    myMotor1->run(RELEASE);
  }

  else if (limitSwitch1.getState()==LOW){ //Checks if limit switch 1 is activated to extend the tower a small amount after reaching bottom
     myMotor1->run(FORWARD);
     myMotor1->setSpeed(200);
     delay(50);
     myMotor1->run(RELEASE);
     delay(3000);
  }
}
```

Figure D.1: Arduino code for the functional system prototype.

9.5 Appendix E

Figure E.1: Deployment of wind turbine tower on the MVP.

9.6 Appendix F

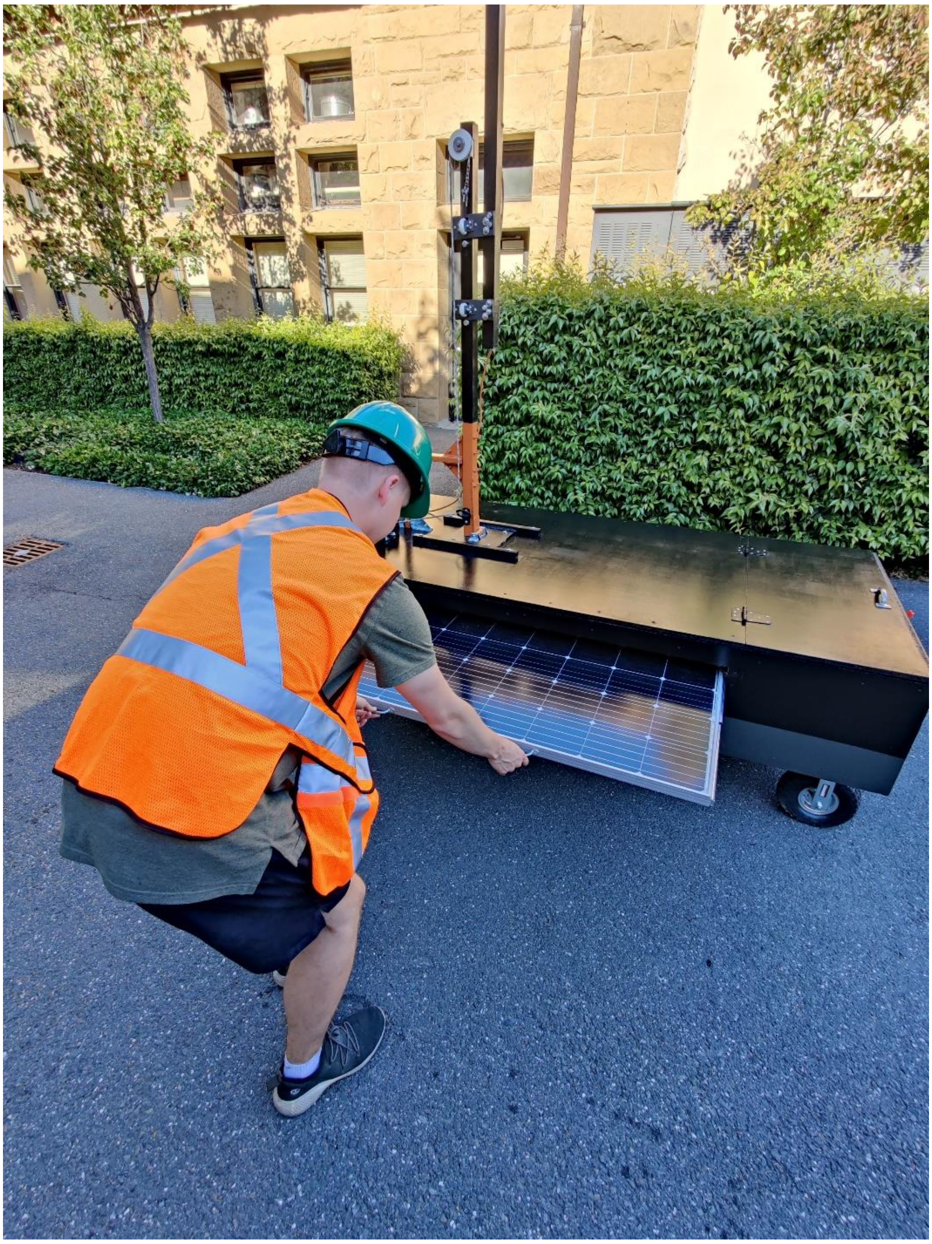

Figure F.1: Deployment of the solar panels on the MVP.

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