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Investigating off-grid systems for a mobile milking facility

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ABSTRACT

This study examined the possible renewable energy sources that can provide the necessary power for a mobile Off-grid Automated Milking System (AMS) at a grazing pasture. This involved choosing the most cost effective, environmental friendly and sustainable mean for a mobile AMS which aims to be operating between months of May to September at a rate of milking 20 cows per day.

The approach involved using weather data, input from the milking system manufacturer-DeLaval along with two models, Insight Maker and HOMER which were used to investigate various renewable energy sources for the mobile facility. Renewables such as Biodiesel, Ethanol, Biogas run generators along with Solar PV panels + Batteries were considered for the current study.

Based on site's specifics and given environment, three main evaluating parameters were used to identify the most suitable renewable energy source. These entailed Net Present Cost, Levelized Cost of Energy, and Levels of CO_2 emissions per year.

In line with the obtained results and comparisons made, the study recommended the adoption of Solar PV panels + Batteries for the mobile facility. Moreover, the study discussed further means for addressing possible challenges that could be encountered upon implementation. Recommendations provided by the manufacturer DeLaval were also highlighted for achieving better energy conservations and hence a more efficient system.

The thesis also highlighted the technological development and the continuing reduction of Solar PV+Batteries costs worldwide along with Sweden's grid and off-grid projections for years 2030 & 2040 and how these both stand in favor of off-grid systems diffusion and adoption in the near future. Yet simultaneously and in order to achieve a successful off-grid system for a mobile AMS, close monitoring and assessing of other factors was recommended. Factors such as the Milking Frequency, Cow and Grazing management, understanding the effects to and from the surrounding environment, maintaining cattle welfare along with grasping the knowledge of both present and future scenarios would help achieve the resilient environmental friendly off-grid mobile AMS facility aimed for.

Keywords: Off-grid systems, Renewable Energy RE, Solar PV, Biofuels, Insight Maker, HOMER

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STORT TACK!!!

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NOMENCLATURE

AMS	Automated Milking System
LCOE	Levelized Cost Of Energy
HOMER	Hybrid Optimization Model for Electric Renewable
IM	Insight Maker Model
IRENA	International Renewable Energy Agency
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
PV	Photovoltaic
RE	Renewable Energy
RTP	Room Temperature and Pressure
SMHI	Swedish Hydrological Meteorological Institute
VMS	Voluntary Milking Station
VMS300	Voluntary Milking Station (Model type300)

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1. INTRODUCTION

Interests in fully automated milking systems routes back to the 1970's. The main driver for adopting such systems, which were first developed in Europe, was the overall growing burden of labour costs associated with the milking process. It was however not until a decade later where more reliable and fully integrated Automatic Milking Systems (AMS) became a reality. In essence this involved automating all the functions of the milking process and cow management (i.e. motivation to visit the AMS) (Koning K. & Rodenburg J., 2004, p.2).

Today Automated Milking Systems are internationally accepted as a valid alternative to conventional milking parlour and an advanced mean for dairy farm management. In fact in the past decade, 8,000 farms worldwide have installed AMSs in their farms (Pezzuolo A. et al., 2017, p.736).

Moving even further, considerations for introducing mobility for the AMS technology is gradually becoming a highly encouraging path. So far, research of AMS in mobile systems has been conducted in several countries, including Belgium, Denmark, France and the Netherlands. The mobility studied here ranged from systems being moved few times a year to daily movement (Neal, M., 2014, p.1). Table 1 lists few key prototypes conducted in various countries.

Table 1. Mobile AMS Prototypes (Van den Pol-van Dasselaar,A. et.al., p.3)

Organization/Country	Year	Number of Cows	Characteristic
Århus University/Denmark	2007	90	Installed in a standard container. Water supply provided by pipe and electricity supply by generator.
University of Liége/Belgium	2010	45	Installed on trailer with an electric point
Trévarez farm/France	2012	45 to 60	Installed on trailer

Initial conclusion for adopting the mobile setup indicated the advantage of milking cows in the field without additional labour. Cows milked using this setup are allowed to stay for longer hours on pasture. Thus, implying fresh air for the cattle, in take of feed on pasture, reduction of problems with regards to removal of manure and nevertheless natural fertilization of land (Gaworski M. & Kic P., 2017, p.402).
Flexibility in land usage is also seen to be another key advantage especially for landowners with high potential new entrants in lease or share-farming arrangements (Neal, M., 2014, p.1). Moreover, the mobile setup in pasture increases the chances of having more farms, even ones not necessarily close to farm centres or barns, to be grazed by the cattle. Having properly managed grazing schemes does not only serve the well-being of the cows but also improves the soil biological activity and results in high productive pastures and better cycling of nutrients within the soil, a characteristic which is significant to both plants and other soil life (Chelsea Green Publishing, 2020).

On the other hand, there are still many factors that need to be thoroughly investigated with the integration of pasture based milking facilities in general or mobile milking in particular. Factors such as the economics of the milk yield, pasture availability and management, along with the practicalities of installing and managing the AMS on site. According to 21 studies covering pasture based milking, a common persistent challenge was within the low levels of Milking Frequencies (MF) (Lyons, N.A.; Kerrisk, K.L.; Garcia, S.C., 2013, p.102). A drawback which has been associated to the low cow traffic. The studies recommended further research within areas of both frequency and location of feed incentives.
Results reported by University of Liége for tests conducted in year 2010 where comparisons were made between indoor and pasture based milking, pointed out clear differences in milk yield between the two. Provided hereunder is an excerpt from the University's first findings when using a mobile AMS:

"The cows were easily accustomed at milking robot indoors and their milk production increased. During the indoors period (60 days), they produced 29.5 kg milk per day (173 days in milk), the mean number of milking was 3.09 and there was 1.06 milking refusal per day. During the period at grass (50 days), the daily milk production was 21.1 kg (215 days in milk), the mean number of milking was 2.12 and the milking refusal was 0.22" (Université de Liége, 2010, p.1).

Realizing the limited research and short history of the mobile AMS's adoption on pasture; explains why there are still many aspects concerning the technology, associated animal behaviour and surrounding environment, yet to be explored. This thesis and through an example from a local farm in Sweden, seeks to contribute its share of knowledge concerning the potential of integrating off-grid renewable systems to mobile AMS facilities on pasture. Key drivers that prompted studying this field of area were:

- *Enhancing self-resilience*: Where there is no requirement to rely on a stationary power point or connection to receive the necessary power supply to run the AMS, thus putting no limits to the mobility of the setup or limitations in logistics.
- *Seeking sustainable and renewable sources of energy*: Hence providing several options to choose from in terms of environmental impact, costs and availability of power sources that would suit a mobile AMS in question.
- *Addressing research gap*: Realizing absence of studies and research concerning power sources for an off-grid AMS sheds both the significance and uniqueness of this study.
- *Transition of energy:* Off-grid renewable energy capacity has witnessed a spectacular three-fold increase from under 2 gigawatts (GW) in 2008 to over 6.5 GW in 2017 (IRENA, 2018, p.2). While a proportion of the deployed capacity is to support household electrification, a majority (83%) is dedicated for industrial (e.g., co-generation), commercial (e.g., powering telecommunication infrastructure) and public end-uses (e.g., street lighting, water pumping) (IRENA, 2018, p.2). Mobile AMS can certainly benefit and

utilize such rapid diffusion and advancements of off-grid renewable systems.

With the potential of integrating a mobile AMS on pasture at Lövsta farm in Sweden, the objective of this thesis entailed examining the possible renewable energy sources that can provide the necessary power for a mobile off-grid AMS. This involved choosing between various sources with considerations heavily weighted on cost effectiveness, environmental impact and sustainability of the energy source within the given environment and potential of utilization. According to Lövsta farm, the anticipated use of the mobile AMS involves milking a total of 20 cows per day during Spring and Summer seasons. Housing of the AMS and associates is expected to be in a 30 feet (9.14 metres) cargo container.

In the following subsections, more information will be given about the Lövsta farm area along with both the aim and research questions of the study.

1.1 Lövsta farm in brief

Seven km south-east of Uppsala lies the Swedish Livestock Research Center at Lövsta. The center which attracts many researchers from private enterprises, local and international researchers incorporates different farms between dairy cattle, pigs and poultry (See Figure 1 below) (The Swedish Livestock Research Centre, 2017, p.3). Besides the farming facilities, exists also a biogas plant in the vicinity. The purpose of building the plant was to ensure the self-sufficiency in both electricity and heat for the surrounding farms. According to the Swedish Livestock Research Centre, (2017, p.7), the facility produces 4 GWh of electricity and a similar quantity of district heating.

Figure 1. Sky view of Lövsta (Swedish Livestock Research Centre, 2013, p. 2)

Since the study entailed means for supporting renewable energy to a potential mobile AMS, hence further discussions will only cover the dairy cows farm (shown above).

The stock at Lövsta farm is made up of about 280 SRB (Swedish Red) and Holstein cows, of which about 250 are lactating. Housed in a heated cubicle systems (free-stalls), the cows are typically grouped into 4 groups (each having between 60 to 64 heads). Where three out of these normally four groups are milked in a milking rotary parlour (DeLaval AMR) with 24 milking places, the fourth group however is milked in an automatic milking system (DeLaval VMS) (The Swedish Livestock Research Centre, 2017, p.16). Details of the AMS equipment used and its respective key components will be discussed in the coming chapters.
As per year 2016, the farm's annual production of milk reported was 2,725 tonnes of milk with an average yield per cow of 10,282 kg.

1.2 Aim

The main objective of the thesis was to investigate the possible renewable energy sources that can provide the necessary power for a Mobile AMS at Lövsta farm. This involved choosing the most sustainable means, particularly cost effective and environmental friendly for the mobile automated milking system that could be used on pasture.

1.3 Research question

The key research question which the study aimed to find an answer for was:

What are the most cost effective, environmental friendly and sustainable means of renewable energy source(s) to be used for mobile Automated Milking Systems that could be used on pasture?

2. METHODS AND LIMITATIONS

Two key pillars built the fundamental approach for answering and addressing the above research question. One was the available Input Data and the other involved the Methodology of using the data.

2.1 Input Data

This entailed all the necessary data needed to facilitate the designing of the renewable energy source for the mobile AMS to be used. This primarily included:

- Data of AMS used in the mobile setup
- Present operational parameters for the stationary AMS and the anticipated mobile AMS setup
- Weather conditions around Lövsta Uppsala region.
- Environmental and Sustainability impacts concerning the considered Renewable Energy source (RE)

Figure 2 (under subsection 2.2) demonstrates details of the required input data in a simple schematic. Details and discussions concerning the data will be addressed in the following chapters.

2.2 Methodology

One key tool used in assessing the considered renewable energy sources for the mobile AMS, was modeling software Hybrid Optimization of Multiple Energy Resources (HOMER). This originally developed software at the National Renewable Energy Laboratory (NREL) nests three powerful tools in one product, so that the engineering and economics work side by side (Homer Energy, 2020).
Another assisting software was the Insight Maker model (Insight Maker, 2020). Prime aim for using this software was to represent energy consumptions and reflect how these were divided between the key components of the AMS of interest.

The obtained set of input data mentioned earlier was processed into the software to help provide conclusive results. Using the Simulation, Optimization and Sensitivity Analysis tools, HOMER is able to provide a thorough highly reliable and yet quick estimated design for both off-grid and grid connected composed of various types of modules (from both renewable and non-renewable sources). Following are few key features of each tool.

- **Simulation:** Here, the software attempts to stimulate a viable system for all possible combinations of the equipment that the operator would wish to consider (hundreds to thousands of systems may be simulated).

- **Optimization:** All possible combinations of system types are examined in a single run and sorted according to the optimization variable of choice. This for instance helps identify least-cost options for the chosen combination.

- **Analysis:** Questions like "What if?" get addressed using this tool. Since not all aspects of a system can be controlled or weighted in terms of importance, this tool helps the operator see the impact of variables beyond his/her control. Prime use involves understanding how variables such as wind speeds, fuel costs etc. may change and affect optimal systems through time (Homer Energy, 2020).

In addition to the modeling results, studies covering both environmental and sustainability aspects of the proposed system and energy source were also taken into consideration.

The combination of both tools, being utilized (i.e. modeling softwares and other aspects), were intended to provide a holistic approach in studying the feasibility of this pilot project. While the two models namely the Insight Maker and HOMER helped reflect the magnitude of power consumption, level of costs associated and emissions put out into the environment; other supplementing yet significant factors such as the practicalities and sustainability of the AMS-Renewable Energy source setup provided even a greater insight and hence a better picture of the system altogether. Figure 2 below reflects the input data used in the models along with the anticipated outcome. Provided, too, are the other key parameters that were looked into (i.e. environmental and sustainability factors).

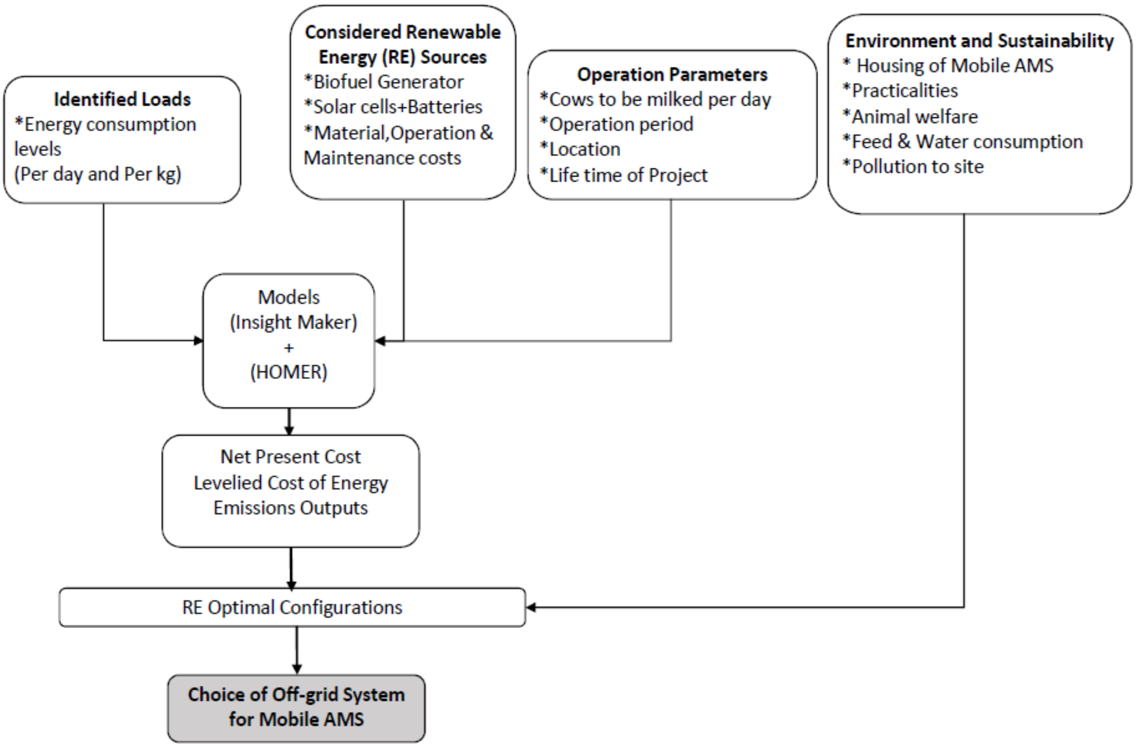

Figure 2. Methodology approach chart

2.3 Limitations

The limitations in both time and resources have inevitably affected the particulars of the results. Certainly, this included lack of a detailed design concerning the considered and recommended renewable energy source(s) and mobile AMS setup as a whole.

Finding relevant and reliable papers covering the subject was a challenge, especially since the mobile AMS setup is a fairly a new concept and continues to be in the research phase.

3. BACKGROUND

As discussed earlier, the thought behind considering a mobile Automated Milking System was without doubt a compelling one. However, question(s) which remained unanswered was how this can be achieved in terms of power supply and setup. Prior to any discussions of any potential setup, it was important to identify the appropriate renewable energy sources to be considered.
Factors such as site weather conditions, the surrounding environment and practicalities in general formed the basis of the choice.
In the following subsections, a closer look into the environment where the potential AMS may be operated was examined. Consequently and according to this input a list of potential renewable energy sources were compared to conclude ones which best suited further exploring.

3.1 Insight into surrounding weather conditions

For the purpose of this study and due to the clarity and simplicity of weatherspark's presented plots, preliminary conclusions concerning Lövsta weather conditions were derived from below graphs (i.e. Figures 3, 4 and 5).

3.1.1 Graphs from Weather's park website

The following graphs shown in Figures 3, 4 and 5 represented key ones derived from Weather's park website:

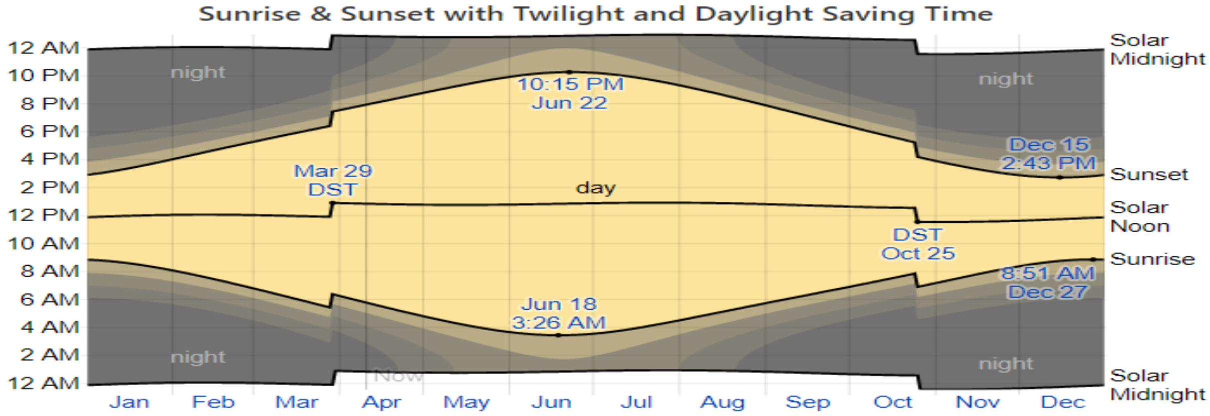

Figure 3. Sunrise and Sunset in Uppsala city year 2019 (Weatherspark, 2019).

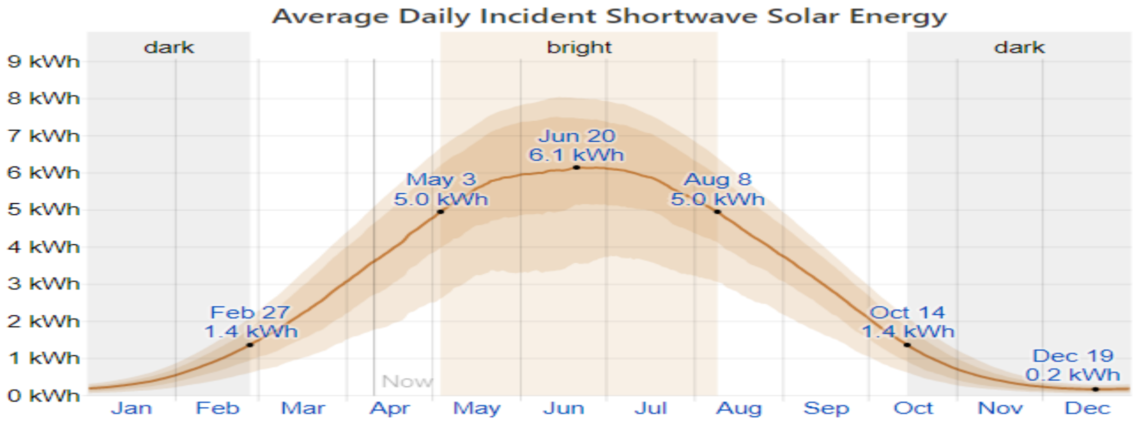

Figure 4. Average daily incident shortwave Solar Energy in Uppsala city year 2019 (Weatherspark, 2019).

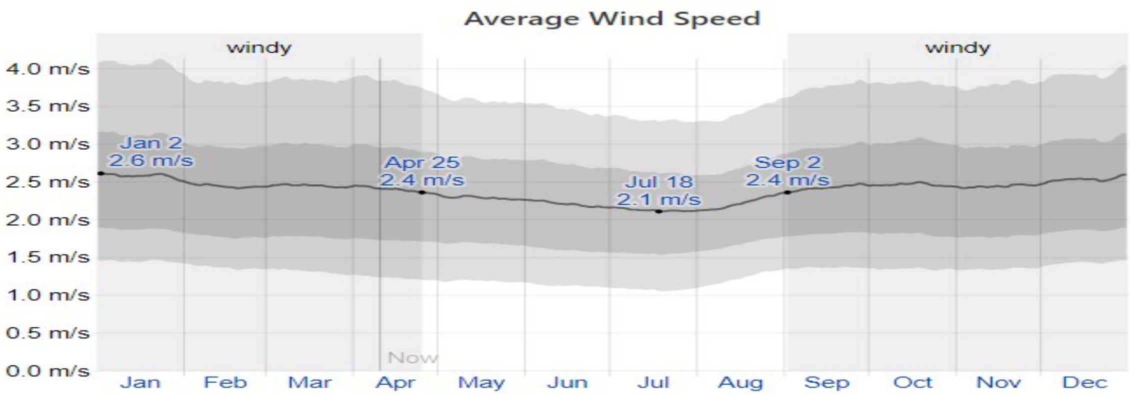

Figure 5. Average Wind Speed in Uppsala city year 2019 (Weatherspark, 2019).

3.2 Considered renewable energy sources

Prior to discussions of any potential setups, it was important to identify the appropriate renewable energy sources (REs) to be considered. Factors such as site weather conditions, the surrounding environment and practicalities in general, formed the basis of the choice.

The commonly used renewable energies examined for consideration were: Solar, Wind power and Biomass energy. The reason for choosing these was that these are all commonly used within off-grid setups and provide rather low costs per kWh. Another factor was the abundance of their primary energy sources (e.g. solar radiation, wind and biofuel).
Comparing these renewables to each other provided a better picture of which one suited the mobile AMS best. Table 2 reflects a set of parameters, where these three REs were compared and shortlisted in this study for further investigation.

Choice of the suggested parameters provided in Table 2 was intended to provide a first impression regarding the REs. The parameters helped reflect how cost-effective, sustainable and practical these considered REs were for this particular study. For instance, parameters such as ***availability of energy sources*** and ***abundance of primary energy sources*** indicated how sustainable the REs and their corresponding energy source were. Similarly, the minimal environment impact parameter helped demonstrate the environmental aspects. In terms of REs cost-effectiveness the ***overall cost per kWh*** parameter was a satisfying indication. In addition to this, an important characteristic for consideration was how practical these REs were in terms of installation and mobility. Thus, the two parameters of ***practicality*** in both ***setup installation*** and ***mobility*** in ***operation*** helped to point out any possible shortcomings in installing or operating these within a mobile setup.

Table 2. Comparison of REs (G, Good; A, Average; P, Poor).

Potential RE	**Availability energy source**	**Abundance primary energy source**	**Applicable in given environment**	**Practicality in setup installation**	**Practicality Mobility in operation**	**Minimal environment impact**	**Overall cost per kWh**
Solar	**G**	**G**	**G**	**G**	**G**	**G**	**A**
Wind	**A**	**G**	**G**	**P**	**P**	**A**	**G**
Biomass	**A**	**G**	**G**	**G**	**G**	**A**	**G**

As indicated in Table 2, the solar power was the most promising renewable energy amongst the three, and biomass energy (biofuel) came as the second best option. Although, all these three renewables have abundances in their respective primary energy sources (i.e. wind, solar radiation and biomass) and may certainly be applicable to function within the surrounding environment, there were other parameters which indicated ones being more reliable than others. For instance, the availability of the energy source at the site during the operational months (i.e. Lövsta/Uppsala area between May and September).
Referring to weather data from Lövsta area, it was concluded that the solar power finds its ideal environment with both the longer days and the highest solar energy potential during the intended operational period. This was certainly unlike the levels of wind speeds which undoubtedly drop during the same period of the year. Similarly, the absence of a nearby biofuel filling station (except for biogas supply) within Lövsta's area was not the ideal circumstance. Hence, due to these reasons, both biomass and wind powers scored an average score in terms of the availability of their energy source. With regards to the practicality in both setup installation and room for mobility, the wind power scored the least. The reasons for this was that the

nature of a mobile wind turbine would neither be feasible nor would it be practical to have a stationary turbine connected to a mobile setup (i.e. AMS).
Attributes for the average scores to both biomass and wind powers within the minimal environmental impacts was that the first and through the biodiesel generator create noise and pollution, while the second if installed, could create risks for the birds.
The overall general cost was also a significant parameter to take into consideration. According to the US Department of Energy, wind and biomass have relative lower average cost (0.04 USD – 0.12 USD per kWh) than solar (0.21 USD – 0.81 USD per kWh) (Zhang Z. & Sun M., 2017, p.242). With these figures, this implied that solar power scored the least for this parameter.
In consideration of the above, it seemed obvious that only the solar and biomass energies were to be taken further in this study to examine how reliable and successfully these could be in providing the necessary power to the potential mobile AMS.
Unlike solar, there are certainly many types of biofuels to choose from (Ethanol, Methanol, Biogas, Biodiesel etc.). However, what is significant for this project, was to seek and investigate fuel(s) which are readily available, environmentally friendly, and practical to use within the mobile AMS setup. Presented below, are a set of characteristics which helped understand the choice of fuels to be investigated further for the study:

- *Readily available*: Availability of the fuel (being an integral part of the system) is quite significant as this affects the sustainability of the whole AMS system. Generally speaking, fuels such Biogas, Ethanol and Biodiesel were found to be quite accessible and within the vicinity of Lövsta's farming area. While both Ethanol (E85) and Biodiesel (B100) were available in filling stations within Uppsala city, biogas may be even more readily accessed within the vicinity of the farm, if the locally produced gas there was found to be useful and suitable for the AMS setup. Methanol on the other hand, unlike other fuels, was not quite common in Swedish markets or filling stations.
- *Practicality in usage*: With the mobile AMS to be installed inside a 30 feet (9.14 metres) cargo container, finding room for the power generator and other accessories becomes another challenge. Therefore, it was quite important that the fuel setup takes less of a space. This implied that liquid state fuels (at Room Temperature and Pressure-RTP) may be favored in this circumstance, since these tend to accommodate less room. Biogas which is gas at RTP would certainly occupy more room either due to the need of a Reformer or the storage of the fuel itself (e.g. in Gas cylinders). So in terms of practicality usage, fuels such as Ethanol and Biodiesel appeared to be more favorable from this perspective.

Understanding the significance of above characteristics especially in terms of the availability of the biofuel, it was then concluded that Ethanol, Biodiesel and Biogas fuels would be the ones to be studied further.

In order to be able to examine and conclude the outputs for introducing those two types of renewables to the mobile AMS, it was important that one should first understand how the current stationary AMS operates. The details covering this vital information are presented in the following chapter.

4. SYSTEM DESCRIPTION

Representing the Automated Milking System (AMS) used in Lövsta farm is the Voluntary Milking System (VMS300) model manufactured by the dairy and farming producer DeLaval. The following sub sections will discuss the major components forming the VMS300, it's milking procedures and energy requirement.

4.1 Major components

Designed to provide a complete automatic milking solution in a cow-friendly, hygienic and efficient way the VMS300 station comprises of the following major components:

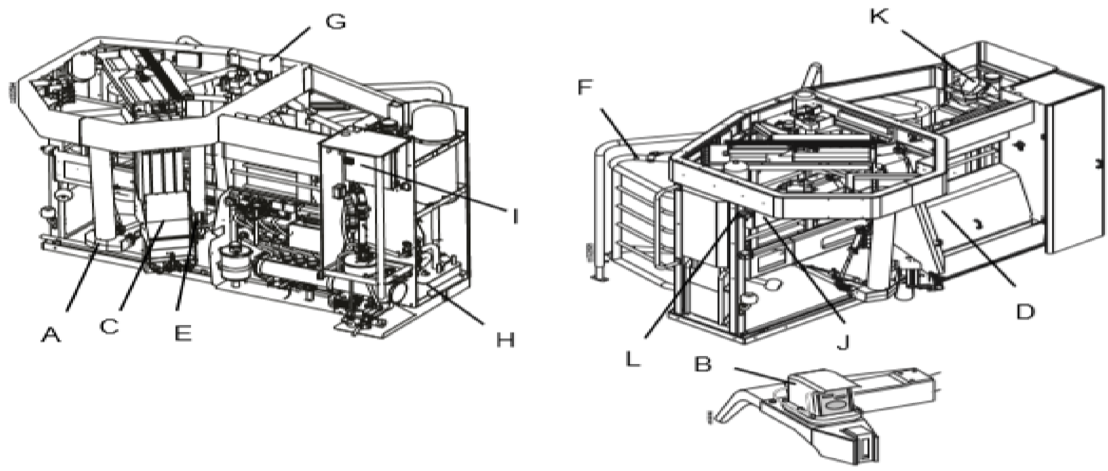

Figure 6. VMS300 major components (Instruction Book, 2007, p.21).

A: Multi-purpose arm **B:** Camera Unit **C:** Magazine **D:** Milking Module **E:** Teat Preparation module **F:** Stall and Gates **G:** Hydraulic Pump unit **H:** Cleaning unit **I:** Power box **J:** Electrical box **K:** Feeding module **L:** Services switch (Instruction Book, 2007, p.21).

4.1.1 Multi-purpose arm

One key integral unit of the VMS300 station is the Multi-purpose arm. The arm which is driven by hydraulic cylinders, equipped with two lasers and a camera performs the following seven basic operations during the entire milking process:

1. *Fetching the teat preparation cup from its home position*
2. *Holding and moving the teat preparation cup to each teat during teat preparation, and finally releasing the cup*
3. *Fetching the teatcups from the magazine*
4. *Locating and recognizing teats*

5. *Attaching the teatcups*
6. *Holding the milk tubes*
7. *Post-treatment of teats* (Instruction Book, 2007, p.22).

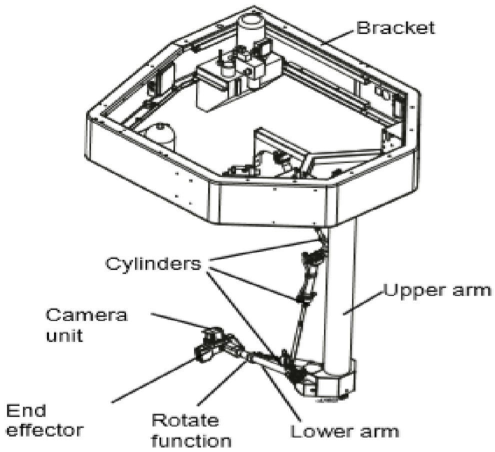

Figure 7. Multi-purpose arm sketch Figure 8 Mutli purpose arm
(Instruction Book, 2007, p.22) and (DeLaval, 2010, p.2) respectively.

4.1.2 Magazine

The Magazine contains the teatcups, milk tubes and the teat preparation module. At appropriate levels the magazine releases and retracts both the milk tubes and the teatcups during the milking process (Instruction Book, 2007, p.24). The teat preparation module however is in charge of teat cleaning, drawing foremilk and drying teats (Instruction Book, 2007, p.29).

4.1.3 Milking module

In the Milking module, a quarterly milking is carried out i.e. the module milks each quarter separately. The performed tasks involve monitoring milk flow, measuring the quantity of milk, supplying the correct vacuum levels in the milk tube and initiating teatcup removal at the proper time (Instruction Book, 2007, p.24). One key unit forming the module is the milk pump. This pumps the milk to the storage tank after milking each cow.

4.1.4 Cleaning unit

In the integrated Cleaning unit, the detergents are pumped into the charge vessel where these are mixed with warm water to ensure the cleaning of the teats prior and after milking and that the teat cups are rinsed between the cows (Instruction Book, 2007, p.33).

4.1.5 Feeding module

The feeding from the dispensers is collected in a funnel. The feed via a tube is lead to the manger which has a transponder reader that identifies each cow carrying a transponder (Instruction Book, 2007, p.35).

In addition to the above key components, comes also other essential units that are connected to the VMS300 station. The key ones which are displayed in the figure below, include: The Milk tank (C) , the Vacuum Pump (F), the Compressor (H), the ventilator (J), and the Chiller (N).

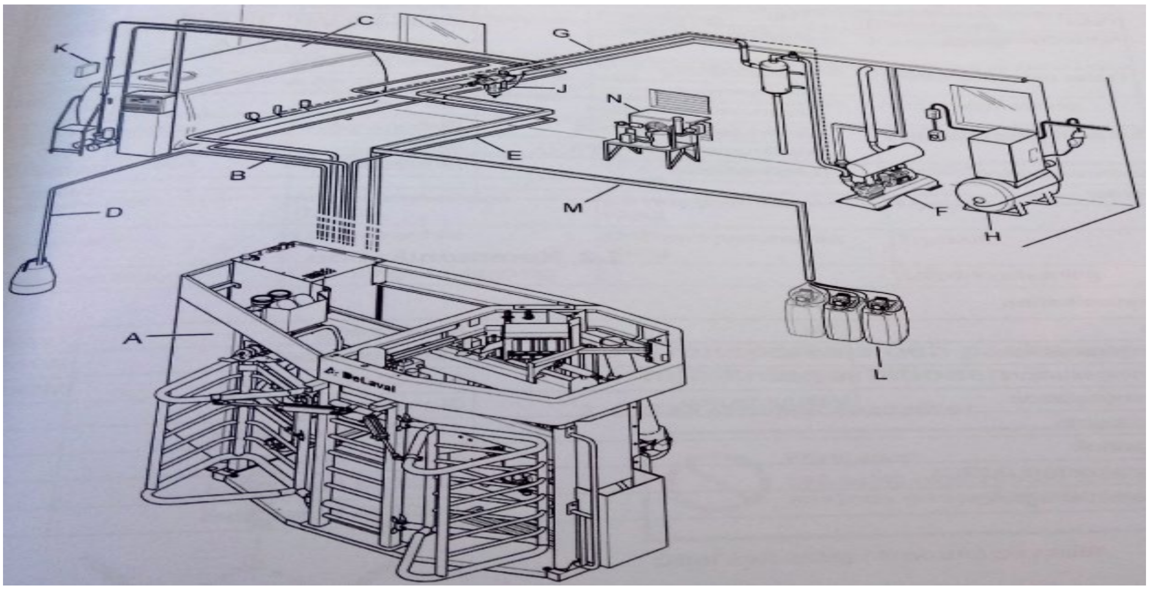

Figure 9. Typical VMS and key associates (DeLaval_Catalogue_English, 2014, p.48).

4.2 Milking session

4.2.1 Entry (Feeding)

When the cow (one ready to be milked) enters the milking station, she is delivered with a customized supplement feed mix.

4.2.2 Preparation

Following the entry step, the cow will be prepared to be milked. The preparation process involves the removal of an equivalent of 45 seconds amount of milk from the cow's udder and teats. This is achieved with a pre-spray with two nozzles on the cow's teats using a combination of water, air and even soap. Once cleaned, a dedicated cup is attached onto the concerned teats. The cup's function is to stimulate, strip, clean and dry the teat to make it ready for the actual milking process. Each teat goes through this same procedure one at a time by the robotic arm (Westberg, M., 2009, p.3). It is also during this process that the pre-milk is collected, transported and dumped using separate lines and containers to avoid any risks of cross contamination (DeLaval VMS V300, NoDate, p.16).

4.2.3 Milking

Once the preparation cups are removed, the second set of cups (i.e. milking cups) are attached to the teats and the milking process commences. According to both, the analysis made by the VMS in terms of the milk quality and contamination along with the pre-set criteria set by the operator, the drawn milk will be diverted to the applicable destinations (e.g. milk tank, dump etc.) (DeLaval VMS V300, NoDate, p.18). After completion of the milking step, the teats are sprayed again with a combination of water, air and soap and the cow is let out from the booth.

4.2.4 Cleaning

To maintain a high level of milking hygiene, both the booth floor and the teat cups are automatically cleaned after the milking step is completed (Westberg, M., 2009, p.4). Moreover, after each milking session, a full cleaning flush of the prep, milking teat cups and hoses (outside/inside) takes place. Included too in the process is the cleaning of both the camera and station's deck (DeLaval VMS V300, NoDate, p.18).

Figure 10. Typical VMS during a milking session (DeLaval_Catalogue_English, 2014, p.48).

4.3 Energy Consumption

As per direct correspondence with the manufacturer DeLaval and their research data on other sites within Sweden, it was found that the total energy consumption was represented through 4 main components: (a) VMS300 (AMS type and model), (b) Vacuum Pump, (c) Compressor and (d) Cooling System (See Table 3).
Table 3 below presents the energy consumption for these 4 main components provided in two sets of forms. One being kWh per 24 hours and the other being kWh per 1000 kg of milk.

Table 3. Total energy consumption (Klass, I., 2020) & (TerWeele, J., 2020)

Component	Energy Consumption			Peak Power (kW)
	Energy consumption (kWh) per 24 hours	Energy consumption (kWh) per 1000 kg of milk	Rated Power (kW) per 1000 kg of milk	
VMS300	8.94	2.79	3.11	1.52
Vacuum Pump	17.40	5.44	7.41	1.88
Compressor	15.98	4.99	5.54	6.28
Cooling System	22.40	7.00	8.53	2.50
Total	64.72	20.22		

As per DeLaval's input, the Cooling system here involves a 6,000 litre tank with a 4.5 kW condensing unit (using 35°C to 4°C) which results into 11 kWh per 1000 kg. However and as per DeLaval's advice installing a pre-cooler plate helps cut the energy consumption considerably. Savings up to 58% can be achieved, hence resulting in a total energy consumption drop from originally 11 kWh to 7 kWh for the cooling system unit as stated above in Table 3.
According to DeLaval, the Cooling system kWh per 24 hours figure given above reflects the total capacity of the VMS300 robot which presents 2,800 kg per 24 hours.

Another factor that needed to be noted and taken into account was the average milk yield per cow during a milking session. In this case and according to DeLaval the milk yield happened to be 20 kg. By incorporating this value it meant that in essence and in order to produce 1000 kg of milk (1000 kg / 20 kg per cow) a total number of **50 cows** needed to be milked. It can also be derived that with a 64.7 kWh per 24 hours a total of 160 cows could be milked (50*64.7)/20.22). However, by looking back at the total capacity of 2,800 kg per 24 hours this translated to a maximum number of cows being (2,800 / 20) rather **140** cows instead.
In summary, the total energy consumption per 24 hours was 64.72 kWh ≈ **65.00 kWh**, while for a 1000 kg of milk yield this concluded to 20.22 kWh ≈ **21.00 kWh** or in other words 21.00 Wh per kg.

In support of the above concluded figures (i.e. 65 kWh and 21 kWh), other farm test results have shown similar values. Figure 11 below displays VMS energy consumption summary results obtained through the Danish Agricultural Advisory (Dansk landbrugsrådgivning). Note how the red circled electricity consumption kWh per 1000 kg of milk figures, i.e. 24.7 and 19.4 were not far away from the earlier concluded value of 21 kWh.

Electricity consumption measured per AMS per ton of milk and per milking				
Make of AMS – Breed of cattle	Number of milkings per 24 hrs. per AMS	Number of cows per AMS	Electricity consumption per ton of milk	Electricity consumption per milking
RDS Futureline – SDM	161	64.7	33.7 kWh	0.36 kWh
VMS (1) SDM	163	61.3	24.7 kWh	0.32 kWh
VMS (2) – SDM	159	67.0	19.4 kWh	0.27 kWh
Astronaut 3 (1) – SDM	186	66.5	19.4 kWh	0.20 kWh
Astronaut 3 (2) – SDM	172	57.5	20.5 kWh	0.21 kWh
Merlin (1) – SDM	134	62.6	41.0 kWh	0.44 kWh
Merlin (2) – SDM	141	58.0	31.4 kWh	0.33 kWh
TITAN – SDM	309	133.3	57.6 kWh	0.54 kWh

Figure 11. Test results from the Danish Agricultural Advisory (Farm Test Cattle # 61 2009, 2009, p.9).

Similar values have also been noted with regards to the power consumption per 24 hours. According to the Danish Agricultural advisory report these corresponded to 52.30 kWh and involved the milking of 122.5 cows. Should the concluded 65 kWh energy consumption be applied for 122.5 cows instead of 140, then the energy consumption will result into a value of 56.88 kWh ((65*122.5)/(140)) which is close to the corresponding 52.30 kWh figure.

4.4 Energy Costs

Along with the total energy consumption figures, the energy cost per kWh was one key significant parameter to be used in the model. According to Statista (2019) and as of 2018 the average **industrial prices** of electricity consumption amounted to 7.06 Euros per kWh. In today's currency exchange rate, this was equivalent to 77.05 SEK per kWh (Rate exchange being 1 Euro equivalent of 10.9135 SEK) (Xe, 2020).

By referring to the earlier total energy consumptions, the corresponding costs were concluded as follows:

Total kWh per 24 hours = 65.00. In terms of costs this computed to be (65.00 * 77.05) **5,008.25 SEK**.
Total kWh per 1000 kg of milk = 21.00. In terms of costs this computed to be (21.00 * 77.05) **1,618.05 SEK**.

4.5 Water Consumption

The water supply to the milking station bares its significance when it comes to the overall design of the mobile AMS setup. Identifying the water consumption levels per an entire milking session or 1000 kg of produced milk helped conclude the total magnitude of water quantity required.

According to the farm tests sponsored by the Danish Agricultural Advisory the water consumption levels per an entire milking session for a VMS milking stations setup ranged between 4.64 to 5.62 litres; whereas per 1000 kg of milk and 24 hours these have been found to be in the respective ranges (328 to 432 litres and 735 to 915 litres) (Farm Test Cattle # 61 2009, 2009, p.9) (See table 3 below).

Table 4 Total water consumption for VMS milking station and associated units (Farm Test Cattle # 61 2009, 2009, p.9).

Range	Water Consumption (Litres)		
	Per Milking session	**Per 1000 kg Milk**	**Per 24 Hours**
Minimum	4.64	328.00	735.00
Maximum	5.62	432.00	915.00
Adopted	**6.00**	**440.00**	**1000.00**

To ensure that the mobile setup receives the required water supply, a roundup of the maximum figures as shown in above table was adopted.

4.6 Water Costs

Similar to electricity costs, water costs was also noted and known to facilitate the overall design of the mobile setup. According to Uppsala's vattenfall the water fee rate was 5 Swedish Öre/litre (i.e. 0.05 SEK/litre) (Uppsala Vatten, 2020).

With reference to the earlier total water consumptions, the corresponding costs were concluded to be as follows:
Total water consumption per 24 hours = 1,000.00. In terms of costs this computed to be (1,000.00 * 0.05) **50.00 SEK**.
Total water consumption per 1000 kg of milk = 440.00. In terms of costs this computed to be (440.00 * 0.05) **22.00 SEK**.

4.7 Feed Consumption

The prime purpose of having feed provided at the automated milking stations such as the VMS is to motivate the cows to voluntary enter the station. In addition to this, the feed also generally helps promote frequent milking. A significant factor which enhances higher milk flow yield per hour on a given number of cows.
Whereas the common reasons for serving feed are known, both type of feed mix and quantities per visiting cow remain dependent on other factors and parameters. According to DeLaval, depending on the kind of cow traffic scenario (e.g. free-flow/feed first pre-selection or Milk first pre-selection) both levels of grain and quantities must vary. In these different scenarios, typical feed consumption levels ranged between 2 to 4 Ibs (0.91 to 1.82 kg) i.e. a max of **1 to 2 kg per cow's visit** to a VMS. (DeLaval, 2016)

Translating these figures into the amount required of feed for 24 hours (i.e. 140 Cows as derived earlier); this then computed to a range of **140** to **280 kg** (i.e from 1*140 to 2*140).

Whereas for a 1000 kg produced milk (i.e. 50 Cows); the feed mounted to typical **50** to **100 kg** (i.e. from 1*50 to 2*50).

5. RUNNING THE INSIGHT MAKER MODEL

Two different modeling paradigms that the Insight Maker typically supports are System Dynamics and Agent Base Modeling. Following is a brief description of these:

System Dynamics: concerns itself with the high-level behavior of a system. It helps understand the aggregate operations of system on a macro-scale. An approach which works best for cutting away unnecessary detail and yet focuses on what is truly important in a model (Features, 2020).

Agent Base Modeling: allows modeling individual agents within a system. Whereas in System Dynamics, the population as a whole is being looked at, in Agent Base Modeling, each individual in the population can be investigated. Moreover, differences and interactions between these individuals could be possibly explored (Features, 2020).

Using the methodology approach chart provided earlier in Figure 2, suggested that the System Dynamics model would be the ultimate suitable choice at least for this level of investigation and anticipated depth of conclusions.

The System Dynamics models are typically structured into a set of basic building blocks also known as “primitives”. The key primitives involve:

- **Stocks:** These represent typically a material store. Example of this in this current study could be the Existing AMS and its associates of Total Power Consumption per day.
- **Flow:** This flows between the stocks. An example of this would be Power consumption per day of a Compressor.
- **Variables:** These are dynamically values or constants that could be fixed values or be governed by an equation that changes over time. Cost rate of electricity per kWh could be an example.
- **Links:** At times two primitives are related in some way. One way of presenting this relationship is by having a link.

Using the set of figures concluded in the previous chapter, a new set of figures were drawn, connected and presented using the IM model.

Since energy consumptions represent one key factor in designing the optimum mobile AMS system, it was important that the consumption rates (kWh per day, kWh per 1000 kg) and the corresponding components namely VMS300, the Vacuum pump, Compressor and the Cooling System were clearly presented. Figure 12 below reflects the four main components of concern. The IM model figure illustrates the energy flow from today's existing energy supply within the stationary AMS and how this is divided amongst the four key components. Rates of consumption for each component is also indicated by the various oval shaped forms (e.g. Energy Consumption-1-kWh).

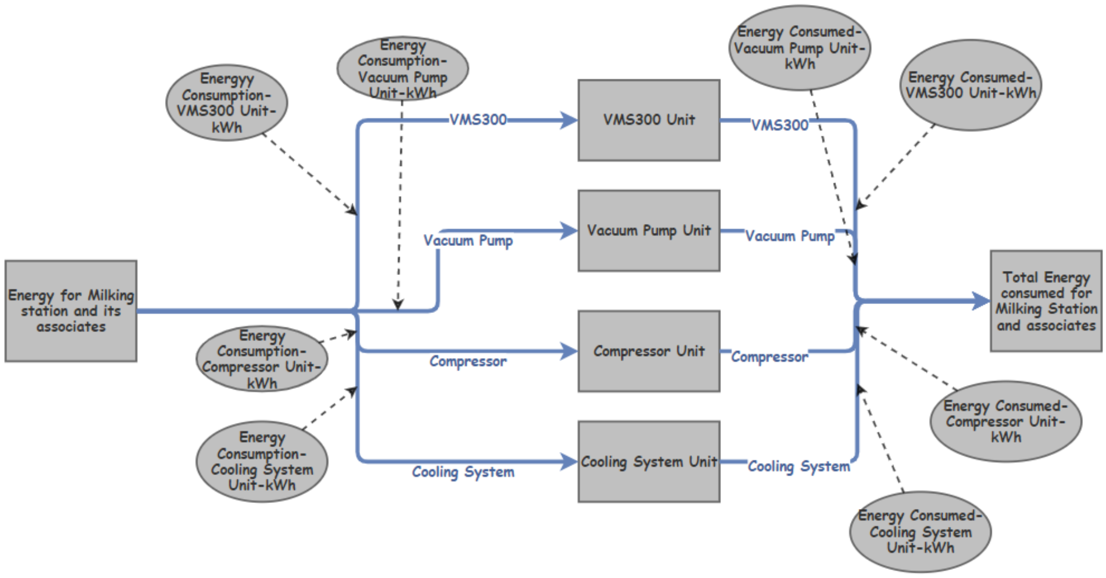

Figure 12. Typical Energy consumption for the AMS facility (VMS300) and its ssociates (Insight Maker, 2020)

Figure 13 below depicts the IM model illustration shown in Figure 12 where the energy consumption levels for the components at Full Capacity is reflected. The anticipated energy consumption levels at the end of the day are expected to reach 8.94, 17.40, 15.98 and 22.40 kWh for the VMS300, Vacuum Pump, Compressor and the Cooling System units respectively.

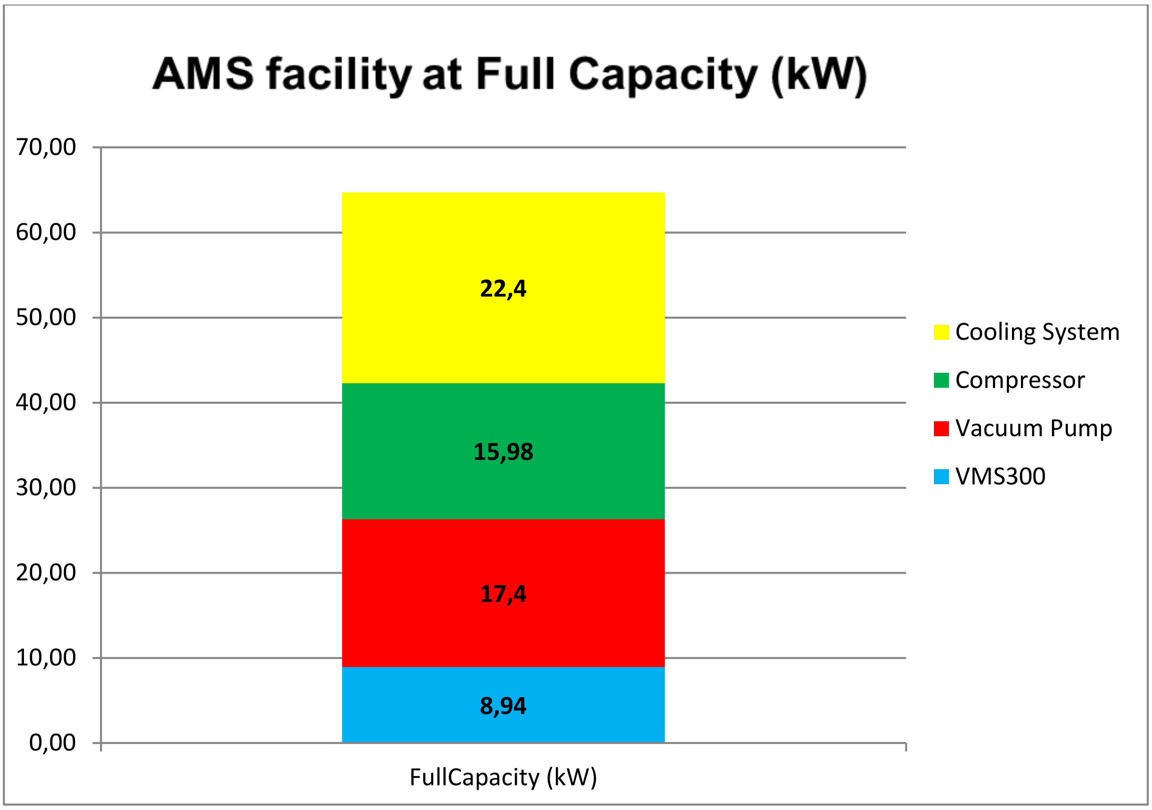

Figure 13. Total Energy Consumption for AMS (VMS300) facility and its associates at Full Capacity

In order to present the energy consumption levels for a 1,000 kg of produced milk or number of cows to be milked per day, these needed to be incorporated within a fixed time frame (*i.e.* 24 hours). Having a unified presentation of these various energy consumptions not only established a consistent unit of measurement but most importantly facilitated the derivation and comparison of any available choices. Table 5 below provides the corresponding conversions for what has been concluded earlier along with rows 3 and 4 of the table which represent 500 and 400 kg of produced milk along with their corresponding derived kWh per day – being 11.0 and 9.0 respectively.

Table 5 Energy consumptions presented in kWh per day

*Rounded up figures

Type	kWh	Typical No. of cows	kWh per day
Full Capacity of AMS and associates	65	140	65.0
1,000 Kg of produced milk	21	50	21.0
500 Kg of produced milk	10.5	25	11.0*
400 Kg of produced milk	8.4	20	9.0*

With above set of information and knowing that the requirements for the mobile AMS setup involved at this stage was only for 20 cows then this entailed an energy load total of 9.0 kWh per day as indicated in table 5 above. Figure 14 below reflects this total energy consumption at 400 kg Milking capacity of 9.0 kWh per day amongst the AMS facility VMS300 and its associates.

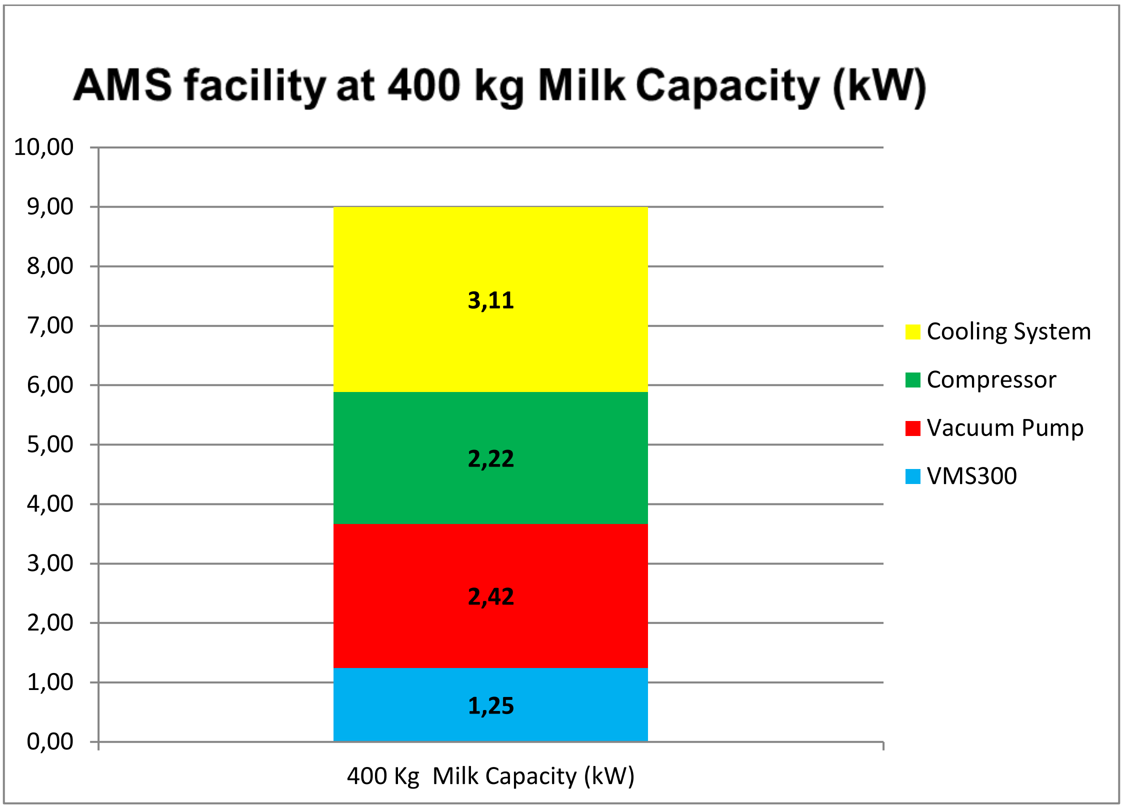

Figure 14. Total Energy Consumption for AMS (VMS300) facility and its associates at 400 kg Milking Capacity.

6. RUNNING HOMER SOFTWARE AND PARAMETERS

6.1 Input to software

In this section, the two main renewable energy sources considered earlier for the mobile AMS setup is run through the HOMER software. Besides providing HOMER with Lövsta's area coordinates 59.5°N , 18.2°E (i.e. hence reflecting the climatic conditions there) The other key parameters such as ones shown in Table 6 below have been suggested.

Table 6. Suggested Electric load parameters

Parameters	Details
Electric Load	9.0 kWh/day
Load Season months	May, June, July, August, September
Load time chosen	From 11:00 to 16:00 (5 Hours)
Load time life	25 Years

In order to enable HOMER software present the best possible combination(s) to match the energy requirements for the mobile AMS setup, a set of input data was provided and assumed in the first place.

One important function within HOMER is the **“Search space”** option. Here, the range of capacities, number of components may be set.
The choice of range is certainly not simple especially if the system designer is unaware of what to expect. Therefore it is always better to have a wider range values rather than a narrow one. Similarly having too wide range may be unnecessary, time consuming and not necessarily useful. Some key parameters that may help identify a reasonable range is by looking at the load requirement parameters. This includes, the total energy requirements kWh per day, largest peak power amongst the load components along with the chosen RE sources and their corresponding capacities.

The **“Sensitivity analysis”** is also a very useful HOMER option to use, especially with any existing levels of uncertainty in the considered systems. Lack of definite exact values of variables such as costs, design life times and magnitudes of primary energy sources in general (e.g. solar radiation levels, wind speeds etc.) could be a strong driver and reason to include a sensitivity analysis in any system design.

Completing the **Emissions levels** for the considered power sources (whenever applicable) is also vital since these will be used to assess how pollutant the systems are and which combinations suit the environment best.

6.2 Main parameters for evaluating results

The evaluation of results, which is presented in the following chapter, involved three main parameters. These included the Net Present Cost, Cost Of Energy along with CO_2 Emissions. Evaluating these parameters allows the designer identify the levels of cost effectiveness and how environmental-friendly or not the considered systems are to the environment – a series of criteria forming the aim of the study.

Definitions of these and what they present within HOMER software is provided hereunder:

- **Net Present Cost (NPC):** *The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each Component in the system, and of the system as a whole.* (HOMER Pro 3.13, 2019)

- **Levelized Cost Of Energy (LCOE):** *HOMER defines the levelized cost of energy (LCOE) as the average cost per kWh of useful electrical energy produced by the system.* HOMER Pro 3.13, 2019)

- **Emissions Outputs:** *The Emissions tab in the Simulation Results window shows the total amount of each pollutant produced annually by the power system in kg/yr. Pollutants originate from the consumption of fuel and biomass in generators, the boiler, and the reformer, as well as from the consumption of grid power. Pollutants consist of carbon dioxide, carbon monoxide, unburned hydrocarbons, particulate matter, sulfur dioxide, and nitrogen oxides.* HOMER Pro 3.13, 2019)

In the following subsections details of the chosen RE sources, the "Search space" ranges and corresponding emission levels are presented.

6.3 Solar PV + Batteries

Tables 7 and 8 below represent a summary of the data being used to come up with the recommended Solar PV + Batteries combination(s). The two right hand side columns indicate how or where-about the listed components and set of data in the tables are coming from. So for instance on the first three rows of Table 7, the PV manufacturer, Model/Type and Capacity have been selected from HOMER's library or more specifically the list of available components to choose from; hence these are titled here an "Assumed suggestion". Selection of components based on their key characteristics were intended and "assumed" to meet the earlier concluded energy loads for the system.
However, on rows 4 to 7 the corresponding data from the selected component is called "Given/Data" (which basically means the extra set of information/data stated on components' data sheet). Copies of data sheets for these key components (i.e. PV modules, Batteries and Inverters) are appended under Appendix A.

Before running the software with the chosen components, the "Search space" function needed to be completed. Possible range of options in which HOMER may choose from for the simulation included the following options:

1. Total PV module Capacity: Between **1 to 10 kW**
2. Total Number of Batteries: Between **1 to 5 Nos**
3. Total Inverter Capacity: **1 to 10 kW**

The "Sensitivity analysis" option was set only for the lifetime section. Options available for simulation included 10, 15, 20 and 25 years of time.

According to the National Renewable Energy Laboratory (NREL, 2012) typical levels of Solar PV emissions indicated a 40g of CO_2 per kWh. Since HOMER models emissions only for Generators, Boilers and Reformers, the levels of emissions for the Solar PV + Batteries was compared and investigated through other means (see Chapter 8).

Table 7. Summary data of Solar PV, Batteries and Inverter suggested to be used in HOMER (SOLARIS, 2020), (E-SOLARE, 2012) and (Electric Power Research Institute, 2015, page 18)

Parameters	Details	Given/Data	Assumed suggestion
PV Manufacturer	Canadian Solar		X
PV Specs (Model and Type)	CanadianSolar Max Power CS6U-330P Flat Plate with 72 Poly-Crystalline cells (6x12)		X
PV (Capacity)	330 W		X
Parameters	Details	Given/Data	Assumed suggestion
PV Efficiency (%)	16.97	X	
PV Total Lifetime	25 Years	X	
PV Dimensions	77.2 x 39.10 x 1.57 inches (1.96 x 0.99 x 0.04 meters)	X	
PV Weight	22.4 kg	X	
Battery Manufacturer	BAE Secura PVV solar		X
Battery Specs (Model and Type)	BAE PVS 4940		X
Nominal Capacity	9.27 kWh		X
Nominal Voltage	2 V	X	
Maximum Charge Current	696 A	X	
Maximum Discharge Current	4.44 E+03 A	X	
Minimum Storage life	5 Years		X

Battery Life Cycle Charges	> 1,500 Cycles at 20 °C	X	
Battery Dimensions	L: 0.215, W: 0.580, H: 0.815 meters	X	
Battery Weight (Dried and Filled)	165 kg and 232 kg	X	
Inverter Manufacturer	LEONICS		X
Inverter (Model and Type)	Leonics S-219Cp 5kW		X
Rated Power	5.5 kW		X
Nominal Voltage	48 Vdc	X	
Recommended generator power	8 kVA	X	
Parameters	Details	Given/Data	Assumed suggestion
Inverter Dimensions	W: 0.6, H: 0.865, D: 0.46 meters	X	
Inverter Weight	104 kg	X	
Life time	10 Years	X	

Table 8. Summary of key costs to be used in HOMER (Solar) (SOLARIS, 2020), (E-SOLARE, 2012) and (Electric Power Research Institute, 2015, page18)

Item	Type of Cost	Unit Price (USD)
PV Module	Capital Cost	345.00
	Replacement Cost	345.00
	General Site Maintenance Cost ($0.20-$3.00/kW-yr), Wiring Electrical Inspection ($1.40 -$5.00/kW-yr), Panel Washing ($0.80-$1.30/kW-yr)	5.85/kW-yr
Battery	Capital Cost	1,121.00
	Replacement Cost	1,121.00
	O&M Cost (Suggested 0.5% of Capital Cost)	5.60/yr

Inverter	Capital Cost	900.00
	Replacement Cost	900.00
	O&M Cost (Suggested 0.5% of Capital Cost)	4.50/yr

6.4 Biofuels

There were certainly many types of biofuels to choose from (Ethanol, Methanol, Biogas, Biodiesel etc.). However what was significant for this project, was to seek and investigate fuel(s) which are readily available, environmental friendly, renewable and most importantly practical to use within the mobile AMS setup. Furthermore, presented below, are a set of characteristics which helped understand the choice of fuels to be investigated further for the study:

6.4.1 Biofuel's choice, limitations and site characteristics

- **Readily available:** Availability of the fuel (being an integral part of the system) was quite significant as this affects the sustainability of the whole AMS system.
  Generally speaking, fuels such Biogas, Ethanol and Biodiesel were found to be quite accessible and were within the reach of Lövsta's farming area. While both Ethanol (E85) and Biodiesel (B100) were available in filling stations within Uppsala city, Biogas seemed to be even more readily accessed within the vicinity of the farm, should the locally produced gas there be useful and suitable for the AMS setup. Methanol on the other hand, unlike other fuels, was not quite common in Swedish markets or filling stations.

- **Practicality in usage:** With the mobile AMS to be installed inside a 30 feet cargo container, finding room for the power generator and any other accessories becomes another challenge. Therefore it was quite important that the fuel setup takes less of a space. This implied that liquid state fuels (at Room Temp and Pressure-RTP) would be favored in this circumstance, since these tend to accommodate less room. Biogas which is gas at RTP would certainly occupy more room either due to the need of a Reformer or the storage of the fuel itself (e.g. in Gas cylinders).
  So in terms of practicality usage, fuels such as Ethanol and Biodiesel seemed to be more favorable from this perspective.

6.4.2 Key parameters for simulation

In order to make simple and yet valid comparisons between these considered fuels and the above mentioned RE (i.e. Solar PV + Batteries) the following four key parameters were addressed and checked for every simulation:

- **The Fuel curve**
- **The Fuel price**
- **The Capital Costs**
- **Levels of Emissions**

Further details concerning these four parameters and the adopted approach are described hereunder:

- **Fuel Curve:** *This describes the amount of fuel the generator consumes to produce electricity. HOMER assumes that the fuel curve is a straight line* and suggests this within its advanced properties option. *The following equation gives the generator's fuel consumption in units/hr as a function of it's electrical output:*

  F_0 = The fuel curve intercept LCOEfficient (units/hr/kW)
  F_1 = The fuel curve slope (units/hr/kW)
  Y_{gen} = Rated capacity of the generator (kW)
  P_{gen} = The electrical output of the generator (kW) (HOMER Pro 3.13., 2019).

- **Fuel Price:** This is an input variable which typically involves USD/Litre. In this project these were investigated and suggested to meet Sweden's current fuel markets and prices.

- **The Capital Costs:** These include the Generator cost, Replacement cost of the Generator along with the annual Operation and Maintenance (O&M) costs. To simplify comparisons between the various liquid state fuels, this parameter (i.e. Capital Costs) was kept exactly same for all. Using a basic diesel generator as a reference to these costs served two functions. One being, achieving a unified cost to allow comparison on other parameters and another being that the considered fuels may be used, with minor adjustments, in a common diesel generator. With regards to the Biogas generator, which has its fuel in a gaseous state at RTP, a different source was referred in this case.

- **Levels of Emissions:** These are calculated by HOMER software and in most cases the value would already be set as a default. For this project and as mentioned earlier it was the CO_2 emissions which will were investigated and assessed.

In Table 9, presented are the considered biofuels simulated by HOMER. The assumed suggestion values here were the Generator and fuel prices which reflected the Swedish markets. As for the Operation and Maintenance costs these were provided as default by HOMER and hence categorized under column Given/Data.

Table 9. Summary of key costs to be used in HOMER (Biofuels). (OKQ8, 2020) and (DUAB-HUSET, 2020) (Alibaba.com, 2020) and (e.on, 2020)

Biofuel Type	Parameters	Given/Data	Given/Data	Assumed suggestion
Ethanol	Fuel Price	1.18 USD / Liter		X
	Capital Cost	300.00 USD / kW		X
	Replacement Cost	300.00 USD		X
	O&M Cost	0.03 USD / Operating hour	X	
Biodiesel	Fuel Price	1.61 USD / Liter		X
	Capital Cost	300.00 USD / kW		X
	Replacement Cost	300.00 USD / kW		X
	O&M Cost	0.03 USD / Operating hour	X	
Biogas	Fuel Price	1.88 USD / kg		X
	Capital Cost	365.00 USD / kW		X
	Replacement Cost	365.00 USD / kW		X
	O&M Cost	0.03 USD / Operating hour	X	

For Ethanol and Biodiesel:

While the Fuel prices were referenced from a Swedish filling station (June 2020's rate) (OKQ8, 2020) the Capital costs were concluded from a suggested 3-Phase Swedish 12.5 kVA diesel power generator (DUAB-HUSET, 2020).
With a 12.5 kVA power generator costing 29,995 SEK (*i.e.* 3,300 USD), this concluded to 264 USD per kW or 300 USD when rounded up. Replacement Costs represented simply the replacement of the generator with a new one after running 15,000 hours of operation and these naturally followed the same cost rate of 300.00 USD/ kW. Conversion of the sourced prices were accordingly converted to reflect USD's currency i.e. fuel prices Ethanol and Biodiesel: 10.89 SEK and 14.87 SEK per Litre respectively (being 1.18 and 1.61 in USD currency). Finally the O&M costs which was advised by HOMER stood at 0.030 USD per Operating hour.

Data sheets of the generator is appended under Appendix A.

For Biogas:

A 10 kW Biogas electric generator costing 3,650 USD was suggested (Tradewheel.com, 2020). In terms of initial capital this translated to 365 USD / kW (3,650 USD / 10kW). As mentioned earlier, Replacement Costs, represented the replacement of the generator with a new one after running 15,000 hours of operation. Replacement rate followed exactly the initial capital rate (i.e. 365 USD / Liter).
Biogas prices according to e.on (2020) was 17.29 SEK per kg (corresponding to 1.88 USD per kg). Finally and to allow for comparisons through other parameters, the O&M costs were kept like other Biofuels at the rate of 0.030 USD per Operating hour.
Data sheets of the generator is appended under Appendix A.

6.5 Diesel (a benchmark)

To provide a point of reference for additional comparison, the non-renewable fuel source type Diesel was also simulated in HOMER. Just like preceding fuels, the same power generator with its associated costs was used. The only difference here was the fuel price which accounted for 14.13 SEK per Litre (this being 1.54 USD).

6.6 Overall Limitations

The overall shortcomings concerning HOMER's simulation for the project rooted from limitations in both time and resources. Lack of these two deprived from what could have been a more thorough study with higher levels of educated assumptions and values to be used/inserted within the simulations. Examples of few limiting factors included: Difficulty in predicting costs of materials and fuel prices over a long period of time (25 years), Studying the choice of materials in depth, Including more varieties of biofuels along with incorporation of other Green House Gas Emissions (GHGs).

7. HOMER RESULTS

The simulation with both the Net Present Costs (NPC) and Cost of Energies (LCOE), being the main deciding factor(s) for all systems considered, are revealed hereunder. Levels of CO_2 emissions concerning the generators was also modeled and presented by HOMER.

Solar PV + Batteries

Results from simulating Solar PV + Batteries revealed that the following combinations yield both the least NPCs and LCOEs and hence the optimum option for those two set critera.

- **5.04 kW** total PV capacity which concludes to 5,040 W / 330W = 15.27 PV panels (i.e. **16 Panels** of the 330 W capacity). In terms of square meters this equates to in being 16 x 1.96m x 0.99m = **31 m^2**
- **3 Nos of** 9.27 kWh **Batteries** of type BAE Secura PVV solar
- **1 No. Inverter** of rated power of 4.83kW
- **25 Years service Life time total** for both the PV panels + Batteries
- **Autonomy 59.3 hr**

- **Production 5,886 kWh/yr**

NPCs, LCOEs along with other associated costs concluded from the above combination entailed:

- **NPC:** 11,804 USD
- **LCOE:** 0.311 USD
- **Initial Capital Cost:** 9,500 USD
- **Annual Operating Cost:** 178.26 USD

As stated earlier, HOMER models emissions only for Generators, Boilers and Reformers. Therefore and in order to find out the levels of emissions for this Solar PV + Batteries setup it was important to refer to the annual power output results along with the typical levels of CO_2 emissions from Solar PV panels. According to the National Renewable Energy Laboratory (NREL, 2012) typical levels of Solar PV emissions indicated a 40g of CO_2 per kWh. Therefore with a 5,886 kWh produced annually this yielded to 5,886 kWh x 0.040 kg = **235.44 kg of CO_2**

- **CO_2 Emissions per year:** 235.44 kg

Comparison of energy system alternatives

Table 10 provides a summary of the evaluating parameters (i.e. NPC, LCOE and Annual CO_2 emissions + other key costs) from all considered REs along with the Diesel run generator. Highlighted in green are the best obtained results among the REs while figures in red indicate the least favorable ones.

Table 10. HOMER simulated results for REs along with the Diesel run generator

S.No.	Power Source	NPC (USD)	LCOE (USD)	Annual CO_2 Emissions (kg)	Initial Capital Cost (USD)	Annual Operating Cost (USD)
1	Solar PV + Batteries	11,804.00	0.31	235.44	9,500.00	178.26
2	Ethanol run generator	26,115.00	0.62	1,344.00	2,580.00	1,821.00
3	Biodiesel run generator	33,312.00	0.78	-33.60	2,580.00	2,377.00
4	Biogas run generator	19,036.00	0.45	0.29	3,139.00	1,230.00
5	Diesel run generator	32,141.00	0.76	3,389.00	2,580.00	2,287.00

8. DISCUSSION

From Table 10, it can be easily visualized that the Solar PV + Batteries would be the most favorable RE to be considered. Not only does this RE has the least NPC (11,804 USD), LCOE (0.31 USD) and Annual Operating Cost (178.26 USD) but also it lies not far away from the best achieved lowest levels of Annual CO_2 emissions. It is also noted how the diesel run generator has exhibited both the highest NPC value (32,141 USD) combined with the largest amount of annual CO_2 emissions (3,389 USD). More discussions covering various perspectives which helped compare and choose between these REs are provided hereunder.

Economic perspective

As indicated in Table 10, Solar PV + Batteries had the lowest costs over other RE candidates. This could clearly be noted by looking at the NPC and LCOE results, where Solar PV + Batteries setup was the least expensive option. Moreover, although the Initial capital cost was the largest for Solar PV setup, being 9,500 USD it still maintained the least Annual Operating cost (only 178.26 USD), making it still the best choice from an economical long term perspective. On the other hand, since the Biodiesel run generator had the largest NPC value (33,313 USD), LCOE (0.78 USD) and Annual Operating costs (2,377 USD), it stood as the least favorable option amongst the REs.
Although the choice of materials for all RE types should have been investigated further to reflect the available option within Swedish markets, the comparison "as is" from an economic perspective could be valid and to a large extent would provide a similar outcome regardless of the choice of materials which after all was a common denominator to all considered REs.
Coming second in the list was the Biogas run generator. This even scored better than Solar RE in terms of the initial capital cost. Certainly, the potential of providing less expensive power to the mobile AMS with Biogas is quite promising should the fuel source (i.e. Biogas) produced within the vicinity suit the AMS setup.
Questions remained though after observing Solar PV + Batteries promising results was what are the future projections of the technology and how would this compare with grid connected systems in terms of costs. Moreover, where does the achieved costs compare with present grid connected systems here in Sweden where this comparison is made.

A recent study exploring off-grid electricity production in Sweden conducted by the Royal Institute of Technology (KTH) Sweden provided valuable data to assess the Solar PV setup attained results. Using HOMER Pro the following four different systems were modeled at two different locations in Sweden (Visby and Östersund) (1) Off-grid household comprising of Hydrogen Tank + PV + Battery Energy Storage System (BESS), (2) Partially off-grid prosumer household comprising of PV + Grid connection, (3) Partially off-grid prosumer (producer and consumer) household comprising of PV + BESS + Grid connection, and (4) Grid-connected household (Björkman, J and Lundqvist, S., 2020, p.83)
Table 11 indicates the study's results for the 4 different systems in terms of LCOE in Swedish Krona (SEK).

Table 11. LCOE for 4 different systems at Visby and Östersund for year 2020 (Sweden) (Björkman, J and Lundqvist, S., 2020, p.83).

Location	Average LCOE (SEK/kWh)			
	Hydrogen+PV +BESS	PV+Grid	PV+Grid+BESS	Grid
Visby	12.33	0.86	0.93	1.94
Östersund	16.42	1.11	1.17	1.68

Comparing above figures with the concluded Solar PV + Batteries LCOE for the mobile AMS (0.31 USD/kWh equivalent to 2.74 SEK/kWh), it becomes obvious that all the considered off-grid systems including Solar PV + Batteries are in fact less economical than most options conducted in the KTH study. Only the Hydrogen+PV+BESS option was more expensive than all the considered off-grid systems. The study however continues and provides future projections of these LCOE in years 2030 and 2040 (see Table 12). (Björkman, J and Lundqvist, S., 2020, p.83)

Table 12. LCOE for 4 different systems at Visby and Östersund for years 2030 & 2040 (Sweden) (Björkman, J and Lundqvist, S., 2020, p.86)

Location	Average LCOE (SEK/kWh)			
	Hydrogen+PV +BESS	PV+Grid	PV+Grid+BESS	Grid
Visby (2020)	12.33	0.86	0.93	1.94
Visby (2030)	5.78	0.84	0.85	2.94
Visby (2040)	4.33	1.05	1.02	4.04
Östersund (2020)	16.42	1.11	1.17	1.68
Östersund (2030)	7.55	1.23	1.21	2.55
Östersund (2040)	5.71	1.54	1.48	3.49

Considering the Grid connected system to feature a mobile AMS connected to the Grid and comparing this to Solar PV + Batteries AMS setup it can be agreed that connecting to the Grid today would be more economical. This however and by looking at the projected figures will eventually change in favor of the Solar PV+Batteries setup. Reason being for this is that while network charges energy taxes in Grid-connected systems are assumed to continue to rise over the years; PV panels, Batteries and Inverters' costs on the other hand and as per KTH study; are expected to drop (by 20%, 50% and 20% respectively) (Björkman, J and Lundqvist, S., 2020, p.86). Furthermore not to mention the rapid development of their efficiencies and the technology altogether (Musafa, R.J. et al., 2020, p.1).

Environmental Impact

Both Biodiesel and Biogas run generator types have scored the least levels of CO_2 emissions as indicated in Table 5 (0.29 kg and -33.60 kg). Coming third was the Solar PV setup with 235.44 kg and thereafter Ethanol and Diesel run generators (1,344 kg and 3,389 kg respectively). Moreover, to maintain a safer and cleaner site environment, the handling and storing of these fuels, which have both flammable and polluting characteristics requires just an extra care with very clear set of precautions. From this perspective in particular, the Solar RE is seen as a better choice. Besides that it produced very low levels of CO_2 emissions, it has also very low potential risks for site pollution when it involves spills of fuels or physical contaminations.
Another important factor to consider is the noise pollution. Ensuring to keep noise levels low is significant, since should this be exceeded (threshold is 85dB) this may cause negative behavioral responses on the cows and consequently the levels of milk produced and profit (Psenka M. et al., 2016, p.189).
From this perspective yet again the Solar RE is seen to be the optimum option amongst other REs simply because this does not produce any noise levels. Interesting enough and on the contrary of causing harm to the cows; installation of solar panels was found to be a source of comfort according to an ongoing research from the University of Minnesota. Panels producing electricity to run the farm provided shade for the dairy cattle and hence offered one way of enhancing the cattle's comfort (see Figure 15 below).
An excerpt from the University's study on the Northeast Organic Dairy Producers Alliance (NODPA) newsletter stated: "*Our study indicates that agrivoltaics may provide an acceptable method of heat abatement to pastured dairy cows, as well as generating electrical energy for farmers. This would reduce the carbon footprint of the dairy operation*." (Northeast Organic Dairy Producers Alliance, 2020)

Figure 15. Solar panels providing shade to cows. (Progressive Farmer, 2020)

Results produced from HOMER indicated that a total of 16 PV panels (yielding an area of 31 m^2), would be required to meet 9 kWh per day load. The idea of installing such a large area of PV panels on the rooftop of the 30 feet container (which has a limited area of 9.12 x 2.44 = 22.3 m^2 , see Figures 20 and 21) becomes quite challenging. Comparing the Solar-RE power source with other RE power sources points out this drawback. Biogas RE setup maybe the second less favorable option here after Solar RE, since this too requires storage space for the fuel used (i.e. cylinders in this case).
Dealing with the installation practicalities and challenges could be addressed either by redesigning the solar system altogether, perhaps by including a higher capacity panels (e.g. 400 W), or reviewing the placement of the solar panels and setup (e.g. number of strings and subarrays). The worst case scenario could be by adding extra space area to the container roof top (in this case 31 m^2 – 22.3 m^2 = additional 8.7 m^2). Keeping in mind, that there are several options/orientations to install the panels. These, can either be installed directly on top of the container's roof top area with no tilt degree, or on top of an additional rooftop space made available by swinging the container sides upwards. The optimum installation certainly requires further investigation.
In addition to the installation challenges, the environmental impacts on the Solar RE setup need to be recognized and addressed. In a study performed on two PV modules, it was found out that out of the following four environmental impacts: dust accumulation, water drops, shading effects, and bird droppings (fouling); the shading effect was seen to be the most to have negative impacts on the modules performance (Musafa, R.J. et al., 2020, p.12).
With three quarters shaded area, the reductions in the short circuit current, open circuit voltage, and power output were 66.5%, 25.3%, and 92.6% respectively. The implication of this is that the PV system must be placed and installed in appropriate locations for maximum efficiency and avoiding shading conditions. Moreover the study recommends regular cleaning of panels (once a week minimum) (Musafa, R.J. et al., 2020, p.12).

Whereas making the right choice for the optimum renewable energy source for the mobile AMS setup is significant, it is however equally important that full attention is paid to the AMS manufacturer's general recommendations. Not only do these help in reducing the overall borne costs of operations and maintenance tasks, but these also enhance a cleaner and safer environment post installation. In fact and as mentioned earlier according to DeLaval, connections between animal welfare, cow longevity and energy-efficient farms are quite strong. Two key recommendations provided by DeLaval included:

- Installing the right pump especially since larger pumps may consume up to 20% more energy than a smaller pump.
- Using a plate cooler. This may cut up to 60% of refrigeration energy costs (DeLaval 2018).

In addition to DeLaval's recommendations and in order to reduce costs further it becomes crucial that key RE materials such as the PV panels, batteries and the inverter are chosen carefully and sourced locally. Although the design for the mobile

AMS-RE setup addresses small number of cows for now, however from a designer's perspective, plan should always be set to accommodate larger numbers for future needs.

Since both, water and feed represent two vital consuming materials to be used during the milking process, it becomes necessary that enough of these are available on site. Whereas, for milking 20 cows, these amounts may not be in large quantities and hence these could be made available or filled on site on daily basis. Should there be need to milk more cows, then perhaps direct access to water from a nearby facility would be necessary or considered. After all, there should be a balance between borne costs and adapting to site constraints and conditions.

With the above set of results and considerations to the surrounding environment of the potential mobile AMS, it appears that there are promising indicators that the Solar PV+Batteries RE would be the most suited off-grid system. Though comparing a grid connected system today in Sweden to the off-grid Solar RE setup may still favor a grid connection power source from an economic perspective. This however, may soon change considering future projections of increasing grid electricity prices coinciding with the technological advancements and rapid cost drops in REs altogether. According to Khalilpour, R. and Vassallo, A., from University of Sydney "leaving the Grid" and "living off-grid" may no longer be an ambition but rather a "Real choice" when observing the continuous reduction in PV prices and a similar trend for battery storage (Khalilpour, R. and Vassallo, A., 2015, p. 207). A combination in which they say has prompted public interest and excitement and a "death spiral" for utility services which see their traditional customers leaving the grid to become prosumers (i.e. producers and consumers). A consequence which will lead to further increase and rise in grid electricity prices with fewer customers left sharing the network.

In the case of the mobile AMS and other innovative experiments, solutions to the challenges shall never be confined to what new technologies or concepts have to offer. The success of these entering the market lies beyond just the technological barriers but furthermore is associated with policies in place, development of the market and infrastructure along with addressing uncertainties about actual environment and benefits. Hence, similarly the success of a mobile off-grid AMS needs to address factors such as Milking Frequency, Cow and grazing management, various pollutions to and from the surrounding environment, cattle welfare and nevertheless all possible future scenarios that shall inevitably affect the diffusion and adoption of this new concept.

Size of Container	Length ('/m)	Width ('/m)	Standard Height ('/m)
30’	30/9.12	8/2.44	8' and 6 inch/2.59
40’	40/12.19	8/2.44	8' and 6 inch/2.59

Figure 16. The 30’ cargo container to be used for the mobile AMS-RE setup. Size of the cargo container to accommodate the mobile AMS (highlighted in yellow) (VMS1). (El Zein, M., 2020) (Containers Direct, 2020)

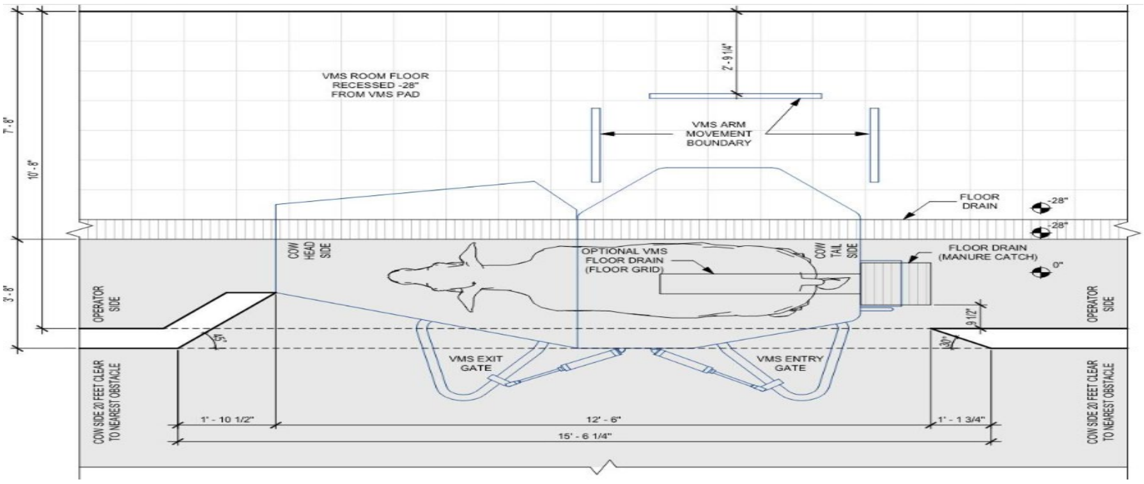

Figure 17. Space accommodated by DeLaval’s milking station. (DeLaval, 2020)

9. CONCLUSION

From the current study, it could be concluded that Solar PV + Batteries setup, within the given environment and anticipated levels of operation and period, would be the most promising off-grid power source to be used on site. In comparison to other considered renewables, the Solar RE proved that it actually does fulfill the key aspects of being environmentally friendly, cost-effective and sustainable. Having attained the lowest NPC, LCOE and Annual Operating costs values (33,313 USD, 0.78 USD and 178.26 USD respectively) amongst other considered REs as shown in the summary of simulated results in Table 5 provided this strong indication. Moreover, the annual CO_2 emissions was still amongst the lowest levels of emissions (235.44 kg). Although, the Initial Capital cost was the highest amongst other REs (9,500 USD), it was still acceptable when considering that the annual operating costs were quite low and in fact the least in comparison with other REs (178.26 USD). Sourcing the materials locally along with following the recommendations of the AMS manufacturer DeLaval is also strongly recommended to reduce costs further and improve system’s efficiency.

One key concern countering the Solar PV setup lies in the limited available space to accommodate the recommended 16 PV panels. Using higher capacity panels,

structuring the array setup or adding more rooftop area to the container could be a reasonable feasible solution.
Moreover, it was also found that the rapid development of solar technologies and associates (PVs Inverters and Batteries) and their reduction in costs through time could be one of the key drivers in supporting an off-grid setup. Although presently in Sweden staying connected to the Grid may be more economical this with the future projections may soon change and be in favor of off-grid systems.
Achieving a successful off-grid system for a mobile AMS certainly requires close monitoring and assessment of other factors. Factors such as the Milking Frequency, Cow and Grazing management, understanding the effects to and from the surrounding environment, maintaining cattle welfare along with grasping the knowledge of both present and future scenarios in terms of policies, technologies development and costs should serve a resilient and environmental friendly off-grid mobile AMS facility.

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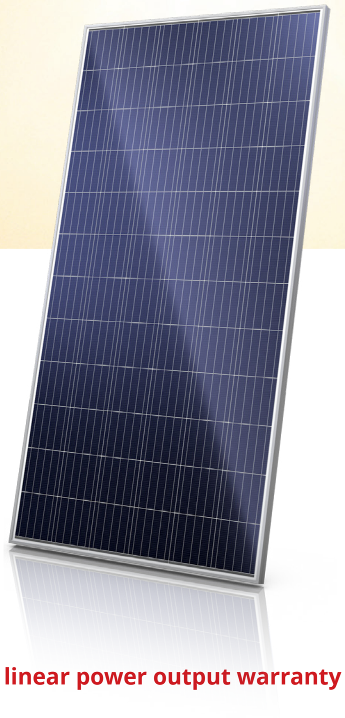

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- No. 1 PTC — High PTC rating of up to 91.55 %
- IP67 — IP67 junction box for long-term weather endurance
- Heavy snow load up to 5400 Pa, wind load up to 2400 Pa

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ISO 9001:2008 / Quality management system
ISO 14001:2004 / Standards for environmental management system
OHSAS 18001:2007 / International standards for occupational health & safety

PRODUCT CERTIFICATES*

IEC 61215 / IEC 61730: VDE / CE / CQC / MCS
UL 1703 / IEC 61215 performance: CEC listed (US)
UL 1703: CSA / IEC 61701 ED2: VDE / IEC 62716: VDE / Take-e-way
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* As there are different certification requirements in different markets, please contact your local Canadian Solar sales representative for the specific certificates applicable to the products in the region in which the products are to be used.

CANADIAN SOLAR INC. is committed to providing high quality solar products, solar system solutions and services to customers around the world. As a leading PV project developer and manufacturer of solar modules with over 15 GW deployed around the world since 2001, Canadian Solar Inc. (NASDAQ: CSIQ) is one of the most bankable solar companies worldwide.

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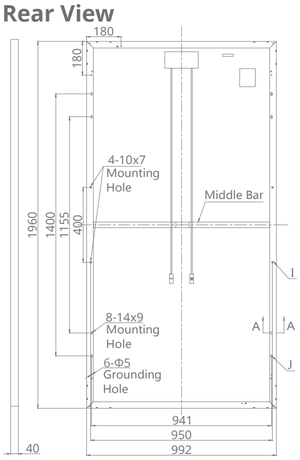
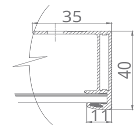
ENGINEERING DRAWING (mm)

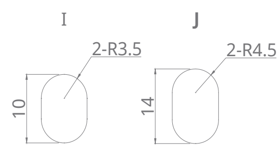
Rear View



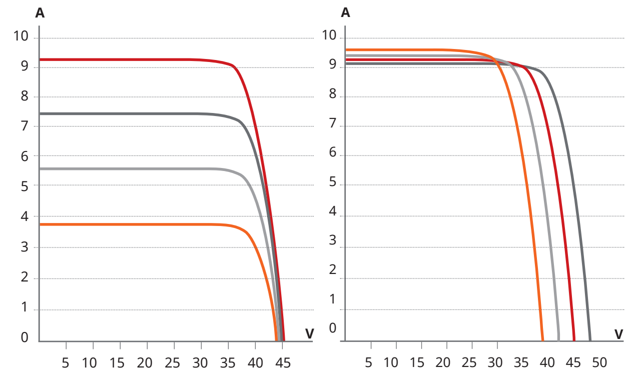
Frame Cross Section A-A



Mounting Hole



CS6U-320P / I-V CURVES



1000 W/m^2
800 W/m^2
600 W/m^2
400 W/m^2

5°C
25°C
45°C
65°C

ELECTRICAL DATA / STC*

CS6U	315P	320P	325P	330P
Nominal Max. Power (Pmax)	315 W	320 W	325 W	330 W
Opt. Operating Voltage (Vmp)	36.6 V	36.8 V	37.0 V	37.2 V
Opt. Operating Current (Imp)	8.61 A	8.69 A	8.78A	8.88 A
Open Circuit Voltage (Voc)	45.1 V	45.3 V	45.5 V	45.6 V
Short Circuit Current (Isc)	9.18 A	9.26 A	9.34 A	9.45 A
Module Efficiency	16.20%	16.46%	16.72%	16.97%
Operating Temperature	-40°C ~ +85°C			
Max. System Voltage	1000 V (IEC) or 1000 V (UL)			
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)			
Max. Series Fuse Rating	15 A			
Application Classification	Class A			
Power Tolerance	0 ~ + 5 W			

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m^2, spectrum AM 1.5 and cell temperature of 25°C.

MECHANICAL DATA

Specification	Data
Cell Type	Poly-crystalline, 6 inch
Cell Arrangement	72 (6×12)
Dimensions	1960×992×40 mm (77.2×39.1×1.57 in)
Weight	22.4 kg (49.4 lbs)
Front Cover	3.2 mm tempered glass
Frame Material	Anodized aluminium alloy
J-Box	IP67, 3 diodes
Cable	4 mm^2 (IEC) or 4 mm^2 & 12 AWG 1000V (UL), 1160 mm (45.7 in)
Connector	T4 (IEC/UL)
Per Pallet	26 pieces, 635kg (1400lbs)
Per container (40' HQ)	624 pieces

ELECTRICAL DATA / NOCT*

CS6U	315P	320P	325P	330P
Nominal Max. Power (Pmax)	228 W	232 W	236 W	239 W
Opt. Operating Voltage (Vmp)	33.4 V	33.6 V	33.7 V	33.9 V
Opt. Operating Current (Imp)	6.84 A	6.91 A	6.98 A	7.05 A
Open Circuit Voltage (Voc)	41.5 V	41.6 V	41.8 V	41.9 V
Short Circuit Current (Isc)	7.44 A	7.50 A	7.57 A	7.66 A

* Under Nominal Operating Cell Temperature (NOCT), irradiance of 800 W/m^2, spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.41 % / °C
Temperature Coefficient (Voc)	-0.31 % / °C
Temperature Coefficient (Isc)	0.053 % / °C
Nominal Operating Cell Temperature	45±2 °C

PERFORMANCE AT LOW IRRADIANCE

Outstanding performance at low irradiance, average relative efficiency of 96.0 % from an irradiance of 1000 W/m^2 to 200 W/m^2 (AM 1.5, 25°C).

The specification and key features described in this datasheet may deviate slightly and are not guaranteed. Due to on-going innovation, research and product enhancement, Canadian Solar Inc. reserves the right to make any adjustment to the information described herein at any time without notice. Please always obtain the most recent version of the datasheet which shall be duly incorporated into the binding contract made by the parties governing all transactions related to the purchase and sale of the products described herein.

Caution: For professional use only. The installation and handling of PV modules requires professional skills and should only be performed by qualified professionals. Please read the safety and installation instructions before using the modules.

PARTNER SECTION

BAE *Secura PVV solar*

Technical Specification for Valve Regulated Lead-Acid Batteries (VRLA-GEL)

1. Application

BAE *Secura PVV solar* batteries don't need to be refilled with water during the whole service life. Therefore, this battery type is maintenance-free. This eliminates checking of electrolyte level.

The batteries are used to store electric energy in medium and large solar photovoltaic installations.

Due to the robust tubular plate design BAE PVV Batteries are excellent suited for highest requirements regarding cycling ability and long lifetime.

2. Technical data (Reference temperature 20 °C)

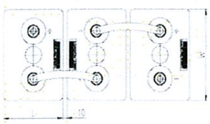
Type U_e V/cell	$C_{1\,h}$ Ah 1.67	$C_{10\,h}$ Ah 1.80	$C_{20\,h}$ Ah 1.80	$C_{72\,h}$ Ah 1.80	$C_{100\,h}$ Ah 1.80	$C_{120\,h}$ Ah 1.80	$C_{240\,h}$ Ah 1.80	R_i 1) mΩ	I_k 2) kA	Length (L) mm	Width (W) mm	Height (H) mm	Weight kg
2 PVV 140	71	121	134	153	157	158	165	1.65	1.30	105	208	420	12.4
3 PVV 210	107	182	202	229	236	238	247	1.15	1.86	105	208	420	17.1
4 PVV 280	143	243	268	306	314	318	331	0.89	2.40	105	208	420	19.4
5 PVV 350	179	304	336	383	393	397	412	0.73	2.91	126	208	420	23.3
6 PVV 420	215	364	404	460	472	477	496	0.63	3.39	147	208	420	27.4
5 PVV 550	254	447	506	570	583	589	609	0.68	3.14	126	208	535	31.4
6 PVV 660	302	529	598	671	686	693	715	0.58	3.64	147	208	535	36.9
7 PVV 770	350	610	688	770	788	795	820	0.52	4.12	168	208	535	42.4
6 PVV 900	417	729	834	943	968	978	1,012	0.46	4.63	147	208	710	51.0
7 PVV 1050	492	858	980	1,116	1,140	1,154	1,195	0.36	5.81	215	193	710	61.9
8 PVV 1200	559	970	1,106	1,252	1,280	1,296	1,344	0.32	6.54	215	193	710	68.8
9 PVV 1350	616	1,090	1,252	1,418	1,450	1,464	1,524	0.34	6.29	215	235	710	77.0
10 PVV 1500	691	1,200	1,382	1,562	1,600	1,620	1,675	0.28	7.50	215	235	710	83.9
11 PVV 1650	748	1,320	1,512	1,713	1,750	1,764	1,836	0.28	7.56	215	277	710	92.2
12 PVV 1800	822	1,440	1,644	1,857	1,900	1,920	1,989	0.24	8.63	215	277	710	99.2
11 PVV 2090	839	1,570	1,772	2,023	2,070	2,088	2,169	0.27	7.86	215	277	855	108.2
12 PVV 2280	927	1,710	1,918	2,181	2,230	2,256	2,337	0.23	9.18	215	277	855	116.5
13 PVV 2470	1,040	1,890	2,120	2,426	2,490	2,508	2,592	0.18	11.91	215	400	815	131.4
14 PVV 2660	1,125	2,070	2,320	2,678	2,740	2,772	2,880	0.17	12.63	215	400	815	141.2
15 PVV 2850	1,191	2,170	2,420	2,772	2,840	2,868	2,976	0.16	13.25	215	400	815	147.9
16 PVV 3040	1,265	2,300	2,580	2,937	3,000	3,036	3,144	0.15	13.94	215	400	815	156.2
17 PVV 3230	1,358	2,480	2,780	3,182	3,260	3,300	3,408	0.14	15.32	215	490	815	173.6
18 PVV 3420	1,433	2,610	2,920	3,348	3,420	3,468	3,576	0.13	16.03	215	490	815	181.4
19 PVV 3610	1,507	2,740	3,080	3,506	3,590	3,624	3,744	0.12	16.70	215	490	815	189.6
20 PVV 3800	1,581	2,870	3,220	3,664	3,750	3,792	3,912	0.12	17.37	215	490	815	197.8
22 PVV 4180	1,740	3,210	3,600	4,118	4,220	4,272	4,416	0.11	18.43	215	580	815	205.7
24 PVV 4560	1,887	3,470	3,900	4,442	4,550	4,596	4,752	0.10	19.76	215	580	815	222.0
26 PVV 4940	2,014	3,650	4,060	4,608	4,710	4,764	4,920	0.10	21.02	215	580	815	235.1

1, 2) Internal resistance R_i and short circuit current I_k according to IEC 60896-21

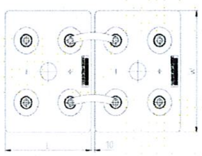
Height (H) is the maximum height between container bottom and top of the bolts in assembled condition.

All values given in the table correspond to 100 % DOD without voltage drop of connectors. Please consider item 7.

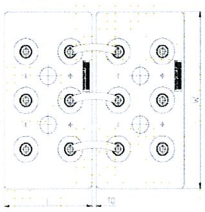
3. Terminal positions



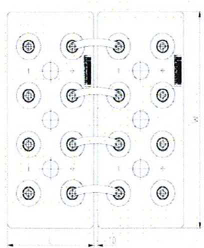
2 PVV 140 to 6 PVV 900



7 PVV 1050 to 12 PVV 2280



13 PVV 2470 to 16 PVV 3040



17 PVV 3230 to 26 PVV 4940

Terminals are designed as female poles with brass inlay M10 for flexible insulated copper cables with cross-section 25, 35, 50, 70, 95 or 120 mm^2 or insulated solid copper connectors with cross-section 90, 150 or 300 mm^2.

BAE
Energy from Batteries

Technical Specification for BAE *SECURA PVV solar*

4. Design

Positive electrode	tubular-plate with woven polyester gauntlet and solid grids in a corrosion-resistant PbCaSn-alloy
Negative electrode	grid-plate in PbCaSn-alloy with long-life expander material
Separation	microporous separator
Electrolyte	sulphuric acid with a density of 1.24 kg/l (20 °C), fixed as GEL by fumed silica
Container and lid	high impact ABS (Acrylonitrile-Butadiene-Styrene), grey coloured (colour may vary slightly from given image), UL-94 rating: HB, on request also in UL-94 rating V-0
Valve	valve with flame arrestor, opening pressure approx. 120 mbar
Pole bushing	100 % gas- and electrolyte-tight, sliding, plastic coated "Panzerpol"
Kind of protection	IP 25 regarding EN 60529, touch protected according to VBG 4
Horizontal operation	Please use BAE special type PVV "horizontal". The construction and production of this type is adapted to the horizontal operation.

5. Installation

BAE *SECURA PVV solar* batteries are designed for indoor applications.
For outdoor applications please contact BAE.

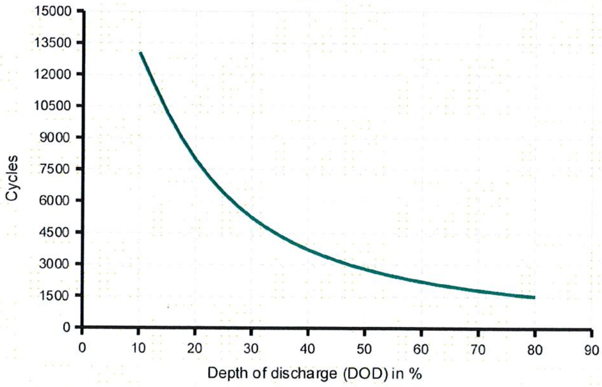
6. Maintenance

Every 6 months	check battery voltage, pilot cell voltages and temperatures
Every 12 months	check connections, record battery voltage, cell voltages and temperatures

7. Operational data

Depth of discharge (DOD)	max. 80 % (U_e = 1.91 V/cell for discharge times >10 h; 1.74 V/cell for 1 h), deep discharges of more than 80 % DOD have to be avoided
Initial charge current (I or bulk phase)	unlimited, the minimal charge current has to be 1.5 A/100 Ah C_{10}
Charge voltage at cyclic operation	restricted from 2.30 V to 2.40 V per cell, operating instruction is to be observed
Float voltage/non cyclic operation	2.25 V/cell
Adjustment of charge voltage	no adjustment necessary if battery temperature is between 10 °C and 45 °C (50 °F and 113 °F) in the monthly average, $\Delta U/\Delta T$ = -0.003 V/cell per K below 10 °C (50 °F)
Recharge to 100 %	within a period of 1 up to 4 weeks
IEC 61427 cycles	>3,000 (A+B) at 40 °C (104 °F)
Battery temperature	-20 °C to 45 °C (-4 °F to 113 °F), recommended temperature range 10 °C to 30 °C (50 °F to 86 °F)
Self-discharge	approx. 2 % per month at 20 °C (68 °F)

8. Number of cycles as function of Depth of discharge



9. Transport

Batteries are not subject to ADR (road transport), if the conditions of Special Provisions 598 and 238 (Chapter 3.3) are observed.
BAE cells/batteries are conform to the IMDG-Code, therefore these products are no dangerous goods on sea transport.

10. Standards

Test standards	IEC 60896-21, IEC 61427
Safety standard, ventilation	EN 50272-2

12/2012 4805218 Technical details may be subject to alterations.

BAE
Energy from Batteries

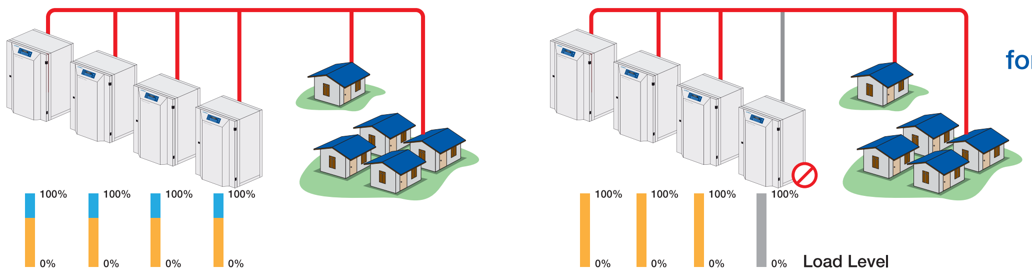
LEONICS®

APOLLO S-210p

Bidirectional Parallel Inverter

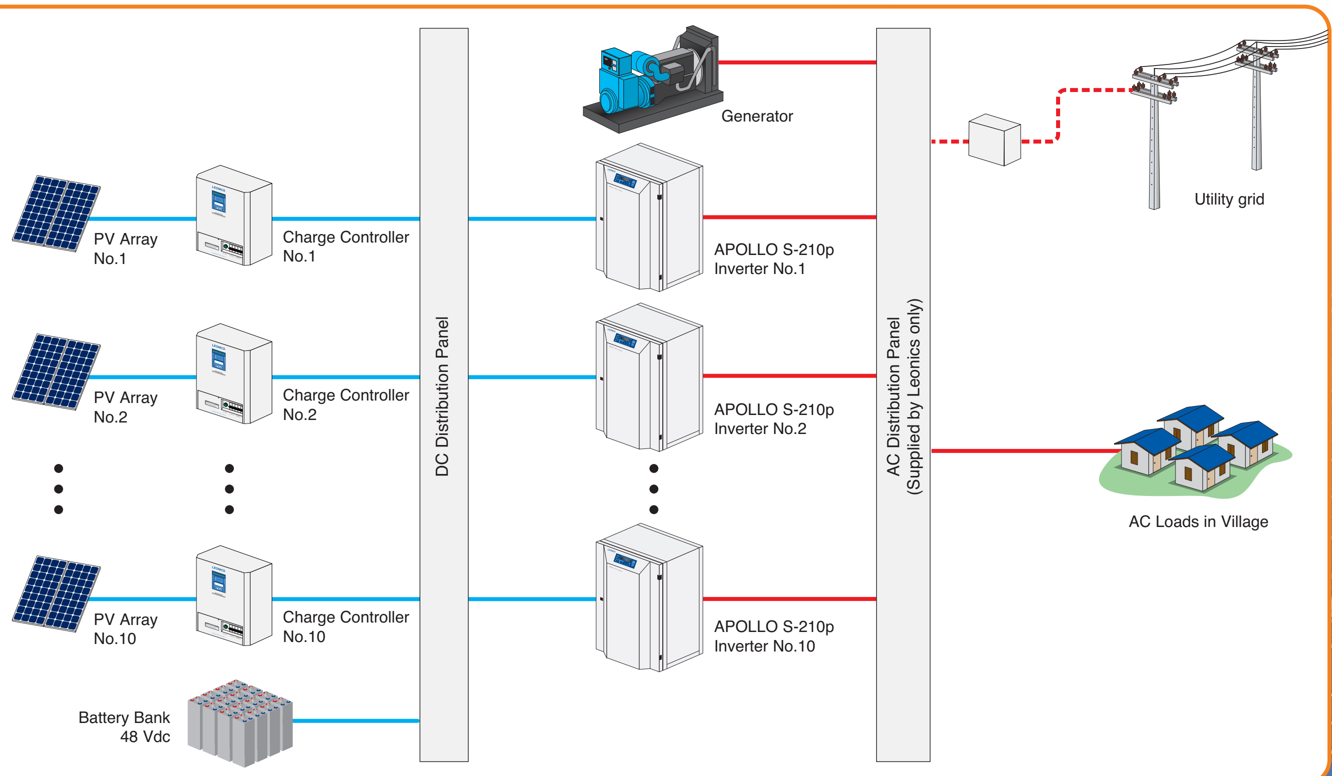
- Parallel output capability
- Parallel configuration up to 10 units
- Capable to operate in N+1 redundancy configuration for very high reliability in remote area

- High efficiency bidirectional inverter with built-in output transformer
- Capable to use with multiple renewable energy sources in both DC coupling and AC coupling such as PV panel, wind turbine generator and micro hydro generator
- Frequency shift energy management control
- Seperate DC Bus for multiple source charging
- No master unit required
- Expandable power by adding inverter from 1 to 10 units without master controller
- Digital input to select operation between inverter mode or charge mode
- Capable to interact with utility grid line (option)
- Capable to make in 3 phase configuration (option)
- ISO 9001 and ISO 14001 certified factory



N+1 Configuration for village with stable load power

The system demands for high reliability of operation



LEONICS®

MASCI
ISO 9001 QMS 01098/349
ISO 14001 EMS 01007/045

NSC-TISI-TIS 17021
QMS 002 / EMS 005

APOLLO S-210p series Bidirectional Parallel Inverter

SPECIFICATIONS

MODEL		**S-218Cp**	**S-219Cp**
POWER	Rated Power	3.5 kVA / 3.5 kW	5.0 k VA / 5.0 kW
	Max. power at 25˚C for 1 hour	4 kW	5.5 kW
BATTERY	Nominal Voltage	48 Vdc	
	Maximum charging current	40 A	60 A
AC SOURCE (GRID LINE OR GENERATOR)	Recommended generator power	6 kVA	8 kVA
	Voltage	220 / 230 / 240 Vac (L-N) ± 10%	
	Phase	Single phase	
	Frequency	50 / 60 Hz ± 3 Hz	
	Max. AC current (for charge mode)	15.9 A	22.7 A
	Start / stop generator	Relay dry contact 10 A (ACC contact)	
AC OUTPUT	Voltage	220 / 230 / 240 Vac (L-N)	
	Voltage regulation	± 1% (steady load), < 7% at 100% step load within 0.1 sec.	
	Phase	Single phase	
	Frequency	50 / 60 Hz ± 0.1% (auto sensing)	
	Wave form	Pure sine wave	
	Total harmonic distortion	total < 3%	
	Maximum surge current	200%	
	Maximum AC current	15.9 A	22.7 A
ISOLATION	Galvanic isolation	yes	
EFFICIENCY	Inverter peak efficiency	> 96%	
PROTECTION		Over current, over load, short circuit, over temperature, over voltage, under voltage	
	Battery temperature sensor	option	
DIGITAL INPUT SIGNAL		Auxillary inverter circuit breaker, Auxillary generator circuit breaker, Auxillary Bypass circuit breaker / Load transfer switch	
INDICATOR	LED	Stand by/Run, AC, Full battery/Low battery, Alarm	
	LCD display	Inverter (voltage, current, frequency, power, reactive power), Load (voltage, frequency), Battery (voltage, current, state of charge (%)), External DC charging current, Equalization charge date, Heat sink temperature, Battery temperature (option), Today AC inverter energy (input / output), Today DC inverter energy (input / output), Accumlated AC inverter energy (input / output), Accumlated DC inverter energy (input / output), System status, Load transfer switch signal status, Digital input signal status, Time, Date, Data log	
AUDIABLE ALARM	Buzzer	Low battery, inverter fault, overload, short circuit, over temperature	
COOLING		Automatic cooling fan	
ENVIRONMENT	Temperature	0 - 45˚C	
	Relative humidity	0 - 95 % (Non - condensing)	
DESIGN REGULATION	Standard	AS/NZ 3100:2002, IEC 61683 (for efficiency test)	
DIMENSION	W x H x D	60 x 86.5 x 46 cm	
WEIGHT	Approximate in kg	104 kg	

Continuous product development is our commitment. In that manner, the above specifications may be changed without prior notice.

Authorized Distributor

LEO ELECTRONICS CO.,LTD.

27, 29 Soi Bangna-Trad Rd 34, Bangna, Bangna, Bangkok 10260 THAILAND
Tel. 0-2746-9500, 0-27468708 Fax. 0-2746-8712 e-mail : RNE@leonics.com

▪ www.leonics.com ▪

Authorized Dealer

Elverk MDG12-3 3-fas diesel fjärrstart

Artikelnummer: 117626

Pris:

29 995 kr inkl. moms

23 996 kr exkl. moms

DUAB-POWER MDG12-3 är ett kraftigt dieselelverk på hjul utrustat med stor tank. Elstartad Mellgamotor som dessutom är utrustad med fjärrstart. Elverket är försett med oljenivåvakt, batteriladdningsuttag 12 volt, överbelastningsskydd och voltmeter.

Detta elverk är utrustat med trådlös fjärrstart som klarar ett avstånd på cirka 50-100 meter beroende på hinder.

Startbatteri medföljer vid leverans.

Tekniska data:

Generator
Spänning 230 V/400 V 3-fas
Frekvens 50 Hz
Effekt, kontinuerlig (3-fas) 12,5 kVA
Effekt, max (3-fas) 13,7 kVA
Antal uttag 1x230 V, 1x400 V
Kaplsingsklasss IP23M

Motor
Typ Mellga LA290
Motoreffekt 20 hk
Varvtal 3000 rpm
Kylning Luftkyld
Typ av start Elstart
Oljenivåvakt Ja
Drivmedel Diesel
Tankvolym 25 liter
Bränsleförbrukning 4,5 l/h
Drifttid 5,5 h
Ljudnivå vid 7 m 82 dB(A)

Dimensioner och vikt
Mått (lxbxh) 910x578x800 mm
Vikt 174 kg

10KW Small Gas Turbine Biogas Electric Generator

Product Description

Basic Specs for 10KW Small Gas Turbine Biogas Electric Generator:

Product model	SDK8NL-J
Model Description	SDK+ rated power + gasoline P+ natural gas N + liquefied gas L+ silent J+Open frame K
Output	
Rated power (LPG)	8KW
Rated power (NG)	7KW
Rated voltage (V)	230
Phase	Single-phase
Rated speed (rpm)	3000
power factor	1
Frequency (Hz)	50
GenSet	
Warranty (years)	1
Protection level	IP 23
Sound insulation device	Metal plate + sound insulation cotton
Under low speed operation, the noise output at 23ft (7M) dB (A)	63
Under normal operation of the generator at full speed, the noise output at 23ft (7M) dB (A)	69
NG consumption 100% load ft3/hr(m3/hr)	113(3.2)
LPG consumption 100% load ft3/hr (kg/hr)	56.68(3.0)
Size	960*620*630mm
Package size	1000*660*670mm
Gross weight (kg)	230