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Abstract

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Anna Jernlund and Niklas Pedersen

The mobile preschools of Uppsala are buses that are provided as a complement for stationary preschools. The buses are connected to one stationary preschool that provides the necessities such as food and a place for the children to be before and after the daily trips. In Uppsala, there are five mobile preschool buses and they have been operated since 2009. For the bus to provide heat, warm food and energy for activities on the bus, there is a generator installed that runs on biodiesel. The emissions from the generator, in combination with the loud noises that it emits, are of concern for both the children and educators on the bus as well as the people around it. This has caused for alternative ways to deliver electricity to the bus.

This study examines three scenarios for delivering electricity and tries to evaluate what the best option could be from different Points of view. The three scenarios are replacing the generator with either a battery, replacing the generator with electricity poles and to replace the generator with a more efficient and quieter one. When evaluating the different scenarios from an economical point of view, the study found that the electricity poles would be the best option. When evaluating the best option with respect to the children and educators, the study found that the battery would be the best option. The negative consequences for continuing to use a generator to supply electricity would be a health hazard for the children and a limitation for the educators in the freedom of choosing location for the bus to visit.

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Introduction

Since 2007 there is a new type of preschools in Sweden that changes the way preschools work and operate. These are the preschools on wheels, and as the name suggests, these schools are not stationary but visit different places in and outside of town in specially equipped buses (Pettersson. 2016). One city in Sweden that has adopted these new buses is Uppsala, and they have been using them since 2008. The mobile preschools of Uppsala are all connected to regular stationary preschools and act as separate units, where the children are being picked up by the bus in the morning and returned in the afternoon. The stationary preschool provides prepared food and extra equipment to the bus and acts as a base for the preschool activities. To keep the food and the bus warm and to generate electricity to run lights and equipment, a generator is installed in the bus (Gustafson & Van der Burgt. 2015). The generator is running when the bus needs to be heated, when the food needs to be kept warm or electricity needs to be generated, to be used on the bus (Thomas, interview 2017-04-01). The generator can be run on both diesel and a new type of fuel called hydro treated vegetable oil (HVO). This fuel resembles diesel but consists of plant and animal oils and is therefore carbon neutral, means that it emits as much carbon dioxide as is sequestered by the plants during their lifetime. Even though it is carbon neutral it still emits harmful particles from its exhaust, just like diesel (IEA, 2017b). According to Tommy Rydbeck (2017), all the generators used on the buses in Uppsala are fuelled by HVO.

When the generator is running there is noise produced that resembles the noise of a running engine. This has caused people to complain and wondering why it needs to be running. It has also led to it not being welcome in certain places in the city (Gustafson & Van der Burgt. 2015). The noise is also a concern for the educators who work on the bus since it causes extra stress (Gustafson & Van der Burgt. 2015).

The municipality of Uppsala has high goals and ambitions for the climate and the people living there. These goals are made clear in its regulatory documents, which describe different goals and ambitions for the different areas of the municipality**.** The regulatory documents that describe the goals and ambitions for 2017 to 2019 are being initiated with the vision, that all people should have the possibility to live a good life, that Uppsala should be a model for the protection of human rights and that all work of the municipality should be done with the wellbeing of children in mind (Uppsala kommun, 2016). For the schools and preschools of Uppsala, this makes extra sense since they are directly affecting the wellbeing of children and have the greatest power to influence.

To interpret this with respect to the preschool buses would mean that the generator should be seen as a problem needing to be solved and the most obvious way would be to replace it. In order to get rid of the generator, a new source of energy would be needed. There are several options available, including installing batteries, installing electricity poles for the bus to connect to, installing generators running on liquefied petroleum gas (LPG) or biogas or using fuel cells. There are also newer generators today that could meet the criteria for Uppsala.

1.1 Aim

The aim of this project is to examine the possibilities of replacing the diesel/HVO generator on the mobile preschool bus and to discuss the consequences of keeping it. It will focus on three scenarios for supplying the bus with electricity and they are: continuing with a generator, installing electricity poles that can be connected to the bus with a power cable and installing a battery.

The questions that this report aims to answer, in respect to the three scenarios, are

- What scenario is the optimal from an economical point of view?
- What scenario is the best from the perspective of the children and educators?
- What are the negative consequences for continuing to use a diesel/HVO generator, with respect to the children and educators?

1.2 Scope and delimitations

For the three scenarios, the focus lies on sustainable development in the aspects of environment and economics. The environment aspect will focus on the local emissions, in the form of particles emitted from the generator in Uppsala, since they are having the greatest impact on the choice. The economic aspect will be focusing on the fixed costs for purchase and the variable cost of operation for the different solutions.

There are other options to deliver power to the preschool bus that have been excluded from this report. They are briefly mentioned in section 2.5.

1.3 Limitations

The interviews and visits have been geographically limited by the city of Uppsala and the use of the mobile preschools in Uppsala. Calculations of the variable cost are limited by uncertainties in exact values for fuel consumption which is directly connected with the power consumed. Lack of data of intensity for places that are visited by the buses limits the ability to calculate the installation cost for the electricity poles due to the variation of places. This will therefore be excluded in this study. Data on effects from HVO are not available in time for this report so the data from diesel is used and then compared to HVO.

2. Background

This section presents necessary information about the organisation, the generator, the electricity poles, the battery and other alternatives for replacing the generator for a greater understanding of this study.

2.1 The organisation

The mobile preschool is a form of preschool that operates in and around a bus. Each mobile preschool is connected and cooperates with one stationary preschool that provides food and other facilities. It starts and ends at the stationary preschool every day and switches between the daily locations depending on the plans for the day (Gustafson & Van der Burgt. 2015). There are 42 mobile preschools in Sweden and five of them are located in Uppsala. They are individually distributed to the preschools of Boländerna, Åriket, Österleden, Botulv and Gudrun (Gustafsson & Van der Burght. 2017). Three of the buses operate since 2008 and an additional two operate since 2009. They are all leased from the county owned bus company, Gamla Uppsala Buss (GUB), on a contract that runs for ten years. In the coming years the contracts will be renegotiated and this report will discuss this in the results. GUB is also the company that stores the buses during the night and is responsible for all the maintenance. (Korpi Kardell & Petrusson, Interview 2017-04-26)

2.2 The generator

When using electricity to power a machine, the unit used is watt (W) and describes the power output needed at a given time to power an electrical component (Stenfelt. 2010). All electrical components have a rated power that can range from a few watts for a phone charger to a couple of thousand watts for infrared heaters. To power a preschool bus, that uses electricity for heating and food preparation, the output of the generator must be able to cover all activities (Thomas, 2017). The generator used on the bus today is rated 2.5 kW and can therefore deliver 2.5 kW of continuous power, as long as there is fuel left in the tank (Thomas, 2017).

The fuel that is used, both for the generator and the engine, is called HVO that stands for hydrogenated vegetable oils. HVO is made from crude tall oil, animal fats and oilseeds such as rapeseed and palm oil, which is illustrated in figure 1 (Energimyndigheten, 2016). The palm oil that is used in Sweden is certified by the voluntary certification approved by the European Commission, which proves that the palm oil that is used is produced according to certain sustainability criteria (Energimyndigheten, 2016). HVO can be used as it is or blended with diesel to be sold as renewable diesel (Energimyndigheten, 2016). In heavy vehicles such as buses and trucks it is more common to use HVO100, meaning a fuel that consists of one hundred percent HVO (Energimyndigheten, 2015). In passenger cars, the use of HVO is mainly in a mix with diesel to have a viscosity that regular diesel engines can use (TRB, 2014). The HVO used by GUB in the generators is bought from OKQ8 (Rydbeck, 2017).

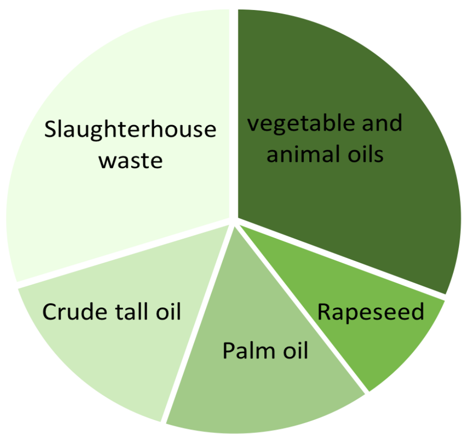

Figure 1. Distribution of the raw materials of HVO produced in Sweden.

The generator is mounted behind a hatch on the right side of the bus and in order to make it stay there, it is bolted into the chassis. It weighs 70 kg and fills most of the space it is placed in (Dometic, 2009). Since it is an internal combustion engine it has to get rid of its exhaust and this is done through a short pipe that ends just beneath where the generator is standing. It has no filtration of the exhaust since this is not done for generators of this size, due to efficiency losses and costs (Dometic, 2009). The entrance to the bus is located on the other side of the bus so that the children and educators are as far away from the generator as possible. The effects of exhaust from diesel generators and engines are well documented and the risks are known (Saiyasitpanich et al, 2005). There have also been comparisons between diesel and HVO. In order to estimate the effects, the emissions from diesel have been used as a base and comparisons in other reports have then been applied in order to see what the effects are.

The generators are also rated for the level of noise that it produces. The noise is measured in dB, a logarithmic unit that is used since the levels of hearing from the quietest to the loudest are so large. When increasing the volume with ten decibels, the noise is perceived as being twice as loud. The way that this is measured for generators is usually by measuring at a distance of 7 meters (Aaberg, 2011). For the generator used today, the rated level of noise is 60 dB, which is equivalent of standing near a running bus engine. Bboth the educators and people that are around the generator have expressed concerns about it being disturbing (Gustafsson & Van der Burght. 2017).

2.3 Electricity poles

When connecting something to the grid the current and the voltage need to be considered in order to calculate the power. The power P in watts [W] is equal to the voltage V in volts [V] times the current I in amperes [A] shown in equation 2.1 (Stenfelt, 2010). The voltage in the bus is constant at 230 V and uses one phase since this is the main electricity for small devices in Sweden. The current on the other hand can be changed in order to deliver more or less power depending on the need.

$$P = I * V \tag{2.1}$$

If the preschool bus would be directly connected to the grid, the total amount of power needed on the bus needs to be considered in order to correctly dimension the electricity poles and the cables. The poles consist of a foundation with a power outlet on top where the cable from the bus is connected in order for the bus to operate. The poles are placed at the locations that the bus visits in an area that can easily be accessed by the educators. When installing a pole, there is always a fuse installed that will cut the power at a predetermined current limit that is low enough to not risk any failure of the cables or equipment. These are supplied in different sizes depending on the purpose and usage. For electricity poles used for engine heaters, the normal sizes are 6, 10, 16 and 32 A (Vattenfall AB, 2017). When used for six hours a day, this equals 1.4, 2.3, 3.7 and 7.4 kW respectively.

Since the "fuel" for this solution is electricity, the prices for electricity are important. Sweden has a generally low price for electricity since the supply is good and the costs of transmission are low. The prices are also stable since the variation of supply is low and only shift a bit from summer to winter (Vattenfall AB. 2017). Since the electricity is also reliable with few outages and a constant supply, there are no real disadvantages with using electricity as source of power.

2.4 Battery

Batteries store chemicals in cells, which can be connected or used separately, for transporting energy or to be used at a different time. The cells can be made from different materials that each have different properties, where the most distinct one is the ability to be recharged or not. The rechargeable ones are called secondary batteries and one of the most common types is lithium-ion (Li-ion) (NE, 2017). Li-ion batteries have the highest energy to weight ratio of all rechargeable batteries which is very important for applications such as mobile phones, laptops and electric cars. This property makes the li-ion batteries desirable but the metal is expensive and li-ion batteries have a high cost per amount of energy stored.

There is much work done in scaling up the production of batteries in order to bring the cost down. In the last years the battery prices have dropped significantly and they are expected to fall even more in the years to come (Vishwanath & Kalyanaraman, 2014). The cheapest batteries produced today are not sold directly to consumers but used in other products by the same producers. These are products like electric cars, larger power backups and in combination with renewable energy. The batteries that are sold to consumers are not produced on the same scale, are a bit more expensive and are mainly made by companies in China and sold over the web.

A battery consists of several parts that together form what is commonly known as a battery. The cell is the core in the battery and it can consist of one or more cells that together with external connections form the battery. When it comes to the measurement of batteries, the standard is having a voltage for a specific type of battery and letting the current over time determine the amounts of power. For li-ion battery cells that can be used in electric vehicles and storage, the voltage is around 3.2 V and the storage capacity varies from 40 to 1000 Ah (Ampere-hours). In order to make it easier to compare with electrical power from the generator, the power will be converted to Wh. This means that the li-ion battery cells have between 128 Wh and 3.2 kWh of energy capacity.

Batteries degrades with age and to measure this, the batteries have a rated amount of cycles. This refers to the amount of times a battery can be completely charged and discharged before it has reached a limit of 80 percent of the original capacity (Capasso & Veneri. 2014). When 20 percent of the capacity is lost, the battery is considered obsolete, even though it still functions. The amount of cycles that a battery can last is directly affected by the percentual amount of charge and discharge it is exposed to. If it is fully charged and 100 percent discharged it will last a lot fewer cycles than if it would be only 80 percent discharged (Capasso & Veneri. 2014). It lasts even more cycles if it would only be discharged 60 percent, but in order to maximize the cost of the batteries the optimal discharge is usually 80 percent (Capasso & Veneri. 2014).

2.5 Alternatives excluded from the study

There are a couple of alternatives that come to mind when wanting to generate electricity, this part will cover three of them and give a short explanation why they will not be a part of this report.

The first alternative to a regular generator run on diesel or HVO is a generator run on LPG. LPG generators work in a similar way but use a different propellant. The LPG is also a fossil fuel that is burned in order to create energy and even though it is emitting less CO2 and particles than oil, HVO is emitting even less and is fully renewable (Energigas Sverige, 2017). One advantage with LPG compared to the diesel/HVO generator is that it produces a little less noise, but only a few decibels making it only slightly more silent. The differences between the current solution and LPG are not large enough to make it a separate option, leaving more room to focus on the generator used today.

The second alternative is using fuel cells in order to produce electricity with very low emissions. There are a couple of different fuels that can be used in order to generate electricity through fuel cells they all do however work in a similar way. One version that is available today uses methanol as a fuel and separates the hydrogen gas that it then burns. This creates a water vapour and a bit of carbon dioxide as a waste product. These are very quiet and only emitting about 25 dB. of noise, making them 96 percent quieter than a regular generator (EFOY, 2014). This technology is relatively new and therefore very expensive, the rated lifetime of the fuel cells is also very low making the overall cost even higher (Hart, David 2016). The last part making this not an option is the power output. The strongest fuel cells available on the Swedish market today only produce 105 W of power at a cost close to

50 kSEK. This results in the need for several fuel cells or the need of a battery that could be supported by a fuel cell (EFOY, 2014).

The last option is using biogas, this is also a renewable type of fuel and is already in use in buses, trucks and a limited number of cars in Sweden. The biggest problem with this option is the lack of generators suitable for supplying electricity to a bus. There are no generators running on biogas out on the market at this time, resulting in the lack of data to make it an option for this report.

3. Method

This section presents the possible sources of errors and method due to interviews, literature and data.

3.1 Interviews

There have been three interviews conducted with educators working on three separate preschool buses in Uppsala. In the interviews with the educators, opinions on the generator were of great importance in order to evaluate the problems experienced today and possible problems with the proposed solutions. Interviews were made with Danielle van der Burgt and Katarina Gustafson who are the leaders of the research group "Mobility, informal learning and citizenship in mobile preschools, 2016-2019" to broaden the perspective of the work with the mobile preschools in Sweden. Interviews with preschool local planners Anja Korpi Kardell and Olof Petrusson, who both work for the municipality of Uppsala, were of great importance for analysing and working with the economic aspect of this project. For further technical information on the bus and the generator, interviews were conducted with technical manager Tommy Rydbeck at Gamla Uppsala Buss (GUB). For advice on how to acquire the desired size of batteries and what the price would be, an electric car enthusiast named Admir Ribic was consulted. Meetings with Hans Nylén, our contact at STUNS who mediated the project, were held on a regular basis. Nylén was important to steer the project in a direction that would make the results relevant for the municipality of Uppsala, GUB and the educators. The supervisor for this project was Rasmus Luthander, postgraduate at Uppsala University and he supervised the structure of the report and delivered feedback on how to proceed with different parts of the project.

3.2 Literature

In order to evaluate the health effects and local emissions of the generator, several studies on the subject have been reviewed. Since the generator runs on HVO, focus has been to estimate the emissions from this new type of fuel and to evaluate it using the literature. The data on HVO emissions is difficult to find, since the research on the fuel mainly focuses on the differences to regular diesel. As a result, the diesel emissions were first evaluated and then compared with HVO using the existing studies. When evaluating the batteries, the aim was to analyse the costs and the expected price development for the coming years. Literature was used to estimate the number of cycles that the battery could last, depending on the discharge in order to estimate the lifespan of the battery.

3.3 Data

Costs of electricity and fuel were found by statistics from Energimyndigheten, Statistiska Centralbyrån (SCB) and OKQ8. To be able to calculate the total cost for the generator, the data needed was collected from the websites of the suppliers. The data for the electricity poles was found by contacting Vattenfall AB and a company manufacturing electricity poles, called Garo. Finding data for the battery was done through suppliers and the information shared on their sites. Forums with electric car enthusiasts were used to get in contact with individuals well informed on the subject who helped us with collecting data.

3.4 Source of errors

All interviews and literature have been critically reviewed for the best result. Some of the interviews have been recorded for the opportunity to review them again in order to minimize the risk of errors.

The main sources of error are related to the data collected for today's operations. There is no data on actual fuel consumption or costs for maintenance. This has resulted in using the rated consumption and estimating the costs from the interview with Rydbeck.

The HVO and electricity prices have been estimated on the costs received from OKQ8 and Vattenfall. These vary depending on what contract that is signed with them and how the prices change with time.

4. Results

This section presents the results, both the quantitative and the qualitative. The results are divided as the organisation, the bus, electricity poles, generator and battery.

4.1 The organisation

Everyone interviewed who worked on the mobile preschool or who had been in contact with the operation expresses that changes were needed primarily due to the loud noise from the current generator. Another problem with the generator was that some of the educators were experiencing a lack of power produced. The emissions of the generator were also said to be a concern due to uncertainties of the emissions and its effect on the children and the environment. All the educators valued the freedom of choosing location for the stops.

Although all three educators interviewed thought that changes were needed, none of them were open to the scenario with electricity poles due to the limitations they were afraid it would lead to. The scenario with the battery was seen as more attractive, primarily due to the freedom of choice of location and decrease of noise. From the interviews knowledge about the number of places visited with the buses were collected which summarized to 40 places. These are illustrated in figure 2.

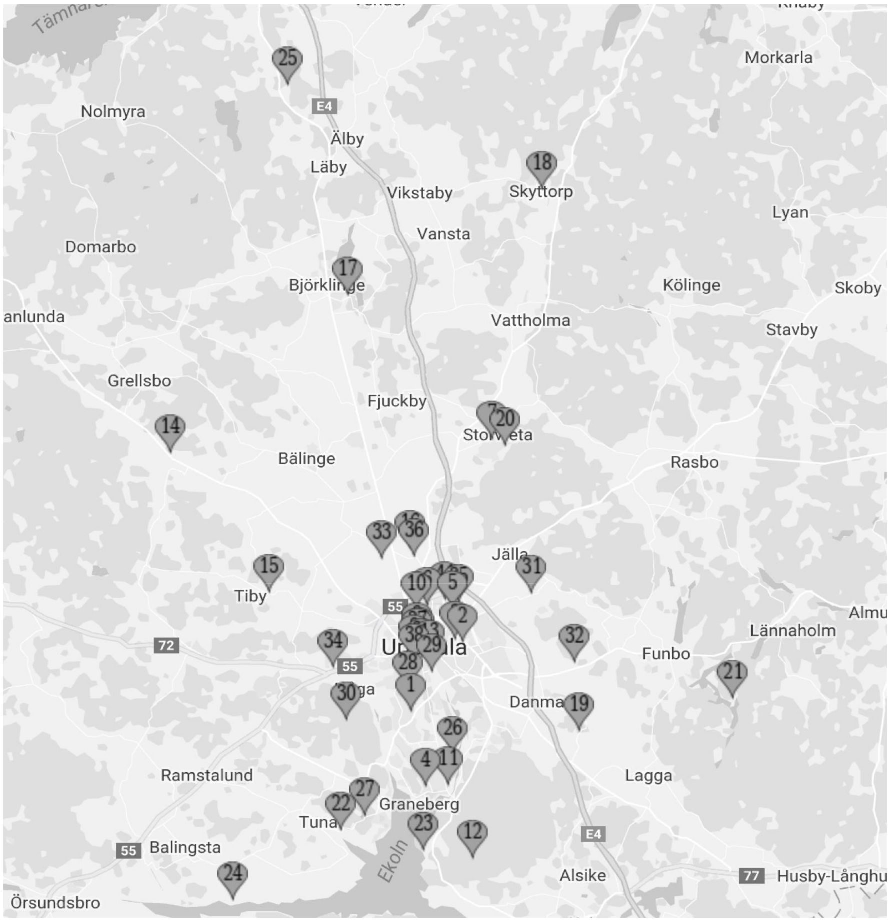

Figure 2. A map with all the places currently visited by the five mobile preschool buses of Uppsala.

Anja Korpi Kardell and Olof Petrusson, who work for the municipality of Uppsala, were both positive to changing the current generator for a newer, more efficient, more environmentally friendly and possible cheaper one. They were also open for any of the electrical solutions but preferred the electricity poles. This was caused by some scepticism regarding the battery due to the progresses in the battery industry and the fear that this technology would still be too young. When the municipality of Uppsala first acquired the mobile preschool busses they negotiated a contract over ten years. The buses were invested in two stages and by year 2009 Uppsala had invested in five mobile preschool buses for three million SEK each. There are now plans in expanding the fleet depending on the results of the ongoing negotiating with GUB and the costs for doing it. If there is a possibility they are hoping to invest in one or two new buses.

The interview with Danielle van der Burgt and Katarina Gustafson from the department of education at Uppsala University gave important information on the work with the mobile preschools in the rest of Sweden, that was compared with the work in Uppsala. The impression that they got, relating to the generator, was that it was underpowered. The main complaint was that it was cold and that the generator could not produce enough electricity to keep the bus warm. For the different scenarios presented they also noted that the freedom of choice ranked high for many preschool buses but also said that many wanted to park more in the city, something that is not done today due to the noise and emissions of the generator.

4.2 The bus

The interview with Tommy Rydbeck (2017) resulted in important technical information of the bus and the generator. The implementation of a battery or modifications to use electricity poles should not be that comprehensive in consideration of either financial nor technical matters. If implementing any of the electrical solutions, the service costs would be significantly lower in comparison to the service of the generator. All the service for the mobile preschool buses is provided by GUB to maintain the high standard and keeping track of the individual status of every bus. The mobile preschool buses have not been driven that far in relation to their age, especially not in comparison with the regular city buses. A regular city bus is supposed to last at least one million kilometres, which is managed in eight to ten years and the mobile preschool buses are not even near that number (Rydbeck 2017). The bus "Maja", that is being used by Boländernas preschool, has a trip meter showing less than 60 kkm for now according to Thomas (2017). Despite the short, accumulated distance that they have travelled, the mobile preschool buses are being worn out on the inside in a different way. This could mean that the interior would have to be replaced, something that could reduce the savings from not having to invest in a new bus. When it comes to the generator, the estimated life span is between eight to ten years and until now, at least two of the generators have been replaced (Rydbeck, Tommy. 2017). Interviews with educators who works on the bus resulted in a number up to 40 places that the buses visited.

4.3 Generator

The generator used is rated for using 0.7 litres of fuel per hour when operated at full power (Dometic, 2009). Since the generator is running for 6 hours a day that means that it consumes 4.2 litres of fuel per day, which is calculated in equation *4.1*. The HVO fuel that is used is delivered by OKQ8 and according to their available data on fuel prices, stretching from the beginning of 2015 when it was introduced until today, the average price for the fuel is 13.64 SEK/litre (OKQ8, 2017). The prices for HVO vary a bit and there is no clear trend, even though they seem to be dropping. Using the average price for fuel, the daily cost of the fuel consumption is calculated using equation *4.2*. This information is then used to calculate the yearly cost and the cost for ten years as shown in equation *4.3*. Equation *4.4* shows the total cost per bus over a ten years period and is estimated to be close to 200 kSEK.

$$0.7\ liters * 6\ hours\ =\ 4.2\ liters/day \qquad 4.1$$

$$4.2\ litres\ * 13.64\ SEK/litre\ =\ 57.28\ SEK/day \qquad 4.2$$

$$(57.28\ SEK/day\ *\ 251.3\ days) * 10\ years\ = 143\ kSEK/10\ years \quad 4.3$$

$$143\ kSEK/10\ years\ +\ 55\ kSEK\ =\ 198\ kSEK \quad 4.4$$

Table 1. *Data of the current generator and two alternatives for exchanging it. Dometic TEC 30* (Dometic, 2009) *is the current generator and Dometic BLUTEC 40D (Batteriexpressen, 2017) and W-SQ MOBIL (Whisper Power, 2017) is two alternatives for exchanging the current generator.*

Type	Dometic TEC 30	Dometic BLUTEC 40D	W-SQ 6 MOBIL
Power	2.5 kW	3.5 kW	5.0 kW
Noise level	60 dB	54 dB	51 dB
Weight	70 kg	85 kg	240 kg
Purchase price for each generator	55 kSEK	80 kSEK	105 kSEK
Fuel cost for 10 years per bus	144 kSEK	267 kSEK	614 kSEK
Total cost for 10 years per bus	198 kSEK	346 kSEK	730 kSEK

For estimating the health effects of HVO emissions, the diesel emissions will first be evaluated and then compared. For diesel emissions, there are two components that have the greatest effect on human health, particles and NO_2 (OEHHA, 2001). NO_x is a collective name for nitrous oxide (N_2O), nitric oxide (NO) and nitrogen dioxide (NO_2) that are all released when fuel is burned in internal combustion engines. The component that is affecting the human health the most is NO_2 and it affects the lungs and the respiratory system with even short-term inhalation being associated with emergency room visits for respiratory distress (IEA, 2017a).

The particles released are called diesel particulate matter (DPM) and are microscopically. They range between 1 μm and 5 nm in size where more than 90 percent are smaller than 1μm (Saiyasitpanich et al. 2012). This is smaller than one-fifth the thickness of human hair and the particles can therefore travel into the lungs where they can cause several health problems (OEHHA, 2001). According to the Office of Environmental Health Hazard Assessment (OEHHA), the parts of the body that are directly affected are the eyes, nose, lungs and throat and the particles also increase allergies in people already suffering from them. The effects of this can be potentially large and OEHHA estimates that as much as 70 percent of the cancer risk resulting from breathing toxic air comes from diesel exhaust particles in California. The number of particles emitted varies depending on the amount of power produced, how it is being filtered and what type of diesel is being used. This means that there is no way to calculate the number of particles produced and the only way to do this is doing measurements directly from the exhaust pipe.

When comparing diesel with HVO there are some differences but since the two resemble each other, the fundamental problems still remain. The total emissions are reduced, since emissions are lower with HVO. The particles released are reduced with 12-45 percent and the NO_x emissions are reduced with up to 16 percent (IEA, 2017b).

4.4 Electricity poles

When using electricity poles, designed for engine heaters, the reference is still the 2.5 kW generator. Most poles in Uppsala are rated 2.3 or 3.7 kW since they are connected to the grid through a 230-volt connection with a current of 10 or 16 A. If they were to be upgraded to handle a 32 A current the output would be increased to 7.4 kW and would thereby be able to handle a much higher demand. If the poles would be upgraded to a three-phase connection, using 400 volts with a 16 A current, the output could deliver 11.4 kW. The cost for the poles are shown in table 2.

Table 2. *Information about three different electricity poles due to voltage, current, power and cost of purchase* (Vattenfall AB, 2017).

Voltage	230 V	230 V	400 V
Current	16 A	32 A	16 A
Power	3.7 kW	7.4 kW	11.4 kW
Cost	6.4 kSEK	7.1 kSEK	9.9 kSEK

Since this solution requires a power outlet at the destination, the poles will need to be available at all locations that the buses consider stopping at. The locations that fulfil this criterion are limited and depend on how many places the preschools want to have available. This means that the number of poles, and thereby the cost, will vary.

The prices for electricity will be calculated using data supplied by the Swedish energy company Vattenfall AB. The business agreements that Vattenfall supplies are on a three-year contract, in the area of Uppsala, and the prices are currently close to 0.80 SEK/kWh (Vattenfall AB, 2017). The price for electricity that GUB is paying is estimated to be close to this number and will be used as a reference. Calculations for the four alternatives are made using equation *4.5* and the results are presented in table 3. The four alternatives are calculated together with the costs for investments for 10, 20 and 30 electricity poles. The numbers are used in the calculations of the total cost for use of the poles during one and ten years. This results in a total cost including operational and purchase costs shown in equation *4.5*. Asides from the cost of purchase and electricity, the cost for the reconstruction of the bus and installation of the electricity poles has to be taken into account. According to Tommy

Rydbäck (2017) the reconstruction of the bus should not be of great impact of the total price and is in this study excluded. The cost for the installation of the electricity poles varies due to the differences in availability of electricity in the different places. Depending on which places are chosen for installation the cost will vary and this is therefore left for the buyer to evaluate.

$$(kW * price * hours * number\ of\ workdays) + (purchase\ cost * number\ of\ poles) = total\ cost \qquad 4.5$$

Table 3. *Total cost including purchase and operating cost for ten, twenty and thirty electricity poles divided by today's five buses in a perspective of ten years.*

Total cost per bus for 10 years	10 Electricity poles	20 Electricity poles	30 Electricity poles
3.7 kW	57 kSEK	70 kSEK	83 kSEK
7.4 kW	103 kSEK	118 kSEK	132 kSEK
11.4 kW	157 kSEK	177 kSEK	197 kSEK

4.5 Battery

In order to estimate the cost for implementing a battery, the first thing that needs to be known is what capacity the battery needs to have. The wanted size for the battery is directly linked to the power of the generator, since the battery will replace it, and for the battery to replace the generator, the battery needs to be able to provide the same power output for the same amount of time. According to Thomas (2017) the preschool buses are usually operated for six hours per day, from Monday to Thursday and a bit shorter on Fridays. This means that the useful battery capacity, that corresponds to the generator, needs to be 15 kWh, as shown in equation *4.6*.

The capacity corresponds to how much energy the bus would need a regular day during full load. In order to prolong the battery life, the total capacity needs to be higher. Since the battery should not be discharged more than eighty percent, called the depth of discharge, in order to maximise both lifespan and usage, the battery needs to be 25 percent larger (Capasso, Veneri. 2014). Taking this into account, the minimum capacity needed equals 18.8 kWh as shown in equation *4.7*.

$$2.5\ kW * 6\ hours = 15\ kWh \qquad 4.6$$

$$15\ kWh\ /\ 0.8\ =\ 18.8\ kWh \qquad 4.7$$

With the total capacity now known, the next step is to calculate what type of cells the battery should consist of. This includes what size, and as a consequence, how many cells there should be. The majority of the cells on the current market range from 128 Wh to 3.2 kWh, meaning that the number of cells needed to achieve a battery of at least 18.8 kWh ranges from 6 to 147 cells, as shown in equation *4.8* and *4.9*.

$$18.8\,kWh\;/\;3.2\,kWh\;\approx 6\text{ cells} \qquad 4.8$$

$$18.8\,kWh\;/\;0.128\,kWh\;\approx 147\,cells \qquad 4.9$$

The cost of the cells varies a bit and the larger the cell the lower the price per Wh will be, however the difference is less than 10 percent. The cheapest supplier available in time for this report was GWL Power with an approximately price of 0.38 dollars per Wh of battery capacity, this price applied to the two larger cells with a capacity of 2.2 and 3.2 kWh. In order to choose one, the power to weight ratio was calculated since this would have an effect on the bus. The smallest cell was found to have the highest energy density, by comparing the result of equation *4.10* and *4.11*. The number of cells needed for a minimal capacity of 18.75 kWh was calculated through the same method as equation *4.10* and determined to be 9. The total capacity would then be 20.2 kWh and the cost, converted to SEK, would be 70 kSEK as shown in equation *4.12*.

$$3.2\,kWh\;/\;41\,kg\;=78\,Wh/kg \qquad 4.10$$

$$2.2\,kWh\;/\;21\,kg\;=\;105\,Wh/kg \qquad 4.11$$

$$9\,cells\;*\;861\,\$/cell\,*\;9\,SEK/\$\;=\;70\,kSEK \qquad 4.12$$

The lifespan of the batteries also needs to be calculated and the rated amount of cycles for the lithium battery is used, derived from the depth of charge used, and divided with the number of working days per year in Sweden. According to Capasso & Veneri (2014), the rated number of cycles for this type of battery, with an 80 percent discharge, is 3000. The number of working days in Sweden varies between 249 and 254 and depends on which days the holidays occur. For the years 2018 to 2028 the mean value of working days is 251.3 days, leading to equation *4.13* (Mallverkstan, 2017). The estimated life cycle for the battery is therefore calculated to 12 years according to equation *4.13*.

$$3\,000\,cycles\;/\;251.3\,days\;=\;11.94\;\approx 12\,years \qquad 4.13$$

In order to make a sensitivity analysis for the battery, calculations have been done on one smaller battery and one larger, with the same type of cell. The differences have been chosen to plus minus 10 percent, resulting in batteries with a capacity of 17.9 kWh and 22.4 kWh. The results are shown in the table 4 and represent the costs for each bus individually.

Table 4. *Showing the cost for each component and the total cost of the battery, over a period of ten years per bu*s.

Actual size/ usable size	Cost for battery cells	Cost for accessories	Electricity cost for 10 years	Freight cost	Total battery cost
17.9/14.3 kWh	62 kSEK	7 kSEK	36 kSEK	3 kSEK	108 kSEK
20.2/16.2 kWh	70 kSEK	8 kSEK	41 kSEK	3 kSEK	122 kSEK
22.4/17.9 kWh	77 kSEK	8 kSEK	45 kSEK	4 kSEK	134 kSEK

In order for the cells to become a battery that can generate power to the bus, it needs some more components (Ribic 2017). According to Ribic (2017) the first part needed are connection plates that can connect the cells together in order to form one big cell or unit. In order to handle the power flowing from cell to cell and in order to monitor the cells to make sure that they are used in an optimal way, a battery monitor system (BMS) needs to be installed. This will be connected to each of the cells and can be monitored through a panel or a device connected through Bluetooth. The last piece needed is an inverter that can convert the DC current from the batteries to AC current used in the bus (Ribic, Admir. 2017). The inverters are only available in whole kW steps, meaning there is no 2.5 kW alternative to match the existing generator. Since the view from the educators of the preschool has been that the power is a bit limiting, a 3 kW DC-AC converter has been chosen. The total cost for all these parts, depending on the option, are shown in the table 1 and as it shows, the differences are not that big. The main reason for this is the fact that the converter and the BMS are the costliest parts and they are both needed for all three solutions. This means that the price is not linearly scalable.

In order to replace the generator, the battery needs to fit in the existing space that the current generator uses. The measurements of the cells have therefore been compared to the generator and the conclusion is that all chosen alternatives would fit. It is also important that the weight of the batteries is not to high, so that it can be mounted in a safe way. The weight of each individual cell chosen for this scenario is 21 kg. This results in a total weight of 168, 189 and 210 kg for the different sizes (GWL Power, 2017). In relation to the generator, which only weighs 70 kg, this seems to be a factor to be taken into account.

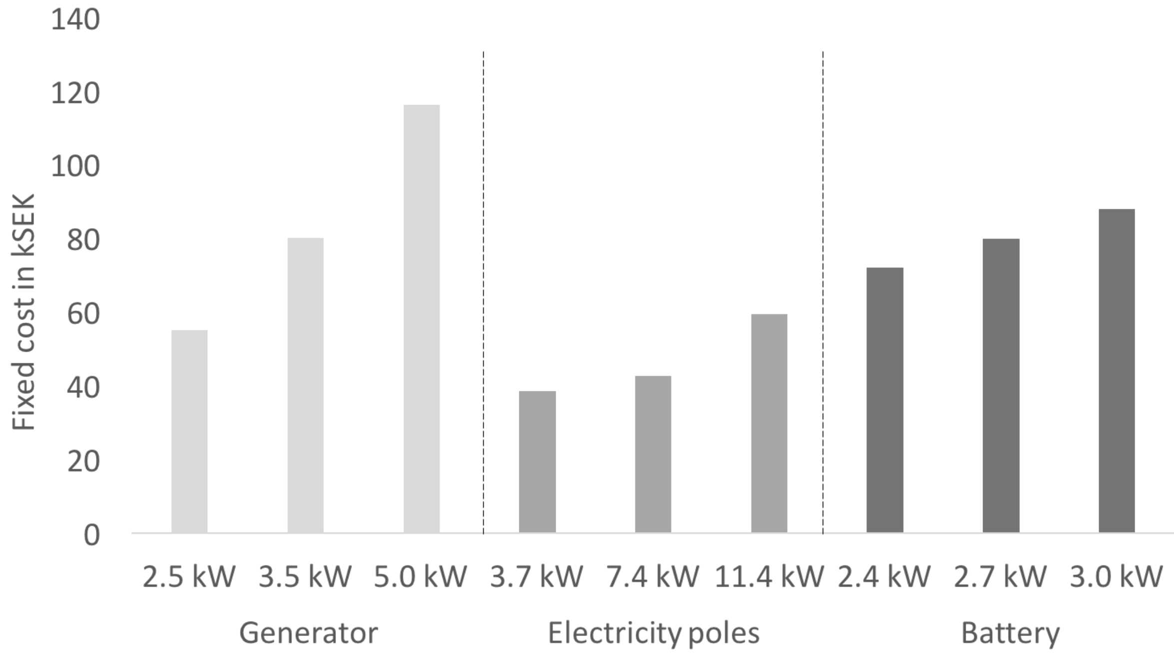

Figure 3. The fixed costs, consisting of the purchase price, for the three scenarios: generator, electricity poles and battery, together with its three alternatives.

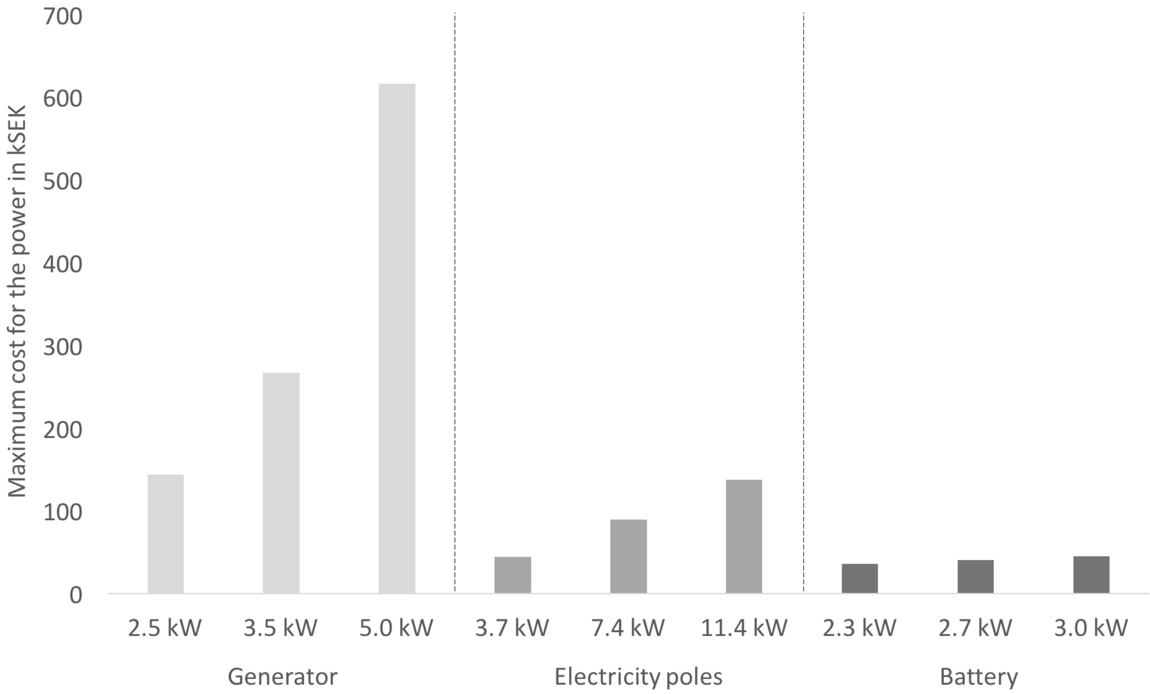

Figure 4. The variable cost for the three scenarios: generator, electricity poles and battery together with its three alternatives. The variable cost is a maximum and is reached when the generator and electricity poles are used at their maximum potential. For the battery, this means that the potential of the batteries is evenly distributed over the time used.

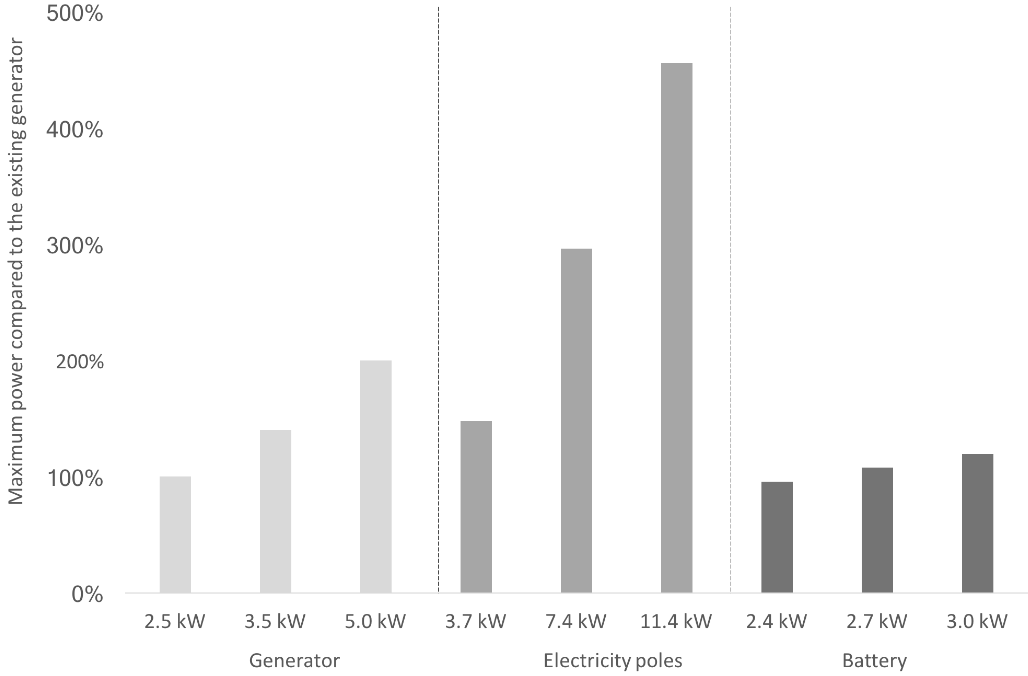

Figure 5. The power produced of each scenario with its alternative in relation to what the generator produces today.

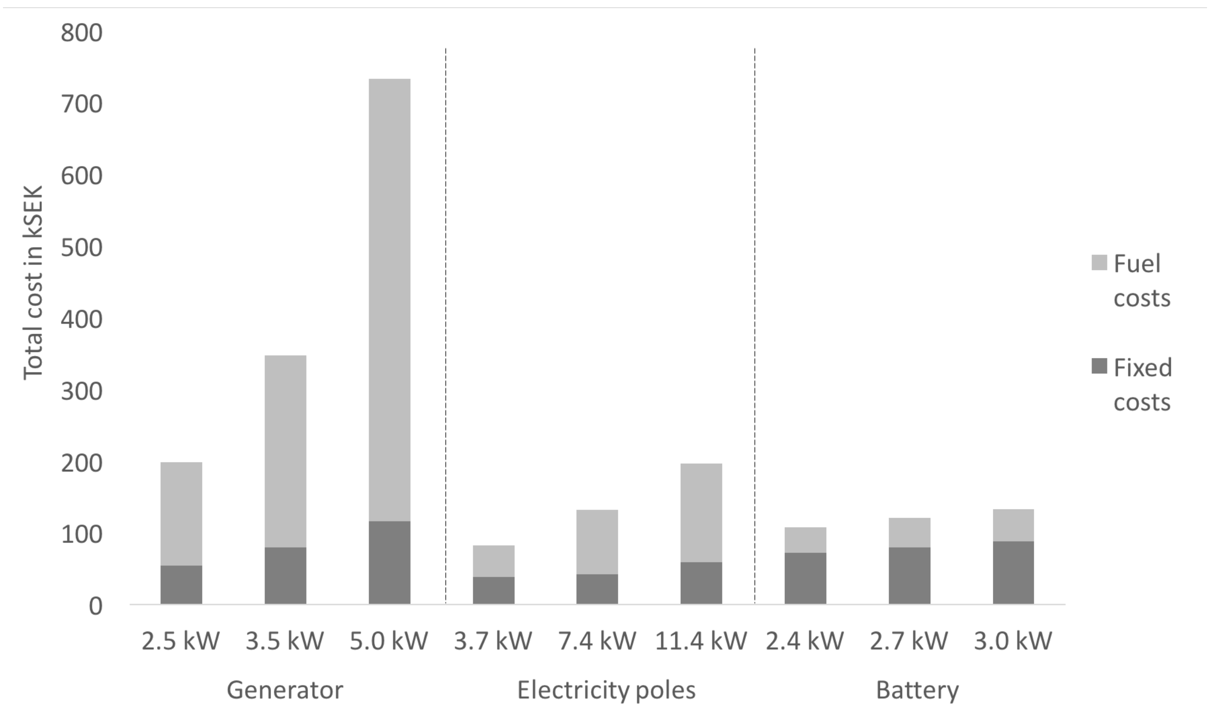

Figure 6. The total cost, including both fixed and variable cost, for all three scenarios with its alternatives.

5. Sensitivity analysis

A sensitivity analysis has been done to evaluate the study's reliability. The energy consumption is a parameter that has a great impact on all three scenarios. Due to the lack of knowledge of the generators real fuel consumption and utilization, in combination with it being seen as underpowered, the generator is assumed to be running at full power and as result, the fuel consumption is assumed to be at a maximum. This affects the fuel cost in all three scenarios, and therefore the total cost. The variable fuel cost for the generator is significantly higher than the variable electricity cost for the poles and the battery, as shown in figure 4. This is directly connected to the cost of electricity when using a generator to produce it or use it as it is. The differences would still be significant if the generators would produce less electricity than they are rated for and thereby consume less fuel.

An important parameter for the total cost is as mentioned the fuel cost. The fuel cost depends on the energy consumption but also of the price for the fuel. The energy density of HVO is much less than electricity which is a great factor to the big differences for the fuel costs. This means that equal differences in fuel price will have different effect on the fuel cost. The price for the electricity is low compared with HVO but it is a bigger percentage differences in price over time for electricity compared with HVO. Changes of fuel prices will affect the fuel cost and the result but the estimations should illustrate the reality in a fair way.

The total cost for the electricity poles is low in comparison with the other two scenarios. The installation cost for the poles are excluded and could potentially be very high, depending on the choice of locations. The total cost for the cheapest alternative for poles is less than half of the cheapest battery but with installation cost this could even out.

6. Discussion

The electricity poles are very beneficial due to the availability it provides for all buses. They are not tied to one specific bus, which has a great impact on the total price in the long run. The purchase cost is a one-time expense and is not depending on the replacement of buses. Since the lifespan of the buses is shorter than that of the electricity poles, they will most likely last longer than the ten years that the contract stretches. If changing to a fully electrical solution, with electricity poles, the cost of reconstruction of the buses has to be taken into account. Due to the low complexity of the installation and the high competence in doing this type of modification by GUB, the solution should be both financially and technically viable.

There are big differences in total cost for the three scenarios and there is one scenario that is consistently cheaper than the others, the electricity poles. There are costs that are not considered and one of them is the installation cost of the poles. How much it will affect the total cost in the end is hard to determine, mainly due to the variation in locations. This is a big factor to consider when determining the total cost since absence of electricity or digging new cables is very costly.

The main reason why the educators of the bus opposite the electricity poles is the lack of freedom they think it would mean. In the organisation today, the buses visit about thirty to forty different places and there are some favourites that get visited more often than others. In the scenario with the electricity poles, the alternatives chosen include ten, twenty and thirty poles, in order to minimize the sense of limitation. The solution with thirty poles seems the most appropriate and the total cost per bus, with the five buses used today, is 83 kSEK with a potential power of 3.7 kW. As figure 3 illustrates, the electricity poles are the cheapest solution when comparing the fixed costs. Figure 5 illustrates the capacity for the different alternatives, and the potential power produced ranges from close to 100 percent of today's capacity to a power that is 350 percent higher. The chosen alternative for the electric poles deliver almost 150 percent of today's power. Figure 6 illustrates the total cost for the three scenarios and the cheapest scenario is the electric poles with its alternative of electric poles of 3.7 kW. This makes the poles even more attractive since many of the limitations experienced today would disappear.

Unlike the electricity poles, the purchase cost for the battery is directly linked to one specific bus and a replacement of the bus would mean that a new battery would have to be purchased or that the existing one would have to be transferred. The life span for the battery is estimated to be twelve years, which is similar to the length for the current contract and generator. The total cost for the three different alternatives with a battery, over ten years and divided by the current five buses is as shown in table 4. The usable capacity of the batteries is only eighty percent of the actual size and compared to the generator used today they have the potential to deliver 95, 108 and 120 percent of the daily power needed. Since the inverter chosen is capable of delivering 3 kW, the peak power is higher than the average.

The total cost of the generator used today, over ten years, is 198 kSEK per bus and has a noise level of 60 dB. The alternative generators found on the market today, that have a lower sound and a similar fuel consumption are few. The best alternatives are presented in Table 1 and even though the fixed costs are not that high, the fuel costs make them the most expensive alternatives. The potential relative power produced by the two alternatives is 150 and 200 percent compared to the current generator, placing them in between the potential of electricity poles and batteries. The sound levels of the alternatives are about half or a little more than that of the current generator, making them a reasonable option. They also keep the freedom for the educators to go wherever they want without being concerned with the power available.

Some educators on the buses wish to increase the power and energy delivered and the municipality of Uppsala would like to have the most beneficial solution in cost and environment. Comparing the capacity of 2.5 kW installed today, with a total electric energy of 15 kWh consumed, and the three scenarios chosen, the most appropriate scenarios are the electricity poles and the battery. When choosing alternatives within the scenarios, the 3.7 kW electricity poles and the 16.2 kWh battery should meet the most criteria. The total cost for thirty electricity poles would be 83 kSEK and for the battery 122 kSEK, per bus. The service costs for an electric solution is cheaper than that of a generator, giving these even more of an advantage. With all the total costs for the different scenarios illustrated in figure 6 the most beneficial alternative in financial matter is the electrical poles with a size of 3.7 kW.

The educators' biggest concern with the generator was the loud noise and local emissions. Both of the electrical solutions answer directly to the problems. The battery is also beneficial due to the freedom it provides in the choice of location. A variation in locations is mostly beneficial for the children that get variety, but also the educators of the bus that have the chance to be spontaneous while choosing location for a varied teaching. The generator does in some way provide freedom but on the other hand also limit due to its loud noise. Some of the educators' main concern with the electrical poles was the lack of freedom they thought it would mean, but investing in electrical poles would make new places available that could not be used due to the noise of the current generator. The initial plan to building electrical poles, which was presented to some of the educators, was to only build ten poles. This changed when the costs were determined to be really low and options with more poles would still be inexpensive.

One important aspect of the battery solution that has to be taken into account is the extra weight it will add to the bus. The extra weight could pose a problem in securely mounting it, since the extra weight would mean that reinforcements could be needed. If investing in the electrical poles, the loading capacity of the bus could increase, due to the extra space provided when taking out the generator. Today the educators only have to push a button to start the generator and if implementing the electrical poles, the educators have to plug in the bus by a cable to get electricity. A battery solution on the other hand, would not mean any big changes to how the bus is operated by the educators today.

The consequences in keeping the generator would mainly be its disadvantage in loud noise and local emissions but also a continued high cost in fuel and service in comparison with the corresponding cost for the electrical solutions.

The optimal solution does not have to be one solution alone but could be a combination for the best possible result in all matters. A combination of keeping the generator and installing electrical poles could be a way to achieve both the freedom in visiting places lacking the infrastructure for electrical poles and still be able to have most of the business run with the electrical connections with zero local emissions and zero noise. If instead a combination of both the electrical poles and the battery could be implemented, the life length of the battery could be extended while the poles could be used where it is most economically reasonable. Investing in either of the electrical solutions will result in zero local emission and a silent source of energy.

7. Conclusion

When evaluating what scenario would be the most beneficial in terms of economy, there are two costs that have been estimated, the fixed and the variable costs. The fixed costs show that the cheapest solution, for all three alternatives, is the electrical poles. The differences are not that significant but could change a lot if the installation costs were calculated. For the variable costs, the battery scenario is the cheapest alternative and here the difference are more remarkable. For the total cost the conclusion is not as easy to determine. The cheapest scenario of all is the electric poles with its first alternative that delivers a power of 3.7 kW. As illustrated in figure 6 the total cost for that alternative is 83 kSEK per bus for a period of ten years.

When evaluating what scenario would be the best for the children and educators, there are also two aspects. The first is the freedom of choosing location and the second is the consequences to the health. The freedom of choice makes the generator and battery a winner since there are no theoretical limits. There are however limits to the regulator depending on the noise and emissions it makes. When evaluating the electrical poles, the freedom of choice can also be catered for if enough poles are being installed. When determining the best scenario in respect to the health of the children and educators, the best options are the battery and the electrical poles since they have no local emissions. There are no health benefits making any of the two more or less of an option. The conclusion here is that the battery fits all criteria but that the electrical poles have the potential to do almost as good.

The consequences for keeping the generator can also be divided into parts. The cost for keeping the generators running is high since both the maintenance and the cost of fuel is a lot higher than for the electrical solutions. The health of the children and educators is also likely to be effected in a negative way, although there should be more research conducted in this area before a concrete conclusion can be made. The noise that the generator makes is also affecting the daily operations in a negative way, making it impossible to visit certain locations in the city and disturbing the environment around the bus. For the municipality of Uppsala, it also means that certain criteria expressed in its regulatory documents cannot be met, regarding the task to work with the wellbeing of children in mind at all times.

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