Recovering energy from excess heat at Gevalia’s roasting-house in Gävle

Agnis Zambars
Abstract

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This thesis examines the roasting process at Gevalia’s coffee roasting house in Gävle and describes the possibilities to recover the energy in roasting gasses that are released into the atmosphere from the factory’s chimneys. The roasting gasses leave the factory’s chimneys at temperatures upwards of 370 °C in large volumes all year round. It is possible to extract energy from them via an economiser. The extracted energy can then be used to replace Gevalia’s consumption of district heating. The estimated potential for energy extracted from the roasting gasses is approximately 10 GWh per year. The monetary gain can be estimated up to 5 million SEK annually if it is possible to sell excess heat into the local district heating grid. It remains uncertain if it is possible to sell the excess heat due to a number of regulations and other external factors. Should this not be possible, the factory can still cover their own heating demand through heat recovery from roasting gasses. An alternative solution to economiser is absorption cooling in order to produce refrigeration. This process, however, is more complicated. There is also a very limited number of cooling consuming elements within the factory. A planned extension of the local district cooling grid in the area could make this a more viable alternative. The estimated potential for cooling production is approximately 7.6 GWh per year.
Sammanfattning


Den mest energikrävande delen av processen är själva rostningen av kaffebönor, som förbrukar stora mängder gasol genom förbränning. För att upprätthålla en optimal rostning av kaffebönor erhålls det höga temperaturer i rostskålen, vilket innebär att rostgaser lämnar rosteriets skorstenar vid temperaturer mer än 370 °C. Dessa rostgaser innehåller fortfarande stora mängder värmeenergi, vilket idag bara avges till atmosfären.

Detta arbete beskriver förutsättningar som krävs för att utnyttja den kvarvarande energin i rostgaser. Energin i rostgaser kan lättast återvinna genom en rökgaskylare (economiser) och kan användas för att ersätta rosteriets användning av fjärrvärme. Eventuellt kan Gevalia även sälja överskottsenergin ut i fjärrvärmenätet. De värmetillgångar som går att återvinna har uppskattats till ca 10 GWh per år.

Uppskattningen har gjorts utifrån mätning av temperatur, uppskattning av gasflöde samt loggning av anläggningens drifttimmar. Om rosteriet försäkrar sig om ett avtal med Gävle Energi att kunna sälja värme till fjärrvärménätet uppskattas den årliga vinsten kunna uppgå till ca 5 miljoner kronor, delvis genom en minskad fjärrvärmnotan och delvis genom såld överskottsvarme. Det är dock oklart om ett sådant avtal kan uppnås. Ett antal faktorer såsom nya lagar eller självinitiativ av industrin kan dock gynna förutsättningar för en överenskommelse.

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1 Introduction
Gevalia is the largest coffee roasting house in Scandinavia and a wholly-owned subsidiary of Mondelēz International (part of former Kraft Foods). Gevalia’s roasting house is situated in Gävle, Sweden, and is responsible for the production of over 100 different coffee products sold primarily in Europe, but also in North America.

Coffee roasting is a highly delicate but also energy-demanding process that consists of many parts that have to be carefully calibrated for each specific product (Olsson, 2013). Throughout the years Gevalia has not only strived to make the roasting consistent in high quality product output, but also to make the roasting process as smooth and efficient as possible. This includes efforts to reduce the consumption of energy throughout the production line. The most energy-demanding part of the production is the roasting itself, craving large amounts of liquefied petroleum gas (LPG) to fuel the roaster. Roasting has to uphold high temperatures for the process to be effective, but this also means that large quantities of roasting gasses leave the factory’s chimneys at temperatures upwards of 370 °C. These roasting gasses still hold a significant amount of energy that is simply released out into the atmosphere. The intention of this thesis is to take a closer look at the possibilities to recover some of the energy from the roasting gasses after the roasting process.

Gevalia has commissioned several previous analyses of the subject, but so far this has not lead to a successful implementation of a viable solution. A study from 2007 (Mårdäng, 2007) looked at the potential to recover heat from roasting gasses at set temperatures of 300 and 370 °C and with operational hours set at 48 or 50 weeks every year. The results showed potential energy-savings of 900 – 2100 MWh per year and roaster, depending on the scenario. The estimated investment costs were 4.4 million SEK, not including construction costs, administrative authority fees and VAT. Another study from 2010 (Hedman, 2010) used a set temperature of 370 °C for the roasting gasses and a total operational time of 7900 h/year. The study determined that the yearly heat-savings could be estimated to 5 GWh, achieving which would require an investment of 4.3 million SEK excluding VAT. The study also noted that a maintenance cost of 145 000 SEK/year should also be expected. The estimated results vary and it can be seen that a lot of static data is used in calculations. Some of the conditions relevant to the subject have changed and the intention of this report is to provide Gevalia with the latest and most relevant information that reflects the actual operation of the roasting-house to make the decision of whether or not to proceed with an investment in energy recovery.
1.1 Purpose
The purpose of this thesis is to examine the roasting process at Gevalia’s coffee roasting house in Gävle and describe the possibilities to recover the energy in roasting gasses that are released into the atmosphere from the factory’s chimneys. By calculating the amount of energy that can be recovered and comparing it to the possible uses of this energy utilising different technologies, several scenarios have been described.

1.2 Method
The results were achieved by regular trips to the roasting house, getting acquainted with the roasting process as well as doing measurements of the temperatures and gathering other available data. Further information was obtained from contact with Gävle Energi, the main energy company in Gävle, the Swedish Energy Markets Inspectorate (Energimarknadsinspektionen, EI) and also people with relevant knowledge on the subject. This was combined with literature studies and calculations.

Accompanying this report is an Excel document that can be used to calculate the possible energy production and compare it to the energy sinks such as heating the factory or selling heat into the local district heating grid. The document also contains economic calculations to determine the payback time in the different scenarios. It contains the data gathered during the process of this thesis; however it can easily be updated with new data as it becomes available or if there are changes to the existing input data.

1.3 Examined solutions

1.3.1 Heating
The solution deemed most likely to succeed is recycling the energy in the roasting gasses for heat production. The produced heat would primarily be used to cover the roasting house’s own consumption of heating, which at the moment is provided by the local central heating grid, owned by Gävle Energi.

The roasting house itself as well as the adjacent buildings belonging to it, such as the office building, the storage facility for green coffee beans and the warehouse for finished products, all use considerable amounts of heating energy during the winter. However, during the summer little to no district heating is purchased, while the coffee production is still going on. This would mean that for a large part of the year the factory would be capable of producing heat in considerable excess of what it actually consumes.

In order for the heat-recovery process to be at its most effective the excess heat that Gevalia does not consume for its own purposes should be sold back into the district heating grid. To achieve this, an agreement to purchase the excess heat must be established with Gävle Energi. It would also
involve some restructuring and re-dimensioning of the existing substations connecting the buildings to the district heating grid. Such an agreement would not only diminish or even eliminate Gevalia’s heating costs but also generate income for the sold heat. If such an agreement cannot be reached, then Gevalia could still use the generated heat to cover its own needs to the possible extent and release the excess heat into the atmosphere as it is done today.

The deciding factor for choosing this solution is the acceptable payback time of the investment that would be needed for its implementation. The investment would have to be covered either by the reduction in heating bills or preferably by the combination of the reduction of the heating bills and the generated income for sold heat. Both options have been looked at in this project.

1.3.2 Absorption cooling
An alternative solution for recovering the energy in the roasting gasses is to use it for the production of cooling utilising absorption cooling technology. Similarly to the option of generating usable heat, the produced cooling would be used for the roasting house’s own needs with the possibility of selling the excess cooling produced.

Gevalia purchases some comfort cooling from Gävle Energi mostly during the summer. The roasting house also utilises process cooling during the production process. Over the course of the project the possibilities of covering these cooling needs have been examined as well as the needs of any possible external parties that would be interested in purchasing Gevalia’s produced cooling.

1.4 Limitations
The original intention of this thesis was to provide a set solution to the problem and calculate whether or not it would be economically feasible to make such an investment. However, over the course of the project it became apparent that such a detailed solution demands an intimate knowledge of the technologies involved and relevant field experience. Without detailed description of a final solution, installation companies are reluctant to provide an exact quote for the final costs of such a project.

A decision was therefore made to focus on examining and providing the relevant information needed for an experienced engineer to design a specific solution. With the help of final designs, a quota can be requested by a company of Gevalia’s choice and compared with the latest economical calculations with an Excel document provided together with the final report.

The range of possible technologies used for energy recovery is very wide, but to limit the scope of the project, the two most realistic technologies were chosen for closer examination. The first of these is using an economiser to extract the energy from the roasting gasses and subsequently using the heat to either heat the roasting house itself or to sell the heat to the local district heating grid.
The other technology is absorption cooling, a process that utilises heat to generate cooling. The option of generating electricity was also considered, but discarded because technologies like the Stirling engine that can achieve this have more moving parts implying more maintenance. Conversion between different forms of energy usually also entails more losses.
2 Theoretical background

2.1 Recoverable energy from roasting gasses

To be able to calculate the amount of power that can be generated from roasting gasses via an economiser, which is basically a large heat-exchanger, the following equation can be used:

\[ P = \left( \frac{\dot{V}}{3600} \ast (h_1 - h_2) \right), \quad (1) \]

where

- \( P \) = recoverable power (kW),
- \( \dot{V} \) = gas flow through the chimney (Nm³/h)
- \( h_1 \) = specific enthalpy in the roasting gasses before the economiser (kJ/m³),
- \( h_2 \) = specific enthalpy in the roasting gasses after the economiser (kJ/m³).

By multiplying \( P \) with the number of hours that the roasting gasses flow through the chimneys, the amount of recoverable energy can be calculated over a given period of time. (AWRI, 2006)

2.2 Absorption Cooling

Absorption cooling is a technology that utilises thermal energy to provide cooling. A traditional cooling cycle is driven by a compressor, which in turn is run on electricity. Absorption cooling is an alternative to the traditional cooling machine, where the compressor is replaced by a smaller cycle, which can be referred to as a thermal compressor.

Figure 1 provides a basic overview of the absorption cycle. A refrigerant is circulated throughout the whole cycle similarly to a traditional refrigeration unit. As the refrigerant typically has a low dew point, it is evaporated in the evaporator, taking on the thermal energy of the space that needs cooling (\( Q_{in1} \)). It then passes on to the absorber where it is sprayed with an absorbent (which has to have a lower dew point than the refrigerant) to reduce the refrigerant back to liquid form. During this part of the cycle, the refrigerant releases some of its thermal energy, which is removed from the cycle (\( Q_{out1} \)).

The mixture of the refrigerant and the absorbent is then pumped further to the generator. The pump is the only part of the cycle that requires electrical energy (\( W_m \)). The generator is the part of the cycle where the external heat source (\( Q_{in2} \)) is introduced into the cycle. Using the external heat (which in Gevalia’s case would be the roasting gasses), the mixture is heated. As the refrigerant has a lower dew point than the absorbent it evaporates first in the process separating the two.
From the generator, the absorbent is returned to the absorber, while the refrigerant is pumped further to the condenser where the thermal energy leaves the system \(Q_{\text{out2}}\). (Welch, 2009)

![Diagram of the absorption cycle](image)

**Figure 1.** The basic absorption cycle (Welch, 2009)

A typical refrigerant/absorbent combination used in the absorption cycle is ammonium (refrigerant) and water (absorbent) (Alvarez, 2006)), but there are many variations available on the market.

One of the most problematic aspects of absorption cooling is its rather low efficiency, which is expressed as Coefficient of Performance (COP) for thermal cycles. The COP is calculated by dividing the amount of thermal energy removed from the cooled area (Cooling Duty) with the thermal energy added to the system in the pump and the generator (Generator Heating Duty), see Equation 2. A typical COP for absorption cooler is around 0.7.

\[
COP = \frac{q_{\text{in1}}}{q_{\text{in2}} + w_{\text{in}}} \tag{2}
\]
3 The roasting process at Gevalia

3.1 Roasters

The roasting house in Gävle has three roasters that are used for coffee roasting, referred to as RZ1, RZ2 and RZ3. A German company called Probat that specialises in manufacturing coffee roasters and grinders as well as plant components manufactures all three roasters (Probat, 2013). RZ1 and RZ3 are older models called Radial-Turbo-Röster RZ 4000. RZ2 however is a more recent model called Radial-Turbo-Röster SATURN 4000 type 2 LT installed in 2011-2012. This roaster has a built-in heat-recovery technology that diverts the majority of the hot roasting gasses after the roasting is done to a unit that pre-heats the green coffee beans before they are roasted. The purpose for this is to reduce the consumption of LPG in the burner that provides heat for the roasting process.

![Figure 2. Schematic view of roasters RZ1 and RZ3](image_url)

Figure 2 gives a schematic view of roasters RZ1 and RZ3. The roasting bowl (1) is located in the centre in which the green coffee beans are roasted in batches of more than 400 kg. The beans are moved around while the LPG heated air passes and circulates among them. After the roasting bowl, the hot air passes through a cyclone separator (2) to remove any solid particles that have separated from the
coffee beans. Some of the hot air is re-entered into circulation and sent back to the LPG burner while the rest is transported to the exhaust chimney (3).

Figure 3 depicts the more advanced roaster RZ2. The basic principle is the same, roasting is done in batches of over 400 kg, but an additional step is introduced to recover some of the heat trapped in the roasting gasses. After the catalyst in the chimney (1), the majority of the hot gas flow is diverted to a chamber (2) where green coffee beans are pre-heated before entering the roasting bowl. After the pre-heating process the roasting gasses are released into the atmosphere (through chimney Y10 in Figure 3), but at much lower temperatures. For the purposes of this project, only the original hot roasting gasses are relevant, which is the gas flow volume through chimney Y1.

It can also be noted that RZ2 includes a second LPG burner (3) that can heat the roasting gasses before entering the chimney. The purpose of this is to adjust the temperature of the roasting gasses when their temperature is too low for the catalyst to function optimally.

![Figure 3. Schematic view of roaster RZ2](image)

### 3.2 Process cooling

Gevalia uses a certain amount of process cooling in the production procedure. After the coffee beans are done roasting, they pass through a stage that rapidly cools them down to much lower
temperatures. The process ensures that the ground coffee beans retain much more of the aroma before being packaged. The retained aroma lasts until the first time the coffee packaged is opened by the consumer.

This cooling process is ensured by a refrigeration unit in the factory referred to as Crystal. Crystal consists of two compressors and a closed loop containing liquid ammonium. The compressors have the capability to produce up to 320 kW of cooling power and the coolant may reach temperatures as low as -26 °C.

The initial intent of this project was to try and incorporate the coverage of the process cooling as one of the analysed options; however, this has been dismissed after a personal conversation with the cooling technician employed by Gevalia, Ed Svensson (2013). According to Svensson, the refrigeration unit has to retain the capability to supply 320 kW of cooling at all times, despite the fact that the refrigeration unit is not always used to its full capacity. Given the intermittent nature of the roasting schedule, this could not be guaranteed, so covering the process cooling was eliminated from this point onwards.

3.3 Measurements

Temperature throughout the roasting system is one of the most crucial factors to regulate to achieve the optimal product. It is therefore meticulously measured and logged at various points in the system and could be readily obtained. The roasting temperature and subsequently the roasting gas temperature varies to achieve the various roasting degrees needed for different products, so a choice was made to measure the temperature while the most common coffee roasting recipe was used in each of the machines. The roasting recipe chosen is referred to as C1 Dark at Gevalia.

Another important aspect to note is that the temperature of the roasting gasses fluctuates over each 7-8 minute cycle of roasting one batch. Therefore a number of cycles were recorded with measurements at 5-second intervals and an average temperature throughout the cycle was calculated. The minimal and maximal temperatures were also noted. The measurements were taken at the point in the exhaust chimneys after the catalysers that clean the roasting gasses before releasing them into the atmosphere. It takes several cycles after the start-up of a roaster for it to achieve normal operation and cycle length, so the measurements were taken after this initiation period.

The average temperature over one cycle for RZ1 was determined to be 405°C, with a minimum temperature of 371°C and maximum temperature of 469°C. The average temperature over one cycle
for RZ2 was determined to be 397°C, with a minimum temperature of 369°C and maximum temperature of 451°C. The average temperature over one cycle for RZ3 was determined to be 371°C, with a minimum temperature of 355°C and maximum temperature of 413°C. These are depicted in Table 1. See also Appendix 1 for examples of temperature variation over a roasting cycle.

| Table 1. Roasting gas temperature and energy content values for the three roasters |
|---------------------------------|-------------------|-------------------|-------------------|
| Temperature, C°                 | Min               | Max               | Average           | Average           |
| RZ1                             | 371               | 469               | 405               | 550               |
| RZ2                             | 369               | 451               | 397               | 550               |
| RZ3                             | 355               | 413               | 371               | 525               |

Using the obtained average temperatures, the energy content of the gasses could be determined from a table provided by Energihandbok.se (2013). The table is originally intended for looking up energy content of chimney gasses, and can also be applied in this case. There are differences in the composition of roasting and chimney gasses; however below the temperatures of 500°C, the difference in energy content is not significant.

The average energy content in the roasting gasses coming from RZ1 and RZ2 is therefore 550 kJ/m³, due to the similar temperatures. For RZ3 the energy content in the roasting gasses is 525 kJ/m³.

### 3.4 Gas flow

Estimating the flow of roasting gasses from each of the chimneys has been one of the most problematic parts of the project and possibly one of the largest sources of error. There are no measurements of the gas flow taken on operational basis. The only flow measurements available come from environmental emission analysis, which are done twice a year, executed by ILEMA Miljöanalys AB. These range from just above 2000 m³/h to over 10000 m³/h. The reason for this is that these measurements are taken as singular test samples and it is unknown during which part of the cycle the sample was taken, which is important, because the gas flow also varies over the roasting cycle.

Another issue is that the chimneys after the catalyst are very short. To measure the flow with high precision, a laminar flow is preferable. To achieve this there must be a straight chimney segment of length of about 5 hydraulic diameters before and after the measurement point. Due to the shape of the existing chimneys, this is not the case and the flow becomes turbulent. This causes the flow measurements to have a large error. According to an emissions analysis by ILEMA from November of 2012, the flow measurements have an error of up to 46.61%.
It was therefore decided to use the flow specified by the manufacturer of the roasting machines, PROBAT. The flow used in calculations is therefore 4700 Nm$^3$/h for RZ1 and RZ3 and 630 Nm$^3$/h for RZ2. The flow for RZ2 is significantly lower, because only the relevant chimney that exhausts the hot roasting gasses was examined. The rest of the gas flow is directed through the pre-heater, where it loses most of its energy content, deeming this flow irrelevant for the project.

### 3.5 Operational hours

Although the roasting house is normally operational 24 hours a day, the roasting is not continuous throughout the week. All three roasters are seldom operational simultaneously and production is regulated according to demand. During the weekends there is also a 12 hour break in production to accommodate any short-term maintenance. For larger maintenance projects and to allow for employee vacations, there is a two-week factory shutdown planned every summer, usually in July. In reality however, this does not always take place due to existing demand or other reasons.

The operational hours for each of the three roasters is logged throughout the year via a centralised system called Waterfall Line Utilization. The system calculates the theoretical maximum operational hours if the roasters were working at full capacity and compares it to the actual hours that the roasters were online. It also logs all the different reasons for downtime, such as maintenance, changeovers, sanitation, equipment delays, speed losses, low demand or operational limitations due to regulations. The downtimes are then divided with the theoretical operational time and expressed as percentage of time assigned to each reason. For the purposes of this project though, only the actual amount of operational hours are necessary. The monthly operational hours from 2011 to early 2013 were collected for all three roasters and used for calculations (see Tables 2-4).

**Table 2. Operational hours RZ1**

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Table 4. Operational hours RZ3

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The operational hours over the years can vary significantly due to fluctuating demand, larger maintenance projects or some products being allocated for production at a different location. It is therefore advisable to update the data in the calculations spreadsheet to have the most realistic estimation of available roasting gasses.

4 Energy consumption measurements

4.1 Buildings

There are several buildings that belong to the Gevalia roasting house and all are important for the full functionality of the factory. The largest building is the factory itself which is directly connected to the adjacent office building (address Drottninggatan 51-53). The factory and the offices share a district heating substation. The next biggest building is the warehouse (address Drottninggatan 56), where the finished product is being stored. This building has its own district heating substation. There is also the storage facility for green coffee beans where also finished products are being stored until shipped off (address Drottninggatan 50), with its own substation. However, this building is slightly further away and consumes comparatively less heating. It is therefore not considered for attachment to the local heat production.
4.2 Heating consumption

Figure 4 shows historical data of the district heating consumption for the main factory building and the office building with the address Drottninggatan 51-53. The data was acquired from Gävle Energi’s annual energy report to Gevalia (Gävle Energi, 2013).

![Figure 4. Monthly district heating usage, 2008 – 2012 for Drottninggatan 51-53](image-url)
Figure 5 depicts historical data for district heating consumption for the second biggest consumer among the roasting house’s substations, serving Drottninggatan 56 or the warehouse.

![Figure 5: Monthly district heating usage, 2008 – 2012, for Drottninggatan 56](image)

These figures show the large variation in heating consumption between summer and winter. It can also be observed that the main factory building and the office building together consume about four times more heating than the warehouse building.

### 4.3 Cooling consumption

Figure 6 shows historical data over Gevalia’s consumption of central cooling provided by Gävle Energi. The magnitude of energy consumed is considerably smaller than the heating that the factory consumes over the year. The cooling consumption is also concentrated almost exclusively during the summer months.

It can also be noted that Gevalia is not actually connected to the district cooling grid, even though the cooling it receives is referred to as “district cooling”. Instead, every summer a portable cooling machine running on electricity is transported to the factory and kept in a container outside the factory itself.
Additional technical details

5.1 Economiser

The final version of the economiser is dependent of the technical implementation of the system, but there are several things that have to be kept in mind when making the investment choice. Firstly, the economiser has to be capable of handling the gas flow as well as the maximum temperature of the roasting gasses coming from all of the chimneys combined. The total maximum gas flow provided by Probat adds up to $10\,030\, m^3/h$ if all three chimneys are connected to the economiser. The economiser should probably be dimensioned to a gas flow that is somewhat higher for the purpose of fluctuations. Alternatively, a valve can be installed that bypasses the flow that the economiser cannot handle back out to the regular chimney.

The highest registered gas temperature after the catalyst during the measurements was 469 °C coming from RZ1. It is not inconceivable that in certain cases the temperature rises above this and the economiser should be designed to be able to handle this.

Another aspect that is important is that the roasting gasses contain various chemicals that have evaporated from the coffee beans in the roasting process. These chemicals are in gaseous form while the gas temperature is fairly high, but as the economiser extracts the heat from them, the temperature is lowered and there is a risk of the chemicals starting to condense inside the
economiser. A build-up of these condensed chemicals would require regular cleaning of the economiser, which can be a messy and costly process. There is no exact list of the chemicals trapped in the roasting gasses to determine the dew point of each of them, so to be on the safe side Gevalia has determined that the gasses should not be cooled below 150 °C. This also forms the lower limit when it comes to heat extraction. The temperature of 150 °C and the corresponding energy content for chimney gasses of 200 kJ/m³ (energihandbok.se) was used in the calculations for the possible amount of heat that can be extracted from the roasting gasses.

5.2 Hot water storage tank

The purpose of the hot water storage tank is to even out the differences in heat production and consumption, by temporarily storing the produced heat in the form of hot water. The choice of the hot water storage tank should reflect the needs of the project, when it comes to the size and temperature. One of the deciding factors when an adequate hot water storage tank is its capability to store a certain amount of energy over a given period of time.

To accommodate for the intermittent use of roasters as well as the break in production over the weekend, an adequate size for the chosen hot water storage tank should be similar to the maximum energy consumption over the course of one day. If we look at the district heating consumption of the two main buildings in the middle of winter, the heating consumption adds up to around 600 MWh per month. Divided by 30 days this gives a number of circa 20 MWh per day, which should also be the amount of energy that the hot water storage tank is built for.

6 External factors

This chapter provides an overview of other factors that may influence the success of implementation of energy recovery. These are factors that are independent of the technical possibilities of engineering, but which can still be extremely relevant for making the final decision.

6.1 Proposition for regulated access to the district heating grid

In April of 2013 the Swedish Energy Markets Inspectorate (Energimarknadsinspektionen, EI) published a report titled “Reglerad tillträde till fjärrvärmenäten” (Regulated access to the district heating grid, Heldesten, 2013). The report outlines proposed changes in the District Heating Law that would favour small-scale heat producers by supporting their right to sell their produced heat into the local district heating grid. However, the report specifies that this would only happen in cases where
such an access is reasonable from the economic perspective for both parties involved, but where today an agreement is hard to come to.

Today, the district heating companies have no obligation to grant access to their district heating grid to external heat producers. Numerous agreements exist throughout Sweden, but in some cases agreements are hard to establish because of problems dividing up the risks and benefits of such collaboration. The proposed model for regulated access should grant the right for external heat producers to request access to the district heating grid, but the district heating company should never be put at any real risk for actual losses. Therefore the model only supports the right to sell first-grade heat into the supply pipeline, because second-grade heat is entered into the return pipeline and requires additional heat or pump power to be usable, which may put the district heating grid below optimal functionality.

In order to further limit the financial liabilities of the district heating grid, EI proposes that the external heat producer should cover the entire investment for construction of the access point. The price that the heat producer receives is regulated by the costs that are saved for the district heating company by producing more expensive heat and the costs that arise for both parts in the heat transfer process. Because the heat producer takes on the entire investment, it is also proposed that the heat producer should receive all the generated profit until the initial investment is basically paid off. This would mean that the district heating company initially would not receive any of the benefits of the collaboration, while also not gaining any extra costs. In such a scenario EI suggests that the district heating company should not have the right to deny the heat producer access to the district heating grid. EI has determined that a set period of ten years is a reasonable time period for the investment in most such collaborations to be paid off while also not creating a situation where external access to the heating grid becomes too attractive.

After the ten-year period has elapsed, the investment should be paid off while the access point and the potentially cheaper heat production are still there. From this point on, it should be beneficial for both parties to continue the collaboration and split the benefits. EI emphasises that these requests for access still need to be evaluated and examined in each particular case to ensure that all the conditions are met.

6.2 Open district heating initiative by Fortum

Fortum is originally a Finnish energy company and one of the largest providers of district heating in Sweden, especially in Stockholm. Fortum has initiated their own project called Öppen Fjärrvärme
(Open district heating) and is in the process of testing it in pilot plants over the course of 2013. [http://oppenfjarrvarme.fortum.se] If the tests are successful, the project is set to become fully operational in 2014.

Table 5. Proposed prices for open district heating 2013-2017 in pilot contracts

<table>
<thead>
<tr>
<th>Outside temperature, °C</th>
<th>First-grade heat</th>
<th>Second-grade heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>-13</td>
<td>855</td>
<td>715</td>
</tr>
<tr>
<td>-12</td>
<td>837</td>
<td>699</td>
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<tr>
<td>-8</td>
<td>755</td>
<td>647</td>
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<td>-6</td>
<td>748</td>
<td>624</td>
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<tr>
<td>-5</td>
<td>702</td>
<td>586</td>
</tr>
<tr>
<td>-4</td>
<td>691</td>
<td>576</td>
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<td>-3</td>
<td>683</td>
<td>570</td>
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<td>637</td>
<td>531</td>
</tr>
<tr>
<td>-1</td>
<td>623</td>
<td>519</td>
</tr>
<tr>
<td>0</td>
<td>579</td>
<td>482</td>
</tr>
<tr>
<td>1</td>
<td>484</td>
<td>401</td>
</tr>
<tr>
<td>2</td>
<td>403</td>
<td>333</td>
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<td>3</td>
<td>346</td>
<td>286</td>
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<tr>
<td>4</td>
<td>299</td>
<td>246</td>
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<tr>
<td>5</td>
<td>249</td>
<td>203</td>
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<tr>
<td>6</td>
<td>243</td>
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<td>7</td>
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<td>8</td>
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<tr>
<td>9</td>
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<td>12</td>
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<tr>
<td>21</td>
<td>83</td>
<td>64</td>
</tr>
<tr>
<td>21+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The basic premise is similar to the model set forth by the Swedish Energy Markets Inspectorate (EI), with the main difference being that it is not regulated by law. Fortum proposes to grant a much wider access to external heat producers to its district heating grid. Similarly to EI’s proposal, the main part of the investment in access points would be taken on by the heat producer, which would also be gaining the majority of the initial benefits. By doing this, Fortum would voluntarily be exposing their
own heat production to concurrence, while raising their profile as an environmentally friendly company.

Fortum has even listed a proposed selling price list for both first-grade heat (heat sold into the supply pipeline) and second-grade heat (heat sold into the return pipeline) for their pilot contracts through the years 2013-2017 (see Table 5), which are used in the calculations in this project. The prices are directly tied to the outside temperature as predicted by the Swedish Meteorological and Hydrological Institute (SMHI) at 12:00 the previous day.

The prices are directly dependent on the temperature and are considerably higher at lower outside temperatures. If the outside temperature exceeds 21°C, heating cannot be sold.

6.3 Storing heat in rock shelters

Another aspect that may be of interest concerning the future development of Gävle’s district heating grid has been outlined in a Master’s thesis written by Dan Björsell and Johan Enström of University of Gävle (2008). Due to the availability of excess heat from the industries around Gävle, there are certain times when the heat production has the capability to exceed the consumption. This is especially apparent during the summer months and is one of the reasons why Gävle Energi has previously been reluctant to purchase heat from Gevalia.

In the harbour area of Gävle there are number of disused underground oil storages in rock shelters. Björsell and Enström have come to the conclusion that these rock shelters could be used for temporary or even seasonal heat storage, allowing for heat production to occur when it is cheap and available only to be stored in the rock shelters and sold for a larger profit when the prices for heat are higher.

According to the report, the heat storage should be built to a minimum size of 200 000 m$^3$ to ensure a reasonable payback time on the investment. An additional bonus would be a cleaning effect on the old oil shelters. As of yet, no such project has been undertaken, but if it had been, the heat production outlook in Gävle would change significantly and would increase the possibilities of utilising excess industrial heat produced during periods of high demand.

6.4 Gävle Energi

Gävle Energi is the local energy company in Gävle and provides for the majority of the electricity, heating and cooling needs of the residents and industries of Gävle (Lindmark, 2013).

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One of the most important aspects to note is that Gävle Energi already purchases around 60% of its heat from other, much larger industries such as the local paper mill Korsnäs in the form of recovered waste heat. In addition to this, Gävle Energi own and run a combined heating and power plant. This means that it is in their interest to produce heat there when the electricity prices are high. It is also easier to handle the much larger amounts of energy that the paper mill can provide, comparing to which, Gevalia’s potential output is rather small. This has been one of the reasons why the attempts to implement a heat recovery system in Gevalia with the option to sell energy into the grid has failed before.

Lindmark noted however that it is likely that if Fortum succeeds with its Open District Heating initiative, smaller energy companies around Sweden, including Gävle Energi, would follow the example, which means that it is more probable that Gevalia and Gävle Energi could reach an agreement about energy sales.

When it comes to the technical implementation of the heat transfer into the grid, Lindmark explained that it is important to match the dimensioning of the pipeline in accordance to the new flow and temperature. Depending on the final technical implementation of the heat recovery system, it may be needed to dig up the existing pipes to match them to the new specifications, which would mean a significant increase in the project costs.

District cooling is another subject that was discussed with Lindmark. He explained that there is a district cooling pipeline already built and it is laid only some 50 meters away from Gevalia, on the other side of Gävle River. However, at the moment it is not in operational use and its future is unclear. Lindmark mentioned that if the decision was made to expand the district cooling network and put the pipeline in use, Gävle Energi would be interested in some form of cooperation with Gevalia when it comes to purchasing and selling cooling energy.
7 Results

With the help of all the gathered data and the created Excel spreadsheet (see Appendix 2 for instructions on how to recreate the spreadsheet), calculations could be made. The resulting potential for energy production could then be compared to the existing energy demands of Gevalia. Additionally, economic calculations were applied to the obtained data and this chapter provides an overview of the final results.

7.1 Heating

Given the previously described data, it was calculated that there is a potential to produce 10 644 MWh or more than 10 GWh of heat over the course of a year. The combined heat production using the roasting gasses from all three roasters on a monthly basis can be seen in figure 7 below.

![Heat produced graph](image)

Figure 7. Potential for heat production from roasting gasses on a monthly basis

It can be noted that on average the heat that can be produced is 887 MWh per month with a minimum of 669 MWh per month and a maximum of 1058 MWh per month. The fluctuations are largely dependent on the average amount of operational hours each month.
Figure 8 shows a comparative diagram to illustrate the difference in consumed heating energy and the potentially producible energy. The figure shows that the possible heat production is higher than the total heat consumption for both of the main substations for every month of the year.

Figure 8. Potential heat production compared to heat consumption

In order to compare the different investment options, several scenarios were investigated. Figure 9 provides an overview of the analysed scenarios.

Figure 9. An overview of the analysed scenarios

The scenarios are divided into three major categories. The first one assumes that no agreement can be made with Gävle Energi about selling the excess heat back into the grid. The monetary gain from this is therefore only the money saved in heating bills. Given the current data, on a monthly basis Gevalia should be able to completely cover the heating needs of the two of its largest heat consuming heating substations. The substations are also responsible for the further division of scenarios, i.e. only connecting the heat production to one of them, the one that covers the factory
and the office building (Drottninggatan 51-53) and is responsible for the largest heat consumption or connecting it to both of the major substations, the second being that of the warehouse (Drottninggatan 56). This subdivision is also kept for the other two scenario categories. The price for bought district heating was taken from the homepage of Gävle Energi, where it was set to be 406 SEK/MWh starting from 1st of January 2014.

Scenario categories 2 and 3 assume that an agreement can be made to sell excess heat back to Gävle Energi. The difference between category 2 and 3 is dependent on the final implementation of the heat recovery system. With lower temperature, the heat is considered second-rate and can be sold back into the return pipeline. If sufficiently high temperatures can be achieved however, then the heat can be sold into the supply pipeline as first-grade heat, which is also reflected in the higher price. The monetary gain is therefore the sum of reduction in heating bills and the income gained by excess heat sold to Gävle Energi.

The prices of sold first and second-grade heat are taken from the Open District Heating initiated by Fortum and are subject to change when and if Gevalia negotiates its own contract with Gävle Energi. The average monthly temperatures in Gävle in 2012 were collected from the Swedish Meteorological and Hydrological Institute (SMHI) and cross checked with the prices Fortum has specified for each of the given outside temperatures.

Table 6 shows the potential monetary gain from each of the six described options.

Table 6. Monetary gain from the different scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Monetary gain, million SEK/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1.1</td>
<td>0.81</td>
</tr>
<tr>
<td>Option 1.2</td>
<td>1.05</td>
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<tr>
<td>Option 2.1</td>
<td>2.81</td>
</tr>
<tr>
<td>Option 2.2</td>
<td>2.83</td>
</tr>
<tr>
<td>Option 3.1</td>
<td>5.23</td>
</tr>
<tr>
<td>Option 3.2</td>
<td>5.00</td>
</tr>
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</table>
Figure 10 shows a graphical representation of what the highest conceivable investment in the project can be dependent on the desired maximum payback time.

Figure 10. Maximum investment depending on the desired payback time

Table 7 shows the payback time and maximum investment in a more detailed form. The payback time calculations show that the maximum investment generally increases if both heating substations are connected and if it is possible to sell the excess heat. The trend is broken with options 3.1 and 3.2 where the maximum investment decreases if both substations are connected due to the price difference of buying the heat at Gäve Energi’s proposed price and selling it at Fortum’s proposed price.

Table 7. Payback time vs. maximum investment

<table>
<thead>
<tr>
<th>Payback time, years</th>
<th>Opt. 1.1</th>
<th>Opt. 1.2</th>
<th>Opt. 2.1</th>
<th>Opt. 2.2</th>
<th>Opt. 3.1</th>
<th>Opt. 3.2</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0,812</td>
<td>1,049</td>
<td>2,781</td>
<td>2,808</td>
<td>5,177</td>
<td>4,951</td>
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<td>2</td>
<td>1,624</td>
<td>2,098</td>
<td>5,563</td>
<td>5,616</td>
<td>10,354</td>
<td>9,902</td>
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<td>8,344</td>
<td>8,424</td>
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<td>4</td>
<td>3,249</td>
<td>4,195</td>
<td>11,126</td>
<td>11,232</td>
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<td>5</td>
<td>4,061</td>
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<td>14,040</td>
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<td>4,873</td>
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<td>25,033</td>
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<td>44,559</td>
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<td>10</td>
<td>8,122</td>
<td>10,488</td>
<td>27,814</td>
<td>28,080</td>
<td>51,769</td>
<td>49,510</td>
</tr>
</tbody>
</table>
7.2 Cooling

Assuming that cooling would be produced with an absorption cooler with a COP factor of 0.7, the total amount of cooling that can be produced over the year is 7451 MWh. Cooling production on a monthly basis is presented in Figure 11.

![Cooling production](image)

*Figure 11. Potential cooling production on a monthly basis*

At the moment, Gävle Energi has not specified a price for purchase of district cooling, but an idea of the potential income can be gained by looking at setting the price to 773 SEK/MWh, which is the price Sundsvall Energi uses on their website. That leads to a potential income of 5.738 million SEK per year if all the produced cooling after covering Gevalia’s own comfort cooling needs could be sold at that price. In reality the price would probably fluctuate more.

7.3 Sensitivity analysis

In order to gain an idea of how influential are some of the factors that are only estimated, sensitivity analysis was performed. By raising or lowering input data such as the gas flow or the district heating price at Gävle Energi, the impact on the final monetary gain can be observed.

In this case, five possibilities were observed, namely raising and lowering the gas flow in all roasters by 20%, raising and lowering the district heating price provided by Gävle Energi by 20% and, finally, excluding RZ2 from the calculations (setting the flow for RZ2 to 0). The observed impact on the monetary gain is presented in Table 8.
The results show that these changes have a varying impact, both compared to each other and when comparing the different scenarios.

Most notably, the sensitivity analysis show that a change in flow has no impact on options 1.1 and 1.2, because Gevalia’s own heating needs can still be covered. The same options are influenced quite significantly if the price of district heating fluctuates. Changes in price have a lesser impact on the outcome for the remainder of options.

The flow does have a significant impact on the results for options 2.1 – 3.2, with changes in monetary gain of up to -33% in the flow is decreased by 20% and a change of up to +20% if the flow is increased by 20%. Compared to this, excluding RZ2 has a much smaller impact of decreasing the monetary gain by 7-8%.

### Table 8. Sensitivity analysis

<table>
<thead>
<tr>
<th>Change:</th>
<th>Actual result</th>
<th>Flow -20%</th>
<th>Flow +20%</th>
<th>Price -20%</th>
<th>Price +20%</th>
<th>No RZ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1.1</td>
<td>0.81 (+0%)</td>
<td>0.81 (+0%)</td>
<td>0.65 (-25%)</td>
<td>0.97 (+16%)</td>
<td>0.81 (+0%)</td>
<td></td>
</tr>
<tr>
<td>Option 1.2</td>
<td>1.05 (+0%)</td>
<td>1.05 (+0%)</td>
<td>0.84 (-25%)</td>
<td>1.26 (+17%)</td>
<td>1.05 (+0%)</td>
<td></td>
</tr>
<tr>
<td>Option 2.1</td>
<td>2.81</td>
<td>2.25 (-25%)</td>
<td>3.36 (+16%)</td>
<td>2.65 (-6%)</td>
<td>2.97 (+5%)</td>
<td>2.63 (-7%)</td>
</tr>
<tr>
<td>Option 2.2</td>
<td>2.83</td>
<td>2.28 (-24%)</td>
<td>3.39 (+17%)</td>
<td>2.62 (-8%)</td>
<td>3.04 (+7%)</td>
<td>2.65 (-7%)</td>
</tr>
<tr>
<td>Option 3.1</td>
<td>5.23</td>
<td>4.00 (-31%)</td>
<td>6.46 (+19%)</td>
<td>5.06 (-3%)</td>
<td>5.39 (+3%)</td>
<td>4.83 (-8%)</td>
</tr>
<tr>
<td>Option 3.2</td>
<td>5.00</td>
<td>3.77 (-33%)</td>
<td>6.23 (+20%)</td>
<td>4.79 (-4%)</td>
<td>5.21 (+4%)</td>
<td>4.6 (-9%)</td>
</tr>
</tbody>
</table>
8 Discussion

From the gathered data and calculations it seems apparent that there is definite potential in installing an energy recovery solution at Gevalia’s roasting house in Gävle. All of the six options describing the solutions for using the roasting gasses for production of heat show that there is profit to be gained from implementing them.

However, several things have to be kept in mind before proceeding further. First of all, the data used in calculations, especially the roasting gas flow through the chimneys, has to be deemed to represent the real situation. The gas flow data used is the theoretical data given by the manufacturer and may not represent the reality as indicated by the sample tests by ILEMA. The gas flow has a significant impact on the final results and could thus provide some misleading results. A solution for properly measuring the gas flow during a roasting cycle must be found before proceeding further.

It is also apparent that the external factors influence the future of this project. Whether the proposal for regulated access to the district heating grid from EI or Fortum’s Open district heating initiative come to pass will play a major role in whether an agreement can be achieved with Gävle Energi on selling the heat back into the grid. As indicated by Gävle Energi, if Fortum succeeds with their initiative, other district heating companies, including Gävle Energi, are likely to follow their example. Göran Heldesten at EI has also said that it would be preferable that Fortum’s initiative succeeds, because that would eliminate the need for artificial involvement by the government agencies.

Other external factors include the possible future infrastructure developments in Gävle, such as expansion of the district heating grid or possibly implementing heat storage in rock shelters. Energy prices are subject to change as well and need to be updated in order to have actuality. However, even with updated prices, the future price development is still going to be only an estimate.

The gathered information should help Gevalia get an idea of the size of the investment that needs to be done compared to the payback time they are prepared to settle for. This can be of special importance in a company like Gevalia, which belongs to an international conglomerate, where quick returns on investment are often of high importance.

When it comes to comparing the different scenarios and deciding on whether or not to invest in connecting both of the larger heat centrals, it is important to take a closer look at the differences in investment. It seems that in some cases it may be more beneficial not to connect the second heat central and sell the heat instead. This means however that the heating bill for the second central still
needs to be paid but the investment should be smaller because the second central does not need to be restructured. Another possibility may also be considered, namely to connect one of the heat centrals first with the possibility of attaching the second one later on.

The lifespan of the current roasters as well as the potential heat recovery system also needs to be taken into account. If Gevalia decides to scrap one or both of their older roasters in the foreseeable future, the energy recovery process may become a lot less interesting as a potential investment.

The potential for producing cooling is also something to consider, however it seems that the current conditions would not make this a viable option for investment. Gevalia has very little need for comfort cooling and the demands of the process cooling are too high for what absorption cooling can deliver. What could make this an interesting investment in the future is that Gävle Energi might keep expanding and developing their district cooling network and make it possible to sell the generated cooling into the grid at relatively high prices.

The sensitivity analysis illustrates why it is so important to gather exact data before committing to a decision to invest. If no agreement with Gävle Energi can be achieved, the gas flow measurements don’t really influence the results. If, however, an agreement can be reached, then the impact can be quite large, depending on how big the difference is from the estimated values. It can also be seen that a decreased flow has a larger impact percentage-wise than a flow increased by the same amount.

Changes in the district heating price have a larger impact on the options 1.1 and 1.2 when only Gevalia’s own heating bills are affected but can still have a significant impact on the outcome. The option of not connecting RZ2 to the economizer is also something to seriously consider when assessing the added costs of the project. The flow from RZ2 corresponds to only a few percent of the actual monetary gain, so if the investment is significant, RZ2 could very well be skipped entirely.
9 Conclusions

There is definite potential for energy recovery in the form of heat, however the calculation data needs to be verified and regularly updated, especially the roasting gas flow. The gas flow data as well as the rest of the measurements gathered can be conveniently updated in the spreadsheet provided together with this report. The spreadsheet is the most valuable result of this project and can be continuously used to monitor the current situation at the factory and to calculate the potential outcome of the different scenarios.

The majority of the cells in the spreadsheet are connected ensuring that adjustments to the data can be done to immediately achieve the latest results. The data fields that can be updated include the operational hours, gas flow, temperatures and their corresponding energy contents, data over the consumption of district heating and more. It is, for example, possible to look at the option of not attaching RZ2 with its comparatively small gas flow to the economiser simply by setting the gas flow value to zero.

External factors have a large impact on the possibility for success. Attention must be paid to further developments of Fortum’s Open district heating initiative as well as EI’s proposed model for regulated access to the district heating grid. These are factors that are completely independent of the technological possibilities of heat recovery, yet they have far more influence on the outcome.

Cooling production from the roasting gasses also has potential to succeed, but the current situation in Gävle is not optimal for such an investment. Further development of the district cooling grid can make this a viable option in the future.

9.1 Suggestions for further development

If Gevalia is serious about an implementation of an energy recovery solution, investments must be made in obtaining more exact data for the gas flow. These measurements are necessary to be able to have a more accurate picture of the possibilities and costs of energy recovery.

Gevalia should also keep close relations with Gävle Energi and start talks about the price levels that Gävle Energi is prepared to accept, both when it comes to heating and cooling. Following Gävle Energi’s reaction to both Fortum’s and EI’s initiatives is crucial to making an appropriate decision in this matter.
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Appendix 1

Figure 12. An example of the variation in roasting gas temperature over one cycle in RZ1

Figure 13. An example of the variation in roasting gas temperature over one cycle in RZ2

Figure 14. An example of the variation in roasting gas temperature over one cycle in RZ3
Appendix 2

Due to the fact that the entire spreadsheet used for calculations cannot be attached to the thesis report, this appendix provides a brief description of the necessary information to recreate it.

The spreadsheet includes all the gathered numerical data – the operational hours, temperature and the corresponding specific enthalpy of the roasting gasses, gas flow, historical energy consumption data and the energy prices provided by both Fortum and Gävle Energi.

Using Formula 1 from this report, the possible power generation can be obtained per roaster. These values are multiplied with the average amount of operational hours on a monthly basis to obtain the amount of energy that can be produced. These values can then be used to compare with the energy consumption and for economic calculations.

The remainder of the spreadsheet is largely dependent on the layout preference, but it is important to keep as many of the calculations connected to the rest of the cells, so that a single update in data input can immediately lead to an updated result.